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DIRTY STACKS, HIGH STAKES:

An Overview of Brick Sector in South Asia

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Abbreviations

BBA	Brick Burning Act (Bangladesh)
BDT	Bangladeshi Taka
BC	Black Carbon
CBA	Cost Benefit Analysis
CDM	Clean Development Mechanism
CK	Clamp Kiln
DSCI	Department of Cottage and Small Industries (Nepal)
FCBTK	Fixed Chimney Bull Trench Kiln
FCK	Fixed Chimney Kiln
FNBI	Federation of Nepalese Brick Industries
HHK	Hybrid Hoffman Kiln
HK	Hoffman Kiln
IFCK	Improved Fixed Chimney Kiln
IZZK	Improved Zigzag Kiln
MCBTK	Mobile Chimney Bull's Trench Kiln
MCK	Mobile Chimney Kiln
NBC	National Building Code (Nepal)
PM	Particulate Matter
SEC	Specific Energy Consumption
SLCP	Short-Lived Climate Pollutant
SPM	Suspended Particulate Matter
TK	Tunnel Kiln
VSBK	Vertical Shaft Brick Kiln
ZZK	Zigzag Kiln

Executive Summary

Context

The study is part of the World Bank's regional initiative – "Mitigation Options for Short-Lived Climate Pollutants (SLCPs) in South Asia". The objective of the regional initiative is for the governments of South Asian countries (Bangladesh, India and Nepal) to advance measures in brick sector, among others, to significantly reduce emissions in the next few years and decades of black carbon (BC), ozone (O_3) and other substances that adversely affect near-term climate and air quality from selected urban, industrial and rural sources. Reducing these pollutants from brick sector would contribute to three benefits: (i) less global and regional warming with immediate effect (in the same time frame as implementation of the measures); (ii) fewer deaths and illnesses from poor air quality, especially among the lowest-income people who suffer disproportionately from this, and (iii) better crop yields as a result of better air quality. The higher degree of mechanization and resource efficiency associated with modern brick kiln technologies will also result in larger socio-economic benefit through productivity increase.

This report surveys the brick kiln sector in three South Asian countries: Bangladesh, India, and Nepal, with particular focus on experiences and lessons learnt from Bangladesh, where data and information on the brick kiln industry and market conditions are most extensive, and where engagement of the donor community has been most consistent and widespread. The study was carried out in 2016.

Characteristics of the brick sector market

South Asia is home to nearly a quarter of total global brick production. There are about 7000 brick kilns operating in Bangladesh, producing an estimated 27 billion bricks annually that contribute 1% to the national GDP and employ nearly 1 million people. India is the second largest brick producer in the world, with an estimated annual production of 250 billion bricks through about 144,000 brick kilns operating in the country, and employs approximately 15 million workers. In Nepal, there are approximately 1700 brick kilns operating with an annual production of 5 billion bricks. In all three countries, traditional kiln technologies namely the Fixed Chimney Kiln (FCK) and Zigzag Kiln (ZZK) are the most dominant ones. In India and Nepal, however, there are still a good number of Movable Chimney Kilns (MCKs) operating despite their ban by the Government.

Brick Sector Related Air Pollution and its Impacts

Brick kilns, involving the burning of low-grade coal, are one of the major sectors that contribute to air pollution in South Asia. The brick sector is responsible for up to 91% of total Particulate Matter (PM) emissions in some South Asian cities. In Bangladesh, the contribution of the brick sector to the total annual CO_2 emissions of the country (17%) is far more significant than its GDP contribution (1%). Brick kilns are also estimated to emit 22 and 37 kt/year of $PM_{2.5}$ and

PM_{10} respectively. Similarly, in India, brick kilns contribute nearly 400 kt of $PM_{2.5}$ and over 660 kt PM_{10} each year. In Kathmandu, the brick kilns are estimated to be responsible for approximately 28% of the total PM_{10} concentrations and contribute 40% of Black Carbon (BC) in winter. This study has estimated that in the year of 2015, about 6,100, 55,000, and 600 deaths were caused by pollution of the brick sector in Bangladesh, India, and Nepal respectively. And, the associated DALYs were roughly 49,000, 436,000, and 4,800 respectively. The economic costs on public health of the brick sector in Bangladesh are about US$633 million per year, in India US$ 3.6 billion, and in Nepal US$ 46 million.

Clean Technology Options and Cost Benefit Analysis

Both cost-benefit analysis and sensitivity test suggest that Hybrid Hoffman Kiln (HHK) and Tunnel Kiln (TK) should be the technologies of choice of all entrepreneurs if they are constructing new kilns. This finding applies both to the financial analysis, reflecting private profit alone, and is even more pronounced in the economic analysis incorporating negative health and climate change externalities, which are substantial and which offset all private profit except in the case of the cleanest, most efficient technologies. The sensitivity analysis suggests that hollow bricks – compatible primarily with modern kilns – and relatively low-interest financing (also indispensable for capital-intensive modern kilns) dramatically enhance the profitability of HHK and TK technologies, both in the absolute sense and relative to low-debt, smaller-scale kiln projects such as Zigzag Kiln (ZZK) and Fixed Chimney Kiln (FCK).

Barriers to the Adoption of Clean Technology Options

In Bangladesh, according to the government registration data dominated by ZZK, roughly 60% of all operating kilns are considered as improved/intermediate technologies (namely ZZK, HHK and TK). In Nepal and India, these figures are roughly 17% and 3%, respectively. All three countries have less than 1% market penetration of advanced and efficient technologies (HHK and TK). These figures illustrate that the barriers to modernization and formalization, and to the efficiency and pollution control that follow, are substantial. Many barriers to improvement flow out of the brick industry's entrenchment in the gray economy: the lack of adequate investment and bank financing; low levels of human capital and know-how; weak or absent regulation, oversight, and standards; evasion of taxes and regulations; poor working conditions and wages; and largely stalled transition to higher-quality products and more efficient production technologies and approaches.

Key Recommendations

Provision of Government Support. Sector-wide solutions to transition to cleaner and efficient technologies require government support. Government support can and must take many forms to be effective: regulations and standards, enforcement, legislative mandates, and other enticements such as preferential permitting, access to markets, and concessional financing. In particular, access to land, accessible and reasonably low-cost debt, and internalization of social and environmental costs in government policy are sine qua non conditions of a successful brick sector transition. Sustained support to professionalize the brick sector is needed in a range of areas in concert to ensure a speedy and complete transition. Government roadmaps and policies should take into account the status quo and the challenges of dislocation and retraining for existing kiln operators and workers.

Upgradation and Enforcement of Regulations. Improved enforcement of regulations on labor, air quality, building materials, and other aspects of brick production would lead to better environmental and social outcomes, necessitating substantial monetary and human resources support for government regulatory agencies. In Bangladesh particularly, the Brick Act 2013 needs to be reformed, incorporating the distinctions between different technology types and easing some of the restrictions to reflect the realties on the ground.

Adoption of Pilot Approaches. Pilot projects, demonstrations, and lending initiatives along the lines of those pioneered in Bangladesh can be effective because they localize research and development (R&D), commercialize new business models and technologies, and provide sustained investment in supply chains, training, and access to capital. One particular learning from Bangladesh was that programs with an up-front project financing scheme rather than a reimbursement or refinancing scheme could deliver better results. For instance, the best results from a development perspective would come from combining the project finance model of the Infrastructure Development Co. Ltd. (IDCOL) program, the ADB technical assistance program, and result-based climate financing such as the World Bank Clean Development Mechanism (CDM).

Provision of Training and Capacity Building. Large-scale training for entrepreneurs, kiln workers, financial institutions and investors, suppliers and regulatory agencies on the benefit of performance improvement through adoption of advanced kilns is urgently needed. In addition, targeted training programs are required for kiln owners and entrepreneurs on the availability of modern kiln technologies, and to build their capacity on understanding technical knowhow and design optimization of these new technologies. Further, it is also necessary to enhance the knowledge and capacity of investors and financial institutions to assess financial and technical viability of modern technologies so that it eases access to finance for brick entrepreneurs.

Utilization of Alternate Building Materials (ABMs): ABMs, improved brick design, and improved construction practices are largely untapped opportunities for better fuel efficiency, product quality, construction, and air quality. These approaches should be explored for pairing with kiln technologies of all types to achieve social, environmental, and market objectives.

Structure of the Report

The report commences in Chapter 1 with an overview of brick production methods, size of market and brick characteristics in South Asia along with a detailed overview of the brick kiln sector in each of the three focus countries – Bangladesh, India, and Nepal.

Chapter 2 starts with detailed description of brick production technologies in South Asia, from artisanal kilns that have mostly been phased out to the most modern, capital intensive and relatively efficient and cleaner Tunnel Kilns that have yet to penetrate the market in most parts of the region. This is followed by a cost-benefit analysis comparing baseline and clean technologies, focusing on fixed chimney kilns (FCK), zigzag kilns (ZZK), Hoffman kilns

(HHK), and tunnel kilns (TK). The cost-benefit analysis is predicated on a detailed, customized proprietary financial model prepared for this study based upon market conditions in 2015 in Bangladesh, and examines both financial (project) and economic (public) costs and benefits, extending the analysis to include the health and climate change impacts of kiln emissions. Chapter 3 further explores the emissions profile and assesses the impacts of the brick sector on the environment, public health, and macroeconomics.

Chapter 4 examines the challenges and barriers to the adoption of cleaner brick kiln technologies in greater detail, exploring the technical, financial, governance, policy, capacity and informational barriers, among others. Chapter 5 reviews the authors' conclusions and recommendations for addressing the barriers and market conditions observed in the preceding chapters.

Intended Audience and Purpose of the Report

The primary audience and usefulness of the report are:

(i) the responsible ministries in each country, who can benefit from an evaluation of the real magnitude of the environmental externalities caused by polluting brick technologies (health problems and carbon emissions);

(ii) the brick industry and industry association in each country, who can use the recommendations as a tool for discussing the importance of the brick sector among other industries, and for introducing cleaner kiln technologies in the country;

(iii) the Ministry of Industry in each country, who can use the information to speed up the recognition of the sector as a formal industry

(iv) the international development organizations and I/NGOs, who can use the findings of this report to design targeted operational and technical assistance projects that could assist a quick transition from conventional to modern kiln technologies and in the meantime, reduce brick sector induced air pollution

The report is also intended to facilitate the sharing of lessons among countries through partnerships for knowledge exchange.

Acknowledgements

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The report was written by a team composed of Jie Li (Senior Climate Change Specialist), Andrew Eil (Climate Finance Advisors, Consultant), Prajwal Baral (Hornfels Group, Consultant) and Eri Saikawa (Emory University, Consultant). The report was prepared under the technical guidance of Chandra Shekhar Sinha (Advisor for Climate Change Department of the World Bank) and Jie Li, with contributions from Ashish Shrestha (Consultant) and Alan David Lee (Energy Specialist).

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Chapter 1. Overview of Brick Production across South Asia

The South Asia Region (SAR) is home to 1.8 billion people. As the economy grows steadily at an average rate of 6% over the last 20 years, the region is also in the unprecedented process of fast urbanization. Both economic growth and urbanization lead to increase of demand for living and business space, and therefore, construction materials. Brick is one of the major building materials in Asia. After China, which produces more than 1 trillion bricks per year, SAR is the second largest brick producing-region in the world, producing 310 billion bricks annually.

1.1 Brick production methods, size of market and brick characteristics

Size of the brick sector and technologies used in SAR

SAR produces 21% of the world's total bricks, second only to China, which produces 67% of the world total. The technologies widely used for brick making in South Asia, however, have not changed much for more than a century and are very inefficient, unproductive and highly polluting. The dominant technologies being used are Clamp Kilns (CKs), Mobile Chimney Kilns (MCKs), Fixed Chimney Kilns (FCKs) and Zigzag Kilns (ZZKs).

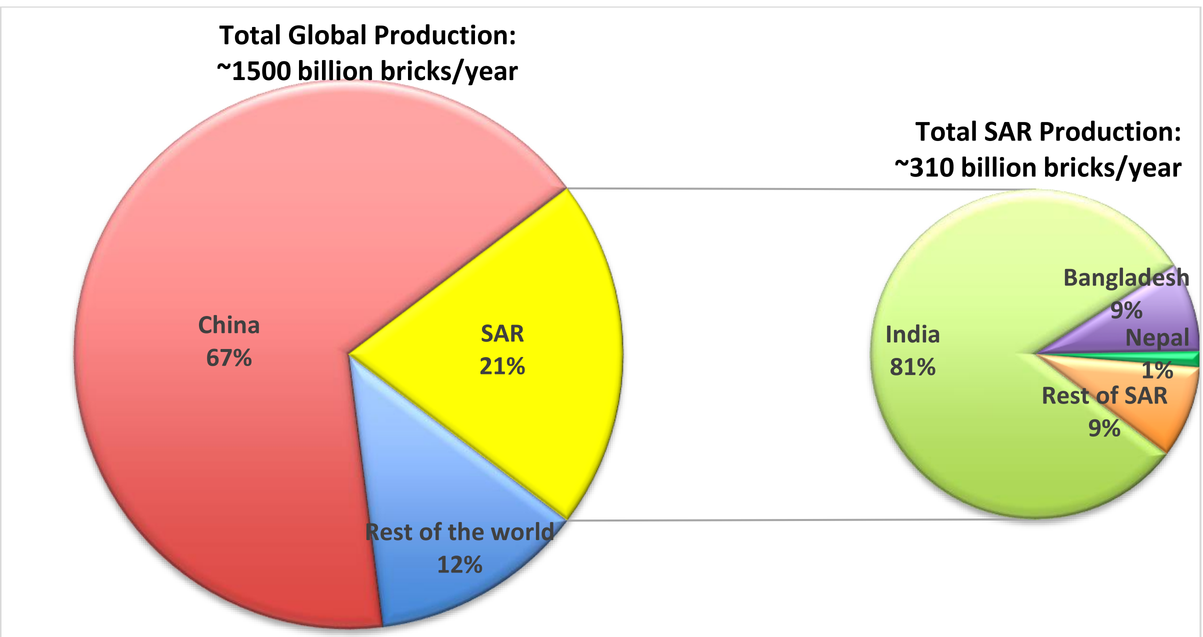

Figure 1.1 Distribution of brick production globally [Source: Baum, 2015; Adjusted by authors]

The relatively advanced technologies like Hoffman Kilns (HKs), Hybrid Huffman Kilns (HHKs) and Tunnel Kilns (TKs) are in limited number despite both domestic and international push towards adopting cleaner brick producing technologies. The majority of brick production comes from four countries – Bangladesh, India, Nepal and Pakistan. These four countries account for 20% of global brick production (Baum, 2015). The three countries covered in this study (Bangladesh, India and Nepal) comprise more than 90% of SAR brick production. As a whole, the SAR brick market is expected to grow at a CAGR of 8%[1] between 2017 and 2025 (dmg events, 2015; BMI Research, Undated and tradingeconomics.com).

A detailed description of all these brick kiln technologies is presented separately at the beginning of Chapter 2.

Types and quality of bricks

Clay is the most commonly used input material for the production of bricks in South Asia. There are six major determinants of a good quality brick – shape, size, color, surface finish, compressive strength and water absorptivity (Biswas, 2013; Civilblog, 2014). A good quality brick should have bright and uniform color, uniform shape as per the national/local standard, sharp and straight edges, and free from cracks or holes or any surface defect. The compressive or crushing strength is an important attribute that is tested in a laboratory by applying pressure under a crushing machine. A good quality brick should have a minimum compressive strength of more than 35 kg/cm^2 although in practice, bricks used in load-bearing structures have a compressive strength of more than 100 kg/cm^2. Similarly, a good quality brick when immersed in cold water for 24 hours should not absorb water more than 20% of its dry weight. Based on the quality and strength of brick, which varies among countries, there are three classes – first, second and third.

In Bangladesh, the first-class bricks are required to have a minimum compressive strength of 3000 pounds per square inch (psi), maximum water absorption of 20% of dry weight after five hours of soaking in water, minimum weight of 3.5 kg per brick and the dimensions of 240 mm x 115 mm x 70 mm. The dimensions, weight and other parameters slightly vary among three countries covered by this study. For instance, in Nepal, the average weight of first-class bricks was found to be approximately 2 kg with great variation in height of the bricks. Similarly, in India, standard brick size is 190 mm x 90 mm x 90 mm as per the recommendation of Bureau of Indian Standards (BIS). The first-class bricks are well uniformly burnt, homogenous in texture, uniform in color (generally copper or deep red), free from cracks, nodules of free lime and other flaws, have plane rectangular faces with parallel sides and sharp straight right-angled edges.

The second-class bricks have non-uniform color and are less uniformly burnt than the first-class ones. Similarly, the third-class bricks are inadequately burnt, have deformed shapes and surface cracks. There is another category of bricks called picked bricks that are over burnt first class bricks with deformed shapes and black color.

The first-class bricks are usually used in load-bearing walls, outer walls, water handling constructions, brick soiling, etc. Similarly, the second-class bricks find their use in inner walls, partition walls and roads. The third-class bricks are generally crushed for masonry and concrete applications. The picked bricks (low quality, over-burnt ones) are not used for construction. But nothing is wasted in Bangladesh, they are particularly used in road construction as aggregates because of their high compressive strength. It is expected that although the general consumption trend is positive for all classes of bricks, there is a gradual shift of consumer preference from

[1] The growth of construction industry is taken as a proxy.

price sensitivity to quality sensitivity. This might lead to greater demand for first- and second-class bricks in the coming years, projecting an eventual elimination of third-class bricks. The demand for picked bricks will likely continue because of their high compressive strength and specialized application in road construction.

Raw materials

Agricultural soil is the major raw material for brickmaking industry in all three countries. Based on the production capacity and type of kiln, the area of land required by brick kilns for clay mining ranges from 5-10 hectares to 17.5-25 hectares per kiln. In Bihar (India), the brick industry procures 90% of brickmaking soil from the agricultural land and the remaining 10% from riverbeds, which has led to an annual loss of 5,500 acres of fertile agricultural land that would have, otherwise, contributed to the production of 7,000 tons of rice (DA, 2012). Since farmers use land for agricultural activities during rainy season, it is available for brick production only in the dry season (Nov/Dec to May/Jun). There is, therefore, a significant variation in total production after every lease cycle.

Fuel consumption

Coal is the primary fuel used for brick production in all three countries. Based on the latest estimate of this study, the brick sector consumes about 5 million, 62 million[2] and 1 million tons of coal every year in Bangladesh, India and Nepal respectively, making this sector the first or the second largest coal consumer in each of these countries. In India, the brick industry is one of the largest industrial consumers of coal, second only to steel industry. Traditional brick kilns have low energy efficiency and are highly polluting, typically consuming about 18–25 tons of coal to produce 100,000 bricks. Many kilns also use coal and rice husk mixture as the primary fuel, and sometimes also a mixture of coal, sawdust and other biomass. Some also use plastic, used tires and wood during the ignition process. In addition to the fuels used to fire the bricks, diesel is also extensively used in the mechanization process because of shortage of or unreliability of grid electricity in many places of the region.

1.2 Brick sector background reviews for Bangladesh, India and Nepal

This report has focused exclusively on three countries of South Asia Region (SAR) – Bangladesh, India and Nepal because of good availability of data and the World Bank's familiarity with the brick sector in these countries. The following sections discuss market share of different brick kiln technologies in each country, institutional mapping and existing regulations along with key international development projects in recent years in brick sector.

Bangladesh

The latest data collected in our study indicates that there are about 7000 brick kilns operating in Bangladesh as of the end of 2016, producing an estimated 27 billion bricks annually that

[2] This number is higher than the 2013 SAARC report (SAARC Energy Centre, 2013c), which mentions the total coal consumption might be around 35 million tons per year. The discrepancy may come from two parts. First, this study updates the brick sector data up to 2016 which may have more brick kilns than the 2013 SAARC report. Second, our calculation is based on the assumptions provided in Chapter 3 and results are given in Table 3.6, assuming biomass use is negligible.

contribute 1% to the national GDP and employ nearly 1 million people. There are six types of brick kilns in Bangladesh: Movable Chimney Kiln (MCK), Fixed Chimney Kiln (FCK), Zigzag Kiln (ZZK; traditional), Hoffman Kiln (HK; gas-fired), Hybrid Hoffman Kiln (HHK; coal-fired) and Tunnel Kiln (TK). The MCKs have already been legally banned in 1990s in the country because of its poor energy efficiency and highly polluting nature.

The brick sector is growing fast but is still dominated by low-end technologies. From FY 2006 to FY 2016[3], the total number of brick kilns grew from 4,140 to 6,758. From 2010 to 2016, total brick production increased from about 19 billion to 27 billion (annual growth of 8 percent).[4] Although the number of HHKs and TKs has also grown dramatically (approximately 50% growth between 2010 and 2016), kilns using low-end technology still constitute the majority by far in the brick sector (Table 1.1). New construction replicates existing kilns, with little variation in kiln design.

Table 1.1 Number of brick kilns and annual production in Bangladesh

Kiln Type	**Approximate Number of Kilns**				**Annual Production Capacity (Million Bricks /Year)**	**Total Annual Production 2016 (Billion Bricks)**
	FY2010	**FY2014**	**FY2015**	**FY2016**		
MCK	200	24	0	0	3.3	0
FCK	4500	4345	3451	2672	4	10.7
ZZK	150	1361	3331	4030	4	16.1
HK (Gas)	20	6	6	6	4	0.02
HHK (Coal)	10	34	39	44	10	0.4
TK	0	4	5	6	23	0.14
Total	4880	5774	6832	6758	48.3 *(44.3 excluding HK Gas)*	27.4

Source: Compiled by authors using data from Bangladesh Department of Environment, Ministry of Environment and Forest as of 2016.

FCK-to-ZZK conversion played a prominent role in the transition of kiln technologies over the past five years. After the Brick Act was passed in 2013, the FCK share shrank from a high of 92 percent (4,500 kilns) in 2010 to less than 40 percent (2,672 kilns) in 2016. During this time, almost 4,000 new ZZKs were either constructed or converted from FCKs, increasing the share of ZZKs from 3 percent to over 60 percent. The number of FCKs dropped off sharply after 2015 because of a government directive to complete ZZK conversions as well as an increase in

[3] In Bangladesh, the fiscal year is 1 July to the next 30 June
[4] All kiln, brick production, and market share data from the Department of Environment, Ministry of Environment and Forest.

enforcement and demolition of illegal FCKs. There are however still many FCKs operating illegally because of lack of complete enforcement of the Brick Act.

However, market information reveals a troubling lack of standardization and quality control in the newly constructed or converted ZZKs. In most of the cases, FCK owners constructed the ZZKs either independently or with the help of local masons experienced in constructing them. The quick uptake of ZZKs was no doubt a direct result of the Brick Act, which simply banned FCKs and promoted ZZKs one of the clean technologies; many kiln owners simply converted to ZZK as it was the easiest and most cost-effective way to come into compliance. Under the World Bank's CASE project, the DoE adopted two new designs: improved ZZKs and standardized FCK-to-ZZK conversions. However, only one Improved ZZK is operational, and fewer than 10 FCK-to-ZZK conversions have been demonstrated. It is unclear how many of the 4,000 new ZZKs were built to specifications. Since most of the existing ZZKs were not constructed according to any standard design, it is difficult to ascertain just how well they perform.

The numbers of HHKs and TKs have been gradually increasing. The combined number of HHKs and TKs increased from single digits to 50, thanks to the support of different development programs providing technical or financial support (see the section below on "Development projects supporting clean brick production"). They have yet to reach the critical mass needed to survive the competition in the market with traditional kilns, particularly the ZZKs and improved ZZKs. Since one HHK or TK is generally equivalent to 3–12 FCKs in terms of annual brick production, comparison would be more reliable and accurate if the exact number of operational kilns were available and the comparison made by the number of bricks produced rather than only the number of kilns. Bangladesh has only six operational Hoffman gas kilns (essentially a gas-fired version of the coal HHK) for several reasons: lack of gas availability in areas where brickfields are located, high costs to finance these kilns, and government policies that discourage the use of gas for the brick industry in order to give priority to other sectors such as power generation and fertilizer production.

Market price of bricks

The following table sums up prices of bricks produced using three major technologies. The FCK/ZZK bricks lie in the lower range whereas TK bricks in the upper range, suggesting that brick operators will greatly benefit from the adoption of superior technologies like TK that produce three to twelve times more bricks than conventional technologies like FCK or ZZK.

Table 1.2 Market price of different brick classes in 2016 (Li, 2017) (US$1 = 77.7 BDT[5]; 2015)

Technology type	1st Class/Picked Brick price (per unit)	2nd Class Brick price (per unit)	3rd Class Brick price (per unit)
FCK/ZZK	6-7 BDT	4-5 BDT	3-4 BDT
HHK	8-9 BDT	6-6.5 BDT	n/a

[5] World Development Indicator Database 2017

TK	10-14 BDT	7-8 BDT	n/a

Mapping and assessment of institutions in relation to brick sector

The brick sector stakeholders in Bangladesh can be categorized into five types – regulatory agencies, industrial associations, financial institutions and project developers, suppliers and technical institutions, and international development partners. Since international development partners have undertaken most brick sector initiatives in Bangladesh, the following figure summarizes the current relationship among various stakeholders vis-à-vis major international development partners that are financing/leading key brick sector projects, namely the Asian Development Bank (ADB), the World Bank (WB) and the United Nations Development Programme (UNDP).

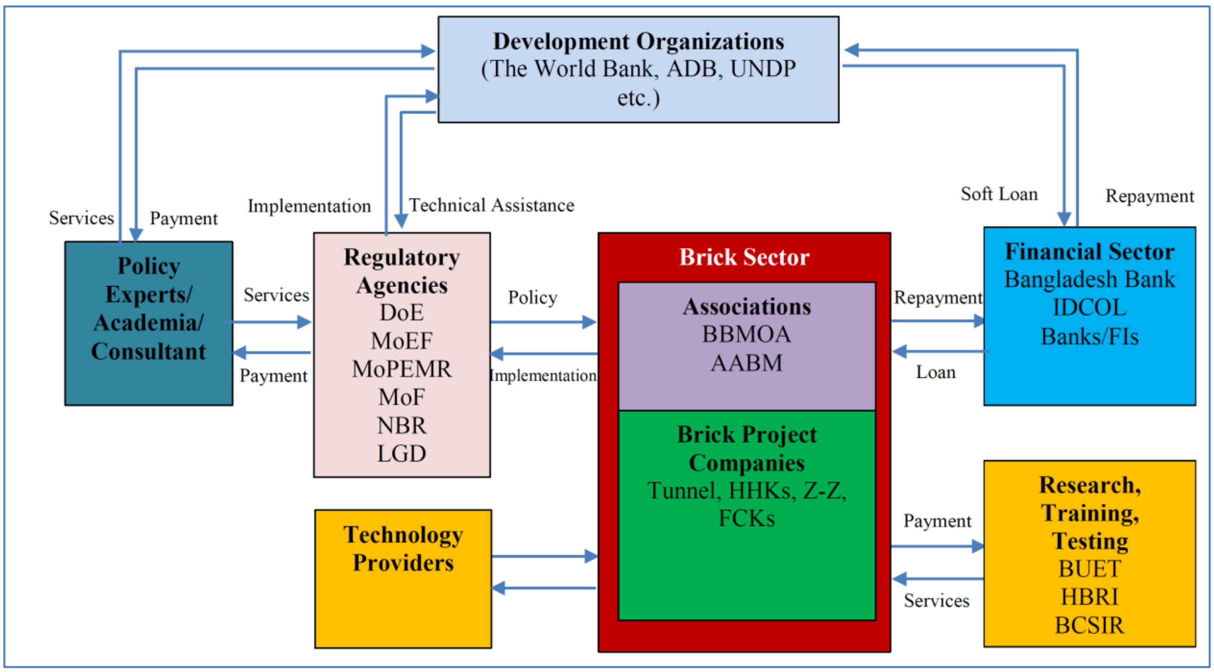

Figure 1.2 Stakeholders Mapping of the Bangladesh Brick Sector[6]

Regulatory agencies

The Department of Environment (DoE) is a government agency under the Ministry of Environment and Forest (MoEF) that is responsible for ensuring a safe, high quality environment of all Bangladeshis through the prevention and control of pollution and ecosystem protection by

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[6] *Note:* ADB = Asian Development Bank. BABMA = Bangladesh Auto Brick Manufacturers Association. BBMOA = Bangladesh Brick Manufacturing Owners Association. BCSIR = Bangladesh Council for Scientific and Industrial Research. BUET = Bangladesh University of Engineering and Technology. DoE = Department of Environment. FCKs = fixed chimney kilns. FIs = financial institutions. HBRI = Housing and Building Research Institute. HHKs = Hybrid Hoffman kilns. IDCOL = Infrastructure Development Company Limited. LGDs = local government departments. MoEF = Ministry of Environment and Forest. MoF = Ministry of Finance. MoPEMR = Ministry of Power, Energy and Mineral Resources. NBR = National Board of Revenue. UNDP = United Nations Development Programme. ZZKs = zigzag kilns.

implementing strategic environmental management system. The MoEF formulates policies for the prevention and control of pollution and sustainable use of natural resources. Both DoE and MoEF ensure the cleaner operation of brick kilns through various regulations. Similarly, the Ministry of Power, Energy and Mineral Resources (MoPEMR) sets policies related to use of energy resources, including coal and natural gas that are heavily used by brick kilns. The District Commission Offices are authorized to issue brick burning licenses as per the Brick Manufacturing and Brick Kiln Establishment (Control) Act 2013.

The Ministry of Finance (MoF) is the financial regulator that approves loans from international development partners as well as provides approval to Bangladeshi financial institutions to extend loans to brick operators. The National Board of Revenue sets Value Added Tax (VAT) rules for different categories of brick products.

Industrial associations

The Bangladesh Brick Manufacturing Owners' Association (BBMOA) and Association of Auto Brick Manufacturers (AABM) are two key brick sector associations in Bangladesh. With 4000 members and representing 4000 brick operations, BBMOA speaks for almost 90% of brick enterprises in Bangladesh. Similarly, AABM is a newly formed association of HHK and TK owners that already represents 41 brick enterprises. Formed in 2014, AABM works on behalf of medium to large-scale automatic brick technologies in Bangladesh and strives towards creating a favourable policy and regulatory framework for auto brick industry. AABM has been actively pursuing with Ministry of Industry to declare HHK and TK technologies as an Industry. The Financial ACT 2015 has already included HHK and TK as eligible technologies for a Tax Holiday.

Financial institutions and project developers

Bangladesh Bank, the central bank of Bangladesh, is currently implementing the "Financing Kiln Efficiency Improvement Project" funded by the Asian Development Bank (ADB), establishing itself as one of the key financial institutions in brick sector. Other key ones are Infrastructure Development Company Limited (IDCOL), a semi-governmental financial institution promoting infrastructure and clean energy projects and Industrial and Infrastructure Development Finance Company (IIDFC), a private financial institution that has pioneered brick sector financing in the country. Apart from these, there are many local banks and financial institutions that have been working with Bangladesh Bank in the ADB funded project.

The project developers include private sector firms that own existing traditional brick kilns as well new market entrants that have been increasingly focusing on energy efficient brick kilns.

Suppliers and technical institutions

The technology and equipment suppliers are one of the key stakeholders in brick sector value chain. They not only supply technologies, but also provide support in design and construction as well as training related to machineries. There are private consulting firms as well as individual experts who provide consulting services related to brick projects/programs supported by the Government of Bangladesh and funded and implemented by international development partners and financial institutions.

The Bangladesh University of Engineering and Technology (BUET), Housing and Building Research Institute (HBRI) and Bangladesh Council for Scientific and Industrial Research (BCSIR) are some of the pioneering research, testing and training institutes in Bangladesh. BUET is well known for its technology arbitrage evaluations and is recognized by the Government of Bangladesh. HBRI, headed by the Honorable Minister of Housing and Public Works, is funded directly by the government, and is involved in research and development of building materials, testing and capacity building of the building material sector. Similarly, BCSIR, an autonomous research organization and regulatory body under the Ministry of Science and Technology, is engaged in research and development for the industrial sector of Bangladesh as a whole.

International development partners

International development partners have consistently played a key role in providing both technical and financial assistance to the Government of Bangladesh and different stakeholders in brick sector. Some of the notable agencies and organizations include the World Bank, the Asian Development Bank (ADB) and United Nations Development Program (UNDP).

Review of policies and regulations in relation to brick sector

A number of policies and regulations affect brick sector operation in Bangladesh, either directly or indirectly. These can be divided into four types: environmental, mining, tax and labour related, each one of them described below.

Environmental Regulations

Consent to Establish (Site Clearance), Environmental Clearance and Consent to Operate are three important environmental regulations, the first two regulated by the Department of Environment under Ministry of Environment and Forest and the third one by District Commissioner. Every industrial unit, including the brick kilns, is obligated to obtain Consent to Establish and Consent to Operate while Environmental Clearance (under Category 'Orange B') is given for commercial operation only after Site Clearance is provided. Once consent is obtained, it remains valid for one year, after which it has to be renewed.

Consent to Establish is the most difficult to obtain and the most important as compared to the other two because it is a prerequisite for issuance/renewal of other permits/registration with other Government Departments. The application requires a submission of Initial Environment Examination (IEE), Environment Management Plan (as per the Department of Environment format), and No-Objection Certificate from the Local Government Office, Sub-District Agriculture Office and Department of Forest, among others. The entrepreneur is also required to submit an affidavit stating that the kiln will comply with all environmental regulations including the standard industrial emission standards. There is a provision of kiln's inspection after it becomes operational to check whether it is complying with the regulations. The other conditions for obtaining Consent to Establish are (i) the brick kiln shall be located at a specified distance from certain establishments/areas such as hospitals, schools, forests, rivers, orchards, monuments, highways, railway lines, etc., (ii) the prime agricultural land shall be avoided as far as practicable, and (iii) the brick kilns shall not form clusters i.e. a minimum distance of 500m should be maintained between two kilns. 5044 brick kilns operating in Bangladesh have obtained

Consent to Establish so far. There are, however, around 1700 brick kilns that are operating without license, which reflects poor and irregular inspection by the Department of Environment.

In addition to these regulations, the Department of Environment is also responsible for inspecting whether or not the brick kilns are operating within the permissible limit of emissions, as defined below by the National Air Quality Standard as per Environment Conservation Rule 1997 (corrected in 2005).

Table 1.3 Particulate Emission and SO_2 Emissions Standard (Bangladesh)

Categories	Suspended Particulate Matter [7], PM_{10} µg/ m^3	Sulphur dioxide		Carbon monoxide		Oxides of Nitrogen	
		µg/ m^3	PPM	µg/ m^3	PPM	µg/ m^3	PPM
Industrial and Mixed (1997)	500	120	0.045	5000	4.36	100	0.053
Industrial and Mixed (2005)	150	365	0.14	5000	35	100	0.053

Mining Regulations

The Brick Manufacturing and Brick Kiln Establishment (Control) Act 2013 has put restrictions on collecting raw materials from agricultural land, hill or hillock. The excavation of soil from dead pond, canal, swampland, char land, creek, rivers or fallow land also requires approval from appropriate authorities. The Brick Act 2013, however, has not clearly mentioned who these appropriate authorities are. The Rules related to Brick Act 2013 (under preparation as of Sept 2017) have identified Chairman of the Local Government Authority as the appropriate authority for this purpose. An application for mining, subject to license to operate from the District Commissioner, can then be submitted to Chairman of the Local Government Authority along with a completed application form. Other than the Brick Act 2013, there are no other specific regulations related to mining.

Tax regulations

The Government of Bangladesh has made it mandatory for the brick manufacturers to submit income tax payment certificates for renewing licenses and obtaining environmental clearance certificates[8]. The Department of Environment is responsible for issuing environmental clearance certificate while the District Administration Office provides any permission or renewal of permission. Section 52F of the Income Tax Ordinance (1984) has laid out specific instructions for the collection of tax from brick manufacturers. According to the instructions, the authority responsible for issuing fresh license or permission for renewal will collect advance tax from the brick manufacturers at the following rates[9]:

i) BDT forty-five thousand for one section[10] brick field;
ii) BDT seventy thousand for one and half section brick field;

[7] µg/ m^3 = micro gram per cubic meter
[8] http://archive.newagebd.net/53762/tax-certificate-must-for-brick-field-licence-doe-clearance/
[9] Applicable for Dhk – 7, Ctg – 4 and other regions
[10] 'section' indicates production capacity of the brick field

iii) BDT ninety thousand for two section brick field;
iv) BDT one lakh and fifty thousand for brick field producing bricks through automatic machine.

Similarly, Section 46B has provided tax exemption to industrial undertakings engaged in production of brick using automatic HHK or TK technology (refer to Annex II. Bangladesh. Rate of tax exemption for HHK or TK producers).

Labour regulations
The brick sector in Bangladesh operates in the gray economy, as the sector is yet not recognized as a formal industry. The Department of Labour is the regulatory authority of all Acts or regulations that are relevant to labour rights, labour working conditions and social security benefits to workers. Although brick making is a seasonal business and consists of seasonal migrant workers, the Companies Account (1994) has ensured payment to staff as per commitment. Similarly, the Factories Act (1965), which is applicable to all brick making enterprises with more than twenty employees, has made mandatory, (i) the application of a maximum of an eight-hour-workday with one day off per week, (ii) the provision of safety equipment for coalmen, firemen and other workers, (iii) the availability of basic facilities such as safe drinking water, first aid box, sanitation, etc., and a day care center for any kiln with more than thirty female workers, and (iv) appropriate safety standards in place while entering into the confined space inside the kiln and during firing.

Development projects supporting clean brick production
There are a number of brick sector related development projects that have been implemented in Bangladesh with support from both government and international development partners. Since brickmaking is the largest source of greenhouse gas (GHG) emissions in Bangladesh, an increasing number of projects have focused on introducing cleaner technologies and enhancing energy efficiency of existing technologies with both functional and design improvement. Some notable projects are discussed briefly below with key achievements (as of December 2015) summarized in a table in Annex XII. Summary of key achievements of development projects in Bangladesh.

The Clean Air and Sustainable Environment (CASE) Project (2009-2016)
The Clean Air and Sustainable Environment (CASE), a World Bank/International Development Agency (IDB) funded project, implemented by the Department of Environment (DoE) under the Ministry of Environment and Forest, aims to decrease particulate emissions by 20-30% per brick kiln and GHG emissions by 15-20% per brick kiln by the end of the project through the adoption of cleaner technologies. The project has completed a piloting of ten demonstration projects so far – eight FCK to Zigzag conversions, one improved zigzag and one VSBK. Since there was limited interest in demonstration of VSBK technology, FCK-Zigzag conversion got the topmost priority. These demonstration projects have been able to reduce the particulate emissions as well as GHG emissions as per the project outcome indicators.

HHK CDM Project (2009-2016)
"Improving Kiln Efficiency in the Brick Making Industry in Bangladesh" is a project that utilizes the concept of carbon finance through Clean Development Mechanism (CDM), one of the

financing mechanisms under the United Nations Framework Convention on Climate Change (UNFCCC). The World Bank has acted as a trustee/broker of the Community Development Carbon Fund (CDCF) by also providing all upfront cost related to CDM project development. The project is implemented by Industrial and Infrastructure Development Finance Company (IIDFC) and aims to reduce coal consumption, CO_2 emission and fine particulate matter, and produce approximately 210 million high quality bricks (Class 1) per annum using the new energy efficient technology, Hybrid Hoffman Kiln (HHK). The project currently includes two bundles, with a total of 12 kilns. Although the technology is slightly expensive as compared to other conventional technologies, the project provides financial incentives in the form of carbon benefits, making the technology economically viable. As of February 3, 2015, a total of 17,403 tCO2e Certified Emission Reduction (CER) has been issued, out of which 12,051 tCO_2e CERs have been delivered to the World Bank for the first monitoring period (Sept 2011 – Aug 2012). An additional 50,889 tCO2e of CERs for the period of Sep 2012 – Aug 2014 are under verification.

Improving Kiln Efficiency in the Brick Making Industry (IKEBMI) – The Green Brick Project (2010-2016)

The project titled, "Improving Kiln Efficiency in the Brick Making Industry (IKEBMI)", popularly known as "The Green Brick Project", funded by the Global Environment Facility (GEF) and executed by the United Nations Development Programme (UNDP), aims to remove barriers to the widespread adoption of energy efficient kilns by implementing 16 demonstration energy efficient kilns in a five year period. The project has already made five Hybrid Hoffman Kilns (HHKs) commercially operational as of May 2016 that will contribute towards a total reduction of 16 kilotons of CO_2 emission and six kilotons of coal usage per annum. The project's advocacy role in the Supreme Court of Bangladesh's ruling against brick kilns in 11 ecologically critical areas is also praiseworthy.

Financing Brick Kiln Efficiency Improvement Project (FBKEI) (2012-2016)

The "Financing Brick Kiln Efficiency Improvement (FBKEI)" project is the first of its kind in Bangladesh, providing direct financing to brick operators (in the form of reimbursement) to promote energy efficiency in the brick sector. The project has two separate tracks, (i) upgrade existing polluting FCKs to Improved Zigzag Kilns, and (ii) promote the most advanced brick kiln technologies, including the advanced VSBKs, HHKs and Tunnel Kilns. The project has already disbursed USD 15.82 million as of May 2016, financing five HHKs, two Tunnel Kilns and one Hoffman Kiln. A total of additional USD 25.92 million has also already been approved for financing seven HHKs, four Tunnel Kilns and one Hoffman Kiln. Out of those, two HHKs and two Tunnel Kilns have already got clearance from the ADB and are awaiting Bangladesh Bank's approval and disbursement of fund from the PFI. A total of 300 million bricks are expected to be produced annually from these approved projects.

Brick Kiln Efficiency Program (BKEP) (2014-Present)

Infrastructure Development Company Limited (IDCOL), a special semi-public financial institution, has launched "Brick Kiln Efficiency Program (BKEP)" with a loan facility of USD 50 million (BDT 4 billion) and at an interest rate of 10%. BKEP exclusively focuses on high-end kiln technologies such as HHKs and Tunnel Kilns. BKEP offers upfront financing to brick operators, provided that a substantial portion of the equity has already been mobilized. IDCOL has already approved three Tunnel Kilns and one HHK as of 2015 end, amounting to a total loan disbursement of USD 14.5 million (BDT 1.1 billion) and a total daily production capacity of 0.6 million bricks. The program has effectively addressed existing investment barrier for large-scale energy efficient brick production with a clear certainty of financing before the start of the project.

India

India is the largest producer of bricks globally after China, accounting for an estimated production of 250 billion bricks annually and employing approximately 15 million workers. Building construction in India is estimated to grow at an annual rate of 6.6% during the period 2005 to 2030 that would ramp up the annual demand of walling material to approximately 500 billion brick equivalent masonry units by 2030 (Lalchandani and Maithel, 2013; SAARC Energy Center, 2013c), an increase of 50% relative to current demand. The alternate building materials such as solid/hollow concrete blocks, Fly Ash-Lime-Gypsum (FaL-G) blocks, Cement Stabilized Soil Blocks (CSSB), and Autoclaved Aerated Concrete (AAC) blocks have successfully penetrated Indian market. An interview with brick sector experts revealed that non-fire technologies such as Autoclaved Aerated Concrete (AAC) are rapidly penetrating the market, whose market growth is currently already near 400%. Despite this, conventional firing technologies still dominate the brick market. FCK is the most widely used technology for brick production in India, contributing to 70% of the total production, followed by clamp kilns (20%) and other firing technologies, such as VSBK, HK and ZZK (less than 5%) (refer to table 1.4 below). The Gangetic plains of North India, consisting of the states of Assam, Bihar, Haryana, Punjab, Uttar Pradesh and West Bengal account for India's 65% brick production, the rest 35% is concentrated in the peninsular and coastal India that consist of the states of Gujarat, Orissa, Madhya Pradesh, Maharashtra, Karnataka and Tamil Nadu (Lalchandani and Maithel, 2013). A state that is fairly reflective of the northern plains region and offers many opportunities for brick technology improvement, Bihar has been selected for the case study that follows below.[11]

Table 1.4 Number of brick kilns and annual production in India

Kiln Type	Approximate Number of Kilns	Average Production Capacity (Million Bricks/Year)	Total Annual Production (Billion Bricks)
Clamps/DDK	100,000	0.5	50
MCK	100	3	0.3
FCK	40,000	4.5	180
HDK/ZZK	3,000	5	15
VSBK	100	3	0.3
HK	500	3	1.5
TK[12]	4	NA	0.3
Total	143,704		247

[11] Various states and regions exhibit a diversity of kiln technologies, pollution sources, brick market characteristics, and air pollution levels, and that Bihar is not necessarily representative of the entire country in these respects.
[12] There are 3-4 tunnel kilns operating in India having annual production capacities ranging between 5-15 million bricks in addition to a large tunnel brick plant of Wienerberger (production capacity: ~175 million bricks/year).

	~144,000		**~250**

Source: Compiled by authors as of 2016.

Bihar as a subnational case study

The fertile alluvial soil in the Gangetic plains of India is considered good for brickmaking which explains why large-scale brick production in India is mainly concentrated in this region. The State of Bihar that falls in the Gangetic plains consists of an estimated 6,800[13] brick kilns that produce 19-20 billion fired clay bricks annually, similar to the size of that of Bangladesh. Bihar has been chosen for a subnational case study in this report because it is an important brick-producing region: the state hosts mostly large-scale brick producing industries and its brick production is growing at an annual rate of 9% (DA, 2012).

Market share of brick kiln technologies

Bihar is one of the few states in India that has successfully converted banned MCKs to FCKs without much technical and/or financial support from the Federal Government, which is largely attributed to strict enforcement of the regulation by concerned regulatory authorities in Bihar (DA, 2012). This high conversion has made FCKs the dominant brickmaking technology in Bihar. There are approximately 6700 FCKs in Bihar. Other than FCKs, there are 7-8 natural draught ZZKs, 10-15 induced draught ZZKs and 4-5 VSBKs. The rest are clamp kilns.

In order to improve the ambient air quality in the city of Patna (the capital of Bihar), Bihar State Pollution Control Board (BSPCB), in February 2016, directed all brick kilns located in the vicinity of Patna city to shift to cleaner brick production technologies before the commencement of next brick making season (commencing from December 2016 or January 2017). This region has around 200 brick kilns (FCK technology) and it is expected that around 35-40% of these will upgrade their technology, predominantly to natural draught or induced draught ZZKs, by the end of 2018. As of now, the contribution of fired clay bricks in Bihar is 99%, with only 1% of alternate products, particularly the fly ash bricks. There are currently 100-125 units producing fly ash bricks in Bihar.

The demand for bricks in Bihar has grown at a healthy rate of 7-10% per annum during the last 10-12 years because of economic growth[14] and infrastructure development. The growth in infrastructure development and construction projects has slowed down in recent years because of political instability in the State and the building by-laws being under revision. This has resulted in decreased demand as well as reduced price of bricks. The price of bricks has gone down as much as 20% in the city of Patna[15].

Mapping and assessment of institutions in relation to brick sector in Bihar

The brick sector stakeholders in Bihar can be categorized into five types: regulatory agencies, industrial associations, financial institutions, project developers, suppliers and/or technical institutions and civil society organizations.

[13] Department of Mines and Geology, Government of Bihar (2014-15), http://mines.bih.nic.in/

[14] Economic Survey, Government of Bihar

[15] Based on the feedback received from various brick makers.

The Department of Environment and Forest (DoEF), Bihar State Pollution Control Board (BSPCB), State Environment Impact Assessment Authority (SEIAA), the Department of Mines and Geology (DoMG), the Department of Labour Resources (DoLR), the Department of Commercial Taxes (DoCT) and District Industries Center (DIC) are the key regulatory agencies. While the DoEF oversees the overall implementation of environmental policies in the State, BSPCB does the crucial job of issuing 'No-Objection Certificate (Consent to Establish)' and 'Operation Certificate (Consent to Operate)' to brick kiln enterprises along with regular inspection of those kilns to ensure compliance with environmental regulations. SEIAA issues environmental clearance for Category 'B' projects and also appraises mining activities of B2 Category brick kilns. While the DoMG performs an important function of issuing clay-mining license to brick kilns and collecting mining royalty, the DoCT collects the value-added tax on sale of bricks. The DoLR plays a key role of bringing the brick operators under Factories Act, and implements various labour and employment related laws applicable to the brick industry sector, including rules for minimum wages and social security benefits to the workers. The DICs promote the medium, small and micro enterprises at the district level. All these regulatory agencies suffer from limited human resources and technical expertise, leading to poor inspection of brick kilns and weak implementation of regulations. The DoLR, for instance, department is currently running at 30% of its sanctioned human capacity.

United Bank of India (a nationalised commercial bank), Bihar State Financial Corporation (a state-owned development sector bank) and Madhya Bihar Gramin Bank are the three major financial institutions in Bihar. Barman (2016) has reported that Bihar State Financial Corporation might have financed few brick kiln projects in the past, but Madhya Bihar Gramin Bank's experience with brick sector is not positive because of a high percentage of defaults in the past. All three institutions are well placed to provide loans to brick enterprises if there are government supported brick sector projects with appropriate risk mitigation mechanisms.

Industrial Finance, Enterprise Development & Project Services Division (IFEDPRO) of the Bihar State Financial Corporation (BSFC), Raj Industrial & Technical Consultancy Organization (RITCO), National Productivity Council (established by the Ministry of Industry, Government of India), Bihar Board of Open Schooling & Examination (BBOSE), and Industrial Training Institutes (ITIs) under the Directorate General of Employment & Training (DGET), Ministry of Labour & Employment are some of the technical institutions in Bihar that also provide project development services. The ITIs, in particular, have an adequate expertise in vocational training, with extensive geographical outreach. There are roughly 60 government-owned and approximately 600 private ITIs/ITCs in the State that could potentially deliver training/courses in brick manufacturing.

In Bihar, brick sector associations are limited to the district level, are small in number, mostly informal in nature, and not as effective as in other brick producing states of India in terms of having regular meetings, building consensus among the members on any issue, negotiations with the government, etc. The fly ash brick manufacturers have an association, the "Bihar Fly Ash Brick Industry Association", which has recently been active in pushing the government for policies promoting fly ash bricks, with support from interdepartmental task force on cleaner building materials.

Asian Development Research Institute (ADRI), Nidan, Public Health Environmental Engineering Trust, and Mascot Foundation are some well-recognized civil society organizations in Bihar that have good expertise in environmental impact assessment in relation to mining activities and previous experience of working with the unorganized and informal sector of the economy, that includes major brick making clusters in the State. The brick sector in Bihar generally suffers from inadequate involvement of both financial institutions and civil society organizations. The government agencies are playing a fair bit of their role, but could be expanded to make their services more enterprise friendly. The technical institutes have extensive experience in various sectors, although focus little on the brick sector. The State government could potentially draw the attention of both public and private financial institutions with government supported brick sector programmes for small and medium sized enterprises.

Review of policies and regulations in relation to brick sector in Bihar

A number of policies and regulations affect brick sector operation, ranging from mining of clay to sale of bricks. These can be broadly categorized into four types – mining, environmental, labour and tax related (see figure below). Each of them is discussed separately below.

Environmental Regulations

Environmental Clearance, issued by the State Environment Impact Assessment Authority (SEIAA), and Consent to Establish (No Objection Certificate) and Consent to Operate, issued by Bihar State Pollution Control Board (BSPCB) are three important environmental regulations that affect brick operation in Bihar. Category ‘B2’ projects involving mining of minor minerals, with mining lease area less than 5ha, and Category ‘B1’ projects where the excavation sites form clusters (where distance between two excavation sites is less than 500 m) are obligated to obtain Environmental Clearance. The clearance for Category ‘B1’ projects is issued only after conducting an Environment Impact Assessment (EIA). Similarly, every industrial unit, including the brick kilns is obligated to obtain both Consent to Establish and Consent to Operate. Some additional conditionalities to obtain these clearances are listed in Annex IV. Bihar Environmental Regulations.

The Bihar State Pollution Control Board (BSPCB) is also responsible for inspecting whether or not the brick kilns are operating within the permissible limit of emissions, as defined below by the Ministry of Environment and Forest (MoEF) in its emission standard (2009). This standard for brick kilns applies only to Particulate Matter (PM) emission. The MoEF has already initiated an amendment process to revise these standards so as to make them more environmentally stringent and promote cleaner production technologies. In addition, the Central Pollution Control Board (CPCB) has issued a directive to all State Pollution Control Boards (SPCBs)[16] to shut down all brick kilns in their respective states that have been operating without permission and valid consent from SPCBs and not meeting norms and siting guidelines.

[16] IPC-V(SSI)/Brick Kiln/2017 dated 27.06.2017

Table 1.5 Emission standards for brick kilns in India (Ministry of Environment, Forest and Climate Change, Government of India)

Type of brick kiln	**Standard (maximum permissible emission limit) for total PM emission (in mg/Nm^3 measured at stack port[17])**
FCK (Production capacity < 15,000 bricks/day)	1000
FCK (Production capacity > 15,000 bricks/day)	750
DDK[18]	1200
VSBK	250

The implementation of these regulations has been weak because of limited human resources and technical expertise. In particular, only 2300 brick kilns in Bihar, representing 34% of the total brick kilns in the State, have obtained environmental clearance as of April 2015 (GKSPL, 2015b). This leaves a huge proportion of total production outside of government regulation. Similarly, the fly ash reutilization enforcement has also been ineffective because of lack of economic incentive to make it commercially profitable. There is also poor and irregular inspection of kilns owing to limited manpower at BSPCB's disposal.

Mining regulations

The Department of Mines and Geology issues permits for brick earth mining that is mandatory for brick earth quarrying or excavation. The Bihar Minor Mineral Concession Rules 1972 and its amendment in 2014 states that the mining area should be less than 5 hectare, and depth of clay mining should not go beyond 3m (contradictory to the 2m depth limit required by SEIAA for Environmental Clearance). Blasting is not permitted under this regulation. The mining area is required to be at a minimum specified distance away from restricted or protected areas such as forests, rivers, railway lines, flood embankment, and others. The miner is also liable to restore the excavated pit after the operation is complete.

To get a mining permit, the incumbent must first obtain an Environmental Clearance from SEIAA and submit an application form with proof of ownership of land as well as mining plan. The application fee is INR[19] 200 for clamp kilns and INR 2000 for all other types of brick kilns. The permit, once obtained, is valid for five years.

The royalty on clay mining is charged at a rate of INR 11.60 per cubic meter of clay mined (equivalent of 400 bricks). The Department of Mines and Geology has limited capacity to keep track of frequency and amount of clay mined from different parts of the State, resulting in ineffective collection of royalty. In order to address this challenge and to also reduce the transaction cost of royalty collection, the Department has introduced a consolidated royalty system. Under this system, the State has been classified into different regions based on market

[17] The stack port is usually located at a height of 7-10 m in the stack/chimney from the kiln top surface in case of FCK or ZZK, where the stacks are 20-30 m tall. Usually located at around one fourth to one third of the height of the chimney.

[18] DDK is a small, intermittent, batch type kiln prevalent in Southern India. Typical production capacity ranges between 20,000 – 40,000 bricks per batch. For smaller production capacity, DDK is an improvement over the clamp kiln.

[19] US$1 = 67 INR

demand of bricks, and an average production capacity is estimated for brick kilns operating in those regions. A consolidated royalty amount is then determined based on the production capacity of bricks in each region (see the table below). This amount can be paid in two instalments – 50% before mining and 50% before 31st March of each mining season. There is an incentive of 5% rebate for those who make the payment in a single instalment.

Table 1.6 Consolidation of royalty amount on mining of brick earth (GKSPL, 2015b)

Districts and regions	Estimated average production capacity (number of bricks produced per year per kiln for a specific region)	Consolidated royalty amount (INR/annum)
Urban areas of the districts of Patna, Muzaffarpur, Bhagalpur, Gaya and Darbhanga (i.e. major cities of the State)	4,500,000	130,500
Urban areas of other districts (mostly consists of smaller towns)	3,500,000	101,500
Rural areas	2,500,000	72,500
Clamp kilns in all areas*	100,000	4,350

***No royalty is collected on bricks produced from clamp kilns for non-commercial or personal consumption.*

The Department of Mines and Geology has reported that most brick kilns operating in the State have obtained mining permits, on account of which the Department also has the most extensive brick kiln database in the State. Through its district offices, the Department effectively enforces mining regulations and collection of royalties. Since the Department has made the previous issuance of mining permit and submission of royalties as prerequisites for the renewal of permit, there is a negligible rate of non-compliance.

Brick sector experts have opined that the restriction on depth of clay mining needs reassessment because of the contradiction between mining and environmental clearance regulations. The agricultural experts have recommended segregating mining zones into different clusters based on the quality of soil so as to allow mining activities in only those regions having low quality of soil for agricultural purposes.

Tax regulations

A 5% Value Added Tax (VAT) is levied on the retail price of all bricks as per the Bihar Value Added Tax Rules of 2005. The Department of Commercial Taxes has made it mandatory for all brick kilns to register with it and pay applicable VAT on the sale of bricks. The Department has simplified the tax system by introducing a compounding system of tax and allocating a lump-sum tax amount based on districts and regions where the brick kilns are operating. The lump sum amount is revised regularly. The current lump sum allocation is presented in the table below.

Table 1.7 VAT levied on brick kilns as per the compounding system (GKSPL, 2015b)

Districts and regions	Estimated average production capacity (number of bricks produced per kiln for a specific region)	Lump sum tax amount (INR; US$1 = 67 INR)
Urban areas of the districts of Patna, Muzaffarpur, Bhagalpur, Gaya and Darbhanga (i.e. major cities of the State)	4,500,000	115,000
Urban areas of other districts (mostly	3,500,000	92,000

consists of smaller towns)		
Rural areas	2,500,000	69,000

The Central government has also levied clean energy cess on the gross quantity of raw coal produced in or imported to India. The cess is levied at the production or import source and is contributed to the National Clean Energy Fund (NCEF). The cess stands at INR 200 per ton of coal as of fiscal year 2015/16. Since the cost of cess is included in the price of coal when it is sold to brick kilns, all brick operators are already paying this cess. It is estimated that the Bihar brick industry currently consumes around 3.5 million tons of coal annually, contributing approximately 700 million INR (roughly US$10.5 million) to the NCEF.

An interview with the government officials and brick enterprises (GKSPL, 2015b) has found that a majority of brick enterprises have been duly paying VAT. Such compliance has been further supported by the fact that the SEIAA has made it mandatory for brick kilns to submit the VAT registration certificate as well as VAT payment receipt during the evaluation of applications for 'Environmental Clearance'.

Labour regulations

The Department of Labour Resources is the regulatory authority of all Acts or regulations (listed in Annex V. Bihar Labor related regulations) that are relevant to labour rights, labour working conditions and social security benefits. The brick making is a seasonal business, and primarily consists of seasonal migrants from different parts of the State or the country. Most workers live at the kiln sites because they usually migrate from distant places for work.

It is mandatory for all brick kilns in Bihar to register with the Department of Labour Resources (DoLR) under the Factories Act, and non-registration leads to monetary fine if found guilty by the judicial system. Despite that, only 1000 out of 6800 brick kilns in Bihar are registered with the DoLR, and a further 1000 are under prosecution for not adhering to labour regulations (GKSPL, 2015b). Experts say that such non-adherence to these regulations is because of poor inspection by the DoLR, long judicial process to bring the offenders to book, and DoLR registration permit being non-mandatory for getting environmental clearance and mining permit from other government departments.

One of the major constraints in guaranteeing the workers their social security benefits and implementing the provision of provident fund and other social welfare schemes is the seasonal nature of brickmaking industry. Most traditional brick kilns do not operate during rainy season, and the labourers are brought in only during operating season. This is done primarily through contractors, often times sourced from far-away places. Since the labourers are contracted externally and do not fall on the brick kiln owner's payroll, they are automatically excluded from the provisions of minimum wages and other social security benefits. Even for labourers employed directly by brick kiln owners, the seasonal nature of operation has created high turnover of workers because they look for other employment opportunities during off-season and might not come back to the same brick kiln later. This high turnover of labourers has discouraged most brick owners to design relatively long-term incentive schemes for labourers.

To ensure effective implementation of labour regulations, the human and technical capacity of the DoLR must be strengthened first so that a regular inspection of registered kilns and identification of unregistered ones is possible. Similarly, there should be interdepartmental collaboration within government to streamline permitting. Finally, to ensure that the social welfare schemes are properly implemented, the DoLR should develop a database to track all workers to assure them of their benefit entitlement wherever they might work. Further, the government should design economic incentive schemes to encourage brick kilns to mechanize brick operation so that the workers are not exposed to harsh working conditions.

Development projects supporting clean brick production in Bihar

In recent years, 'Shakti Sustainable Energy Foundation' has supported some projects in the brick sector of Bihar, including training programme for brick makers and officials of the State Pollution Control Board on cleaner brick production practices. The most notable project was the constitution of an interdepartmental task force (June 2012) for "accelerating cleaner production systems in building material sector" and its functioning. Various initiatives have been taken up by the task force for promoting cleaner brick production in Bihar, such as, (i) revising the schedule of rates of Public Works Department (PWD) to remove the mismatch between the rates of fly ash and fired-clay bricks; (ii) facilitating setting-up demonstration brick production units; (iii) organizing awareness generation seminars; (iv) recognizing the efforts of brick makers who have set up brick manufacturing units using cleaner technologies through special awards. These initiatives have resulted in establishment of a few brick production units based on cleaner firing technologies. In addition to that project, Shakti implemented a one-year technical support programme to assist the brick makers of Patna to upgrade their kiln technology and its operation to comply with the recent directive of Pollution Control Board. The main elements of this support programme were: (i) awareness generation among the brick makers about cleaner technology options, their operation, associated cost and benefits; (ii) preliminary feasibility assessment of kilns and assistance in selecting suitable technology option; (iii) guidelines on best practices in the design and construction of kilns; (iv) handholding technical support in commissioning and operation of kilns.

Nepal

The construction sector is the sixth largest economic sector in Nepal after agriculture, trade, transport/communications, real estate, and education. According to the Federation of Contractors' Association of Nepal (FCAN), the construction industry contributes 10-11% to national GDP, and uses approximately 35% of government budget. The industry is expected to grow in the aftermath of 2015 earthquake, due to huge demand for new and reconstructed buildings. In an economy where brick has been the preferred building material, this surge in demand for buildings is certain to increase the demand of bricks as

> **Post-earthquake assessment**
>
> The 2015 earthquake damaged most of the brick kilns, mainly the chimneys, ducts and fans. This resulted in a 50% reduction in brick production in 2015. The repair work has been constrained by the expensive cost of labour and lack of financial resources. An average of NPR two to three million (roughly US$20,000-$30,000) is expected to be required for full-fledged repair and renovation activities.
>
> Even while supply remains depressed, according to the Government of Nepal, the demand for bricks is likely to increase to 12 billion bricks annually, almost more than twice the current annual production (MinErgy, 2015). This is owing to an increased demand from post-earthquake reconstruction work.

well. The Government of Nepal has estimated that brick demand might increase nearly fourfold in the coming years as compared to 2013-14.

An estimate based on the data from the Federation of Nepalese Brick Industries (FNBI), recent studies (e.g. SAARC Energy Center, 2013a) and interviews with brick sector experts in Nepal reveals that there are approximately 1600 brick kilns operating in Nepal with an annual production of 5 billion bricks. Only around 8% of the total brick kilns operate in Kathmandu Valley. MCKs and FCKs are the most widely used technologies in Nepal, although efforts are now underway to switch from MCKs to FCKs and/or ZZKs with technical support from bilateral agencies, international NGOs and private sector experts. VSBK has not succeeded much despite technical assistance from Swiss Development Cooperation (SDC). Ample opportunities for non-fired solutions exist, but little international support has been observed to date. The following table summarizes the number of kilns by technology types for both Kathmandu Valley and Nepal as a whole.

Table 1.8 Number of brick kilns and annual production in Nepal

Kiln Type	Approximate Number of Kilns	Average Production Capacity (Million Bricks/Year)	Total Annual Production (Billion Bricks)
Clamps/DDK	450	0.3	0.15
MCK	50	4	0.2
FCK	950	4	3.8
HDK/ZZK	120	5	0.6
VSBK	20	3	0.06
HK	5	17.5	0.09
HHK	0	NA	-
TK	0	NA	-
Total	**1595**		**4.9**

Source: Compiled by authors based on estimates by FNBI and data from SAARC Energy Centre (2013a) as of 2016

Kathmandu Valley as a subnational case study

122 brick kilns are estimated to be operating in Kathmandu Valley (the Valley consists of three districts – Kathmandu, Lalitpur and Bhaktapur) with an annual production of 600 million bricks (slightly more than 10% of national brick production). While the total number of kilns in Kathmandu Valley is less than 10% of the national figure, the concentration of these kilns in a relatively small area (220 square miles, roughly the same size as San Francisco), the bowl-shaped topography of the Valley (restricting air movement) and the relative abundance of researched data makes it an interesting case study.

Market share of brick kiln technologies in Kathmandu Valley

There are five main brick kiln technologies operating in Kathmandu Valley, namely Fixed Chimney Kiln (FCK), Vertical Shaft Brick Kiln (VSBK), and Hoffman Kiln (HK). Variants of FCK exist in the Valley – Natural Straight FCK and Forced Straight FCK etc, among which Natural Straight FCK is the most popular one. Since the Government of Nepal has banned the operation of MCKs in Kathmandu (came into effect in 2004) and Clamp Kilns have also been phased out already, there is a shift towards adoption of FCK, particularly the zigzag one. The uptake of VSBKs has been relatively low in Nepal as compared to rest of the South Asia, with only thirty-eight kilns in Nepal, including three (only one functional as of 2016) in Kathmandu

Valley. The low uptake of VSBKs has been attributed to inferior quality of bricks produced and also to higher per unit investment requirement than other brick kilns.

Mapping and assessment of institutions in relation to brick sector

The brick sector stakeholders in Nepal can be categorized into five types: regulatory agencies, industrial associations, financial institutions, technology and service providers and international development partners and NGOs.

Regulatory agencies

Most brick industries in Nepal qualify as cottage industries and therefore fall within the jurisdiction of the Department of Cottage and Small Industries (DCSI) of the Ministry of Industry, which is responsible for verifying the Initial Environmental Examination (IEE) or Environmental Impact Assessment (EIA)[20] required of any brick kiln and subsequently for making a decision on the license application. A no-objection letter, on behalf of local community and local government administration, from the village development committee (VDC) or municipality of the area where the kiln is to be located is also necessary for the license application to be considered. In addition, the DCSI is tasked with the monitoring of brick kilns for complaints of adverse environmental impacts and for making recommendations to the Industrial Promotion Board, which devises policy on investment in industry, on any concessions or incentives that may be granted to cottage and small industries. The Ministry of Population and Environment (MoPE) also plays an important role in regulating the brick sector with respect to environment protection and pollution control: it is charged with issuing pollution standards and monitoring to ensure compliance with those standards. The Department of Inland Revenues (Ministry of Finance) and Industrial Promotion Board (IPB) and the Department of Urban Development and Building Construction (DUDBC) are also important government stakeholders.

Industrial associations

Federation of Nepal Brick Industries (FNBI), VSBK Entrepreneur Association, Federation of Contractors' Associations of Nepal (FCAN) and Federation of Nepal Cottage & Small Industries (FNCSI) are four key industrial associations relevant to Nepal's brick sector. FNBI is the federation of all district level brick entrepreneur associations that lobbies with different stakeholders on behalf of nationwide brick entrepreneurs for the growth and welfare of the industry. Similarly, VSBK Entrepreneur Association does the same, but limited to only VSBK entrepreneurs. FCAN is an umbrella association of all construction companies of Nepal and has five regional and 75 district associations as general members and 253 construction companies as associate members. FNCSI is an umbrella organization of micro, cottage and small entrepreneurs of Nepal, and has district chapters, national level commodity associations and some associate members.

FNBI has recently formed a sub-unit called Technology Research and Development Committee (TRDC) to carry out different activities related to improved energy efficiency, reduced pollution and other pertinent issues of the brick sector (SAARC Energy Secretariat, 2013a).

Financial institutions

[20] IEE required for brick industry with annual production capacity of 20 million units or less; IEA required for brick industry with annual production capacity above 20 million units.

The brick kiln operators in Nepal have limited access to bank financing or commercial loans because of the non-recognition of brick sector as a formal industry. According to SAARC Energy Center (2013a), 54% of registered kilns in Nepal are single proprietorships, operating mostly without commercial financing. Despite this, the Switch Asia Project has reported that the Clean Energy Development Bank (CEDB), now merged with NMB Bank, provided a total loan of EUR 250,000 for VSBK projects (GFA, 2016). NMB Bank has positioned itself as a leading player in renewable energy and agribusiness in Nepal and thus, can be considered as a major financial institution that is well acquainted with brick projects.

Technology and service providers

MinErgy Pvt. Ltd., PACE Nepal Pvt. Ltd. and Innovative Machineries Pvt. Ltd. are three key technology and service providers in Nepal's brick sector.

MinErgy evolved from the Swiss Agency for Development and Cooperation (SDC)'s Vertical Shaft Brick Kiln (VSBK) Project in Nepal, and has since then been providing technology services for the construction and operation of several brick kiln technologies. The company also works with other stakeholders in promoting energy efficiency measures, for instance substitution of coal by cleaner fuels, in existing brick kilns. Lately, the company has been proactively making efforts to help transfer the know-how of modern energy efficient kilns such as TKs to the Nepali market.

PACE Nepal provides services in the areas of industrial energy efficiency, productivity, energy auditing and environmental monitoring. In the past, PACE Nepal had completed a baseline study of several industries for Nepal Energy Efficiency Programme (NEEP). Brick sector was one of the industrial sectors for that baseline study.

Innovative Machineries has recently launched a locally designed and manufactured soft moulding brick making machine called "Innovative Brick Making Machine" that has a production capacity of 32,000 bricks per day. The company also offers after sales service along with design and fabrication of other relevant machineries.

International development partners and NGOs

Danish International Development Agency (DANIDA), Swiss Development Cooperation (SDC), the Asian Development Bank, Norwegian Agency for Development Cooperation (NORAD), International Finance Corporation (IFC) and International Centre for Integrated Mountain Development (ICIMOD) are the key international development partners that have supported a number of brick sector projects in Nepal. Similarly, BrickClean Network (BCN), an informal network of NGOs working in the brick sector, particularly within the brick kilns, and Winrock Nepal are important non-government players in this space.

Review of policies and regulations in relation to brick sector

A number of government regulations that have general provisions to promote cleaner technologies and energy efficiency also apply to brick sector. These include but not limited to Environment Protection Act 1997, Environment Protection Regulation 1997, Industrial Enterprises Act 1992, and Industrial Policy 2010. The table in Annex VI. Nepal Government decisions pertaining to cleaner technology in the brick sector summarizes a list of government decisions that are specifically applicable to brick sector. The most consequential among these was the 2009 decision to replace all MCKs in the country with modern kilns within two years (by the end of 2011). The definition of modern kilns included HHK, TK, VSBK and FCK. Some districts were granted a one-year extension to comply with this directive (MoPE, 2017). A similar ban on clamp kilns and MCK in Kathmandu Valley was applied sever years earlier, including the requirement to maintain a minimum radius of 200 feet from the center of the kiln and to submit plans for mining the soil. The kilns were also prohibited from using firewood, rubber tires or plastic as fuel (ibid).

The government has introduced few other policies to incentivize the introduction of cleaner technologies. In 2010, the government provided exemption to VSBK from having to obtain permission from the local District Forest Office, recognizing it as a technology that is not reliant on wood as a fuel. VSBK was previously required to maintain a 2km distance from the nearest forest (Premchander et al., 2011). FCK and MCK are still required to maintain a minimum distance of 500m from the nearest forest. The government has also promulgated standards of minimum stack height and maximum PM emissions for different kiln types. The newly proposed standards are listed in the table below.

Table 1.9 Proposed brick kiln emission standards as of 2009

	BTK (Natural Draft)	**BTK (Induced Draft)**	**VSBK**	**HHK**	**TK**
Stack Height (Minimum Limit)	30m	17m	15m	7m	10m
PM Emission Standard (Maximum Limit)	500mg/Nm^3	250mg/Nm^3	250mg/Nm^3	200mg/Nm^3	100mg/Nm^3

Source: MoPE, 2017

The enforcement of these various regulations and standards remains lax, and there are still many clamp kilns and MCKs operating in the country after many years of ban. The excise duty exemptions given to cleaner technologies also did not have desired effect because of its low magnitude of exemption. VAT exemption has not been tried as an incentive to promote energy efficiency improvement in the brick sector and would be impractical without VAT registration of the majority of brick kilns in the country. Indeed, government records indicate that only 150 have come into the VAT network (Republica, 2012). Apart from the lack of enforcement, the low penalties (if any) applied to brick kilns that fail to meet the established pollution standards remains a notable policy failure.

After the April 2015 earthquake, the Department of Urban Development and Building Construction (DUDBC), Government of Nepal, along with international agencies, released a design catalogue on earthquake resistant houses for rural areas in October 2015, “Design Catalogue for Reconstruction of Earthquake Resistant Houses, Volume 1 (DUDBC, 2015).” The acceptance of the building models in this catalogue is low among the public because of limited flexibility in design (Okapi, 2017a).

Development projects supporting clean brick production

The history of projects promoting energy efficiency and reduced pollution from brick kilns in Nepal dates back more than 25 years. The Government of Nepal’s development partners have been implementing various programs and projects related to brick sector since early 1990s. Some of the notable ones include are briefly described below.

ESPS (1999-2005)
Under the Environment Sector Programme Support (ESPS) (1999-2005), DANIDA supported the switch of most MCKs to FCKs in the Kathmandu Valley. The Institute of Environment Management (IEM) provided technical assistance for this project.

VSBK Transfer Programme (2003-2011) (Premchander et al., 2011)
Funded by the Swiss Development Cooperation (SDC), the VSBK Transfer Programme started in 2003 with Swiss Resource Centre and Consultancies for Development (SKAT) as an implementing partner. The fourth phase of this programme started in 2008 with VSBK track as one of the thematic components. The VSBK track had a specific focus on dissemination of cleaner brick firing technologies.

The project was successful in reaching a market penetration of 5%, amounting to a total of 26 VSBKs installed in the country. The 26 units have a total of 58 shafts and an annual production of about 75'000'000 bricks. A similar project in India could make a market penetration of only 0.2%. The project faced a number of teething problems in the beginning as the sensitivity of the technology to proper soil selection and green brick making and the lack of familiarity of the entrepreneurs with the technology led to inconsistent quality in production and skepticism from existing brick entrepreneurs, but the project gained momentum after 2008 as 20 VSBKs were constructed with a subsidy per kiln of NPR 400,000-450,000 as well as technical assistance.

A few important policies of the Government of Nepal led to such high penetration in Nepal, namely

- The Department of Forest under the Ministry of Forest and Soil Conservation recognized VSBK as a non-forest fuel wood industry, lifting the certification requirement of forest distance from the plant (5km).
- The Government of Nepal banned the construction and operation of MCKs in Kathmandu Valley by 2003 and all over the country by 2011. This led to shift towards either different forms of FCKs or VSBKs.

This success has also been attributed to a sound technical team involved in project implementation. An external review of the project done by Premchander et al. (2011) states that the favorable policy atmosphere greatly contributed to the success this project has achieved. The same review, however, reports that a closer engagement with the Government of Nepal and local entrepreneurs could have led to ensuring sustainability of this project after its phase out in 2011.

SCP Project (2012-2015)
The VSBK and Other Sustainable Construction Practices (SCP) Project, funded under the SWITCH-Asia Programme of the European Union, aimed at reducing energy consumption and CO_2 emissions from the production of bricks and other building materials by both creating an enabling policy and regulatory framework and mobilizing private sector for the use of green building materials and solutions. The project has also helped entrepreneurs access bank financing for cleaner technologies and energy efficiency. Unlike the VSBK Transfer Programme, the EU project's emphasis was not on kiln owners and instead offered technical assistance to technology

providers and kiln construction companies, although VSBK technology remained critical to the project, with the establishment of 35 additional VSBKs as one of the project outcomes.

CCAC Brick Initiative (2016-17)

The Climate and Clean Air Coalition (CCAC) implemented the Nepal country component of its brick initiative (2016-2017) for the promotion of cleaner brick production practices to achieve reductions in black carbon and CO_2 emissions with health and development co-benefits.

Nepal Clean Bricks Initiative (2016-21)

The Department for International Development (DFID) and the International Centre for Integrated Mountain Development (ICIMOD) have signed a five-year arrangement, titled the ‘Nepal Clean Bricks Initiative’, that will be operational from 2016 to 2021. This project will concentrate on the modification, mechanization and upgrading of technology for cleaner brick production in Nepal, and will promote alternative building materials and energy sources, support environmental policy development, and work on building the capacity of stakeholders, and evaluating the impacts of a cleaner brick industry in the country (ICIMOD, Undated).

Chapter 2. Technical and Economic Assessment of Baseline and Clean Technologies

South Asia is home to nearly a quarter of total global brick production (Baum, 2015). The types and methods of brick production in this region are, more or less, similar in all brick producing countries. Following are the dominant ten methods (GKSPL, 2014) that are used in most brick producing countries in South Asia, including Bangladesh, India and Nepal, listed in ascending order from the oldest, least efficient technology to the newest, most efficient or cleaner technology.

1. Clamp Kilns

Clamp kilns are the simplest types of and intermittent kilns that have no permanent structure. On a base of fired bricks, further layers of green bricks are stacked with interspersed combustible material. This method suffers from non-uniform combustion and a high percentage of heat loss, proving to be a highly inefficient method. There is usually no chimney on the kilns. Therefore, they are extremely polluting. These kilns have, therefore, been phased out in most South Asian countries except for India where they still account for 20% of total annual production of bricks. It is also believed there are numerous unregistered clamp kilns in Nepal outside of Kathmandu Valley.

2. Down Draught Kiln (DDK)

An intermittent kiln in which bricks are fired in batches, Down Draught Kiln (DDK) utilizes the concept of downward draught. The hot gases from burning of fuel are first deflected to the roof of the kiln, which are then drawn downwards with the help of chimney draught and passed through stacks of green bricks. Similar to clamps kilns, since the fire needs to be shut down and the entire kiln has to be cooled down to finally unload the fired bricks, there is no possibility of heat recovery. The non-uniform distribution of heat also leads to non-uniform firing of bricks, producing a low percentage of high-quality bricks.

3. Mobile Chimney Kiln (MCK)

The Mobile Chimney Kilns (MCKs), also called Mobile Chimney Bull's Trench Kilns (MCBTKs), replaced most of the clamp kilns in early 1950s. These kilns are circular or elliptical in shape where green bricks are arranged in a row of two or more in a trench that is dug into the ground. The bricks are stacked in such a way that fuel can be fed inside through holes between brick rows that also allow air circulation. Chimneys are placed on top of the brick stacking and are manually moved around as the firing progresses. This is why these are called "mobile" BTKs. The portable nature of chimneys, however, restricts their height, leading to higher exhaust temperature, and thereby a lesser reutilization of exhaust gases. The fuel economy of such kilns, therefore, is much less than that of more modern brick kiln technologies.

4. Fixed Chimney Kiln (FCK)

Fixed Chimney Kiln (FCK), also called Fixed Chimney Bull's Trench Kiln (FCBTK), is the most popular technology in South Asia where the chimney (20-38m high) is fixed. The fire is continuously burning and the stacks of bricks continuously revolve in a closed oval or circuit towards the direction of airflow because of the draught provided by a fixed chimney. The green bricks are stacked in multiple rows between the outer and inner wall of the kiln. The three distinct zones (brick firing zone, brick pre-heating zone and brick cooling zone) ensure that the bricks are being simultaneously fired, warmed and cooled. On a daily basis, the fired bricks are taken out from the cooling zone and an equivalent number of green bricks are loaded ahead of the pre-heating zone. To maintain a steady supply of fuel, there are a number of feedholes at the top of the kiln.

5. Zigzag Kiln (ZZK)
Zigzag Kiln (ZZK) is a slight modification of FCK technology. There are two types of ZZK:

Natural Draught Zigzag Firing kiln (ZZK ND)
In Natural Draught Zigzag Firing Kilns (ZZK NDs), the bricks are stacked in multiple rows between the outer and inner wall of the kiln in a zigzag fashion so that airflow also zigzags through the kiln, resulting in more efficient combustion of fuel and more uniform firing of the bricks. It is called natural draught kiln because of the natural draught provided by a chimney (30-40 m high) located at the center of the kiln.

High/Induced Draught Zigzag Firing kiln (ZZK HDs)
High/Induced Draught Zigzag Firing kilns (ZZK HDs) are similar to ZZK NDs except for the draught provided by a fan. The chimney is, therefore, of a lesser height (15-30m) and usually placed at the center of the kiln. These kilns are more energy efficient than their predecessors, FCKs and ZZK NDs.

6. Hoffman Kiln (HK)
Hoffman Kilns (HKs) have similar working principles as those of FCKs except for the fact that HKs have a permanent roof and shade, increasing the capital cost by almost twofold. HKs have much better insolation than FCKs and therefore improve the performance of energy efficiency. This increase in cost is also, however, justified by the fact that quality of bricks from HKs is better than that from FCKs. HKs can also be used to exclusively produce value-added products like roofing tiles and hollow bricks, which is not possible in the case of FCKs. HKs also offer better occupational health and safety conditions to the workers, which in most of the cased are linked with use of machineries.

In HKs, the fire continuously burns and moves forward through the stacked bricks because of the draught provided by a chimney (25-25m high) or a fan. Fuel is regularly fed through feedholes in the roof of the kiln. The chimney is located at one side of the kiln, and is connected to the central flue duct of the kiln through an underground duct. The three distinct zones of HKs are similar to those of FCKs described above.

7. Vertical Shaft Brick Kiln (VSBK)
Vertical Shaft Brick Kiln (VSBK) is an improvement over traditional up-draught technology used in rural China in the 1950s. VSBK is a continuous, updraft, moving ware kiln in which bricks are stacked in a vertical shaft of rectangular or square cross-section. The entire shaft (6-10m high) is divided into three distinct zones – the top pre-heating zone, where green bricks are loaded, often with crushed coal or briquettes; the middle firing zone, where fuel combustion

takes place; and the bottom cooling zone where the fired bricks are cooled down with the help of cold ambient air entering the shaft. VSBK usually comprises two or more shafts, and each shaft is connected to two chimneys, located diagonally opposite to each other, and green bricks are loaded to the top with the help of a lift or a conveyor belt. The kiln works based on the principle of counter current heat exchange and laws of convection, where hot air is continuously moving up and the fired bricks are moving down.

VSBK is considered as one of the more energy efficient technologies because of efficient heat transfer and a minimal heat loss, further improved by sufficient insulation around the kiln. However, this technology never has been scaled up in SAR, though after strong supports from development programs in several countries. This was mainly due to the complexity of operation, its sensitivity to the quality of soil, and the quality of the brick products (lower burning temperature leading to lighter color and lower strength) in general.

8. Hybrid Hoffman Kiln (HHK)

The fire movement, draught principles as well as three different zones of Hybrid Hoffman Kilns (HHKs) are similar to those of HKs. A major distinction is a separate drying or pre-heating chamber (with roughly 8 tunnels) where green bricks produced by mixing powdered fuel with clay are dried and pre-heated, reutilizing the hot flue gases diverted to these drying tunnels through a duct connected to the central flue duct of the kiln. The hot flue gases are then finally released into the atmosphere through a rectangular opening of five to six meters in height. HHKs do not have high chimneys for release of flue gases. It is not necessary, since most of the PMs have been scrubbed off while the flue gas goes through the drying tunnels. In addition, the introduction of internal fuel, mixing of ground coal or other fuels with clay before producing green bricks, further improves efficiency performance and leads to less air pollution.

The heat reutilization feature makes HHKs not rely on sun drying any more. This technology can operate year-round in the region, which help provide more stable employments in the sector. Migrant labors working in HHKs can very likely settle down after working several years in the factory. This is one critical step from artisanal kilns toward a formal industry.

9. Tunnel Kiln (TK)

A Tunnel Kiln (TK) is a continuous moving ware kiln where green bricks produced by mixing powdered fuel with clay are dried and pre-heated, reutilizing the hot flue gases coming out of the kiln. These pre-heated bricks are loaded in carts and pushed in the kiln. The carts continuously move inside the kiln at fixed time intervals, and whenever ready, they are passed through a cooling zone where cold air entering from the cart exit cools down the fired bricks. The unutilized flue gases coming out of the kiln are finally released into the air through a chimney. The length of a tunnel kiln varies from 60 to 150m. This technology is regarded as one of the most advanced ones because of its ability to control the firing process and produce a wide variety of high-quality clay products.

Similar to HHK, by using exhaust heat from the flue gas to dry the green bricks, TK gets rid of constraints of sun drying and can operate year-round. It has all the social and environmental benefits of HHKs. Furthermore, because TK as a modern technology can be operated by computer intelligence system and has the potential to be expanded to super large scale. It can be operated with much higher productivity by utilizing less labor, provide much better quality of bricks by using computer to monitor the burning temperature, and reduce pollution to much lower level by connecting scrubbers to the flue gas.

2.1 Technical attributes of kilns by technology types

Each technology type differs from the rest by three key parameters – energy consumption and emission profile, quality of bricks produced and labor productivity. Each of these brick kiln specific attributes is discussed separately below. The emission and energy consumption profile is generally similar for brick kilns in all three countries although there could be small differences because of geography specific factors such as clay characteristics, weather conditions, etc.

Energy consumption and emission profile

Predominantly, all technologies discussed above use coal as the primary source of energy. A study by Weyant et al. (2014) reveals that coal is the primary input in most Indian brick kilns with wood, sawdust or a mixture of the two as secondary inputs in many kilns. Similar is the case of Bangladesh where more than 80% of brick kilns still use imported coal as the primary energy source (SAARC Energy Centre, 2013b). In Kathmandu Valley too, coal is the dominant source of fuel used with 50% kilns using a combination of coal and rice husk (in the proportion of 9 parts of coal to 1 part of rice husk), 26% using a combination of coal, sawdust and other biomass, and 24% using coal as the only fuel.

India alone uses 62 million tons of coal annually for the brick sector, making it the second largest industrial coal consumer in the country. Similarly, the brick sector in Bangladesh and Nepal use, respectively, 5.1 and 1 million tons of coal annually. Besides coal, a number of kilns in Bangladesh and India use natural gas (in gas fired kilns) and other petroleum products such as diesel (in various steps of mechanization process)[21]. On an average, assuming that coal is the only fuel used by brick sector in these three countries and the majority of kilns are artisanal types, this study found that the aggregate fuel efficiency of the brick sector of three countries combined is 170-200 grams of coal per brick produced. This finding falls within the range of 110-700 grams of coal consumed for the production of every brick (of 3 kg weight) found by Heierli and Maithel (2008). It should be noted that fuel efficiency of kilns varies even among the same kiln types. The kilns are designed and constructed by different contractors or by the owners themselves. The technologies are largely not standardized. In addition, factors such as the quality of fuel used, the clay characteristics (moisture content, refractoriness, etc.), and climatic conditions (ambient temperature, direction and strength of wind, etc.), affect the amount of energy required. The way how energy consumption is monitored and how the data are collected is generally not strictly scientific, either, given the informal operational environment of brick kilns. Specific Energy Consumption (SEC), therefore, as an important parameter for the performance of brick kilns, is a rough number and may vary in a range among different studies. The numbers provided in Table 2.1 are averaged values of former studies reviewed by this study.

[21] The Ministry of Power, Energy and Mineral Resources (MoPEMR) has recently banned the use of natural gas for brick industry because of the scarcity of natural gas for use in the power sector and household cooking.

Table 2.1 Comparison of emissions and specific energy consumption of different brick kilns (collated by authors in this study from former studies - refer to Appendix
Annex I. Specific Energy Consumption (SEC) and emission factor for various brick kilns *for complete data sources)*

Types of Kilns	Average Emission Factor (g/kg of fired bricks)						Average SEC Coal consumption (tons of coal/100,000 bricks)*	Average SEC (MJ/kg fired brick)
	SPM	PM_{10}	$PM_{2.5}$	SO_2	NO_x	BC		
Clamp/DDK	1.6	1.6	0.97	3.6	0.069	0.29	42	2.9
FCK/MCK	2.2	0.36	0.21	3.6	0.069	0.17	21/24	1.3/1.5
ZZK/HDK	0.31	0.20	0.12	0.88	0.061	0.035	17	1.3
VSBK	0.13	0.18	0.11	0.54	n/a	0.002	13	0.8
HK	0.31	0.24	0.15	0.62	0.029	0.003	14	1.2
TK	0.23	0.15	0.09	0.67	0.15	0.001	14	1.2

**for a 3kg brick with a size of Bangladeshi brick in South Asia*

The brick sector is a massive source of conventional air pollution as well as carbon dioxide, contributing to climate change. Among the conventional air pollutants released in brick production are carbon monoxide and fine particulate matters, particularly black carbon and organic carbon, which are hazardous for human health and also now understood to contribute to global climate change and other regional climate problems such as weakening monsoon and accelerated glacier melt. A report by Weyant et al. (2014) has found that an estimated annual production of 260 billion[22] bricks in South Asia emits approximately 120 ± 24 Tg[23] CO_2, 2.5 ± 0.6 Tg CO, 0.19 ± 0.17 Tg $PM_{2.5}$, 0.12 ± 0.7 Tg Elemental Carbon (EC), and 0.02 ± 0.01 Tg Organic Carbon (OC). $PM_{2.5}$ emissions from brick production are found to be in the same range as $PM_{2.5}$ emissions from transportation in South Asia. The report (p.6482) further illustrates that the radiative forcing from South Asian brick production is positive (warming) and primarily attributable to traditional kilns and BTKs (MCKs and FCKs). The table 2.1 above has made a comparison of emission profiles of different types of kilns.

From the table, it is evident that artisanal technologies (MCK, FCK, ZZK) differ from modern technologies (HK, TK) in intensity of emissions and consumption of energy per unit of brick produced. Some studies (e.g. Shakti & CW, 2012; Weyant et al., 2014) have ranked VSBK and ZZK as the most energy efficient and the least polluting kilns whereas others (e.g. FS-UNEP Collaborating Centre, 2016) have suggested TK as the most efficient and the least polluting, followed by HHK, VSBK and improved ZZK. One needs to be very critical when using the emissions factors (EFs) in the table above. So far there are not so many brick kilns measured in the region, because emissions measurement has been highly costly. Most of data are from former studies where the EFs are provided based on measurement of a few number of kilns. The studies

[22] The most recent estimate is 310 billion/year.
[23] 1 Tg = 10^{12} g = 10^9 kg = million metric tons

used different equipment and were done by different teams. Some of the measurements were done by contractors through self-reporting where numbers might be optimized. Therefore, cross technology comparison does not always convey a convincing message. For example, the EFs of ZZK/HDK seem to be too optimistic to authors of this study. There are good performing ZZKs. However, most of them are not built according to standards. That said, Table 2.1, though not perfect, provides a useful snapshot on the emissions profile and the ladder of energy and emission performance of different brick kiln technologies.

Our study has undertaken a comprehensive cost benefit analysis (see Section 2.3 below) to determine the most cost-efficient kiln technology from both commercial and environmental point of view. Though different kilns vary in their emission profiles (volumes and proportions of emitted substances), brick sector is undoubtedly a major source of Short-Lived Climate Pollutants (SLCPs), in particular Black Carbon (BC). SLCPs currently account for 30-40% of global warming to date (FS-UNEP Collaborating Centre, 2016), making the brick-making industry an opportunity for significant emission reductions, particularly BC in South Asia. Emission reduction in the brick sector will not only aid reducing impacts on health through improving urban air quality but also create significant co-benefits in climate change and agricultural productivity. The reduced air pollution will also help address economic damage so created by disappearance of talented workers from the local community (World Bank, 2016).

In India, the use of high-ash, high-sulfur coal as well as industrial wastes and loose biomass fuels is on the rise in recent years because of higher cost and shortage of good quality bituminous coal (SAARC Energy Secretariat, 2013b). Weather and climatic factors notwithstanding, the types and proportion of different fuels used are the primary determinants of the emissions profile as well as of the energy performance of the kiln. For example, the coal to natural gas switching project (a proposed CDM project) at Corobrik's Driefontein Brick Factory (tunnel kiln) in South Africa found that the project would be able to eliminate the emissions of particulates and SO_2 from coal combustion and also reduce the environmental impact of coal mining, also reducing the CO_2 emissions by more than 60% (CDM Executive Board, 2006). It should, however, be noted that replacing the coal with natural gas, diesel, Heavy Furnace Oil (HFO) or renewable biomass would require a significant capital investment and need to overcome associated logistical, fuel supply, and/or technology barriers as well. Hence fuel-switching barriers are formidable except in limited cases, such as where viable drop-in fuels necessitating negligible capital investment are readily and cheaply available (e.g., rice husks).

These alternative fuels are also typically more expensive than coal, which poses a financial barrier due to the increase in operating costs. An investment comparison analysis conducted by the aforementioned CDM proposal found that the most economic option for them would be to continue using coal to produce energy needed for brick firing. Similarly, a CDM project in Egypt (a 21-year project) converted 50 independent brick kilns from burning heavy oil to natural gas. From 2005 to 2009, the reduction in CO_2 emissions was already more than 15% (LGCL, 2010).

One other way of reducing SO_2 and BC emissions would be to add internal fuels in brick making by mechanizing the fuel and clay mixing process[24]. The addition of internal fuels such as coal slurry, coal dust, sawdust and charcoal dust makes sure that there is a steady-state combustion, thus significantly lowering emissions and also lowering the cost (Shakti & CW, 2012). This improved operating practice could reduce the fuel consumption by10-15% in FCKs. This requires introduction of machinery, and has been used in SAR in relatively advanced kiln technologies such as HHK and TK.

Retrofitting vs. adoption of newer technologies – Energy and emission performance

There are two options for improving energy and emissions (both CO_2 and SPM) performance in the brick sector without changing the type of fuel used: (i) retrofitting existing kilns, and (ii) replacement of existing kilns by construction of new kilns that use superior technologies. Each option differs in investment needs as well as energy efficiency and emission improvement. Retrofitting refers to upgrade or improvement of different aspects of the current kiln design and structure, and includes but is not limited to interventions such as design improvement to create additional recirculation zones, redistribution of heat supply, widening of the drying yards, improvement of the roof structure, addition of better preheat combustion system and larger cooling air systems, mechanization and automation of kiln operation, and better kiln insulation. Retrofitting does not require kiln relocation. Larsen (2016) has found that retrofitting provides no substantial production benefits, but offers significant energy savings and thus cost reductions.

A World Bank report (World Bank, 2011) found that both retrofitted and new technologies provide pollution reduction and energy efficiency gains, but the gains are moderate in case of retrofitted ones and considerable in case of new ones as compared to the traditional FCKs. For instance, HHK reduces CO_2 emissions by almost double the amount and PM emissions multiple times than by retrofitted technologies. From the labor perspective, although both retrofitted and new technologies reduce labor hardship by introducing mechanization features, only the newer technologies such as HHK and TK, unlike FCKs, IFCKs and IZZKs, operate year-round, eliminating the issues of seasonal migration and allowing the workers and their families to receive social benefits guaranteed by the employment. A cost-benefit analysis done by the World Bank (2011)* for Bangladeshi kilns found that the retrofitted fixed chimney kiln (IFCK) fared competitively against newer technologies VSBK and HHK in terms of private profit, but lagged far behind in terms of net social profit. On average, the retrofit approach improved energy efficiency by 20% and reduced PM emissions by 50%. The newer technologies, however, demonstrated 30% greater reduction in PM emissions and 20-30% greater energy efficiency than retrofitted kilns.**

Before drawing any conclusions on retrofitted vs. newer technologies, one should also look into respective country contexts. In Bangladesh, for instance, most FCK owners operate in lowlands where land prices are cheaper, and operation of newer technologies requires flood-free highlands that are comparatively expensive or completely unavailable. Furthermore, newer technologies such as HHK and TK typically require much greater investment capital, and financing options may be limited for traditional brick sector operators. Other barriers such as limited know-how or unproven demand for different brick types may also dissuade technology switching versus retrofitting. In many cases, this is also because entrepreneurs are not even aware of financially and environmentally profitable technology options available in the market. In such circumstances, and others where market and non-market barriers may impose limiting parameters on technology choices, retrofitting might be the most cost-effective option, or simply the only viable option. The adoption of newer technologies will be shaped by a number of interventions such as associated economic incentives (e.g. green subsidies), technical/technological support and assistance from the government as well as brick sector associations, effective enforcement of existing regulations and policies (e.g. ban on FCK in Bangladesh), and introduction of regulations and policies that incentivize the adoption of cleaner forms of brickmaking technologies, including non-fired ones. (These enabling factors and barriers associated with them are discussed at length in chapter 4.)

* *The 2011 World Bank cost benefit analysis included only FCK, IFCK, VSBK and HHK, using FCK as a baseline technology.*

** *It should be noted that, vis-à-vis retrofitting benefits, some other studies such as ADB (2012) corroborate the 2011 World Bank findings, while other studies, such as CASE [CASE Final Report: DoE-S08, World Bank], have found significantly greater energy efficiency improvements (37%-54%) and dramatic reductions in particulate matter emissions (64%-94%) in FCK to ZZK conversion. The CASE study was not accompanied by a CBA and was thus not included here. Other analyses including ADB (2012) and Guttikunda (2012) find greater fuel savings (38-50%) and particulate matter emissions reductions (60%), respectively, for transitioning to TK and VSBK relative to FCK.*

[24] Internal fuel refers to mixing of fuel with clay in the molding stage itself. Any waste material having a calorific value of more than 1000 KCal/kg can be utilized as an internal fuel. A uniform mixing of fuel and clay is difficult with manual molding, hence is mechanization of the production process desirable.

Brick quality

Maithel et al. (2014) have analyzed various types of brick kilns in practice in South and Southeast Asia and compared brick quality of each kiln type. Except for VSBK and Clamp Kilns, all kilns can produce all varieties of products (e.g. solid bricks, hollow or perforated bricks, roof tiles, floor tiles, etc.). Only solid bricks can be fired in a Clamp Kiln, and only solid and perforated bricks in a VSBK. Except for Clamp Kilns, MCKs and FCKs, all other kilns generally produce bricks of more than 80% good quality, reaching 90% in VSBK and HHK and 95% in TK. Unlike FCKs that are most commonly used in India and Nepal, HKs, HHKs and TKs can be used exclusively for production of roofing tiles and hollow bricks. The improvement in product quality of TK, VSBK, HHK, ZZK ND and ZZK HD is because of the improved combustion and uniform temperature attained throughout the kiln cross-section.

In India, a survey conducted by Development Alternatives (2012) has found the quality of bricks better in Bihar as compared to those of adjoining States. The study has attributed this high quality to the availability of silty soil and processing of soil by pugmill. A compressive strength of 70-125 kg/cm^2 with good metallic ringing has been measured in the surveyed clusters. The color of bricks is, however, not uniform because of variation in soil quality in different clusters.

Labor and gender issues

The brick sector employs an estimated total of 16 million people in three countries – Bangladesh, India and Nepal[25], assuming that a significant number of people also work in unregistered kilns in these countries. Many of these people are seasonal migrants from various disadvantaged parts of the country and are contractual laborer's in most cases. They are employed on a contractual basis for a maximum of six to eight months in a year, and are used specifically for labor-intensive work such as mud-pugging by foot, brick molding by hand, monitoring and regulating the fire in the kilns, and head-loading of green and red bricks (World Bank, 2011). They do not usually have access to emergency medical facilities and live at the kiln site in poor sanitary conditions. Because of the contractual and seasonal nature of work, they are also mostly excluded from receiving the minimum wage as determined by the government, and other social welfare benefits such as pensions.

The workers normally bring their entire family with them when they migrate for brick sector work. This exposes the entire family to occupational hazards, particularly the children. In many cases, under-age children join their parents in work in order to enhance the family income (World Bank, 2011). A study done by Choudhury et al. (2014) has found that nearly 50% of the workers in the Indian brick industry are women, who are paid almost half the wages of men. The study showed that men are mostly engaged in skilled and semi-skilled work such as molding, shaping and stacking of bricks whereas women in non-skilled work such as carrying head loads.

Mechanization of a number of processes in brick manufacturing (digging clay, crushing clay, wetting clay, mixing clay, loading wheelbarrow, pushing wheelbarrow, shaping raw bricks, arranging bricks to dry, loading bricks on to the truck, etc.), which is more common in advance technologies such as HK, HHK and TK, could significantly reduce the exposure of laborer's to sun, heat, blowing dust and other harsh working conditions, thus contributing towards a safe and

[25] 15 million in India, 1 million in Bangladesh and 140,000 in Nepal (SAARC Energy Secretariat, 2013a)

comfortable work environment. In the meantime, doing so would also require proper training of the labor force so that there is no corresponding shortage of labor. In all three countries, the brick sector has already been experiencing serious labor shortage that has led to some degree of mechanization such as use of wheelbarrows for loading and unloading of bricks, introduction of pug machines for molding, etc. (World Bank, 2011).

In addition, because of the use of drying tunnel, HHK and TK can operate year-round. This means these technologies can provide the workers permanent employment. Instead of migrating every year, the workers and their families can choose to settle down in the town of the brick factory. Schools and other facility can also be built in the communities. The advanced technologies that can operate year-round provide an opportunity for the brick sector to resolve many associated social issues.

2.2 Alternate and resource efficient building materials – Regional outlook

The construction sector is one of the key emitters of CO_2 in South Asia. Eighty percent of emissions from the construction sector is attributed to production and use of four major products – steel, cement, brick and lime (APN, 2014). Among these four products, brick is further responsible for a substantial volume of particulate matter, including noxious Black Carbon (BC) emissions, that cause detrimental impacts not only on environment, but also on health and agricultural productivity (see chapter 3 below for details). In India, the largest black carbon emitter in South Asia, brick sector represents 9% of the total black carbon emissions, which is two-thirds of the total industrial sector black carbon emissions (US EPA, Undated).

Taking the growth of construction industry as a proxy, the brick sector in India, Bangladesh and Nepal are expected to grow at a rate of 7-8% (2015-2025), 8.5% (2017-2025) and 4% (2017-2020) respectively (dmg events, 2015; BMI Research, Undated and tradingeconomics.com). In the capital city of Bangladesh, for instance, 44% houses used bricks as the major wall material (1991 census; World Bank, 2011). An attempt has been made by international development agencies as well as governments of these countries to introduce cleaner technologies for brick production (examples discussed in Subsection 3.2). While this is a step in the right direction, one other area that has been relatively overlooked is the use of alternate resource-efficient and less environmentally-polluting building materials in construction such as bricks made of waste products and other less resource-intensive raw materials, including more resource-efficient walling methods such as rattrap brick bond masonry.

Types of alternate and resource efficient building materials

Alternate Building Materials (ABMs) are derived from both clay and non-clay materials such as cement, and waste materials like fly ash. 'Alternate methods' also refers to the use of conventional bricks with the addition of resource-efficient raw materials, or innovation in placement of bricks (e.g. rat trap bond[26]) while building the wall. Various alternate and resource

[26] "Rat trap bond is a brick masonry method of wall construction, in which bricks are placed in vertical position instead of conventional horizontal position and thus creating a cavity (hollow space) within the wall. The bricks are placed in vertical position, so that 110 mm face is seen from front elevation, instead of the 75mm face (considering brick of standard size 230 X 110 X 75 mm). Since width of wall remains 230mm, an internal cavity is created. This is where approximately 30% Material

efficient building materials are discussed in a comparative summary table in Annex VII. Comparison of Alternate Building Materials. Unlike traditional brick kilns, which need to be fired at 1,000 degrees Celsius, most alternate building technologies can be cured at ambient temperatures, reducing energy use to a considerable extent. For instance, energy consumption per cubic meter production of compressed earth blocks is 5-15 times less than that of fired bricks, also reducing emissions by as much as four times. Some materials reduce the overall embodied energy of a building because of lesser requirement of virgin materials such as cement and steel as a result of less deadweight of the structure. The lesser requirement of virgin materials also contributes to lowering the overall cost of final product. The rattrap brick bond masonry, in particular, requires approximately 20-35% less bricks and 30-50% less mortar than by a conventional brick wall, reducing the cost of a 9-inch wall by 20-30% and also enabling quicker construction. Furthermore, ABMs like solid/hollow concrete blocks and Autoclaved Aerated Concrete blocks (AAC) reuse waste materials such as fly ash and stone dust generated from other industrial processes, thus significantly lowering the life cycle GHG emissions of the final product.

Market availability, supply chain and implementation status of Alternate Building Materials (ABMs)

Conventional fired clay bricks dominate the building sector in Bangladesh, India and Nepal. There are, however, alternate building materials increasingly being available in these markets that are also resource-efficient in most cases. The resource efficiency relates to efficient consumption of both primary materials and energy.

In Bangladesh, the uptake of ABMs has been slow and sporadic because of non-availability of raw materials such as cement, sand and stone chips in the country, and having to import them from other countries makes the final product economically unattractive for the entrepreneurs (World Bank, 2011). The return on investment of producing ABMs is much lower than of conventional bricks. Further, technologies based on non-fired bricks are believed to be unfeasible because of unsuitable weather conditions in Bangladesh (ibid). The Housing and Building Research Institute (HBRI) of Bangladesh reports that this is also because of lack of information regarding efficiency and durability of ABMs. Among the various ABMs, only concrete blocks have been introduced in the Bangladeshi market with small success. One factory was successfully piloted under the CASE project financed by the World Bank (see table 2.2).

In India, cement, fly ash, and concrete based walling materials (Fal-G bricks, Aerated Autoclaved Concrete (AAC) blocks, cement concrete blocks, monolithic concrete walls, etc.) account for approximately 25% of total consumption of walling materials, with the rest accounted for by traditional solid fired clay bricks. The alternate and resource-efficient walling materials are becoming increasingly popular in urban areas of India because of lighter weight and lesser construction time. Many commercial buildings have also opted for some of these materials in order to get the green building certification. A survey conducted by GKSPL (2016b) in 10 urban cities of India found that the market for cement and fly ash-based products (mainly

(brick and mortar) is saved and thus overall construction cost is reduced. Cavity provides effective thermal and sound insulation. This makes rat trap bond energy and cost-efficient building technology." (Source: http://www.istudioarchitecture.com/rat-trap-bond/)

three products – fly ash bricks, AAC blocks and cement concrete blocks) has been growing in the recent years as opposed to market for clay-fired bricks that has been shrinking. Another survey conducted by Greentech Knowledge Solutions Pvt. Ltd. (GKSPL, 2016a), however, suggests that although the national market is inclining more towards resource-efficient building materials, the Indo-Gangetic plains and the Himalayan region, which includes Bihar, are predominantly using fired clay bricks. AAC, FaL-G and cement concrete brick/block production is mostly concentrated in peninsular India.

In light of the devastating earthquake in Nepal in 2015, there has been an increasing trend towards reinforced concrete structures in Nepal. Many experts believe that these are much more resilient than the conventional brick structures. The ones particularly suitable for earthquake prone areas (with medium to high earthquake resistance) are ferro cement wall panels, rat trap bond brick masonry, autoclaved aerated concrete blocks, hollow and solid concrete blocks. There are, however, only a handful of concrete block manufacturing plants – ten in Kathmandu Valley and six outside. Concrete blocks have relatively lesser market penetration in Nepal as compared to prefabricated wall panels, for instance. Much of concrete blocks, prefabricated wall panels, ferro cement wall panels and autoclaved aerated concrete blocks are imported to Nepal from India and China.

Figure 2.1 Production of compressed bricks in Nepal

Fly ash reutilization in India – A case study

The fly ash notification in 1999 by the Ministry of Environment and Forest was India's first regulation on the reuse of fly ash. The 1999 rule set a 100% fly ash reutilization target by 2009 (GKSPL, 2016b). This regulation has been subsequently revised in 2003, 2009 and 2016. The revised notification from the Central Pollution Control Board (CPCB) requires all brick manufacturing plants within a 100 km radius of a thermal power plant to reuse the fly ash generated from those plants. The CPCB has further asked to consider cancellation of permits to brick manufacturing units that are not complying with these provisions. CPCB has issued this directive to all state pollution control boards and pollution control committees in order to strictly implement the Centre's notification on utilisation of fly ash from coal and lignite-based thermal power plants. Going further, the fly ash notification of 2016 has made it mandatory for all cities with a total population of more than 1 million to amend building by-laws to make the use of fly ash bricks mandatory in building construction. Similarly, the use of fly ash-based bricks and products has been made mandatory for all government schemes and programs (ibid). In a recent letter issued by the Ministry of Rural Development[27], relevant authorities in all States/Union Territories of India have been requested to do the needful to encourage use of fly-ash based

[27] M-12016/06/2017-RH(M&T) – Use of Fly-Ash based construction materials in PMAY-G construction, issued on September 12, 2018.

construction materials in Pradhan Mantri Awas Yojana for the rural poor (PMAY-G)[28] with the twin objectives of conserving scarce natural resources as well as reducing environmental issues related to deposited fly-ash.

Some of the fly ash-based walling materials include Autoclaved Aerated Concrete (AAC) Blocks, Fly Ash Bricks (FaL-G) and Clay Fly Ash Bricks. The composition of fly ash in each of these walling materials varies along with the variation in composition of other constituents used. For instance, AAC Blocks consist of 55-60% of fly ash along with gypsum, cement, lime and aluminum powder, whereas FaL-G blends fly ash (Fa), lime (L) and Gypsum (G) in varying proportions resulting in differing strength on hydration. The fly ash composition in FaL-G varies from 60-65% to only 15%. Similarly, Clay Fly ash bricks in Maharashtra State of India mix 20-40% of fly ash (by weight) with clay while those in the Indo-Gangetic plains generally only add 5-15% fly ash (by weight). This variation is attributed to different nature of soil in those regions (GKSPL, 2016a).

The Central Electricity Authority (CEA) is the government body of India that collects fly ash reutilization data from thermal power plants. The CEA data show that a total of 184 million tons of fly ash was generated during 2008-13, of which 56% (103 million tons) was reutilized. Out of 103 million tons of fly ash reutilized, cement plants accounted for the largest share of reutilization (42%) while brick brick/tile manufacturers accounted for only 12%. The data from the same period suggest that among the brick/tile manufacturers, AAC manufacturing accounted for almost 30% of the fly ash reutilized for brick making. Despite such encouraging news, the share of fly ash-based walling materials in the total Indian walling material market is only around 5%[29] (GKSPL, 2016b). In Gujarat and Andhra Pradesh, lower installed capacity of fly ash brick production was observed because of a number of reasons, particularly the power plants giving preference to large-scale cement producers as opposed to small-scale fly ash brick producers, perception among the public that fly ash bricks are inferior to conventional bricks, and weak implementation of fly ash regulation. A survey conducted by Greentech Knowledge Solutions Pvt. Ltd. suggests that low share of fly ash-based walling materials is because of low utilization of the installed capacity, problems related with fly ash supply to micro and small enterprises, problems in maintaining good quality in case of fly ash bricks, weak institutional arrangements

Figure 2.2 Fly ash bricks in India

[28]PMAY-G is a social welfare flagship programme created by the Indian Government, to provide housing for the rural poor in India.

[29] In Bihar, there are around 100 fly ash-based brick manufacturing units.

for technology supply and quality control. The existing fly ash regulation needs to be reviewed in order to make access to fly ash convenient for and affordable to small scale producers, and state-wide technical programs need to be rolled out in order to educate existing brick operators and public about the advantages of fly ash-based bricks.

A World Bank CDM project titled, "FaL-G Bricks and Blocks Project" (World Bank, 2013b) in India[30] (2004-17), considered a successful carbon finance project and contributed significantly to the adoption of fly ash brick technology in India. The number of plants using FaL-G technology was negligible when the project started, but currently, more than 16,000 FaL-G plants are in operation throughout the country. This CDM project used carbon revenues and "bundling" approach as incentives for micro-entrepreneurs to adopt FaL-G technology, thus enabling the involvement of approximately 100 small entrepreneurs within the project scope.

Existing policy and program support for ABMs in Bangladesh, India and Nepal

In Bangladesh, the government has a vision of substantially reducing the production of traditional bricks and switching to alternative bricks. However, so far there has not been any specific policy tailored to ABMs.

In India, the policy and regulatory framework is conductive to the promotion and growth of alternate and resource efficient building materials. Some of the notable ones include:

- Emission Standards for Brick Kilns
- Fly Ash Regulation of the Ministry of Environment and Forest to promote fly ash-based bricks (refer to the section on fly ash reutilization above)
- State program to promote fly ash brick production (Two States in India, Bihar and Odisha, provide incentives for fly ash-based walling material manufacturing. Fly ash brick manufacturing units are also exempted from environmental clearance because they come under green category. The Bihar Government provides a 20% subsidy for setting up fly ash-based brick manufacturing units. Similarly, the fly ash bricks have been included in the Schedule of Rates of the State Public Works Department (PWD) since 2012, which makes the procurement of fly ash bricks for Government construction possible. Further, the State Government has decided that fly ash bricks conforming to relevant BIS (Bureau of Indian Standards) specifications will be used in the construction of all government buildings located within a radius of 100 km of fly ash generating units. The District Industry Centers in the State are also providing technical support to industries to access bank finance for setting up fly ash-based manufacturing units.)
- Environment Impact Assessment for Construction Projects (promotes the use of walling materials with green characteristics, particularly fly ash products)
- Model Building By-Laws of the Ministry of Urban Development (MoUD), 2016 (use of fly ash-based bricks mandatory in all buildings having built-up area >20,000 m^2)

In the same way, there are several government-led programs in India that directly or indirectly promote the use of resource efficient building materials. 'Housing for All', now renamed as

[30] Implemented in ten districts in the State of *Andhra Pradesh*, ten districts in the State of *Tamil Nadu*, and one district each in the States of *Jharkhand*, *Chhattisgarh* and *Madhya Pradesh*.

"*Pradhan Mantri Awas Yojana (Prime Minister Housing Plan)*", for instance, promotes the use of alternative building materials such as cement stabilized earth, fly ash, monolithic concrete construction system, expanded polystyrene core panel system, industrialized 3-S System using precast RCC columns, beams and cellular light weight concrete precast RCC slabs, etc.
In Nepal, existing polices and regulations do not directly relate to promotion of alternate building materials. There is, however, a clear policy focus on the use of resilient building materials (e.g. the National Building code includes sub-codes for different parameters and compliance indicators, like material specifications, requirements for buildings to withstand wind load, snow load, and others). In October 2015, a few months after the earthquake, the Department of Urban Development and Building Construction (DUDBC) and the Ministry of Urban Development (MoUD) released a catalogue of 17 earthquake resistant house models for rural areas (DUDBC, 2015). This design catalogue provides details (3D view of the design, floor plan, elevations, technical details, number of manpower required) for four broad categories of buildings: stone and mid mortar masonry, brick and mid mortar masonry, stone and cement mortar masonry, and brick and cement mortar masonry (ibid). The catalogues released are only meant to serve as a guideline for municipalities, are not mandatory, and are meant to expedite the review process for individual building construction.[31] Expert interviews with the MoUD revealed that, in addition to the first catalogue, they are in the process of completing a second catalogue with 26 materials, technologies and specifications.[32]

2.3 Cost/Benefit Analysis (CBA) of different technologies

The cost-benefit analysis undertaken in this study looks at both private (financial) and social (public) net benefit of four kiln technologies: FCK, ZZK, HHK and TK along with hollow bricks with 15% hollow rate produced in tunnel kilns (TK-Hollow). Two additional cases, although derived from external studies with different input parameters and methodological assumptions, are presented for a quick comparison – FCK to ZZK conversion and non-fired brick production using alternate building materials (or ABM; concrete block in this case). Any comparison needs to bear that in mind.

In an ideal scenario, an entrepreneur chooses a particular kiln technology that is both socially and financially more profitable than the rest. This is not always the case, due to divergence in the externalized social costs of operating different kiln types, and because of lack of appropriate public regulations to internalize those social costs. Even kiln selection from an optimized private profit perspective does not conform to observed market behavior due to various barriers to adoption of more modern and efficient technologies. It is thus imperative that both public financial institutions and policy makers analyse social and financial net benefit and assign appropriate weight to each benefit before making any lending or incentivizing decision. Because of the presence of a large number of FCKs in all three countries, this particular technology is taken as the baseline case, and all benefit parameters of modern/cleaner technologies are compared against those of the FCK.

Assumptions made for the selected technologies

[31] Interview with official at the Ministry of Urban Development, 22 September 2016.
[32] Interview with official at the Ministry of Urban Development, 22 September 2016.

The financial model was constructed using extensive market research surrounding brick kiln economic, financial, operating, and market conditions in Bangladesh. Bangladesh was chosen because of the high density of brick kilns in the country; the diversity of kilns in operation (including a quite significant number of and relatively mature demonstration of modern, high-efficiency kilns); and the great extent to which that country's brick sector has been studied by experts. The financial model estimates the life-cycle capital and operational costs in great detail, as well as projection of revenues over the lifespan of a brick kiln project. The model uses annual average brick production capacity of each kiln type as a benchmark to estimate total project cost (e.g. cost of land, buildings and machinery) and cost of goods sold (e.g. fuel price). The FCK and ZZK are each assumed to have a production capacity of 30,000 bricks/day and whereas the HHK and TK 100,000 bricks/day each. Based on the market situation of Bangladesh in 2015, The national inflation rate and income tax are assumed to be 7.4% and 37.5% per annum while annual escalation in selling price of bricks, price of raw materials and manufacturing overhead expenses are assumed to be all 5%. Similarly, salaries and wages are assumed to be increasing at the rate of 7.4% per annum, in accordance with the national inflation rate.

Methodology of the CBA

The cost-benefit analysis (CBA) is based on the results of two separate analyses: the construction of the financial model, and the calculation of negative externalities to health and climate change from kiln emissions.

The private (financial) CBA and social (public) CBA are done from the entrepreneur's and social viewpoints respectively. The private (financial) analysis includes costs (e.g. cost of buildings, kilns, land, taxes, raw material inputs, etc.) and benefits (i.e. value of the total brick production) for the entrepreneur, and looks at the profitability of a kiln across its lifetime as a single investment opportunity. The social (public) analysis includes costs and benefits from private cost-benefit analysis as well as environmental and social impacts of brick kilns, particularly health impacts of air pollution (only PMs are considered in this study) and the social cost of CO_2 emissions. All these analyses refer to the year 2015 and assume the kilns' lifetime as ten years for FCK and ZZK, and fifteen each for HHK and TK. Considering the real market situation in Bangladesh, for base case analysis of all kiln types, a discount rate of 10% are applied in the case. As to the interest rate of debts, interest rates of 9% (Tenor: 8.5 years; Grace Period: 1.5 years) and 12% (Tenor: 6.5 years; Grace Period: 1.5 years) are used for Soft Loan (SL) and Hard Loan (HL) respectively. For all the cases where a loan is taken, the assumption is made in the way that 30% of the total investment comes from equity and the rest 70% from loan. In the scenario where SL is considered (still 30% is equity), 50% of the total investment is assumed to be soft while the rest 20% of the total investment is on commercial term. This assumption is in line with the two real credit line programs financed by ADB and ICDOL respectively.

Independent of the project-based financial model, the economic analysis has been conducted focusing on health and environmental costs of particulate matter (PMs) and carbon dioxide (CO_2) emissions, respectively. While the sensitivity analysis examines various social cost of carbon values applied to CO_2 emissions, the base case, in accordance with World Bank (2014) guidelines, selects a US$30/ton price for year zero in 2015, escalating gradually to US$50/ton in 2050. The calculated cost of CO_2 emissions is based on the CO_2 quantity emitted annually by each type of kiln based upon coal consumption coefficients applied for each kiln type, multiplied by the CO_2 price in the corresponding year. Only part of the environmental and social externalities is captured in the social CBA. There are still other environmental and social impacts associated with brick making not yet included in our analysis, due to lack of data and inadequacy of methodology. This means in our assessment the social costs have been underestimated. Future studies with more data and further advanced methodology may consider include other externalities into the calculation.

Health costs are derived through a more complex process. The valuation of health impacts of brick sector pollution is done based on the Disability Adjusted Life Years (DALYs) method, acknowledging the limitation posed by impacts of non-brick sector emissions (e.g. transport) on health. Solid particulate matter (SPM) is used as a proxy for all kiln emissions deleterious to human health, and costs are calculated in terms of tons of SPM. Unit costs (US$/brick) are calculated using the total costs divided by total number of bricks produced in Bangladesh. The estimate of total health impact of three countries is discussed in greater detail in chapter 3.

The financial and economic costs and profits were calculated for the life cycle of a project for each kiln type. Various discount rates were subsequently applied to calculate unit costs and profits in net present value (NPV) terms, as discussed below. In addition to the brick kiln life-cycle analysis that analyzes profitability on a per-project basis, profits and costs are subsequently normalized per 1,000 bricks to allow apples-to-apples unit cost comparison across kiln types and across projects of varying size and lifespan. Monetary values are reflected in Bangladeshi Taka (BDT), the local currency of Bangladesh; the kiln life-cycle analysis values are reflected in millions of BDT. The 2015 currency exchange rate has been used for all analysis in this study, which is **1 US$ = 77.7 BDT** (Source: World Development Indicators).

Results from private and social cost benefit analysis

The private cost-benefit analysis considers the direct costs and benefits for the entrepreneur, estimated at market prices for 2015 and the social cost-benefit analysis includes (i) the direct costs and benefits, (ii) the health impacts from PM-related pollution (cost of SPM is taken for the calculation) and (iii) the cost of CO_2 emissions from the brick sector (refer to Annex VIII. Social values of carbon recommended for the World Bank Group and Annex IX. Health cost of PM for the calculation of cost of CO_2 emissions and SPM pollution, respectively). The following table summarizes the comparative cost benefit analysis of four different kiln types along with hollow bricks from TK. The analyses for FCK-ZZK conversion and concrete block production should be taken with caution as these are derived from external studies[33] with different assumptions. It should be noted that the FCK-ZZK conversion cost is relative to the baseline FCK consumption rather than a new build kiln, while concrete block production figures include capital and operational costs for brick production of 2013.

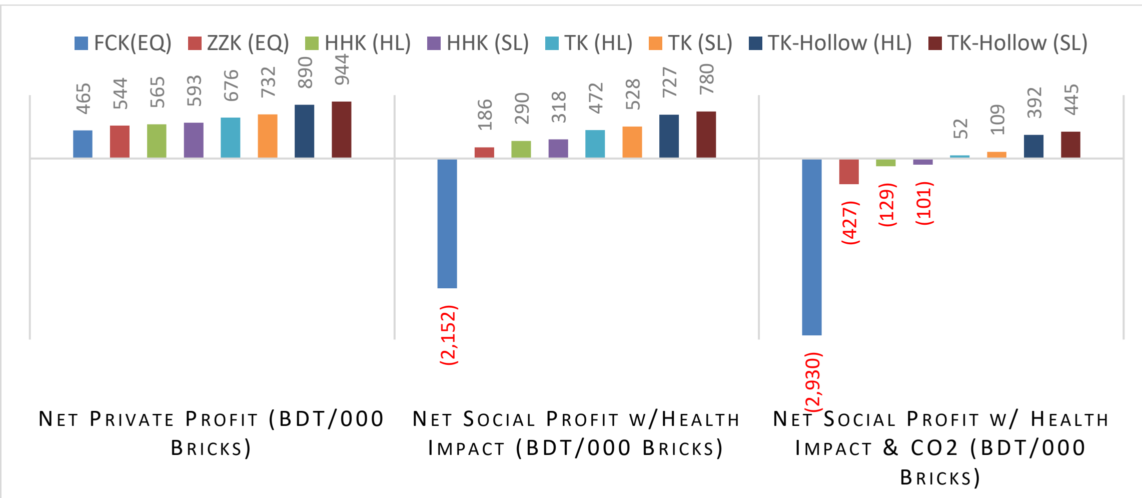
[33] One piloted financed under CASE project conducted by Heat Engineering and Refrigeration (IHERE), Vietnam and BCL Associates Limited of Bangladesh

Table 2.2 Comparison of cost and benefit of selected kiln technologies (all costs and profit in BDT, 2015; detailed results in Annex XI. Comparison of cost and benefit of selected kiln technologies (all costs and profit in BDT, 2015))

Unit Profit & Cost Comparative Analysis	**FCK (100% Equity)**	**ZZK (100% Equity)**	**HHK-HL (Debt[34] 70%, Equity 30%)**	**TK-HL (Debt[35] 70%, Equity 30%)**	**TK-HL-Hollow (Debt[36] 70%, Equity 30%)**	**FCK to ZZK Conversion[37] (2013 data)**	**ABM[38] (Concrete Block)[39] (2013 data)**
CAPEX	9,871,093	11,840,625	301,345,279	544,206,602	539,025,587	7,952,300	18,570,000
Project Payback period (number of years)	1	1	3	4	4	0.4	5.6
Kiln project lifetime (number of years)[40]	10	10	15	15	15	10	20
Project financial IRR	69%	68%	34%	25%	30%	125%	17%
Net Private Profit (BDT/000 Bricks)	465	544	565	676	890	1155	241
Unit NP Cost of PM (BDT/000 Bricks)	2'616	358	275	204	163	358	Not considered
Unit NP Cost of CO_2 (BDT/000 Bricks)	779	613	419	419	336	613	Not considered
Net Social Profit (BDT/000 Bricks)	-2'930	-427	-129	52	392	184	241

[34] Loan tenor 6.5 years, Grace Period 1.5 years and Interest Rate 12%.
[35] Loan tenor 6.5 years, Grace Period 1.5 years and Interest Rate 12%.
[36] Loan tenor 6.5 years, Grace Period 1.5 years and Interest Rate 12%.
[37] FCK to ZZK conversion cost benefit analysis is based on different input parameters and with an assumption of an annual production of 5'865'000 bricks and kiln lifetime of 10 years. Source: CASE Final Report: DoE-S08, World Bank.
[38] ABM = Alternate Building Material
[39] Cost benefit analysis of concrete block is based on different input parameters and with an assumption of an annual production of 2'031'955 blocks and plant life of 20 years. Size of one concrete block is the same as a piece of brick. CASE Final Report: DoE-S08, World Bank.
[40] Although the kiln lifetime of both FCK and ZZK is assumed to be 10 years, they became unprofitable after 7th and 8th year respectively in Bangladesh where this study was conducted.

These results are illustrated graphically in Figures 2.3 and 2.4 below (FCK-ZZK conversion and Concrete Block excluded). Considering the whole investment life cycle, the first figure shows that advance technologies such as HHK and TK are more profitable as compared with the artisanal types such as FCK and ZZK, although in the cases of HHK the difference is marginally. TK is 45-57% more profitable than FCK. If hollow bricks are the production of the TKs instead of solid ones, the NPV will be boosted up to 890-944 BDT/000 bricks compared with 465 of FCK (or two times as profitable as FCK). When health and CO_2 impacts are factored in, the contrast becomes even more startling. The net profit of artisanal technologies plummets significantly as compared with the advance ones. This is clarified further in the second figure where unit costs of PM and CO_2 emissions are compared for all technology types. Both PM and CO_2 emission cost of artisanal technologies are higher than that of modern ones, but most prominently, the cost associated with PM emission is overwhelmingly higher in artisanal ones.



Note: EQ = Equity; HL = Hard Loan; SL = Soft Loan

Figure 2.3 Comparison of net private profit and net social profit (with only health cost and with both health and CO2 cost) in base case (discount rate of 10% and with emission factor of SPM considered)

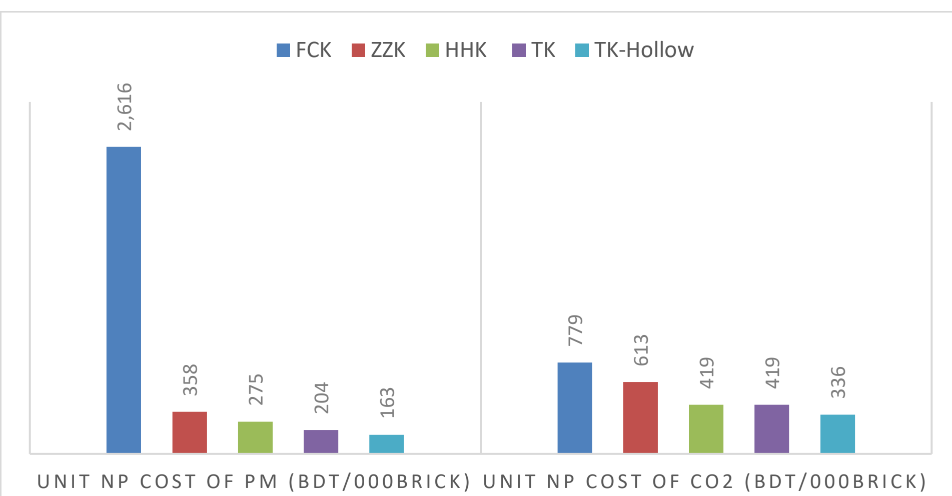


Figure 2.4 Comparison of unit cost of PM and CO_2 in base case (discount rate of 10% and with emission factor of SPM considered)

As evident from the illustrations above, HHK and TK are the most profitable technologies for an entrepreneur judged by total profit (though not by internal rate of return, or IRR). The hollow variant of TK is almost twice as profitable as a traditional technology such as FCK-produced standard bricks. These findings suggest that it is non-market rather than market barriers that are impeding the adoption of HHK, TK, and hollow brick technologies, which on their fundamentals are potentially highly profitable in the Bangladesh context. In particular, despite the higher net returns for HHK and TK, the capital cost for setting up these technology plants is very high, a major factor in the slow adoption of these technologies in all three studied countries.

The superiority of HHK, TK and hollow bricks technologies is even starker when social costs such as particulate matter and carbon dioxide emissions costs are included. If external costs of air pollution and CO_2 emissions are internalized, the net profits for HHK and TK are close to zero, while net profits for traditional technologies such as FCK and (to a lesser extent) ZZK are sharply negative. Only hollow TK bricks yield a substantial net social profit. In particular, the cost of air pollution is substantially higher for FCK as compared to the other technologies, which is a clear indication that this technology should gradually be phased out and replaced by less polluting ones. The massive social burden of health impacts due to FCK and ZZK technologies is borne by the government and taxpayers rather than the polluters who benefit, namely brick producers and consumers. However, the existing theoretical competitiveness of new technologies based upon market fundamentals alone suggests that market-based solutions such as environmental taxes are unlikely to be sufficient to substantially increase the brick production market share of cleaner technologies.

Figure 2.3 also indicates that introduction of soft loan through instruments such as credit line can help improve the viability of cleaner technologies such as HHK and TK. However, the impacts on the attractiveness of the technologies are secondary. This means in places where liquidity is the main constraint while other barriers to cleaner technologies have been largely addressed, injection of softer loans to help improve profitability can help with scaling up. The major hurdle that needs to be surpassed is among the technologies themselves. Therefore, at earlier stage of introduction of new technologies, economic/financial incentives will be needed to make high-investment cost technologies more attractive. Nevertheless, technical assistance to removing other technological, knowledge/capacity, and behavioral barriers would be fundamentally critical.

Sensitivity analysis

The sensitivity analyses of six different variables were conducted to stress test the financial and economic model of all studied kiln technologies (a summary table presented in Annex X. Sensitivity analysis). These sensitivity-tested variables include: discount rate, interest rate, energy cost, labor cost, and the externality costs of climate change and public health impacts.

1) Discount rates

Baseline value: 10%

Sensitivity analysis values: 5%, 15%

Result: Because newer technologies are more capital-intensive and with a longer payback period, lower discount rates benefits HHK and TK, where a larger share of the financial benefits are in the future. Higher discount rates also make FCK and ZZK technologies look better in the early years when the ratio of private profitability to social/environmental cost is highest.

2) Interest rates

Baseline value: 12%

Sensitivity analysis values: 10%, 7%

Result**:** As with discount rates, higher interest rates benefit equity-only or low debt-financed technologies, such as FCK and ZZK. Low interest rates, including soft loans from development agencies, make TK and HHK more profitable, and shorten the payback period.

3) Energy cost (coal)

Baseline value: 5% annual inflator

Sensitivity analysis value: 10% annual inflator

Result: With higher energy costs, high-efficiency kilns, such as HHK and TK, perform better vis-à-vis FCK and ZZK. Also, hollow bricks reduce energy consumption 20%, making all technologies – particularly inefficient ones with high-energy demands per unit of output – more profitable. Technologies with highest share of energy of all Cost of Goods Sold (COGS) will benefit the most.

4) Labor cost

Baseline value: 7.4% annual inflator

Sensitivity analysis values: 10% annual inflator

Result: With higher labor costs, high-efficiency kilns such as HHK and TK, which use less labor per unit of input capital and per unit of output, perform better vis-à-vis FCK and ZZK.

5) Climate/CO_2 externality cost

Baseline value: Cost of CO_2 as USD 30/ton initially and rising to 50/ton in 2030

Sensitivity analysis values: USD 50/ton initially and rising to 90/ton in 2030; USD 15/ton initially and rising to USD 30/ton in 2030

Result: Cleaner, more energy-efficient technologies, such as HHK and TK, will have lower social and environmental costs and perform better on net social profit metrics. Also, hollow bricks reduce energy consumption and therefore emissions by 20%, making all technologies – particularly inefficient ones with high energy demands per unit of output – more profitable and less polluting, reducing social costs. Technologies with the lowest share of energy of all COGS will benefit the most in a high carbon price environment.

6) Health/SPM externality cost

Baseline value: Unit cost of SPM: 583 BDT/kg (using SPM as proxy for air pollution), or roughly US$7.25/kg

Sensitivity analysis values: +50%, -50%

Result: Cleaner, less polluting kiln technologies, such as HHK and TK, will have lower social and environmental costs and perform better on net social profit metrics: health costs from particulates are 5-7 times higher for dirtier technologies like FCK as compared with HHK and TK technologies. If social costs of health impacts decline, FCK and ZZK appear more competitive and have higher net social profit. If social costs of health impacts rise, social costs of dirtier technologies rise very quickly, leading to increasingly large net negative social profit of older technologies.

Also, hollow bricks reduce energy consumption and therefore emissions by 20%, making all technologies – particularly inefficient ones with high energy demands per unit of output – more profitable and less polluting, reducing social costs. Technologies with highest share of energy of all COGS benefit the most.

7) Capacity Utilization

Baseline value: 100% capacity utilization

Sensitivity analysis values: 70% capacity utilization

Result: At 100% capacity utilization, TK is the only technology that has positive net social profit. At 70%, all technologies have negative net social profit. The cleaner technologies HHK and TK outperform FCK and ZZK in terms of net profit even at 70% capacity utilization.

Conclusion of the analysis

Both cost-benefit analysis and sensitivity test suggest that HHK and TK should be the technologies of choice of all entrepreneurs if they are constructing new kilns. This finding applies both to the financial analysis, reflecting private profit alone, and is even more pronounced in the economic analysis incorporating negative health and climate change externalities, which are substantial and which offset all private profit except in the case of the cleanest, most efficient technologies.

The CBA does indicate that FCK and ZZK kiln projects have attractive internal rates of return, suggesting that current FCK and ZZK kiln owners are likely making good profits. However, these rates of return apply to projects that are smaller in size and in duration than HHK and TK kiln projects, thus yielding substantially lower overall private profits. It stands to reason that, based upon market fundamentals, new entrants into the advanced brick kiln market could successfully compete on brick quality, price, volume, and other metrics while also growing profits.

The CBA shows that FCK and ZZK profitability peaks after several years, at which point the rising operating costs and falling performance rapidly erode profitability. This means that such kiln projects must then be replicated again in the near future, at which time market conditions may be different. For example, the sensitivity analysis illustrates that rapidly escalating labor and energy costs can quickly erode the profitability of FCK and ZZK, which are highly dependent on both inputs. Further, an increased stringency of regulation – whether of emissions, kiln types, labor conditions, and/or taxation – that increases the cost of doing business for artisanal kilns – may rapidly diminish the short-term financial attractiveness of incumbent kiln technologies such as ZZK and FCK.

Lastly, the sensitivity analysis suggests that hollow bricks – compatible primarily with modern kilns – and relatively low-interest financing (also indispensable for capital-intensive modern kilns) dramatically enhance the profitability of HHK and TK technologies, both in the absolute sense and relative to low-debt, smaller-scale kiln projects such as ZZK and FCK.

The experiences from three countries, however, do not seem to align with the CBA findings. The observed actions of market actors in the brick kiln sector in South Asia suggest the substantial intrusion of non-market barriers to the adoption of modern, efficient kiln technologies. In Bangladesh, for instance, most FCK owners operate in lowlands that are cheaper and largely available. Operation of cleaner technologies requires flood-free highlands that are scarce resource in the country, and therefore are challenging to obtain and comparatively expensive. They are, therefore, reluctant to switch to cleaner technologies. In addition, a substantially high capital cost for setting up technologies like HHK and TK has acted as a deterrent to the speedy adoption of such technologies – or the inaccessibility of capital entirely for brick-sector entrepreneurs and for technologies and a sector unfamiliar to many lending institutions in South Asia. Furthermore, in many cases, entrepreneurs are not even aware of financially and environmentally profitable technology options available in the market. The adoption of cleaner technologies will be shaped by a number of interventions such as associated economic incentives (e.g. green subsidies), easier access to commercial loans, technical/technological support and assistance from the government as well as brick sector associations, effective enforcement of existing regulations and policies (e.g. ban on FCK in Bangladesh), and introduction of regulations and policies that incentivize the adoption of cleaner forms of brickmaking technologies, including non-fired ones. These barriers and recommendations have been explored further in chapters 4 and 5.

It is worth mentioning that one of the relatively cleaner technologies, VSBK, is virtually non-existent in Bangladesh and exists to a very limited number in India and Nepal. In Nepal, the technology has achieved a limited success, thanks to VSBK Transfer Program (2003-2011), funded by the Swiss Development Cooperation (SDC). Any transition to a new technology comes with risk of increased spoilage, potentially explaining the disparity in percentage of quality bricks produced by VSBK observed between Nepal and Bangladesh. Despite superior environmental performance of VSBK, the regional experts believe that the limited success is because of VSBK's lower production capacity, higher sensitivity to the quality of clay and production of low-quality bricks as compared to other artisanal technologies such as improved FCK and improved ZZK. SAARC Energy Centre (2013b) reports that VSBK failed to attract investors primarily due to failure of the pilot project to produce bricks of desired quality.

Limitations of the study

This analysis focuses on brick kilns located in Bangladesh, thus cannot readily be generalized for the whole of South Asia. In general, input cost, market price, and technology performance values are liable to vary widely geographically and temporally, potentially rendering the CBA assumptions used here invalid; in some but not all cases these variabilities or uncertainties are addressed in the sensitivity analysis. VSBK has been excluded from the assessment because of lack of well-documented data and its unlikely viability in the context of Bangladesh where the study was conducted. Further, the analysis does not include impacts of air pollution on the value of real estate, on recreational areas, and on agricultural productivity, the negative health effects of pollutants other than SPM, and the impacts of harsh working conditions on the health of brick kiln workers. The study also does not attempt to deal with non-market issues such as regulation, non-collection of taxes, land accessibility, or disruption of production due to environmental or economic factors, or other contingencies.

Chapter 3. Air Pollution and Climate Change Impacts of Brick Production

3.1. Air pollution and the brick sector

Air pollution is becoming one of the major development issues in South Asia. According to Yale University's Environment Performance Index (Hsu, 2016), all South Asian countries rank below 100th globally for air quality, with India, Nepal and Bangladesh at 141st, 149th and 173rd position respectively. Particulate Matter (PM) is one of the major air pollutants in South Asia, together with carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen oxides (NO_x), and ozone (O_3). PM released mainly from combustion processes are generally categorized into two types – particles less than 10 microns in aerodynamic diameter (PM_{10}) and particles less than 2.5 microns in aerodynamic diameter ($PM_{2.5}$). In many cities of South Asia, pollutant concentrations, such as those of $PM_{2.5}$ and PM_{10} exceed 2-3 times the recommended level by the World Health Organization (WHO) (Table 4.1). Brick kilns, involving the burning of low-grade coal, are one of the major sectors that contribute to air pollution in South Asia.

Table 3.1 Current ambient air quality standards (in $\mu g/m^3$) for various pollutants in South Asian countries and by the WHO.

	$PM_{2.5}$		PM_{10}		TSP[41]		SO_2			NO_2			O_3	
	24hr	1yr	24hr	1yr	24hr	1yr	1hr	24hr	1yr	1hr	24hr	1yr	1hr	8hr
Bangladesh	65	15	150	50				365	80			100	235	157
India*	60	40	100	60				80	50		80	40	180	100
India**	60	40	100	60				80	20		80	30	180	100
Nepal	40		120		230			70			80	40		157
WHO Interim Target 1	75	35	150	70				125						160
WHO Interim Target 2	50	25	100	50				50						
WHO Interim Target 3	37.5	15	75	30										
WHO Air Quality Guideline	25	10	50	20				20			200	40		100

**for industrial, residential, rural and other areas*
***for ecologically sensitive areas*

An evaluation of the 2015 WHO Global Burden of Disease Report (Cohen et al., 2017) estimated 4.2 million deaths were caused by exposure to ambient air pollution annually, with 59% of these deaths in South Asia (Cohen et al., 2017). An analysis done by the UNICEF (2016) shows that nearly 220 million children of South Asia breathe toxic air. The most recent World Bank Report (2016) shows a large increase of 62,000, 360,000, and 5,600 in the total deaths from 1990 to

[41] Total Suspended Particles

2013, due to air pollution in Bangladesh, India, and Nepal, respectively (Table 3.2). There is 6.1%, 7.7%, and 4.7% loss of welfare in 2013 in these three countries, respectively, due to their countrywide mean annual ambient $PM_{2.5}$ that is approximately 46-48 μg/m^3. These ambient levels are above Nepal's 24-hour average standard and are also above both Bangladesh and India's annual average standard (Table 3.1).

Table 3.2 Mean annual ambient $PM_{2.5}$ concentrations and their impacts in South Asia Region (SAR) (1990 and 2013).

Countries	**Mean annual ambient $PM_{2.5}$**		**Total deaths from air pollution**		**Total welfare losses**		**Total forgone labor output**	
	μg/m^3				Million 2011 USD, PPP-adjusted (% GDP equivalent)		Million 2011 USD, PPP-adjusted (% GDP equivalent)	
	1990	2013	1990	2013	1990	2013	1990	2013
Bangladesh	29.92	48.36	92880	154898	6379 (4.66%)	27452 (6.14%)	1195 (0.87%)	2579 (0.58%)
India	30.25	46.68	1043182	1403136	104906 (6.8%)	505103 (7.69%)	28742 (1.86%)	55390 (0.84%)
Nepal	29.68	46.09	16436	22038	1033 (4.60%)	2833 (4.68%)	195 (0.87%)	287 (0.47%)

Brick Sector's Share of Air Pollutants

South Asia is home to 20% of clay bricks produced globally, concentrated particularly in four countries – India, Pakistan, Bangladesh and Nepal (Weyant et al., 2014). This sector is responsible for up to 91% of total PM emissions in some South Asian cities. A summary of the contribution of brick, power, and transport sectors to common air pollutants is listed below (Table 3.3).[42] In the table, the emissions estimates of PM and BC from other sectors than brick sector are taken from the Regional Emission inventory in ASia v2.1 (REAS v2.1, Kurokawa et al., 2013). For the national level contribution of the brick sector, the table summarizes our calculations in this study, while contributions of other sectors at the national level are combining our study with that from REAS v2.1. The detailed estimate of the emissions of the brick sector by this study is provided in Table 3.1. We list other estimates in literature for the city-level contributions, and their respective references are provided in the notes below the table. The brick kilns are estimated to be responsible for approximately 28% of the total PM_{10} concentrations in Kathmandu Valley (Weyant et al., 2014). Kim et al. (2015) found that brick kilns contribute 40% of BC in the Kathmandu Valley in winter. Similarly brick kilns are estimated to contribute 24% $PM_{2.5}$ in Chittagong city, Bangladesh; in Dhaka city, the percentage is much higher at approximately 84% of $PM_{2.5}$ emitted from brick kilns (Randal et al., 2014). In India, the percentage of PM contributed by kilns varies greatly—Pune city estimates only 3% of total $PM_{2.5}$ emissions from brick kilns (ARAI, 2010). In Delhi, India, on the other hand, approximately 15% of $PM_{2.5}$ emissions were attributed to brick kilns (Guttikunda et. al, 2013).

[42] Data limitations at the time of modeling and analysis in 2016-2017 may not reflect the most recent status of brick sector emissions and newly available data.

Table 3.3 Percentage share of PM and BC emissions by the brick sector in South Asian countries

Country/City	**Brick Sector Share (% of total)**			**Power Sector Share[43] (% of total)**			**Transport Sector Share (% of total)**			**Residential Sector Share (% of total)**		
	$PM_{2.5}$	PM_{10}	BC	$PM_{2.5}$	PM_{10}	BC	$PM_{2.5}$	PM_{10}	BC	$PM_{2.5}$	PM_{10}	BC
Nepal*1	3%	5%	6%	0%	0%	0%	0%	0.7%	0.9%	91%	85%	90%
Kathmandu Valley*2	..	6%	10%	..	..	..	..	60%	..	..	..	..
Bangladesh*1	11%	12%	22%	2%	3%	0.1%	5%	4%	12%	57%	40%	66%
Dhaka City*3	84%	91%	..	2%	1%	..	5%	4%	..	..	..	..
Chittagong City*3	24%	34%	..	2%	1%	..	4%	3%	..	..	..	..
India*1	8%	9%	16%	16%	27%	1%	14%	10%	29%	36%	28%	34%
Pune*4	3%	..	..	..	..	..	..	..	..	..	..	..
Delhi*5	15%	..	..	..	..	..	..	..	..	..	..	..

**1: Regional Emissions in ASia v2.1 (REAS v2.1), Kurokawa et al. (2013)*
**2: Brick Sector PM_{10}: Weyant et al. (2014), BC in Winter: Kim et al. (2015), Transport PM_{10}: Gautum (2006)*
**3: Randall et al. (2014) refers to cities*
**4: ARAI (2010)*
**5: Guttikunda et al. (2013)*
"..": Data not available or not collected

For all the three countries reviewed here, the residential sector (mainly cooking) has the highest share of the PM and BC emissions at the national level. In both Bangladesh and Nepal, brick is the second largest single sector of these emissions. In the case of India, the situation is slightly different. India's power sector is the second-largest contributor to PM and transport is the second greatest for BC, after residential sector. Bricks and agricultural residue burning, which is not included in the table above, are India's third- and fourth-largest emitters by sector. The brick sector in India emits similar amount of PM_{10} and half of BC as the transport sector and about half the amount of $PM_{2.5}$ of the power sector.

In cities where the population is highly concentrated and demand for locally produced bricks is high, the contributions of the brick sector are even more shockingly significant: Bricks account for 84%, 24%, and 15% of the $PM_{2.5}$ emissions in Dhaka, Chittagong, and Delhi, respectively. Considering that this sector only operates about six months during the dry season in a year, its contributions to the ambient air pollution and public health damages are more significant during the operating season of brick kilns than the numbers provided here suggest.

3.2 Brick emissions inventories and impacts on air quality

The major brick sector emissions include CO_2, CO, BC, and PM, which consists mainly of Suspended Particulate Matter (SPM), $PM_{2.5}$ and PM_{10}. The following subsections present an overview of brick sector-related emissions in three countries – Nepal, Bangladesh and India.

Emissions Inventories

[43] Emissions of diesel generators and other captive generation are not included in the share of the power sector.

The following Table 3.4 illustrates average emission factors of different kiln types operating in Nepal, Bangladesh, and India. These estimates are derived by averaging minimum emission factors and maximum emission factors; a table of these minimum and maximum emission factor estimates is provided in the appendix.

Table 3.4 Average Emission Factors by Kiln Type (g/kg of fired bricks)

Kiln Type	SPM	PM_{10}	$PM_{2.5}$	SO_2	NOx	BC
Clamps/DDKs	1.6	1.6	0.97	3.6	0.069	0.29
FCKs/MCKs	2.2	0.36	0.21	3.6	0.069	0.17
HDKs/ZZKs	0.31	0.20	0.12	0.88	0.061	0.035
VSBKs	0.13	0.18	0.11	0.54	n/a	0.002
HKs	0.31	0.24	0.15	0.62	0.029	0.003
TKs	0.23	0.15	0.09	0.67	0.15	0.001

The estimated total annual emissions of SPM, SO_2, NOx, BC, PM_{10} and $PM_{2.5}$ from the seven main kiln technologies in Bangladesh, India, and Nepal as of 2016 are provided in the table below (Table 3.5).

Table 3.5 Estimated Annual Local Air Pollution Emissions from Brick Making (tons/year)

Country	SPM	SO_2	NO_x	BC	PM_{10}	$PM_{2.5}$
Bangladesh	84,327	159,793	5,268	7,148	36,886	22,132
India	1,412,420	2,002,673	50,660	137,044	661,164	396,698
Nepal	24,868	42,839	872	2,044	9,370	5,622

Bangladesh

Bangladesh has an estimated annual brick production of 27 billion bricks from nearly 7,000 brick kilns (World Bank, 2016b). The contribution of the brick sector to the total annual CO_2 emissions of the country (17%) is far more significant than its GDP contribution (1%) in Bangladesh (World Bank, 2011). Brick kilns are also estimated to emit 22 and 37 kt/year of $PM_{2.5}$ and PM_{10}, respectively (Table 3.5). Bangladesh does not have downdraft kilns, but rather most kilns are either FCKs or HHKs/ZZKs.

India

Annually, India produces nearly 250 billion bricks. Currently, there are estimated 144,000 brick kilns in India contributing nearly 400 kt of $PM_{2.5}$ and over 660 kt PM_{10} each year (Table 3.5). The majority of the kilns are either downdraft kilns or fixed chimney bull trench kilns, contributing 98 percent of the estimated $PM_{2.5}$ and PM_{10} emissions attributed kilns.

Nepal

In Nepal, the current annual brick production stands at 4.9 billion bricks a year, a-billion-brick increase compared to 2009 estimates (Federation of Nepal Brick Industries, n.d.). This increase can partly be explained by earlier studies' exclusion of a large number of clamp kilns outside of the Kathmandu area. Although there are still many MCKs operating outside of Kathmandu

Valley, the emission factor for FCK was used as a proxy for MCK (Table 3.4). This substitution likely underestimated our emissions estimates.

The brick sector contributes a substantial share of these countries' coal consumption and CO_2 emissions (Table 3.6). Based on the estimate of this study, it consumes about 5 million, 62 million, and 1 million tons of coal in Bangladesh, India, and Nepal respectively. In Bangladesh and Nepal, brick is the key sector of coal consumption, considering that these two countries' power sectors are coal free. Brick sector accounts for almost all of the country's final coal consumption. Because it is such an informal sector, its coal consumption statistics are in general not well captured by major databases. The national total coal consumption data of Bangladesh and Nepal provided by International Energy Agency (IEA) through its database, *World Energy Statistics*, are way smaller than those of the brick sector estimated in this study. Brick making in India consumes about 62 million tons of coal per year, roughly 7% of the country total (912 million tons). With respect to CO_2 emissions from fuel combustion, our estimate shows that the brick sector contributes to 17%, 6%, and 37% of the country total of Bangladesh, India, and Nepal.

Table 3.6 Estimated Annual CO_2 Emissions from Brick Making and Shares of National Total

Country	Approximate number of kilns	Total production (billion bricks/year)	Total coal consumption by brick (million tons/year)	CO_2 emissions from brick (million ton)	Country total CO_2 emissions[44] (million tons)	% of country total CO2 emissions
Bangladesh	6,758	27.4	5.1	10.6	62	17%
India	143,704	247	62	130	2020	6%
Nepal	1,595	4.9	1.0	2.2	6	37%

From Emissions to Concentration Contribution

The national emissions estimates were used to quantify the contribution of the brick sector to the national ambient concentrations of PM_{10} and $PM_{2.5}$ during their six-month production. A previous study found that 180 kt of $PM_{2.5}$ emissions translated into a concentration increase of 60 $\mu g/m^3$ (Guttikunda, 2009). A study by Croitoru and Sarraf (2012) built upon Guttikunda (2009) and estimated the contribution to PM concentrations for multiple types of kilns with a standard production value. While Guttikunda (2009) focused solely on 530 FTK in the Dhaka area, Croitoru and Sarraf (2012) calculated the emission-to-concentration relationship in four types of kilns: FCK, Improved FCK (IFCK), HHK, VSBK. We applied this array of relationships to the types of kilns observed in each country, matching based on similar emission profiles, allowing us to estimate type-specific kiln contribution to PM concentrations.

In order to account for the spatial density of kilns and total study area, we created an area ratio and a kiln density ratio that were applied to the average estimated PM concentration for each kiln type (Equation 4.1). We assumed that 60% of PM_{10} was $PM_{2.5}$, as indicated in Cohen et al. (2014).

[44] The country total CO2 emissions are cited from International Energy Agency (IEA's) *CO2 Emissions from Fuel Combustion 2016*, and the data are for the year of 2014.

Equation 4.1 Estimation of Contribution to PM_{10} Concentrations by Brick Kilns

Kiln Contribution to Concentration =

Average contribution of kiln type to PM_{10} concentration*kiln density/area ratio

Area Ratio= Area of Interest/Guttikunda Study Area

Kiln Density=Total number of Kilns of Interest/Number of Kilns in Croitoru and Sarraf (2012)

The generated concentration estimates are applicable to the six months of production and do not represent an annual average. Air quality can vary drastically in winter months, when kilns are active, and in the summer when they are dormant. For example, PM_{10} levels in Dhaka, Bangladesh can exceed 300 μg/m^3 in winter months but fall into the range of 40 μg/m^3 in the summertime (CASE, 2013). The regional climate feature of monsoon is another key factor that contributes to the significant seasonal variation. For this reason, the estimates we generated should be evaluated with this context in mind. Also, based on our observation, this method tends to underestimate the contribution to ambient pollution concentration for large areas with kilns clustered in one part of the area.

Bangladesh

As described above, Bangladesh is estimated to have approximately 7,000 brick kilns operating in country. A breakdown of kilns by region was collected by the Department of Environment under the support of the World Bank financed Clean Air and Sustainable Environment (CASE) project provided, based on technology and administrative division.

For all the divisions in Bangladesh with data available, the brick sector contribution to the ambient concentrations of PM_{10} and $PM_{2.5}$ ranges from **2.5 to 21.3 μg/m^3** and **1.5 to 12.8 μg/m^3** increases. Dhaka Division, an area of over 20,000 square kilometers is estimated to have the highest level of concentration increase due to brick production; kilns increase the concentration of PM_{10} by approximately **21 μg/m^3** and $PM_{2.5}$ by nearly **13 μg/m^3** (Table 4.7). This division is the home to the country's capital city, Dhaka, which WHO has named one of the top twenty polluted cities in the world (WHO, 2011). Country wide, the population-weighted average contributions for PM_{10} and $PM_{2.5}$ are **15.3 μg/m^3** and **9.2 μg/m^3** respectively.

Table 3.7 Estimated Brick Kiln Contribution to PM_{10} and $PM_{2.5}$ in Bangladesh by Division

Division	**Area**	**Number of Kilns**	**Adjusted Contribution PM_{10} (μg/m^3)**	**Adjusted Contribution $PM_{2.5}$ (μg/m^3)**
Barisal	13,225	316	4.1	2.5
Chittagong	33,909	1411	7.2	4.3
Sylhet	12,635	212	2.5	1.5
Dhaka without Dhaka District	20,509	2494	21.3	12.8
Dhaka District			47.2	28.3
Khulna	22,284	792	5.9	3.6
Rajshahi	18,135	1533	15.3	9.2
Population-weighted Average			15.3	9.2

Rajshahi and Chittagong Divisions also experience considerable increases in PM concentrations attributable to brick kilns. These regions have had little examination of the concentration increase due to brick kilns, as most kiln studies focus on Dhaka due to its high density of kilns and people. A source apportionment study of Chittagong Division estimated 22 μg/m^3 of PM_{10} and 16 μg/m^3 of $PM_{2.5}$ is contributed by biomass burning and brick kilns (Begum et al., 2009); the study was unable to distinguish between these two sources. Comparatively, our estimates for Chittagong account for 33% of PM_{10} and 25% of $PM_{2.5}$ estimated in the above study; this is not an unreasonable proportion as it is estimated that Bangladesh burns at least 37 tons of biomass each year, making it another significant source of PMs (Streets et al., 2003).

Dhaka City is surrounded by approximately 1,000 fixed chimney kilns; because of this high density of kilns, the contribution to PM contributed by brick kilns is also estimated. Kilns contribute approximately **47 μg/m^3** of PM_{10} and **28 μg/m^3** of $PM_{2.5}$. This estimate is a little lower than the previous estimate of 38 μg/m^3 of $PM_{2.5}$ from brick kilns in Dhaka District, which houses the city (Guttikunda et al., 2013). This gap may be due to our methodology, which cannot fully capture the spatial distribution of PM. It may also be the result of the significant increase in the share of ZZKs in the past 2 years (2015-2016). While no measurement exists to evaluate the performance of the 4000 new ZZKs, a much lower emission factor (Table 3.4) is applied on them in our estimate of emissions inventory.

India

Regional kiln data was unavailable for India, so kiln contributions were only considered on a national level. Countrywide, brick kilns contribute an estimated **7.4 μg/m^3** to the annual average ambient concentration of $PM_{2.5}$ and **12.3 μg/m^3** to PM_{10} (Table 3.8). A previous study of Delhi, India estimated a 5-20 μg/m^3 increase in $PM_{2.5}$ due to brick kilns (Guttikunda and Goel, 2013). Our estimate is consistent with the lower range of this estimate, likely due to dilution of kiln effects by considering the whole country.

Table 3.8 Estimation of Brick Kiln Contribution to PM_{10} and $PM_{2.5}$ in India

	Clamps/DDK	**MCK**	**FCK**	**HDK /ZZK**	**VSBK**	**HK**	**TK**	**Total**
Number of kilns*	100,000	100	40,000	3,000	100	500	4	143,704
Adjusted Contribution PM_{10} (μg/m^3)	8.359	0.008	3.344	0.482	0.003	0.080	0.0001	12.28
Adjusted Contribution $PM_{2.5}$ (μg/m^3)	5.016	0.005	2.006	0.289	0.002	0.048	0.0001	7.37

**Kiln estimates acquired from Brick Kilns in India, by J.S. Kamyotra, Director of CPCB and CCAC Factsheet.*

Nepal

Nepal is divided into fourteen administrative zones[45]. Kiln totals were available for twelve of these districts and were used to calculate an estimate of the PM contribution.

The most significant contributions to PM in Nepal are in Bagmati and Lumbini zones, with approximately **2.5 μg/m³** PM_{10} and **1.5 μg/m³** $PM_{2.5}$ (Table 3.9). Located in the Bagmati zone, the Kathmandu Valley, an area of approximately 899 km², has a high density of brick kilns in the area. To better understand the local effects of these kilns, the contribution to PM_{10} and $PM_{2.5}$ was also estimated for this area. The 122 kilns in the Kathmandu Valley are primarily HDKs or ZZKs. The total estimated contribution to PM_{10} is nearly **64 μg/m³** and $PM_{2.5}$ is **39 μg/m³**. This area has a much higher concentration of PM from brick kilns when compared the Bagmati zone; this is due to the smaller spatial area with a higher kiln density. It is estimated that at the national level the population-weighted average contributions for PM_{10} and $PM_{2.5}$ are **8.1 μg/m³** and **4.9 μg/m³** respectively.

Table 3.9 Estimated Brick Kiln Contribution to PM_{10} and $PM_{2.5}$ in Nepal by Administrative Zone

Zone	Area (km²)	Number of Kilns	Adjusted PM_{10} Contribution (μg/m³)	Adjusted $PM_{2.5}$ Contribution (μg/m³)
Mechi	8,196	33	0.33	0.20
Koshi	9,669	139	1.19	0.71
Sagarmatha	10,591	71	0.55	0.33
Janakpur	9,669	202	1.73	1.04
Bagmati without KV	9,428	292	2.56	1.53
KV	570	122	64.4	38.7
Narayani	8,313	233	2.31	1.39
Lumbini	8,975	278	2.55	1.53
Gandaki	12,275	80	0.54	0.32
Rapti	10,482	21	0.17	0.10
Dhaulagiri	8,148	2	0.02	0.01
Bheri	10,545	122	0.96	0.57
Seti	12,550	122	0.81	0.48
Population-Weighted Average			8.1	4.9

3.3 Aggregate health impacts of the brick sector in South Asia

The brick sector is responsible for many hazardous pollutants as discussed in the introductory section above. All those pollutants, mainly the particulates (PM_{10} and $PM_{2.5}$) have detrimental impacts on human health, causing a variety of respiratory issues such as lung cancer, asthma, chronic bronchitis, and emphysema; cardiovascular and neurological problems. The children and pregnant women are particularly vulnerable to brick sector emissions. Most cities in South Asia are, however, under-researched in terms of attribution of health impacts to different sources of

[45]This study duly acknowledges that Schedule 4 of the new Constitution of Nepal (2015) has provided for the division of the country into seven Provinces. For the lack of data based on new administrative division of the country, this study has used the previously defined administrative zones of Nepal.

air pollution. It is, therefore, hard to assess the specific impact of brick sector emissions on people's health.

Figure 3.1 Workers in an FCK factory in Bangladesh

Brick kiln workers face a variety of hazardous occupational exposures, including chemical, physiological, and physical hazards (Thygerson et al., 2016). Workers are exposed to high concentrations of brick dust, silica and combustion productions, including PM. These exposures have been linked to increase risk of cancer, acute and chronic respiratory disease, and potentially anemia (Kamal et al., 2014a; Kamal et al., 2014b; Skinder et al., 2014). Additionally, frequent repetitive motion and heavy load transportation make workers at higher risk for musculoskeletal disorders (SEED Nepal, 2013).

After converting the emissions to contributions to concentration, these values were used to estimate the impacts of the pollution on public health. In this section, the health impacts assessed include both the mortality and morbidity. For mortality, a simple model is applied. The annual premature deaths due to $PM_{2.5}$ emissions from the brick sector are estimated as the total deaths caused by ambient $PM_{2.5}$ multiplied by the share of the contribution of $PM_{2.5}$ concentration of the sector. The total $PM_{2.5}$ caused premature deaths in each of the countries are cited from the Global Burden of Diseases (GBD) for the year of 2015 (Cohen et al., 2017). With respect to morbidity, the number of cases of disease and associated disability adjusted life years (DALYs) that could be attributed to brick kiln emissions in the geographic areas of interest, are calculated. The population for each area of interest was determined (adult > 14 years, child < 14 years of age). As consistent with the methodology of the Croitoru and Sarraf (2012) study, it was assumed that 90% of the population is exposed to kiln emissions. Other studies have assumed a smaller exposed population (55%), but due to the number of kilns in the countries of interest, this estimate would underestimate the potential health effects (Guttikunda and Khaliquzzaman, 2014). Additionally, in some areas of our analysis 100% of the population is exposed to the excess pollution due to brick kilns. Because of the uncertainty in the exposed population, we chose 90% to best capture the magnitude of the exposure population.

For Dhaka City and Kathmandu Valley, the health impacts and associated costs were evaluated for the populations in these areas and presented below. These populations were then removed from their larger regions, Dhaka Division and Bagmati Zone, respectively. This removal is to avoid a duplication of exposure and outcomes in these populations.

The excess morbidity is estimated based on the increased PM_{10}. Particulate matter pollution affects more people than other pollutants and has been associated with both chronic and acute health affects (WHO, 2016). The concentration-response functions for $PM_{2.5}$ are still developing and have been based primarily on United States and European data (Schwartz et al., 2002; Franklin et al., 2007), so this study focuses on exposure to PM_{10}. This focus will allow these results to be better compared to previous studies examining exposure to ambient air pollution and excess case burden.

Several health endpoints were identified, including chronic bronchitis, hospital and emergency room visits, restricted activity days, childhood lower respiratory illness and general respiratory symptoms; these endpoints were chosen due to the availability of concentration-response functions and the ability to calculate the costs associated with the increased burden. These estimates were based on a per-μg/m^3 PM_{10} estimated contributed number of cases (Table 3.10). The enumeration of the health effects was estimated in both cases per year as well as total number of disability adjusted life years (DALYs) lost for each country.

Table 3.10 Estimated Excess Cases and DALYs lost per 1 μg/m^3 PM_{10}

Health end-points (PM_{10})	**Units**	**Excess Cases per 1 μg/m^3**	**DALYs per 10,000 cases**
Chronic bronchitis	per 100,000 adults	0.87	22,000
Hospital admissions	per 100,000 pop.	1.2	160
Emergency room visits	per 100,000 pop.	23.54	45
Restricted activity days	per 100,000 adults	5750	3
Lower respiratory illness in children (LRI)	per 100,000 children	169	65
Respiratory symptoms	per 100,000 adults	18,300	0.75

Health Impacts

Because the traditional brick kilns in South Asia operate during the dry season only, their impacts on public health are also estimated to be about 6 months. Below, we will present the mortality caused by the emissions of brick making in the three countries first, followed by morbidity.

According to State of Global Air 2017 by Heath Effects Institute (HEI) and Institute for Health Metrics and Evaluation (IHME), in 2015 average annual population-weighted $PM_{2.5}$ concentrations in Bangladesh, India, and Nepal are 92, 74, and 75 respectively. Based on our estimate, the contributions of emissions of the brick sector to the ambient concentrations while the kilns are in operation in the dry season are **10%**, **10%**, and **7%** for the three countries. As a share of the total premature deaths caused by ambient air pollution by GBD, we estimate that in the year of 2015 there are about **6,100**, **55,000**, and **600** deaths were caused by pollution of the brick sector in Bangladesh, India, and Nepal. And, the associated DALYs were roughly **49,000**, **436,000**, and **4,800** respectively.

Table 3.11 Estimated Premature Deaths Caused by $PM_{2.5}$ Emissions of the Brick Sector

	Average Annual Population-Weighted $PM_{2.5}$ Concentration (µg/m3) *	**Population-Weighted Contribution by the Brick Sector while in operation to $PM_{2.5}$ Concentration (%)**	**Number of Deaths Attributable to $PM_{2.5}$****	**Number of Deaths Attributable to $PM_{2.5}$ from Brick Making**	**Mortality DALYs**
Bangladesh	92	10%	122,400	6,120	48,960
India	74	10%	1,090,400	54,520	436,160
Nepal	75	7%	18,300	598	4,782

**State of Global Air 2017, by HEI and IHME (https://www.stateofglobalair.org/data)*
*** Global Burden of Diseases for 2015 (Cohen et al., 2017)*

Table 3.12 presents the summary of the total excess cases and morbidity-caused DALYs in the three countries due to PM_{10} emissions of the brick sector. The most significant excess cases are seen at the health end points of Respiratory Symptoms (RSs) and Districted Activity Days (RADs). Increases in Lower Respiratory Illness in children (LRI) is another critical part of the health impacts of the brick sector. At the national level, we estimate that there are around 1.9 million cases of LRI in children annually due to PM10 emissions from the brick sector in Bangladesh, 13.6 million in India, and 184,000 in Nepal. The total DALYs associated with all the health end points included in this study are approximately 70,000 in Bangladesh, 500,000 in India, and 7,000 in Nepal.

Table 3.12 Health End Point Estimates and Attribution of Health Impacts to PM_{10}

	Excess Cases						
	Chronic bronchitis (CBs)	**Hospital admissions (HAs)**	**Emergency room visits (ERVs)**	**Restricted activity days (RAD)**	**Lower respiratory illness in children (LRI)**	**Respiratory symptoms (RSs)**	**Total DALYs (Morbidity)**
Bangladesh Total	9,616	13,264	260,192	63,279,541	1,867,990	202,273,467	68,835
Dhaka District	2,473	3,411	66,910	16,272,617	480,362	52,015,528	17,701
India Total	70,031	96,594	1,894,862	460,836,165	13,603,723	1,473,065,820	501,296
Nepal Total	949	1,309	25,687	6,247,215	184,416	19,969,263	6,796
Kathmandu Valley	806	1,112	21,809	5,304,076	156,574	16,954,513	5,770

**Population data retrieved from 2011 Bangladeshi Census.*
No data available for the Rangpur zone, leaving a unexamined population of approximately 15.7 million Bangladeshis.

At the time of the last census the Mymensingh division had not yet been created and therefore is not listed in our divisions above.
**Nepal: Population data retrieved from 2011 Nepali Census. No data available for the Kamali or Mahakali zone, leaving an unexamined population of approximately 1.3 million Nepalis.*

Bangladesh

The total number of DALYs attributable to brick kilns in Bangladesh is estimated at approximately 70,000 annually (Table 3.12). Bangladesh's Dhaka Division faces a disproportionate amount of the health burden, due to the highly concentrated population and kilns to meet the demand of the metropolitan center. We also estimate the impacts on Dhaka City separately. The clusters of brick kilns coupled with its high population density results in about 52 million excess cases of respiratory symptoms and 67,000 emergency room visits every year in the city. The estimated total DALYs lost for Dhaka city is 17,700. The city's population also faces 0.5 million early LRI in children per year, while the whole country may expect 1.5 million cases of LRI in children every year.

A previous study of morbidity in Dhaka city estimated the morbidity DALYs lost due to kiln pollution at approximately 200 annually (Motalib et al., 2015); extrapolating this data to the larger population of Dhaka Division, an estimated 1,750 DALYs would be lost. The estimated number of DALYs in this study is considerably larger, due to our inclusion of restricted activity days, lower respiratory illness in children, and adult chronic bronchitis, which were not included in the Motalib's estimation.

India

Given the estimated 12.3 $\mu g/m^3$ PM_{10} contribution by Indian brick kilns, roughly half a million DALYs were lost due to exposure to PM_{10} emitted by brick kilns. There are an estimated 13.6 billion cases of lower respiratory illness in children that are attributed to brick kiln PM_{10} emissions. In addition, 70,000 excess cases of adult chronic bronchitis, 1.9 million excess emergency room visits, and 460 million restricted activity days due to kiln generated particulate matter air pollution.

A previous study estimated approximately 91,000 excess cases of adult chronic bronchitis, 3.5 million excess emergency room visits, and 600 million restricted activity days due to kiln generated particulate matter air pollution in Delhi, India (Guttikunda and Goel, 2013). Comparatively, our estimates are pretty much similar and a bit on the conservative side when compared to this study.

Nepal

The twelve zones of Nepal for which kiln data was available have a combined population of over 25 million. It is estimated that this population will have an excess of approximately 156,000 cases of childhood lower respiratory illness in the KV and nearly 30,000 more in the rest of the country. In total, there is an excess of an estimated 20 million cases of adult respiratory symptoms (Table 3.12). The total number of DALYs lost is approximately 6800 annually.

Unsurprisingly, Kathmandu, which is the country's densely populated capital city, has the highest level of health impacts. The zone accounts for approximately one-fourth of the estimated mortality burden from brick kilns. Previous studies on the impacts of brick technologies have focused on Kathmandu and Kathmandu Valley because of this disproportionate burden. Epidemiological studies in the Kathmandu Valley have shown a 3-4% increase in same day hospitalizations and 4-5% increase in lagged hospitalizations for a 10 $\mu g/m^3$ increase in PM_{10} (Shrestha, 2007); another study found that a one percent increase in PM_{10} caused a 0.5% increase in acute respiratory inpatient visits (Saraf, 2005).

Kathmandu Valley has a population of approximately 2.8 million people. There are an estimated 800 excess cases of chronic bronchitis and over 5.3 million restricted activity days attributed to brick kiln emitted PM_{10} in the Kathmandu Valley. The total number of DALYs lost is approximately 6,000.

Other zones with high levels of health impacts are Narayani and Lumbini, both located in Southern Nepal. These regions have an estimated approximate of 220,000 excess restricted activity days each. Previous studies assessing the health impacts in regions outside the Kathmandu Valley could not be found.

Economic Losses of Health Impacts

To estimate the economic costs of the pollution caused health impacts, the mortality numbers are converted into DALYs. The mortality-caused DALYs are added to the morbidity-caused DALYs to obtain the total DALYs. Their associated annual economic losses are calculated by multiplying by the GDP per capita. The total economic losses are the sum of the losses from DALYs and those in the form of costs of health care, which are assessed based on the excess cases of diseases.

Finally, in an attempt to quantify the cost of the excess health burden attributed to kilns, all endpoints except the LRIs were given a projected cost. The data were estimated based on average daily wage, hospital admission (bed/day), emergency room visit, and doctor visit costs per country. For Bangladesh and Nepal, these per case values were provided by previous World Bank analyses; for India, these values were calculated from WHO estimates of the above costs and the following methods. Restricted activity days (RADs) were calculated as an estimated one day of work lost per 10 RADs. Chronic bronchitis (CB) estimated cost was a complex calculation based on data from the United States and Europe (Schulman, Ronca, and Bucuvalas, 2001 and Niederman et al 1999).

Country specific estimates are presented in local currency and 2015 United States dollars below (Table 3.13). Health costs per case of all morbidities are significantly lower in India compared to Nepal and Bangladesh.

Table 3.13 Country Specific Cost per Case Estimates for Selected Morbidities (2015 US$)

	Chronic bronchitis (CBs)	**Hospital admissions (HAs)**	**Emergency room visits (ERVs)**	**Restricted activity days (RAD)**	**Lower respiratory illness in children (LRI)**	**Respiratory symptoms (RSs)**
Bangladesh*	5715	124	4	1.6	11	1.3
India**	5759	345	11	1.0	11	0.7
Nepal***	1920	96	14	1.7	11	0.9

****Per case values from Nepal Cost Benefit Analysis*

***Average cost of ER Visit, hospital bed per day, and local doctor visit from WHO data for India.*

Average Indian daily wage from Labor Bureau of India.
**Cost per case values come from World Bank's "Bangladesh Country Environmental Analysis" report.*

The economic costs due to health care of the excess cases in the selected health end-points caused by the brick sector are provided in Table 3.14. **The healthcare costs associated with excess morbidity are estimated at approximately US$ 442 million for Bangladesh, US$ 2.1 billion for India, and US$ 32 million for Nepal** (Table 3.14). The majority of these costs are the result of excess respiratory symptoms and RADs. CBs are another major contributor of the total. Cities are again the hot spots. The estimated costs of health care in Kathmandu Valley alone are about US$ 28 million and the costs of Dhaka are as high as US$ 117 million.

A previous study estimated the health cost per brick in Bangladesh was at 0.9 taka per FCK produced brick and 0.5 taka for Improved FCKs (Croitoru and Sarraf, 2012). We estimated an annual production of 11 billion bricks from FCKs and 16 billion from ZZKs in Bangladesh. Using these factors and assuming the current 4,000 Z-Z kilns perform similar like Improved FCKs, roughly the brick sector would be responsible for 18 billion takas (about US$250 million) in costs associated with excess morbidity. We have a total estimate of US$442 million for all kilns combined. Our estimate is about 40% higher. Considering that our estimate is conducted about 7 years later, the result is still quite comparable.

Table 3.14 Estimated Cost of Select Health End-Points Attributed to Brick Kiln Emitted PM_{10} (2015 million US$)

	Chronic bronchitis (CBs)	**Hospital admissions (HAs)**	**Emergency room visits (ERVs)**	**Restricted activity days (RAD)**	**Lower respiratory illness in children (LRI)**	**Respiratory symptoms (RSs)**	**Total Cost of Health Care**
Bangladesh Total	55	2	1	99	21	264	442
Dhaka District	14	0.4	4	25	5	68	117
India Total	403	33	21	461	156	1,046	2,120
Nepal Total	2	0.1	0.4	11	2	17	32
Kathmandu Valley	2	0.1	0.3	9	2	15	28

A previous estimate showed that a reduction of Kathmandu's annual PM_{10} by 100 $\mu g/m^3$ could save approximately 30 million rupees in just hospital admission costs (Clean Energy Nepal, 2003); this translates to roughly 0.3 million rupees or less than $3000 USD per 1 $\mu g/m^3$ reduction. Since our estimated PM_{10} concentration due to brick kilns in Kathmandu Valley is 64.4 $\mu g/m^3$ (Table 3.9), our comparative hospital admissions cost based on Clean Energy Nepal's estimates in 2003 would be almost $0.2 million USD. However, our estimate for the cost of hospital admissions is only $0.1 million USD. This is still in the same magnitude. Nevertheless, our study may have underestimated the health impacts, possibly due to the conservativeness in assumptions.

The table below sums up the total economic costs of health impacts attributable to brick making in the three countries, by adding up the costs from DALYs from mortality and morbidity, and the total costs of health care from the selected health end-points. In total, the economic costs on public health of the brick sector in Bangladesh are about **US$633 million** per year, in India **US$ 3.6 billion**, and in Nepal **US$ 46 million**. These health-related economic costs account for 0.17-0.32% of the countries' GDP in 2015. (Table 3.15)

Table 3.15 Total Economic Costs of Health Impacts of the Brick Sector in SAR (2015 US$)

	Economic Cost of Mortality DALYs (million US$)	**Economic Cost of Morbidity DALYs (million US$)**	**Cost on Health Care (million US$)**	**Total Health Cost (million US$)**	**% of Health Costs in 2015 GDP**	**Total Social Costs of CO2 (US$ million)**
Bangladesh	59	130	442	633	0.32%	318
India	695	799	2,120	3,614	0.17%	3,900
Nepal	4	10	32	46	0.22%	66

For comparison, the total social costs of carbon dioxide emissions, which are based on the unit cost of US$ 30/ton of CO_2 in the *Guideline for Social Value of Carbon in Project Appraisal* by the World Bank (2014), are also included in the table above. We can see that they are in similar magnitude as those of health impacts. The figure below shows the relative importance of CO_2 and PMs in their contribution to economic costs.

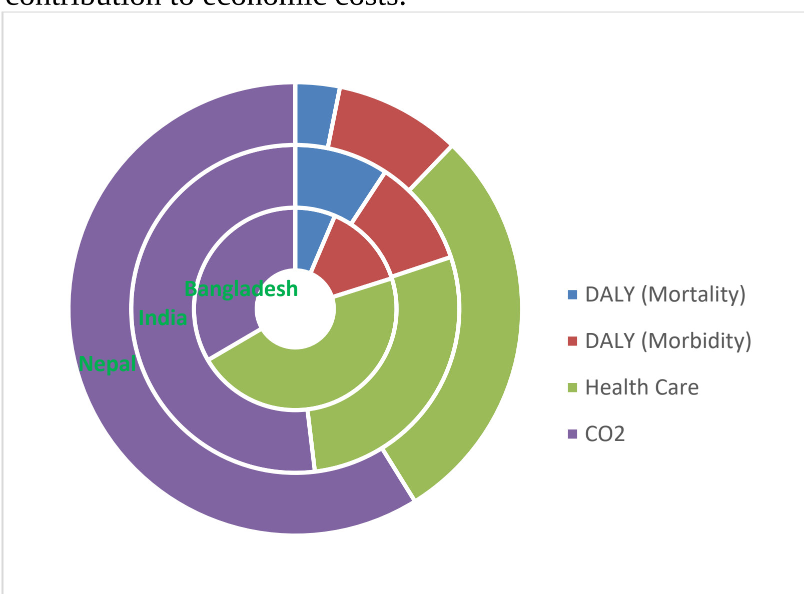


Figure 3.2 Breakdown of Economic Costs of Key Air Pollution

In 2013, a report by the World Bank estimated the healthcare cost of India from particulate matter exposure at 3% of the country's GDP, or approximately 67.5 billion dollars (World Bank, 2013). Assuming 10% of PM emissions (proportional to the share of $PM_{2.5}$ in Table 3.11) are from brick kilns while they are in operation, and during these 6 months they contribute up to 5% of the country's total PM, it could be estimated that the total burden of health cost from brick kilns is US$ 3.4 billion dollars. Our estimate of US$ 2.8 billion per year is not far off from this number, accounting for approximately 82% of this estimate.

Our study may have in general underestimated the health impacts and the associated economic costs of the emissions from the brick sector for the following reasons. First, our method to estimate contributions to ambient concentrations from the emissions inventory tends to underestimate for areas larger than cities. For the impacts on excess cases of health care, the study includes only 6 end-points, and out of which only five are used to estimate the economic costs. To assess the cost due to mortality, we applied the very conservative method where per capita GPD is borrowed as the unit cost. It is also important to note that this study does not examine the occupational health costs associated with brick production, which would raise the estimate considerably, since this population faces a diversity of adverse health outcomes due to their at-work exposures (Thygerson et al., 2016).

3.4 Aggregate agricultural impacts of the brick sector in South Asia

Most brick kilns in South Asia have been constructed on fertile agricultural land, usually in the low-lying areas of the country. The clay-based brick production method uses topsoil from agricultural land, usually up to a depth of 1 meter, as the primary raw material. The topsoil is generally the most fertile and productive layer of any agricultural land and thus its removal causes huge economic loss in terms of lost agricultural productivity. A study conducted in the Philippines estimated that a ton of soil loss leads to productivity decline of 12.5 kg per hectare for corn (Francisco and Angeles, 1998). Another estimate by Carson (1992) calculates that a loss of 1 mm of topsoil causes a loss of 10 kg of nitrogen, 7 kg of phosphorus and 15 kg of potassium per hectare. Oftentimes, farmers use excessive chemical fertilizers to compensate for the loss of soil fertility, causing unintended damage to both soil and the environment. Having huge swaths of land for brick production also causes land degradation. In countries like India, the use of topsoil for brickmaking has been restricted (Ministry of Environment and Forests 1998) (World Bank, 2011), but lacks strong enforcement.

The removal of topsoil from one plot of land also leads to erosion of the adjacent piece of land, which often times encourages the owner of that adjacent land to also sell his top soil in order to make his land equi-leveled for cultivation (ICDDRB, 2013). This cyclical process decreases the water absorption and containment ability of the entire plot of land, eventually impacting the total agricultural productivity, an increasing concern of the Indian government.[46]

CASE STUDY: Environmental cost of using top-soil for brickmaking, Tamil Nadu, India (Reproduced from EY, 2015c)

Approach: Poonamalle taluk[47] in Thiruvalloor district in Northern Tamil Nadu and Sri Vaikuntam taluk in Tuticorin district in Southern Tamil Nadu were selected for the study. In both taluks, the list of survey numbers and the village name from where top soil has been leased/ given to brick makers were procured from the respective collector's office. Five villages from each taluk were chosen randomly for the study. One hundred farmers from each taluk were selected for the study and were post-stratified as sellers or non-sellers of soil. Data on land holding pattern, irrigation sources, area and depth of soil sold for brick making, income obtained from sale of soil, crops cultivated in the last three crop years and detailed information on inputs applied, yield and returns from crop production were obtained from the farmers through a structured pre-tested

[46] The Indian national government's Ministry of Agriculture and Farmers Welfare has noted in comments to the authors, "State Agricultural Departments may be involved as a Primary Stakeholder and building the brick kiln near an agricultural land should be done after obtaining necessary permissions from these departments."
[47] A taluk is an administrative division comprising several villages.

questionnaire.

Analysis: The replacement cost approach[48] was used to estimate the impact of topsoil removal on fertility and its economic costs. Soil samples from plots where topsoil had been sold and plots from which soil was not sold were chemically analysed in a soil-testing laboratory to examine the loss in fertility. The economic cost of topsoil removal was found quite significant.

- On average, the removal of top soil resulted in the loss of about 13 kg of Nitrogen (N), 1 kg of Phosphorous (P) and 16 kg of Potassium (K) in the North and 10 kg of N, 1.4 kg of P and 11.5 kg of K in the South.
- The value of iron lost was INR[49] 560 per acre in the North and INR 625 per acre in the South, the loss of manganese was worth INR 185 per acre in the North and INR 270 per acre in the South. The value of organic matter lost per acre was INR 97 in the North and INR 130 in the South.
- The total cost of nutrient loss due to topsoil removal was INR 1,218 per acre in the North and INR 1,297 in the South, with an inter-regional average of INR 1,267 per acre.
- Using the Productivity Cost Approach[50], it was determined that the reduction in income and yield due to selling soil was INR 1,316 per acre for rice in the North and INR 994.36 per acre in the South; it was INR 1,269 per acre for groundnut in the North, and INR 2,933.65 per acre for banana in the South.

Maria et al. (2011) have reported that the agricultural productivity is adversely impacted by acid deposition from sulfur dioxide (SO_2) and NO_x emitted along with the flue gas from brick kilns. Skinder et al. (2013) have also corroborated this finding, and have additionally found that even particulate pollutants such as SPM have detrimental impacts on certain species of crops such as wheat and mustard because of decrease in total chlorophyll, ascorbic acid and carotenoids content in response to air pollutants. The brick kiln emissions also have negative impacts on biochemical parameters like chlorophyll, phaeophytin, carotenoids, carbohydrate, proteins and lipids of the vegetable species namely Brassica Oleracea, Phaseolus Vulgaris L. and Solanum Melongena L. (ibid).

In a research study conducted to evaluate the impact of brick kiln operation on various physicochemical parameters of agricultural soil in Bhaktapur, Nepal, Bisht and Neupane (2015) found that the concentration of heavy metals such as chromium and lead were higher in soil within a distance of 50 meters from brick kiln, and the soil within a distance of 50-100 meter from brick kiln was also deficient in nutrient content, depicting a proportional relationship between reduced quality of soil and its proximity from the brick kiln.

[48] Productivity loss from soil removal can be estimated on the basis of two economic models. The first model is called the Replacement Cost Method, which estimates the cost of replacing an ecosystem service (soil fertility) with a man-made substitute, which in this case would be chemical fertilizers, to compensate for nutrient loss. The second model is called the Productivity Change Method, which places a value on the services soils provide in terms of typical agricultural output. This method assumes that the value of productivity change is equal to the difference in crop yields with and without that change multiplied by the unit price of the crop, which is or might be grown, potentially adjusted to reflect any differences in the cost of production (Barbier,1998). This approach, in other words, assumes that nutrient value is equal to the change in revenue or profit caused by nutrient change.

[49] 1 USD = x INR

[50] Productivity costs are costs associated with production loss caused by some phenomenon, in this case the removal of soil. PCA is a methodology used to measure the economic value of productivity losses.

3.5 Climate change impacts – Aggregate for the region

As already discussed in Sections 3.1 and 3.2, the brick sector contributes to global climate change through the release of CO_2, black carbon (BC) and suspended particulate matter among other pollutants[51], the latter two being the second-largest contributors to global warming after CO_2 (Lopez et al., 2012; Ramanathan and Carmichael, 2008). The short atmospheric life time of black carbon, hence called one of the short-lived climate pollutants (SLCPs[52]), differentiates it from long lived greenhouse gas emissions such as CO_2 because its short lifespan means both immediate impacts on global climate, and if curbed in a timely manner, positive climate responses within the next few decades (US EPA, Undated) along with measurable health, crop and ecosystems co-benefits. Furthermore, BC absorbs the most solar energy among the various forms of particulate matter[53], making it a significant contributor to near-term global warming (ibid). This is one reason black carbon has been extensively studied in the context of brick industry, and it is particularly important in Nepal, Bangladesh and India where the industry is responsible for 6%, 22% and 16% of all black carbon released in each country respectively. In the case of Bangladesh, the brick sector's CO_2 emissions (16.6% of the total) are also on par with BC emissions (World Bank, 2011), requiring climate impact studies that look at both CO_2 and BC. It is not always easy to tell whether particular climate impacts are attributable to CO_2 or BC because often times, they have combined impacts. The following section specifically discusses black carbon impacts as regional CO_2 impacts have already been comprehensively covered by several reports in the past (e.g. Hijioka et al., 2014; World Bank, 2013c; Ahmed and Suphachalasai, 2014; Bhatiya, 2014).

Black Carbon and its climate impacts in the region

In South Asia, four major sectors contribute to BC emissions – residential, open biomass burning, transport and industry. As depicted by Table 3.3, brick industry takes a significant share of total BC emission in each of the three studied countries – 6%, 22% and 16% respectively in Nepal, Bangladesh and India. In Kathmandu, this figure stands at 10%. The study of black carbon impacts in South Asia is particularly important because of the location of the Himalayan glacier system in this region that is a source of drinking water and irrigation for about 1.5 billion South Asians. A study conducted by the World Bank and The International Cryosphere Climate Initiative (2013) argues that proximity matters when it comes to the climate impact of black carbon. BC particles pose a serious danger to the Himalayas, which is discussed below in detail. It should, however, be noted that aerosol particles are capable of travelling longer distances, and a good portion of South Asian black carbon could have originated in other regions, particularly China, one of the largest BC emitters in the world (Kopacz et al., 2011).

a. Impact on the Himalayan Cryosphere (Direct Effect)

According to Ramanathan (2013), black carbon absorbs as much as 60% to 80% of the solar radiation when it is deposited over the snow and ice, thus contributing to as much as 30% of the melting of glaciers in the Himalayas. Menon et al. (2010) have also quantified the impacts of BC

[51] Other pollutants include, but not limited to Carbon monoxide (CO), sulfur dioxide (SO_2) and nitrogen oxides (NO_x)

[52] The main SLCPs are black carbon (<2 weeks), methane (<15 years), tropospheric ozone (<2 months), and hydrofluorocarbons (<15 years).

[53] Black carbon is a primary component of particulate matter (PM).

aerosols on snow cover and precipitation over the Indian subcontinental region from 1990 to 2010 and found that Indian BC alone contributed to approximately 36% of the total snow/ice cover decline in the Himalayas. A similar study by Xu et al. (2016) has concluded that BC is instrumental in glacier retreat, loss of snow cover and thinning of snow packs in the Himalayas through direct atmospheric heating, darkening of snow surface and the snow albedo feedback. Such impacts could also result in extreme events such as potential flooding and glacial lake flood outburst events (World Bank and International Cryosphere Climate Initiative, 2013).

b. Impact on Cloud Formation and Precipitation (Indirect Effect)

Menon et al. (2010), referring to the IPCC's study on aerosol-cloud interactions, argue that BC particles could change cloud properties and impact cloud formation as well as cloud reflectivity because an increase in aerosol particles increases cloud droplet number concentration (CDNC), reducing cloud droplet sizes. Reduced cloud droplet sizes in turn inhibits precipitation. The Earth Observatory at NASA Goddard Space Flight Center[54], however, also points out the fact that these aerosols could also lead to taller clouds that are more likely to produce lightning and strong downpours. This observation aligns with a study by Menon et al. (2002) where they found that black carbon led to droughts in northern China and extreme floods in southern China. Bond et al. (2013) warn that although few climate models have isolated these indirect effects of black carbon, it is still a large source of uncertainty and warrants further studies.

c. Impact on Global Warming

A study by the World Bank and The International Cryosphere Climate Initiative (2013) used three different methods to estimate radiative forcing[55] from black carbon – the UNEP and WMO (2011) assessment, Bond et al. (2013) assessment and an assessment using NASA Goddard Institute for Space Studies (GISS) Aerosol Indirect Effect (AIE) model. The study found that the "probability that measures aimed at SLCPs like black carbon actually would decrease radiative forcing was much greater in the larger cryosphere regions: both polar regions and the Himalayas (p.51)[56]". There are, however, large uncertainties in evaluating regional radiative forcing, and the study above suggests that "tools with the ability to discern regional impacts are used for assessing the net forcing of species, like black carbon, that vary spatially (p.51)".

[54] Aerosols and Clouds (Indirect Effects) - https://earthobservatory.nasa.gov/Features/Aerosols/page4.php

[55] The IPCC Fourth Assessment Report: Climate Change 2007 has defined radiative forcing as "change in net irradiance at the tropopause after allowing for stratospheric temperatures to readjust to radiative equilibrium, but with surface and tropospheric temperatures and state held fixed at the unperturbed values".

[56] "Implementation of the black carbon mitigation measures assessed in this report yield the greatest benefits in the Himalayas relative to any other region considered. Decrease in radiative forcing from black carbon measures: –7.3 w/m^2 (–3.0 to –11.6) (p.35)".

Chapter 4. Challenges and Barriers to the Adoption of Cleaner Brick Technologies

The adoption of cleaner brick technologies in South Asia is impeded by various overlapping barriers. Some are specific to a particular country while the others are generally true for the entire region.

4.1 Policy, regulatory, and institutional barriers

While the air pollution has taken center stage in policy discourse in South Asia, there are few or absent policy and regulatory frameworks, particularly those that target at air pollution arising from artisanal and traditional brick production technologies. The various underlying causes of such gap in public policy are discussed below.

Non-recognition of brick sector as an industry. The brick production in South Asia is primarily concentrated in peri-urban or rural areas of the country, often shadowing it from the policy making process, which is mainly confined to capitals and big cities. The brick production sector is highly informal and marginal, and out of reach of government ministries and line agencies that would have otherwise utilized state machineries to regulate the sector.

Lack of stringent energy efficiency and environmental emission policy, standards and regulatory enforcement. The brick sector operation in India is slightly more regulated than in Bangladesh and Nepal, with well-defined permissible limits on emissions arising from different types of brick kiln technologies. Since most brick kilns in these countries are unregulated and out of reach of government institutions, industry-wide enforcement regulation exists more on paper than in reality. When polluting technologies such as FCK have a return on investment of up to 80% (without factoring in the social and environmental cost of pollution), there is little incentive for existing brick operators and new entrepreneurs to adopt more energy efficient technologies without stringent energy-efficiency and environmental emission policy and regulatory enforcement (SAARC Energy Center, 2013a). The regulatory weakness is also owing to limited capacity of government institutions and lack of political commitment at both local and national levels.

Lack of demand-side policy and supply-side enforcement push for cleaner construction materials. Despite availability of cleaner production technologies and alternate construction materials in the market, there is not enough demand. Some policies have addressed only the supply side and overlooked demand-side issues. For instance, the Brick Act 2013 in Bangladesh says that 50% of produced bricks have to be hollow, but there is lack of demand for such bricks because of slack enforcement mechanisms for cleaner construction as well as production (as discussed in the earlier section). There also is an absence of public awareness of the benefits of cleaner, more sustainable construction materials, both from the air quality perspective as well as in terms of the quality and suitability of the bricks themselves. Governments have by and large not attempted to fill this public awareness gap.

Lack of standards and measurement tools to assess quality, performance, level of pollution, etc. The countries lack an institutional framework to assess brick sector performance, brick quality and pollution level of the sector as a whole. Although development projects in these countries have proposed appropriate kiln design specifications, production and quality standards in an attempt to push the sector towards cleaner production path, the progress has not been effective so far, thanks to absence of institutionalized approach to cleaner brick production. The weak institutional capacity of government agencies is also partly to blame. Further, the governments do not have resources to invest in monitoring and measurement, and a reliable inventory of existing kilns and their location.

Lack of enabling policies that provide adequate support. Public policy support in the form of technical assistance, appropriate market structures, and fiscal incentives, specifically targeting small sized brick operators, barely exist. Similarly, there is lack of comprehensive and holistic brick sector modernization programs in most countries, except in Bangladesh where there are a number of projects that have focused on introducing cleaner technologies and enhancing energy efficiency of existing technologies, with support from both government and international development partners.

Shifting policy priorities in short term and lack of long-term vision. This is particularly the case of Bangladesh where the government has been shifting its technology priorities for some time. The Government of Bangladesh banned BTKs in 2002 and more recently FCKs. There has been an indication that the Zigzag technology might be next one to be banned in the not far future. This precedent of banning brick technologies in an unsystematic way has made the investors and brick operators wary of adopting newer technologies that are mostly expensive and require trained manpower. It is difficult for investors to plan for long.

Inconsistency of policies from different government agencies supporting clean technologies. There is not a clear policy preference for cleaner technologies, providing little incentive to brick operators to switch to such technologies. For instance, the Brick Act 2013 of Bangladesh does not distinguish between small but polluting artisanal technologies and larger but cleaner technologies such as HHK and TK, and it applies the same classification and location restrictions to both types. Similarly, there is no preferential approval provision for comparatively cleaner and alternative plants using non-fired brick/block technologies. In some cases, while the environment ministry is banning polluting technologies, the ministry of finance may at the same time add more taxes on cleaner products. Joint policies among different government agencies around the sector, which can provide holistic regulations and incentives, are generally missing in the region. The process of obtaining a government permit to set up new brick plants is excessively bureaucratic in all three countries – India, Bangladesh and Nepal. This becomes even more troublesome for large-scale plants, particularly the HHK and TK, because of issues such as land ownership and restrictions related to where the plant cannot be set up.

4.2 Technological barriers

Lack of off-the-shelf technology packages and technology providers, and shortcomings in technology design suited to individual country context. Standard technology packages, customized to local context, are not readily available throughout the region, particularly the HHK and the TK (SAARC Energy Centre, 2013c). Most traditional suppliers do not have technical know-how of modern technologies, as a result of which entrepreneurs are not willing to invest in expensive and operationally complex technologies.

Unsatisfactory performance of new technologies. Imported technologies cannot suit local context immediately. It usually takes time for them to be adjusted and adopted, and the process can be very painful and costly. This has resulted in various technical difficulties, leading to poor performance, both in terms of capacity utilization and financial return. For instance, in Bangladesh, the bricks are 25% larger in size as compared with the Chinese ones, the climate is much hotter and more humid, and physical properties of clay also differ (higher moisture content in Bangladeshi clay, requiring longer drying time). When Chinese technologies were directly transferred to Bangladeshi market without customized improvements and modifications, the efficiency in output dropped significantly, e.g. the World Bank funded Hoffman project had capacity utilization factor of less than 65% (World Bank, 2016b). Some other technical problems faced by HHKs and TKs in Bangladesh are summarized below.

Table 4.1 Illustration of technical problems encountered by HHKs and TKs in Bangladesh (Reproduced from World Bank, 2016b)

Problems	Causes
1. Inefficient drying of green bricks (HHK-Tunnel) • Drying quality less than 60% • Moisture content > 10% • Cracking during drying process	• No investment grade raw material • Drying chamber design did not consider clay properties • Lack of adequate chambers, uncertain drying time (too fast or too slow drying) • Faulty design of drying chambers • Faulty design, unable to draw adequate heat from the kiln to dryer • Water seepage in the underground tunnel • Recirculation of additional moisture in the dryer
2. Kiln construction faults (HHK) • Cracking of kilns • High repair cost and time • Lack of number of doors	• Design did not consider local context • No foundation for kiln • No expansion joint in kiln • 24-26 doors are needed in Bangladeshi kiln as opposed to 18 in Chinese for 50k HHK production lines
3. Increased firing time inside tunnel kiln, slow fire movement inside HHK, reducing the capacity by 30%-50%	• Inadequate drying of green bricks (should be less than <5% moisture after drying)
4. Molding section problems • Poor finishing and distortion of green brick shape • Collapse of brick layer inside dry chamber • Hair line crack in the green bricks	• Machinery selection for clay preparation and molding did not consider investment grade clay analysis • Poor quality extruder with low vacuum pressure cannot exert enough moisture content
5. Inefficient operation (HHK, Tunnel)	• Lack of after sales services from technology supply side • Lack of adequate training arrangements with technology suppliers • Absence of operation manual and troubleshooting manual
6. Overall reduction in production capacity and quality of bricks	• Improper design of dryer and kiln, and non-consideration of clay properties in machinery selection

Limited or no access to grid electricity. Frequent power outages are very common in these countries, and since the mechanization of brick production demands uninterrupted, or at least a reliable supply of electricity, the existing brick operators are hesitant to switch from traditional to modern brick kilns. (Substitution of grid power with diesel generators is not always viable or sufficient and can be very costly in terms of fuel and production delays.) Additionally, most modern technologies such as HHK and TK operate at a relatively larger scale, requiring power supply at the same scale. This is worrisome in most South Asian countries, where rural electrification, on an average, is less than 50%.

Technical issues related to raw materials. Clay is the major raw material used in the production of traditional bricks. The quality of clay varies from place to place, and the same technology might not be applicable in all cases. In addition to this, certain policies, though good in intent, suffer from technical difficulty in implementation. For instance, in India, the regulation mandates a mixing of 25% fly ash with clay for brick making so as to promote waste reutilization. This regulation has become problematic because of three major issues – (i) fly ash is not readily available in the market, particularly for small-scale enterprises, (ii) the cost of fly ash is more than that of clay, increasing the cost of final product, and (ii) manual mixing of clay and fly ash is not possible, and procurement of machines to do that adds to the total cost of production, making the output less competitive in the market. The latter has become particularly problematic in rural areas of India where there are frequent power outages, and use of diesel generators significantly ramps up the production cost (as noted above). A regulation that adds cost to consumers without offering corresponding incentives and/or universal enforcement has, therefore, proved to be not viable.

4.3 Investment/financial barriers

High upfront cost and non-creditworthiness of traditional brick operators. Switching from artisanal to modern technologies is an expensive endeavor, and most brick operators, particularly the small-sized enterprises, lack upfront capital to set up modern facilities. This is further aggravated by the informal nature of the brick sector. The sector as a whole is outside the remit of formal institutional structures of industry and is mostly seasonal in nature. The financial institutions that are the primary sources of large-scale capital usually do not consider the brick sector creditworthy, and do not extend loans. For instance, in Bangladesh, an informal sector not recognized as an industry is not eligible for concessional SME loan windows. Most brick operators are also unable to produce sound accounting and financial records owing to a high level of tax evasion - a major obstacle in securing debt funding, noticed commonly in Bangladesh (World Bank, 2016b).

Limited experience of the finance industry with the brick sector and unattractive financial instruments. Local financial institutions have very limited experience lending to the brick sector, partly because of the informal nature of the sector. Most brick entrepreneurs operate on leased land, and have no other collateral to access commercial loans, to either switch to more energy efficient technologies or set up advanced and cleaner manufacturing plants. Brick kiln enterprises thus seldom can surmount the risk tolerance thresholds of financial institutions, meaning the brick sector is usually excluded from loans with competitive interest rates or other favorable financial instruments.

Higher initial investment but lower returns. In the absence of attractive financial instruments, the entrepreneurs are hesitant to invest in modern cleaner technologies such as HHK and TK because these require significantly high initial capital investment but yield returns over a very long period of time. Entrepreneurs tend to prefer technologies such as FCK, because they cost almost 90 percent less than modern technologies such as HHK and TK and have comparatively shorter payback period (SAARC Energy Center, 2013a). In addition to the initial capital investment, the modern technologies such as HHK have higher inventory, maintenance and overhead costs (SAARC Energy Center, 2013b).

Lack of enabling policies for investment. The lack of government policies to factor in the social and environmental costs of operation has further incentivized traditional and polluting technologies. In the absence of strict emission and energy efficiency standards, there is little incentive for entrepreneurs to invest in cleaner technologies that add to the final cost of product, rendering them uncompetitive in the marketplace. Technologies such as VSBK, though they have ROI of up to 40%, have a longer payback period as compared to traditional technologies, which makes them unattractive to investors in the absence of strong environmental regulation (SAARC Energy Center, 2013a). Often times, even if there are regulatory policies, the implementation and monitoring are weak. For instance, in Nepal, the brick operators with better energy-efficiency performance are entitled to enjoy the benefits of 50% exemption in license fee, as promulgated by the budget of fiscal year 2008/9, but that has not come to fruition in the absence of certified monitoring results (ibid).

Lack of interest in borrowing. The traditional brick kiln owners are used to doing business with the cash they have in hands. They don’t have much experience of working with financial institutes, nor are they interested in. It is a combination of being risk averse, lack of capacity and experience, and behavior habits.

4.4 Knowledge and capacity barriers

Lack of assessment and effective monitoring of pollution caused by brick kilns. Despite growing interest in and awareness of urban air quality problems among policymakers and the public, most countries in South Asia do not have effective mechanisms to assess and monitor emissions arising from the brick production process. The local authorities either lack awareness or have no incentives for oversight. Even in cases where pollution caused by brick kilns is reported to local authorities, there is inaction from the government to hold them accountable to such pollution. The Environmental Performance Index by Yale University (Hsu et al., 2016) has ranked Bangladesh, Nepal and India ranked 173, 149 and 141 respectively among 180 countries globally in terms of overall environmental performance, while WHO and IEA data from 2016 on ambient $PM_{2.5}$ concentrations rank all three countries among the worst ten globally out of 135 countries studied (WEF, 2017). All three countries have ambient air quality standards, except for $PM_{2.5}$ in the case of Nepal, but the monitoring suffers from government oversight and neglect. This weakness in the policy and regulatory framework has disincentivized interest and investment in modern cleaner technologies.

Lack of knowledge and awareness of modern technologies among key stakeholders. The awareness level of modern technologies such as HHK and TK and alternate building/walling materials is generally very low among investors, policy makers and service providers. Although existing suppliers have access to state of the art technologies from various neighboring countries, there is not sufficient market pull for these technologies because (i) the mainstream investors are not aware of investment opportunities and technology availability in brick sector, (ii) the policy makers do not have enough information at their disposal in order to formulate conducive policy and institutional frameworks for cleaner technologies, and (iii) in the absence of sufficient market demand for cleaner technologies, the service providers have little incentive to invest in training manpower required for setting up complex modern technologies. The existing kiln owners and new entrepreneurs are also hesitant to spend their limited resources on technologies that are yet fully untested locally and not proven financially lucrative.

Limited or no experience of appraising technical and financial viability of modern technologies. Investors/entrepreneurs and financiers do not possess adequate knowledge, capacity and experience to assess financial and technical viability of modern technologies, partly due to nascent market of these technologies. On one hand, the entrepreneurs are not able to prepare a good business plan, due to limited availability of technical know-how. On the other hand, the financiers are not able to evaluate and make informed financial decisions on the proposals submitted by entrepreneurs because of unfamiliarity with the brick sector in general and advanced technologies in particular. These two issues have negative repercussions for speedy market penetration of modern brick technologies.

Lack of financial knowledge to prepare business plans and documentation required for applying to commercial loans. Most brick operators are not well versed in financial sophistication and business skills required for commercial loan applications. It is also difficult to get qualified service providers who possess both knowledge of modern technologies and skills in financial proposal writing. Operating in the gray economy, traditional brick kiln entrepreneurs have generally used informal means of securing resources and find the requirement of technical and financial diligence for proposed projects extremely challenging.

Lack of training centers and trained manpower for operation, maintenance and other after-sales services. Since modern brick technologies are complex in operation and require sophisticated maintenance, traditional brick operators must rely on external service providers for technical assistance, training of workers and other post-sales services. There are, however, not enough service providers in the market who are competent in advanced technologies such as HHK and TK.

Lack of R&D Centers and technical experts for design optimization. Most modern brick technologies have been imported from neighboring countries, and there is no local expertise in adapting imported technologies to local context. There is an absolute dearth of R&D centers and technical experts needed for design optimization, raw materials testing and supervision of kiln construction. In a number of cases in Bangladesh and Nepal, implementation of imported technologies without consideration of local context has resulted in low-quality output and financial loss for both investors and entrepreneurs.

Lack of knowledge to conduct environmental and social impact assessment (ESIA). Most donor-funded programs require that environmental and social impact assessment be done for the proposed projects. For example, in Bangladesh, kiln owners and investors are required to conduct ESIA for (re) financing from ADB or IDCOL loans (World Bank, 2016b). The ESIA concept is fairly new to traditional brick operators, and they do not have capacity to perform quality assessments. This has become a deterrent to potential loan applicants.

4.5 Other barriers

Issues related to leased land. This is a crosscutting barrier, having implications on a number of areas. Most traditional brick kiln operators lack land titles and operate on leased land. For instance, more than 90% of brick kilns in the Gangetic plains of Northern India and Bangladesh are located on leased land (SAARC Energy Center, 2013c). The existing brick operators have to shift from low lying plains to highlands to switch to modern advanced technologies, and this shift requires them to either purchase highlands plots that are comparatively more expensive than lowlands, or negotiate a long-term lease agreement with land owners in the new location. The brick operators find this process painstakingly complex and expensive. Further, there is reluctance in investing in leased land, especially the construction of modern brick making facilities when they have to leave the land anyways after the end of lease agreement.

The availability of land is also a big problem, particularly in a country like Bangladesh where there are restrictions applied to construction in most residential, commercial and wetland areas, leaving no land available for modern brickfields. The challenges in accessing commercial financing vis-à-vis leased land have already been discussed in Section 4.3.

Shortage of skilled labor. As opposed to traditional brick kilns that rely on unskilled or semi-skilled labor, modern kilns require highly skilled manpower. Most brick kiln markets in South Asia suffer from a serious shortage of such trained and skilled personnel.

Chapter 5. Conclusions and Key Recommendations

With a total annual production of approximately 285 billion bricks and an average of more than 5% annual growth rate in brick production in the last couple of years, the three countries in South Asia – Bangladesh, India and Nepal are jointly the second largest brick-producing bloc globally. Brick kilns, involving utilizing backward technologies and burning of low-grade coal, are one of the major sources that contribute to the deteriorating air quality in South Asia. The brick sector, particularly the artisanal technologies such as clamp kilns, mobile chimney kilns and fixed chimney kilns, are highly responsible for Particulate Matter (PM) emissions in many South Asian cities (e.g. the contribution is as high as 91% of total PM emissions in the case of Dhaka city).

The stacks are dirty, and the stakes are high. Considering the health impacts from only PMs, this study has estimated that in the year of 2015, about 6,100, 55,000, and 600 premature deaths were caused by pollution from the brick sector in Bangladesh, India, and Nepal respectively. And, the associated DALYs were roughly 49,000, 436,000, and 4,800 translated from mortality and 69,000, 500,000, and 5,800 due to morbidity respectively. Based on that, the economic costs on public health of the brick sector in Bangladesh are estimated to be about US$633 million per year, in India US$ 3.6 billion, and in Nepal US$ 46 million. Despite such devastating impacts of brick sector related pollution, all three countries have less than 1% market penetration of advanced and efficient technologies (hHoffman, hybrid Hoffman and tunnel kiln). These figures illustrate that the challenges to modernization and formalization, and to the efficiency and pollution control that follow, are substantial.

The opportunities for improvement are immense. Both cost-benefit analysis and sensitivity test suggest that HHK and TK should be the technologies of choice of all entrepreneurs if they are constructing new kilns. This finding applies both to the financial analysis, reflecting private profit alone, and is even more pronounced in the economic analysis incorporating negative health and climate change externalities, which are substantial and offset all private profit except in the case of the cleanest, most efficient technologies. The sensitivity analysis suggests that hollow bricks – compatible primarily with modern kilns – and relatively low-interest financing (also indispensable for capital-intensive modern kilns) dramatically enhance the profitability of HHK and TK technologies, both in the absolute sense and relative to low-debt, smaller-scale kiln projects such as zigzag kiln and fixed chimney kiln.

Leapfrogging options are increasingly available. In India, Alternate Building Materials (ABMs) already account for approximately 25% of total consumption of walling materials. Post 2015 earthquake, Nepal has also geared towards reinforced concrete structures. Provided there are favourable policy and regulatory reforms that bring down the cost of raw materials and incentivize property developers to use resource efficient building materials like Fal-G bricks and concrete blocks, developing countries in South Asia could leapfrog from traditional brick kiln technologies to modern ABMs in a very short span of time.

International development partners have begun to facilitate technology transition in pockets of South Asia since more than a decade ago: parts of Bangladesh, Kathmandu Valley, and several places in India, among other regions. Learning and successes have been painstaking, halting, and hard-won. Nevertheless, these successes in the region, as well as lessons learned, technologies, and approaches from other regions, illuminate the potential and possible pathways to a modernization of the brick sector that, albeit in the earlier stages, is already underway.

5.1 Overarching Observations and Lessons Learnt

The barriers explored in chapter 4 and the case studies of donor-funded initiatives in chapter 1 (Bangladesh specifically, but also Nepal and Bihar) provide a rich tableau of guidance, challenges, and lessons learned from which to draw conclusions and recommendations. A number of overarching observations and recommendations transcend country boundaries and narrow market and sub-region characteristics; they apply more globally across South Asia.

The informal, artisanal nature of the sector is a major barrier to investment and modernization. Many barriers to improvement flow out of the brick industry's entrenchment in the gray economy: the lack of adequate investment and bank financing; low levels of human capital and know-how; weak or absent regulation, oversight, and standards; evasion of taxes and regulations; poor working conditions and wages; and largely stalled transition to higher-quality products and more efficient production technologies and approaches. In short, the very features of the sector's informality are also entrenched obstacles to change through policy or investment.

Pilots are still essential. Because there is no silver bullet for brick sector modernization, pilot approaches are needed to give new technologies and operational modalities a beachhead in South Asian markets, and to use the method of learning by doing. Pilot projects, demonstrations, and lending initiatives along the lines of those pioneered in Bangladesh can be effective because they localize research and development (R&D), commercialize new business models and technologies, and provide sustained investment in supply chains, training, and access to capital. It will take a significant period of time. And, the process will be full of challenges and pain.

Sector-wide solutions to transition to cleaner and efficient technologies require government support. It should be of the governments' interest to do so, considering the sector's huge impacts on public health, environmental quality, and agricultural productivity. Government support can and must take many forms to be effective: regulations and standards, enforcement, legislative mandates related to fuel use, emissions, brick quality, labor, and land use; economic incentives such as tax benefits and concessional financing; and other enticements such as preferential permitting and access to markets etc. In particular, access to land, accessible and reasonably low-cost debt, and internalization of social and environmental costs in government policy are sine qua non conditions of a successful brick sector transition. The South Asian governments should also seek various forms of international climate finance to reform their brick industries.

Sustained support to professionalize and formalize the brick sector is needed in a range of areas in concert to ensure a speedy and complete transition. Areas of necessary focus include: registration and certification, standardization and market regulation, labor, environment, and health regulation, vocational and managerial training, and access to capital etc.

Holistic, long-term sectoral transformation roadmaps are needed for the countries in SAR. Despite the government mandate and relative success of advanced technologies in Bangladesh, modernization of the sector has been halting because of mixed messages from government, lack of long-term, consistent strategies and polices, absence of a roadmap for phasing out inferior incumbent technologies, and in many cases missing phased emission standards and their effective enforcement. Consequently, investor certainty is low, retarding investment in the entire sector, particularly in new technologies. Government roadmaps can create market signals and frameworks around which companies and development organizations can invest.

Government roadmaps and policies should take into account the status quo and the challenges of dislocation and alternative livelihood for existing kiln operators and workers. While adoption of advanced technologies is desirable and inevitable, transition plans are needed to ensure sustained near-term progress and to minimize unnecessary dislocation within the industry. In some cases, intermediate technologies and retrofits to transition to improved FCKs, ZZKs, VSBKs and even HHKs should be considered for support. If these intermediate technologies are more feasible, less capital intensive, or more easily available to existing kiln investors and operators, it is likely that they can be adopted more quickly, and may then create a virtuous cycle of competition, dynamic progress, and technology adoption in an otherwise technologically stagnant market, laying the foundation for future technology improvement and transition to higher-skilled labor.

Deeper transformation is yet to initiate. Other options such as alternative raw materials, hollow bricks, and improved brick making and construction practices are largely untapped opportunities for better fuel efficiency, product quality, construction, and air quality. As chapter 2 explores, numerous low-technology approaches exist to reduce fuel consumption, air pollution, and environmental degradation while improving brick and construction quality – many without switching fuels or upgrading kilns (both of which can magnify the benefits). The surface has barely been scratched for transitioning to hollow bricks, non-fired bricks, and other brick products that can in many cases improve brick quality while minimizing energy use and pollution. While Fly Ash-Lime-Gypsum (FaL-G) blocks, Cement Stabilized Soil Blocks (CSSB), and Autoclaved Aerated Concrete (AAC) have penetrated pockets of the market in India, these materials are much less widely used, due to various reasons, in Bangladesh and Nepal and still very much underutilized in much of India. Better upstream or downstream practices and techniques can also help save energy and other resources and mitigate environmental impacts. Likewise, alternative construction technologies such as rattrap bricklaying reduce the volume of bricks per wall; alternative materials can substitute for clay, the mining of which strips of fertile topsoil from agricultural lands. These approaches should be explored for pairing with kiln technologies of all types to achieve social, environmental, and market objectives.

5.2 Recommendations

Based on the observations and learning discussed above, some specific recommendations could be made for the region as a whole, and the three countries in particular.

Recognize the importance of the sector. This is a sector forgotten by development. Urgent attention and actions are required for fundamental modernization. It needs to be recognized as a key sector for pollution management, energy saving, land protection, and labor, gender, and other associated social issues by policy makers and development partners. What is needed first and foremost is that governments in SAR start to treat modernizing brick making as a development priority.

Plan for long-term. At national level, long-term strategies need to be developed or updated. This must be accompanied by concerted cross-ministry policies and clearly defined roadmaps of implementation. The whole strategy and policy efforts will have to be led by one of the most powerful government agencies and coordinated with all other agencies that have this sector in their jurisdictions.

Continue to raise awareness. Awareness raising and knowledge improvement are still broadly in need. Data availability and quality in this sector are low. Much critical information is still missing. More studies and data-gathering are called for to help improve knowledge on energy consumption, emission factors, and health impacts. In particular, future epidemiological studies focusing on impacts of air pollution from brick-making will be critical to enhance understanding of the scale of impacts on public health at the regional level. Large-scale training for entrepreneurs, kiln workers, financial institutions, and regulatory agencies for the benefit of performance improved and advanced kilns is urgently needed. A South-South knowledge exchange could be valuable given that most developing countries are slowly transitioning to improved and more energy efficient brick kiln technologies. South-South exchanges can facilitate the adoption of technologies and methods applicable to other countries to promote the uptake of best practices.

Promote social welfare of the brick workers and their families. There are many social issues linked to the sector, mostly affecting people at the bottom of the income ladder and social status. Drudgery, bad working and living conditions, bound labor and child labor are common in the region. Proper health care, water sanitation, and provision of childcare and education for the workers and their families are missing in most, if not all, brick kiln sites. It is almost impossible for the traditional brick kilns to address these issues, given they operate only on a seasonal basis, and hire mainly migrant labor. It is also very difficult for the government to regulate them, considering their informality. Transition to more advanced technologies opens opportunities to address these social issues at the same time.

More specifically, policy wise, both regulation and enforcement are critical -

1) Both regulatory/enforcement push and technology and capacity pull approaches are needed to upgrade brick kiln stock.

2) Improved enforcement of regulations on labor, air quality, building materials, and other aspects of brick production would lead to better environmental and social outcomes, necessitating substantial monetary and human resources support for government regulatory agencies.

3) Concerted efforts from local government, financial institutions, and international donors will be necessary to overcome obstacles and accelerate the construction of advanced kilns, including concessional lending/loan guarantee programs, technology demonstration and training, and streamlined permitting for siting and regulatory approval.

At the technical level, in order to realize deeper transformation, besides kiln technologies discussed and assessed in detail through this study, the following should be brought up on agenda immediately:

1) Adoption of hollow bricks and other product and construction innovations can yield immediate fuel efficiency, monetary, and emissions reduction benefits even before or as new technologies are adopted.
2) Non-fired technologies are perhaps the most economic options to scale up with existing know-how and infrastructure; they should be supported where already adopted and explored elsewhere.
3) Alternative fuels to coal have promise and should be explored, including biochar, rice husks, and other sustainable forest and agricultural waste products, to reduce emissions and fuel costs and support sustainable land use industries. Dedicated roadmaps or action plans could spur action to directly obtain crop residues from farmers to be used as an alternative fuel by the brick kilns.

Bangladesh

Support scaling up advanced technologies. Among all the countries in SAR, Bangladesh's brick sector has experienced the largest number of interventions. After about a decade of pilots and demonstrations of advanced technologies including mainly HHKs and TKs and various transitional kiln types (e.g. ZZKs and improved FCKs), the sector is at a critical point where continuous, maybe even stronger, support is needed to scale up investment in cleaner kiln technologies.

Provide long-term regulatory certainty. As mentioned earlier, inconsistency and lack of long-term vision is a common issue of brick policies in SAR countries. Bangladesh provides one specific example. The Brick Act approved in 2013 needs to be revisited. The distinctions between different technology types should be considered as less important, and the restrictions against which should be eased to reflect the realties on the ground. Regulations should focus on compliance through performance standards such as specific energy consumption (SEC), emissions levels, and design standards, rather than by banning technologies by name per se. They also have to be designed with enforcement schedule for both existing kilns and new kilns to be built.

Harmonize cross-ministerial policies. Conflicting polices issued by different government agencies can undermine the efforts of promoting cleaner technologies. For example, as a result of higher VAT currently hollow-brick prices are higher than solid-brick prices, despite the fact that hollow bricks are cheaper to produce and use 30 percent less coal and clay (hence, emitting less pollution and saving topsoil) than solid bricks. Some builders also prefer using hollow bricks for non-weight-bearing walls because of their lightweight. However, both producer profitability and consumer demand are eroded because of the higher price resulted from the VAT. Tweaking the tax regulations to fully align with the environmental policy will not only send a positive signal to investors but also encourage consumer demand for and use of cleaner bricks.

Government-led R&D for alternative walling materials. Because of lack of raw materials other than clay, it is challenging for Bangladesh to move away from fired bricks. To initiate production of walling materials alternative to fired bricks, a lot of upstream R&D will be needed to identify, test, and demonstrate locally available, economic, and safe materials to be utilized. Without strong government intervention, this is foreseen to be extremely difficult, considering more challenges still exist downstream the vale chain, such as in market recognition and building regulation, etc.

India

Bring clean and efficient brick sector discourse to the center of sustainable development agenda. As India introduces more solar power, cleans up its dirty coal power plants, and reduces emissions from its transport sector, brick making will stand out as a real major coal consumer and polluter. While new alternative materials are being adopted in urban construction, red-fired bricks will remain as the most important walling material for a very long period. Demand for them will also keep growing together with the economy. How to make the brick kilns cleaner and more efficient needs to be brought on the agenda of sustainable development of the country, considering its immediate and long-term impact on energy consumption, labor, land use, and public health.

Launch state level targeted initiatives. The lack of market information necessitates local- and regional-level barrier analysis to identify measures to facilitate improved and advanced kiln technology adoption, as has been done in Bihar. As the Bihar case shows, state-level initiatives have much potential to transform the brick sector at the local level; as such, state governments should prioritize brick sector strategic planning and management.

Promote non-fired technologies in tandem with cleaner fired technologies. With various alternative raw materials available in the country and successful experiences in non-fired brick such as Fal-G bricks, accelerated market penetration of non-fired walling materials can be promoted in parallel with introduction of cleaner kilns. Efforts to improve supply chain reliability for alternative brick materials, such as fly ash and concrete, are necessary to allow such technologies to scale.

Nepal

Nepal has a much smaller brick market, compared with India and Bangladesh. It is also quite fragmented, due to the geographic nature of the country. Nepal has scarce agricultural land but is relatively rich in alternative construction materials. As a land-locked country with little domestic reserve or production of fossil fuel energy, energy security is a real development constraint for the country. The large amount of coal consumption by brick making has added more pressure to this.

Promote alternative walling materials. This should be treated as a top priority of the construction sector. There have been some small investors bringing non-fired brick technologies from India or China. Due to lack of government engagement in regulation and standardization, it has been difficult for non-fired brick products to take a significant share of the brick market.

Conduct more pilots on cleaner kiln technologies that fit the country context. Large scale TKs that can be ideal for Bangladesh and India for the modernization of brick sector may not be applicable in the context of Nepal, where the markets are more fragmented and the geographic layout makes transport challenging and costly. Small scale TKs with a daily production capacity of 50,000 bricks or less can be a much better choice. In places where VSBK pilots have been successful, they can also be considered as transitional options.

Improve resilience of building materials to natural disasters. Like other SAR countries, Nepal is prone to earthquake and other natural disasters. The slow reconstruction in the aftermath of the 2015 earthquake remains an opportunity for entrepreneurs, the government, and donor community to capitalize upon to accelerate the transition to cleaner and more efficient kiln technologies and redefine the brick market with new alternative products. Most kilns in the Kathmandu Valley areas were damaged or destroyed during the earthquake. Many have already been reconstructed. The energy and emission performance of the reconstructed kilns is concerning. Evaluations in that spectrum can be useful to better understand where the sector stands now.

Appendix

Annex I. Specific Energy Consumption (SEC) and emission factor for various brick kilns

Table A1-1. SEC Coal consumption (tons of coal/100,000 bricks)

Technologies	**SARCC, MinErgy, 2013/ Nepal[57] (Heierli et al 2008, Brick by Brick[58])[59]**	WB BD Report, 2011[60]	Brick by brick, 2008[61]	**CASE [62] FCK: 3.0kg ZZ: 2.8kg**	CASE [63] Brick: 3.1kg	**Universal Kiln, WB, 2008[64] Brick: 3.0kg**	AFil, Jessor, 2012[65] Brick: 3.58kg	**Guangqig JI, Brick and Tile World, 2011-06[66]** Brick: 2.43 kg	**Bangladesh ADB credit line monitoring [67]**	**Average[68] (for roughly a 3kg brick with a size of Bangladeshi brick in South Asia)**
Clamp	40		32-71							**42**
MCK	25		19-28							**24**
FCK	21	20-22	17.5-24	18-20						**21**
ZZK		16-18		16-17	12.4					**17 [69]**
VSBK	12	10~12/11~16	11-16							**13**

[57] SAARC Energy Center, 2013a. *Study on Evaluating Energy Conservation Potential of Brick Production in SAARC Countries - A Report on Nepal*.
[58] Heierli, U. and Maithel, S., 2008. *Brick by Brick: The Herculean Task of Cleaning Up The Asian Brick Industry.* Swiss Agency for Development and Cooperation (SDC), Natural Resources and Environment Division, Berne.
[59] calculated from MJ/kg brick, assuming SEC for FCK is 21 ton of coal/lac brick
[60] The World Bank, 2011. *Introducing Energy-efficient Clean Technologies in the Brick Sector of Bangladesh*.
[61] Heierli, U. and Maithel, S., 2008. *Brick by Brick: The Herculean Task of Cleaning Up The Asian Brick Industry.* Swiss Agency for Development and Cooperation (SDC), Natural Resources and Environment Division, Berne.
[62] Baseline measurement conducted under CASE Project financed by the World Bank for the pilot of conversion of FCK to Z-Z. The measurement was conducted for baseline 5 FCKs and 5 Z-Z kilns.
[63] Measurement was conducted under CASE Project financed by the World Bank for the pilot of conversion of FCK to Z-Z. 3 piloted conversions from FCK to Z-Z kilns was measured.
[64] One HHK (Universal Kiln) in Bangladesh was measured by Dr. Amir H. Khan for WB CASE Project, 2008
[65] One TK(AFIL Auto Bricks Ltd at Rupdia, Jessore) in Bangladesh was measured by Dr. Amir H. Khan for Plasma Plus, 2012
[66] Guangqing JI, 2011-06, Analysis of Structure, heat engineering factors, and Energy Consumption for Tunnel Kilns, Brick and Tile World
[67] Data provided by the consultant working for the "Financing Brick Kiln Efficiency Improvement Project" financed by ADB for Bangladesh
[68] This column is the average of the values collected from the difference courses in the columns before. The average SECs are used in this study for the estimate of coal consumption and CO2 emissions.
[69] good practice piloted through government or MDB projects ~12; regular Z-Z without enforcement of standards of design such as insolation etc. 16-18

HHK		12~14				14.09				**14**
TK							12.13	13-15	13-15	**14**

Table A1-2. SEC (MJ/kg fired brick)

Technologies	**SARCC, MinErgy, 2013/ Nepal**[70] **Brick: 2.2kg**	Brick by brick, 2008[71]	GreenTech, 2012[72]	**CASE** [73] **FCK: 3.0kg ZZ: 2.8kg**	CASE [74] Brick: 3.1kg	**Universal Kiln, WB, 2008**[75] **Brick: 3.0kg**	AFil, Jessor, 2012[76] Brick: 3.58kg	**Guangqig JI, Brick and Tile World, 2011-06**[77] Brick: 2.43 kg	**Average (MJ/kg bricks)**
Clamp/DDK	2.36	2.0-4.5	2.90						2.9
MCK	1.5	1.2-1.75							1.5
FCK	1.25	1.1-1.5	1.22	1.23-1.36					1.3
ZZK				1.24-1.37					1.3
ZZK (good practice)			1.12		1.10				1.1
VSBK	0.72	0.7-1.0	0.95(IN) /0.54 (VM)						0.8
HHK						1.207			1.2
TK							0.969	1.5	1.2

[70] SAARC Energy Center, 2013a. *Study on Evaluating Energy Conservation Potential of Brick Production in SAARC Countries - A Report on Nepal*.
[71] Heierli, U. and Maithel, S., 2008. *Brick by Brick: The Herculean Task of Cleaning Up The Asian Brick Industry.* Swiss Agency for Development and Cooperation (SDC), Natural Resources and Environment Division, Berne.
[72] Greentech, April 2012,Brick Kilns Performance Assessment: A Roadmap for Cleaner Brick Production in India, A Shakti Sustainable Energy Foundation supported Initiative
[73] Baseline measurement conducted under CASE Project financed by the World Bank for the pilot of conversion of FCK to Z-Z. The measurement was conducted for baseline 5 FCKs and 5 Z-Z kilns.
[74] Measurement was conducted under CASE Project financed by the World Bank for the pilot of conversion of FCK to Z-Z. 3 piloted conversions from FCK to Z-Z kilns was measured.
[75] One HHK (Universal Kiln) in Bangladesh was measured by Dr. Amir H. Khan for WBCASE Project, 2008
[76] One TK(AFIL Auto Bricks Ltd at Rupdia, Jessore) in Bangladesh was measured by Dr. Amir H. Khan for Plasma Plus, 2012
[77] Guangqing JI, 2011-06, Analysis of Structure, heat engineering factors, and Energy Consumption for Tunnel Kilns, Brick and Tile World

Table A1-3. Emissions Factor SPM (kg/100k bricks)

Technologies	CCAC Fact Sheet[78] Assuming Brick: 3kg / GreenTech, 2012[79] Assuming Brick: 3kg	CASE [80] FCK: 3.0kg ZZ: 2.8kg	CASE [81] Brick: 3.1kg	Universal Kiln, WB, 2008[82] Brick: 3.0kg	AFil, Jessor, 2012[83] Brick: 3.58kg	China Official Emissions Factors for subsector-3131[84]	Average
Clamp/DDK	468						468
MCK							
FCK	306	983					645
ZZK	72	124	81				92
VSBK	39						39
HHK	87			87.9		103.86	93
TK	82.5				66.1	TK production <30million/yr: 72.92 TK production 30~60million/yr: 60.76 TK production >60million/yr: 47.28	69

[78] FACTSHEETS ABOUT BRICK KILNS IN SOUTH AND SOUTH-EAST ASIA, March, 2014, Prepared by Greentech, sponsored by SDC and CCAC Brick Initiative (CCAC Factsheets)
[79] Greentech, April 2012,Brick Kilns Performance Assessment: A Roadmap for Cleaner Brick Production in India, A Shakti Sustainable Energy Foundation supported Initiative
[80] Baseline measurement conducted under CASE Project financed by the World Bank for the pilot of conversion of FCK to Z-Z. The measurement was conducted for baseline 5 FCKs and 5 Z-Z kilns.
[81] Measurement was conducted under CASE Project financed by the World Bank for the pilot of conversion of FCK to Z-Z. 3 piloted conversions from FCK to Z-Z kilns was measured.
[82] One HHK (Universal Kiln) in Bangladesh was measured by Dr. Amir H. Khan for WBCASE Project, 2008
[83] One TK(AFIL Auto Bricks Ltd at Rupdia, Jessore) in Bangladesh was measured by Dr. Amir H. Khan for Plasma Plus, 2012
[84] *Guidelines for Pollution Emissions Factors for manufacturing industry 3131 of clay bricks, tiles, and building blocks*, edited by the National Center for Quality Supervision, Inspection and Testing of Building and Walling Materials of China and China Association of Coal Utilization (3131 is the code for the sub sector of fired brick and tile and building block manufacturing industry)

Table A1-4. Emissions Factor SO_2 (g/kg brick)

<table>
<tr><th>Technologies</th><th>GreenTech, 2012 [85] Assuming Brick: 3kg</th><th>CASE S08[86] FCK: 3.0kg ZZ: 2.8kg</th><th>China Official Emissions Factors for subsector-3131[87]</th><th>USA-EPA SIC-3251[88]</th></tr>
<tr><td>Clamp/DDK</td><td></td><td></td><td></td><td></td></tr>
<tr><td>MCK</td><td></td><td></td><td></td><td></td></tr>
<tr><td>FCK</td><td>0.66</td><td>6.585</td><td></td><td></td></tr>
<tr><td>ZZK</td><td>0.32</td><td>1.435</td><td></td><td></td></tr>
<tr><td>VSBK</td><td>0.54</td><td></td><td></td><td></td></tr>
<tr><td>HHK</td><td></td><td></td><td>0.62</td><td></td></tr>
<tr><td>TK</td><td>0.72</td><td></td><td><table><tr><td>TK production <30million /yr</td><td>TK production 30~60million/yr</td><td>TK production >60million/yr</td></tr><tr><td>0.73</td><td>0.7</td><td>0.62</td></tr></table></td><td>0.6</td></tr>
</table>

85 Greentech, April 2012,Brick Kilns Performance Assessment: A Roadmap for Cleaner Brick Production in India, A Shakti Sustainable Energy Foundation supported Initiative
86 Baseline measurement conducted under CASE Project financed by the World Bank for the pilot of conversion of FCK to Z-Z. The measurement was conducted for baseline 5 FCKs and 5 Z-Z kilns.
87 *Guidelines for Pollution Emissions Factors for manufacturing industry 3131 of clay bricks, tiles, and building blocks*, edited by the National Center for Quality Supervision, Inspection and Testing of Building and Walling Materials of China and China Association of Coal Utilization (3131 is the code for the sub sector of fired brick and tile and building block manufacturing industry)
88 USA EPA emissions standards for "Brick And Structural Clay Product Manufacturing", whose sector code is 3251.

Table A1-5. Emissions Factor NOx (g/kg brick)

<table>
<tr><th>Technologies</th><th>CASE S08[89]
FCK: 3.0kg
ZZ: 2.8kg</th><th colspan="3">China Official Emissions Factors for subsector-3131[90]</th><th>USA-EPA SIC-3251[91]</th></tr>
<tr><td>Clamp/DDK</td><td></td><td colspan="3"></td><td></td></tr>
<tr><td>MCK</td><td></td><td colspan="3"></td><td></td></tr>
<tr><td>FCK</td><td>0.069</td><td colspan="3"></td><td></td></tr>
<tr><td>ZZK (SD + good management)</td><td>0.061</td><td colspan="3"></td><td></td></tr>
<tr><td>VSBK</td><td></td><td colspan="3"></td><td></td></tr>
<tr><td>HHK</td><td></td><td colspan="3">.29</td><td></td></tr>
<tr><td rowspan="2">TK</td><td rowspan="2"></td><td>TK production <30million/yr</td><td>TK production 30~60million/yr</td><td>TK production >60million/yr</td><td rowspan="2">0.25</td></tr>
<tr><td>0.14</td><td>0.14</td><td>0.07</td></tr>
</table>

Table A1-6. Emissions Factor BC (g/kg brick)

Technologies	Cheryl Weyant et al, 2014,[92]	GreenTech, 2012[93]/ CCAC Fact Sheet
Clamp/DDK	0.19	0.29
MCK	0.16	
FCK	0.16	0.13
ZZK (SD + good management)	0.13	0.04
VSBK	0.0015	0.002
HHK		
TK	0.001	0

[89] Baseline measurement conducted under CASE Project financed by the World Bank for the pilot of conversion of FCK to Z-Z. The measurement was conducted for baseline 5 FCKs and 5 Z-Z kilns.

[90] *Guidelines for Pollution Emissions Factors for manufacturing industry 3131 of clay bricks, tiles, and building blocks*, edited by the National Center for Quality Supervision, Inspection and Testing of Building and Walling Materials of China and China Association of Coal Utilization (3131 is the code for the sub sector of fired brick and tile and building block manufacturing industry)

[91] USA EPA emissions standards for "Brick And Structural Clay Product Manufacturing", whose sector code is 3251.

[92] Weyant et al, 2014, Env. Sci and Tech, "Emissions from South Asian Brick Production"

[93] Greentech, April 2012, Brick Kilns Performance Assessment: A Roadmap for Cleaner Brick Production in India, A Shakti Sustainable Energy Foundation supported Initiative

Annex II. Bangladesh. Rate of tax exemption for HHK or TK producers

Applicable For	Source of Income	Rate of Exemption	Period of Exemption
Industrial undertakings set up in Dhaka and Chittagong divisions (excluding Dhaka, Narayangonj, Gazipur, Chittagong, Bandarban, Rangamati and Khagrachari) between 1 July, 2011 and 30 June, 2019	All income, profits and gains except capital gain and disallowance under Section – 30	100%	First 2 years
		60%	3rd year
		40%	4th year
		20%	5th year
Industrial undertakings set up in Rajshashi, Khulna, Sylhet, Barisal and Rangpur divisions (excluding City Corporation area) and Bandarban, Rangamati and Khagrachari between 1 July, 2011 and 30 June, 2019	All income, profits and gains except capital gain and disallowance under Section – 30	100%	First 2 years
		70%	3rd year
		55%	4th year
		45%	5th year
		25%	6th year
		20%	7th-10th Year

[Source: BDO, 2016.]

Annex III. Bihar Brick sector stakeholder mapping

	Generic functions, and specific role relevant to brick sector (if any)	Institutional capacity	Potential role relevant to brick sector
Regulatory Agencies			
Department of Environment and Forest, Government of Bihar	Administrative agency for planning, coordination and overseeing implementation of environmental policies and programmes in the State. The environment wing deals with the issues of air and water pollution. Coordination with other departments, State Government and Central Government.	Limited capacity in terms of human resources as well as technical expertise.	Policy formulation for the brick sector. Role in coordination, formulation and supervision of implementation of policies/programmes for brick sector.
Bihar State Pollution Control Board (BSPCB)	Implementation of regulations related to prevention of water and air pollution (incl. emission standards) in the State. Issuance of 'No Objection Certificate (Consent to Establish)' and 'Operation Certificate (Consent to Operate)' to brick kiln enterprises along with regular inspection of those kilns to ensure compliance with environmental regulations.	Limited human resources capacity and outreach for issuance of consent certificates[94] (that has to be renewed every three years) and for regular monitoring & inspection of kilns.	Role in formulation and implementation of the programme for brick sector. Implementation of concerned regulations.
State Environment Impact Assessment Authority (SEIAA)	Appraisal of clay mining activities of the brick kilns (B2 Category) and issuance of environmental clearance for Category 'B' projects (MoEF does it for Category 'A' projects) based on the recommendation of State Expert Appraisal Committee (SEAC).	Limited human resources for inspection of proposed brick kilns on the ground.	Issuance of environment clearances in line with international/national best practices.
Department of Mines and Geology	Exploration and mining of minerals across the State, issuance of clay mining license to brick kilns (to be renewed every five years), and collection of mining royalty.	Adequate human resources and outreach in the brick sector, with sound presence at the district level. Has the most updated database of brick kilns in the State, based on the mining licenses issued and royalty collected.	Role in formulation and implementation of the programme for brick sector. Implementation of concerned regulations.
Department of Labour Resources	Registration of brick kiln enterprises under the Factories Act.	Limited human resources and outreach capacity, resulting in poor success in	Role in formulation and implementation of the programme for brick sector.

[94] There are 6500 brick kilns operating in the State, and on an average, 2200 'Consent to Operate' certificates need to be renewed every year.

	Implementation of various labour and employment related laws applicable to the brick industry sector, including but not limited to, the Factories Act dealing with health, welfare and safety of workers; acts related to the prohibition and abolition of child labour and bonded labour; rules for payment of minimum wages fixed by the government; act for equal wages irrespective of gender, and act for providing social security benefits to the workers such as provident fund, pension fund, etc.	implementation of regulations (the department is currently running at 30% of its sanctioned human capacity).	Implementation of concerned regulations.
Department of Commercial Taxes	Registration of brick kiln enterprises, and collection of value added tax on sale of bricks.	Adequate human resources and outreach capacity in the brick sector, with presence in all districts and even at the sub-district level. No separate database of brick kiln enterprises that are registered with the department and paying taxes, making it difficult to identify and prosecute tax evaders.	Role in formulation and implementation of the programme for brick sector Implementation of concerned regulations
District Industries Center (DIC)	Promote enterprises, particularly the medium, small and micro, at the district level and render all possible help and guidance in establishing these units.		
Industrial Associations			
District-level associations of fired-clay brick manufacturers in some of the districts in the state of Bihar. **An association of fly ash brick manufacturers named "Bihar Fly Ash Brick Industry Association".**		Most of these associations informal and not very effective in terms of having regular meetings, building consensus among the members on any issue, negotiations with the government, etc.	Bihar Fly Ash Brick Industry Association could play an even more active role in pushing the government for policies promoting fly ash bricks, with the support from interdepartmental task force on cleaner building materials.
Financial Institutions			
United Bank of India (a nationalised commercial bank)	A regular commercial bank providing banking and financial services.	Adequate human resources capacity. Wide network of branches in almost all districts (a total of 150 branches in the State).	Provide loans/credits to the enterprises if govt. initiates such programmes and develops mechanisms for financing brick kilns.
Bihar State Financial Corporation	State owned development sector bank, providing long-term credits to SMEs that fall outside of regular financing schemes of commercial banks.	Financial health not good because of large number of default loans (40%). Now providing credits of	Its services may not be relevant to majority of small and medium sized enterprises as credit required by them is generally below its minimum

	Might have financed a few brick kiln enterprises in the past.	amount more than 15 million INR only (suitable for large-scale investments such as dryers, tunnel kilns and extruders), and jointly with Small Industries Development Bank of India (SIDBI) in the ratio of 70:30.	limit of 15 million INR.
Madhya Bihar Gramin Bank	Banking and credit facilities in the rural areas, especially to agriculture and allied sector and other SMEs 3 Regional Rural Banks (RRBs), including this, are operating in Bihar in different regions. Experience with brick sector not positive because of high percentage of default loans in the past.	Adequate human resources capacity and good financial health. Extensive geographical outreach with its network of local branches (11 out of 38 districts).	Provide loans/credits to brick enterprises if there are government supported brick sector projects with appropriate risk mitigation mechanisms.
Project Developers, Suppliers & Technical Institutions			
Industrial Finance, Enterprise Development & Project Services Division (IFEDPRO) of the Bihar State Financial Corporation (BSFC)	Technical & management support and assistance in arrangement of finances for establishment or upgrade of industrial units	Adequate human resources capacity, and technical expertise on a number of areas relevant to brick enterprises.	Help enterprises in evaluation and selection of cleaner brick production technologies, and development of management systems. Preparation of bankable Detailed Project Reports (DPRs) and assistance in securing loans. Performance evaluation of technological upgrades. Training of entrepreneurs and assistance for transition towards formal industrial enterprise.
Raj Industrial & Technical Consultancy Organization (RITCO)	A well-recognised industrial consultancy organisation in the emerging fly-ash based brick/block manufacturing sector in Bihar (services include preparation of DPR and facilitation in availing financing from banks, assistance in procurement of machinery, and assistance in getting approvals and licences from govternment authorities).	Adequate technical and expertise and human resources capacity, but no experience of working with traditional fired clay brick making enterprises.	Evaluation and selection of cleaner technologies. Preparation of DPRs. Assistance in securing loans and getting licenses.
National Productivity Council (established by the Ministry of Industry,	Consultancy and training services for improving productivity and quality with key focus on energy efficiency and pollution control (e.g. monitoring & analysis of	The local team has expertise in training related activities. The energy/environment experts are not based at the	Awareness generation and training on technological upgrades. Energy/environment experts

Government of India)	emissions, design of pollution control systems).	local center, thus being unable to provide regular support.	from the head office can assist in formulation and monitoring of programmes.
Bihar Board of Open Schooling & Examination (BBOSE)	Nodal agency for Bihar Skill Development Mission. Skill development and vocational training services in various trades such as plumbing, electrician, building construction, etc.	Adequate human resources capacity and technical expertise. Has a pool of empaneled training providers for specific trades.	Assistance in development of training modules for various trades and practices of cleaner brick production. Training of workers.
Industrial Training Institutes (ITIs), Directorate General of Employment & Training (DGET), Ministry of Labour & Employment, Government of India	Vocational training for developing workforce in various trades such construction. The courses are approved by the Directorate General of Employment and Training, and are usually of 2-3 years duration.	Adequate expertise in vocational training, with extensive geographical outreach (there are around 60 government-owned and around 600 private ITIs/ITCs in the State).	Can deliver training/courses in brick manufacturing, but the courses need to be approved by the DGET.
Civil Society Organizations			
Asian Development Research Institute (ADRI)	Research on social and development issues (e.g. social and migration issues of workers, environmental concerns), and advising government on policies and programmes relevant to development sector.	Adequate human resources capacity and policy/advisory expertise.	Advisory role in the formulation and implementation of brick sector related policies and programmes.
Nidan	Skill development services and assistance in finding an employment. Assistance to unorganized workers in availing entitled benefits related to social security, health benefit, etc.	Adequate experience in Bihar's unorganised and informal sectors.	Skill development and training of workers. Assistance to workers in accessing entitlements. Prevention of child labour.
Public Health Environmental Engineering Trust	Drinking and wastewater testing and treatment, stack emission testing and environment impact assessment.	Limited capacity because of only a few full time staff. Limited geographical reach (the operation confined to a few districts only).	Assist in stack emission testing and brick sector field survey in few districts/clusters. Activities related to emission testing.
Mascot Foundation	Environment impact assessment (particularly, clay mining for brick kilns), field survey/data collection, and awareness generation campaigns on environmental issues.	Limited human resources capacity and geographical outreach, but has experience of working in some of the major brick making clusters.	Environment impact assessment. Field survey related work such as assistance in GIS mapping of kilns. Awareness campaigns on cleaner brick production practices.
Shakti Foundation			

[Source: GKSPL, 2015a]

Annex IV. Bihar Environmental Regulations

	Environmental Clearance (EC)	Consent to Establish (No Objection Certificate)	Consent to Operate
Regulatory Authority	State Environment Impact Assessment Authority (SEIAA)	Bihar State Pollution Control Board (BSPCB)	Bihar State Pollution Control Board (BSPCB)
What is obligated?	Environment clearance under Category 'B2' for projects involving mining of minor minerals, with mining lease area less than 5ha. Environment clearance under Category 'B1' if the excavation sites form clusters (distance between two excavation sites is less than 500 m). Issued only after conducting an Environment Impact Assessment (EIA).	Every industrial unit, including the brick kilns.	Every industrial unit, including the brick kilns. Consent to Operate must be obtained prior to commissioning or operating a brick kiln.
Other Conditions	The excavation activity shall not involve blasting. The excavation activity shall be restricted to a maximum depth of 2m below the general ground level at the site.	In order to protect certain establishments/areas such as schools, hospitals, monuments, highways, railway line, orchards, forests, rivers, etc., the brick kiln shall be located at specified distances from these locations. The prime agricultural land shall be avoided as far as practicable. Brick kilns should not form clusters i.e. a certain minimum distance (500 m) should have to be maintained between any two kilns. The entrepreneur is required to submit an affidavit stating that the kiln will comply to all the environmental regulations including the emission standards notified for brick kilns (there is provision of inspection of the kiln once it becomes operational to check its compliance with regulations).	The brick kiln units located within 100 km radius of any thermal power plant will mix 25% fly ash along with clay for brick making.
Application Process	An application form along with proof of ownership of land, prefeasibility of the project, undertaking of compliance with other regulations, environment management plan, and 500m-radius map of the area from periphery of project site clearly indicating the various industries and other features.	An application form along with information about location of proposed unit with respect to certain protected establishments/areas such as schools, hospitals, monuments, highways, railway line, forests, rivers, etc., and details about raw materials, production process, water requirement, waste (solid as well as liquid), energy requirement and sources, pollutant emissions, etc.	An application form with land documents and location map, project report, affidavit of compliance with consent conditions, and detailed information on raw materials; production process; fuel requirement, its sources and properties; pollutant emissions, emission sampling arrangement and emission control systems; etc.

Application Fee (in INR)	25k	2.5k for units with total capital investment up to INR 2.5 million 10k for units with total capital investment greater than INR 2.5 million and below INR 50 million	5.5k for units with total capital investment up to INR 5 million 7k for units with total capital investment greater than INR 5 million and below INR 10 million 25k for units with total capital investment greater than INR 10 million and below INR 50 million
Validity (in years)	5	Lifetime of the unit unless there is expansion, modernisation or relocation involved	3
Implementation Status	Environment clearance has been issued to around 2,300 brick kiln units only (out of around 6,500 brick kilns in Bihar) as of April 2015.	Since the consent certificate is prerequisite for issuance/renewal of other permits/registration with other departments, almost all brick kilns operating in Bihar have obtained the consent issued by BSPCB. There is, however, poor and irregular inspection of these kilns by BSPCB.	The utilisation of fly ash is not economically attractive for brick makers in Bihar, leading to difficulty in enforcement.

Annex V. Bihar Labor related regulations

Name of Act/Regulation	Key provisions of the Act/ Regulation
Factories Act, 1948 & Bihar Factories Rules, 1950 (applicable to all brick making enterprises with more than 20 employees)	Mandatory application of a maximum of an eight-hour workday with one day off per week. Availability of basic facilities such as safe drinking water, first aid box, sanitation, etc., and a day care center for any kiln with more than 30 female workers. Mandatory provision of safety equipment for coalmen, firemen and other workers. Appropriate safety standards in place while entering into the confined space inside the kiln and during firing.
Minimum Wages Act, 1948	A minimum wage for workers as defined by the Government of India.
Payment of Wages Act, 1936	Mandatory payment of wages to the workers within seven days of the end of payment cycle.
Equal Remuneration Act, 1976	Mandatory equal wages for both make and female workers.
Child Labour (Prohibition and Regulation) Act, 1986	Prohibition of child labours i.e. any child below the age of 14.
Bonded Labour System (Abolition) Act, 1976	Prohibition of bonded labour system i.e. the creditor is prohibited from using labour services as an exchange for the loan or any other forms of payment it had offered to the debtor. The creditor is also prohibited from mortgaging services from any of the family members of the debtor, and also not allowed to deny the debtor a freedom of movement or alternative employment.
The Employees' Provident Funds and Miscellaneous Provisions Act, 1952 (applicable to all brick making enterprises with more than 20 employees)	A provision of social security benefits such as provident fund, pension fund, etc. to the employees.

[Source: GKSPL, 2015b]

Annex VI. Nepal Government decisions pertaining to cleaner technology in the brick sector

Government Decision	Description
The Industrial Enterprises Act 2049 (1992) Section 15:Sub-section K	Permission shall be granted for a reduction of up to 50 percent from the taxable income for the investment of any industry on process or equipment, which has the objective of controlling pollution or which any have a minimum effect on the environment. Such remission may be deducted on a lump-sum or on an installment basis within a period of three years.
The Industrial Enterprises Act 2049 (1992) Section 15:Sub section N	After an industry comes into operation, 10 percent of the gross profit shall be allowed as a deduction against taxable income on account of expenses related with technology, product development and efficiency improvement.
The Industrial Enterprises Act 2049 (1992) Section 16:Sub-section D	On the recommendation of and with the decision of the Council of Ministers, and by notification published in the Nepal Gazette, additional facilities may be granted to any National Priority Industry or any industry established in Nepal by the way of invention therein.
Industrial Policy, 2067	Those industries who adopt environment friendly technology and save energy them self will be provided technical and financial support
Local Self Governance Act, 2055 (1999)	- Section 28.h.3 authorizes VDC to make various programs on environment protection and to carry out or cause to be carried out the same. - Section 28.j.2 authorizes VDC to act as a motivator for carrying out cottage industries in the village development area. - Section 96.c.4 authorizes Municipality to control and prevent, or cause to be controlled and prevented the possible river-cutting, floods and soil erosion in the Municipality area. - Section 96.i.1 authorizes Municipality to act or cause o act as a motivator to the promotion of cottage, small and medium industries in the Municipality area. - Section 189.m authorizes DDC to maintain records of the cottage industries to be establish within the district development area, and to identify and develop an industrial zone in the district.
VAT Act 2052	It mentions that there exists a threshold limit for compulsory registration under VAT Act for the industries with the turnover of Rs. 2,000,000 over last 12 months or turnover of Rs. 200,000 in any month. All the brick industries basically have turnover of more than Rs. 2,000,000 annually. The existing rate for VAT is 13%.
Excise Act, 2058, Schedule in accordance to section 3, (s.no. 25)	It is mandatory for the brick industry to pay excise duty; as the brick (produced with in the country or imported) is listed as the excisable goods under this section.
Excise Duty Regulation, 2059, Schedule 2, (3, G, 2)	The excise duty is waived for the brick kiln producing bricks using the modern technology and emitting under the Nepal emission standard.
Excise Rule (10th Amendment), 2066 (2009 /10), Schedule 2, 3,G	Declared NRs.150,000 per kiln as excise duty for the brick industry, and for the brick kilns out of the valley there is 25% deduction in this amount
Excise Duty Regulation,(10th Amendment),2009/10,Schedule 2, (explanation) 5	Brick kilns those registered for VAT do not need to pay excise license fee amount. However, if the brick kiln pays VAT amount less than the amount of excise duty then the brick kiln should pay the remaining amount as excise duty. (e.g. If a brick kiln pays NRs. 75000 as VAT now, the brick kiln should pay remaining NRs. 75000 as excise duty)
Fiscal Year Budget, 2008/9, 268, E	GON shall provide 50 per cent exemption in license fee with the recommendation of Ministry of Environment, Science and Technology to those brick industries that emit less than 50 per cent of the emission standard set by the Ministry of Environment, Science and Technology.
Fiscal Year Budget 2007/08, 195	For the purpose of providing relief to the brick industries being affected due to unusual situation in the past, exemption shall be provided on arrears including interest, penalty and late fee up to mid July 2006, if they pay all excise duty arrears before mid January2008.
Fiscal Year Budget 2003/04, 219	Excise license fee will be waived to industries, which adopt modern technology and meet the environmental standard. Excise duty on brick factories, which do not meet environmental standard and pollute the atmosphere, has been doubled from Rs. 100,000 to Rs. 200,000.

Fiscal Year Budget 2002/03, 85	To enable the industries produce pure products, conserve energy, install equipment for treatment of polluted water, and to control air pollution of Kathmandu Valley, Rs 456.5 million has been earmarked for environment sector support program.
Industrial Promotion Board meeting 15/12/2009, 183 minutes, decision no. 1	Decide to replace the MBTK within 2 years by VSBK/Fixed Chimney/Tunnel Kiln. Mandatory to use the VSBK/Fixed Chimney/Tunnel Kiln for new registration, compulsory EIA for industries producing more than 20 million bricks per year and IEE mandatory for industries producing less than 20 million. The Forest Distance for VSBK has been removed.

[Source: Winrock, 2011]

Annex VII. Comparison of Alternate Building Materials (ABMs)

Table. Comparison of alternate building materials (Okapi, MinErgy and GKSPL, 2017b; World Bank, 2015; SHEE, Undated)

Brick type	**Raw materials & proportions**	**Compressive Strength (CS) and Water Absorption (WA) by weight**	**Advantages over clay brick**	**Environmental benefits**	**Availability in India, Bangladesh and Nepal (Y/N)**	**Cost per m² of wall (in USD)[95]**
Fly Ash Sand Lime Gypsum Blocks	Fly ash 60%, sand 20%, lime 15%, gypsum 5%	CS: 80-150kg/cm² WA: 8-10%		Reduced energy consumption Utilization of industrial wastes (ashes/sludges) and volcanic ash	Y	
Compressed Solid Earth Blocks (CSEB)	Soil with min. 20% clay, cement 5-10%	CS: 20-30kg/cm² WA: Less than 15%	Cost effective and requires minimum maintenance. Only a little stabilizer is required for production, so firing is not necessary.	Energy consumption per cubic meter production is 5-15 times less than that of fired bricks, resulting in significant energy saving and reduced emissions (about 4 times lesser than the fires bricks).	Y	10.4
Clay Fly Ash Burnt Bricks (can be produced by High Draught Kiln & VSBK)	Soil with min. 20% clay, fly ash, sand, coal	CS: 75-150kg/cm² WA: 12-18%	Percentage of first class bricks is very high Un-burnt carbon present in fly ash helps in reduction of fuel consumption Better thermal insulation	Consumption of coal is 50% less than that by conventional kiln Reduced emissions from kilns	Y	
Marble slurry bricks	Marble slurry 83%, cement 7%, sand 10%	CS: 93kg/cm² WA: 14%	28% less consumption of mortar 32% less consumption of labour	High volume utilization of waste	Y	

			Much stronger than clay bricks			
Solid/Hollow Concrete Blocks	Cement, sand, aggregates	CS: 40-150kg/cm^2 WA: Less than 10%	Highly durable, fire resistant, and hollow blocks in particular provide thermal and acoustic insulation. Increased tensile resistance and ductile behaviour of elements because of uniform distribution of reinforcement in both vertical and horizontal directions, through each masonry element. No additional formwork or any special construction machinery is required for reinforcing the hollow block masonry. Faster and easier construction system with the requirement of only semi-skilled labour.	Lower embodied energy compared to conventional burnt brick masonry. Good potential to use waste materials such as fly ash, stone dust (from stone crushers), which further lowers the embodied energy. Minimal requirement of cement, thus lowering the carbon footprint of cement use.	Y	6.3 (Solid) and 4.8 (Hollow)
Cellular Lightweight Concrete (CLC)	Cement, fly ash, fine sand, foaming agent	CS: 10-250kg/cm^2 WA: 5%	Substantial reduction of deadweight leading to reduction in cost of buildings Less consumption of mortar as compared to brick masonry	Energy efficient Use of fly ash/volcanic ash (waste) as one of the primary raw materials	Y	
Ferro Cement Wall Panels	Cement, coarse sand, aggregates, polypropylene fibres, admixtures, welded mesh	CS: 150kg/cm^2 WA: Less than 5%	Components made of Ferro cement cost 20-30% less than those made of conventional reinforced cement concrete (RCC). Ferro cement panels are lightweight, thus reduces the	Non-requirement of coarse aggregate reduces the life cycle emission of ferro cement wall panes.	Y	37 (cost reduction possible with greater surface area)

			deadweight of the structure, indirectly contributing to cost cutting. The non-requirement of shuttering and lesser requirement of water as well as steel also reduces the cost. Easier to transport from one to the other place. Reduced construction and finishing time.			
Rattrap Brick Bond Masonry	Brick, cement, sand	CS: 150-200kg/cm²	This method of masonry requires approximately 20-35% less bricks and 30-50% less mortar than by a conventional brick wall. This reduces the cost of a 9-inch wall by 20-30% and also enables quicker construction. The walls have approximately 20% less dead weight, reducing the overall cost. One can cut cost resulting from plastering and painting because rat trap bond creates aesthetically pleasing wall surfaces when kept exposed.	Environmental performance is similar to that of a normal brick wall, with reduced number of bricks required to construct a square meter of wall. Some embodied emission can be avoided because of lesser requirement of virgin materials such as cement and steel as a result of less deadweight of the structure.	Y	4.2
Autoclaved Aerated Concrete blocks (AAC)	Fly ash or sand, lime powder, cement, gypsum, aluminum powder	CS: 21-63 kg/cm²	The presence of uniform air pockets in AAC blocks reduces the net weight of block by 80% as compared to conventional bricks, thus reducing the deadweight of the structure. This reduction in deadweight of the structure results in lesser requirement of steel and cement, contributing to lesser life cycle emission and reduced cost.	AAC blocks use fly ash, a residual material from power plants, as a substitute for cement, thus significantly lowering the total GHG emissions. The waste generated from cutting process is recycled and used again. The total energy consumption per block production is significantly	Y	10.8

			Effective against fire. Lesser installation time because AAC blocks are considerably larger than conventional bricks (50% faster compared to clay bricks)	lower than that from other conventional manufacturing processes (30% less for heating and cooling). Higher thermal insulation reduces the heating and cooling requirement, contributing to higher energy efficiency. AAC blocks qualify as green building materials, and used in LEED certified buildings.		
Bamboo Wall Panel	Bamboo				Y	

Annex VIII. Social values of carbon recommended for the World Bank Group

	2015	**2020**	**2030**	**2040**	**2050**
Low	15	20	30	40	50
Base	**30**	**35**	**50**	**65**	**80**
High	50	60	90	120	150

Annex IX. Health cost of PM

Total Emissions of Bangladesh (tons/year)

Country	SPM	SO_2	NO_x	BC	PM_{10}	$PM_{2.5}$
Bangladesh	84'327	159'793	5'268	7'148	36'886	22'132
India	1'412'420	2'002'673	50'660	137'044	661'164	396'698
Nepal	24'868	42'839	872	2'044	9'370	5'622

Calculation of unit cost of SPM for Bangladesh

Economic Cost of Mortality DALYs (million US$)	**Economic Cost of Morbidity DALYs (million US$)**	**Cost on Health Care (million US$)**	**Total Health Cost (million US$)**	**% of Health Costs in 2015 GDP**	**Total Social Costs of CO2 (US$ million)**	**Unit Cost of SPM (BDT/kg)**	**Unit Cost of PM10 (BDT/kg)**	**Unit Cost of PM2.5 (BDT/kg)**
59	130	442	633	0.32%	318	583	1333	2222

Annex X. Sensitivity analysis

Types of Kilns	Sensitive Variables	Net Private Profit (TK/1000 bricks)	External Social Costs (TK/1000 bricks)	Net Social Profit (TK/1000 bricks)	Types of Kilns	Sensitive Variables	Net Private Profit (TK/1000 bricks)	External Social Costs (TK/1000 bricks)	Net Social Profit (TK/1000 bricks)
	Cost of CO2 (USD/ton)					Cost of SPM (USD/ton)			
FCK	Base (30 initial; rising to 50 in 2030)	465	3395	-2930	FCK	Base	465	3395	-2930
	50 initial, rising to 90 in 2030	465	3935	-3471		Increase by 50%	465	4703	-4238
	15 initial, rising to 30 in	465	3036	-2571		Decrease by 50%	465	2087	-1622
ZZK	Base (30 initial; rising to 50 in 2030)	544	971	-427	ZZK	Base	544	971	-427
	50 initial, rising to 90 in 2030	544	1399	-855		Increase by 50%	544	1150	-606
	15 initial, rising to 30 in	544	691	-147		Decrease by 50%	544	792	-248
HHK	Base (30 initial; rising to 50 in 2030)	565	695	-129	HHK	Base	565	695	-129
	50 initial, rising to 90 in 2030	565	998	-433		Increase by 50%	565	832	-267
	15 initial, rising to 30 in	565	510	55		Decrease by 50%	682	557	125
TK	Base (30 initial; rising to 50 in 2030)	676	624	52	TK	Base	676	624	52
	50 initial, rising to 90 in 2030	676	927	-251		Increase by 50%	688	726	-38
	15 initial, rising to 30 in	676	439	237		Decrease by 50%	688	522	166
TK Hollow	Base (30 initial; rising to 50 in 2030)	890	499	392	TK Hollow	Base	890	499	392
	50 initial, rising to 90 in 2030	890	742	149		Increase by 50%	902	580	322
	15 initial, rising to 30 in 2030	890	351	539		Decrease by 50%	902	417	485

Types of Kilns	Sensitive Variables	Net Private Profit (TK/1000 bricks)	External Social Costs (TK/1000 bricks)	Net Social Profit (TK/1000 bricks)
	Cost of labour (Annual Increase)			
FCK	Base (7.4%)	465	3395	-2930
	10%	410	3395	-2986
ZZK	Base (7.4%)	544	971	-427
	10%	472	971	-499
HHK	Base (7.4%)	565	695	-129
	10%	575	695	-119
TK	Base (7.4%)	676	624	52
	10%	652	624	28
	Discount Rate			
FCK	Base (10%)	465	3395	-2930
	5%	595	4041	-3446
	15%	365	2898	-2533
ZZK	Base (10%)	544	971	-427
	5%	706	1182	-476
	15%	421	813	-392
HHK	Base (10%)	565	695	-129
	5%	998	965	33
	15%	320	526	-206
TK	Base (10%)	676	624	52
	5%	1299	868	431
	15%	350	471	-121

Types of Kilns	Sensitive Variables	Net Private Profit (TK/1000 bricks)	External Social Costs (TK/1000 bricks)	Net Social Profit (TK/1000 bricks)
	Interest Rate			
HHK	Base (12%)	565	695	-129
	9.86%	593	695	-101
	7%	613	695	-82
TK	Base (12%)	676	624	52
	9.86%	732	624	109
	7%	766	624	143
	Cost of Energy (Annual increase)			
FCK	Base (5%)	465	3395	-2930
	15%	238	3395	-3157
ZZK	Base (5%)	544	971	-427
	15%	341	971	-630
HHK	Base (5%)	565	695	-129
	15%	480	695	-214
TK	Base (5%)	676	624	52
	15%	481	624	-142
TK Hollow	Base (5%)	890	499	392
	15%	737	499	238

Types of Kilns	Sensitive Variables	Net Private Profit (TK/1000 bricks)	External Social Costs (TK/1000 bricks)	Net Social Profit (TK/1000 bricks)
	Capacity Utilization			
FCK	Base (100%)	465	3395	-2930
	70%	311	3395	-3084
ZZK	Base (100%)	544	971	-427
	70%	271	971	-700
HHK	Base (100%)	565	695	-129
	70%	151	695	-543
TK	Base (100%)	676	624	52
	70%	140	624	-484

Annex XI. Comparison of cost and benefit of selected kiln technologies

(all costs and profit in BDT, 2015)

Kiln Life-Cycle Comparative Analysis	FCK (Equity)	ZZK (Equity)	HHK	TK	TK-Hollow	FCK to ZZK Conversion[96] (2013 data)	Alternate Building Material (Concrete Block)[97] (2006 data)
CAPEX	**9'871'093**	**11'840'625**	**301'345'279**	**533'649'461**	**529'948'736**	**7'95'2300**	**18'570'000**
Total production (number of bricks)	31'500'000	36'000'000	495'000'000	495'000'000	495'000'000	58'650'000	40'639'100
Net Private Profit (million BDT/kiln)	14.64	19.57	279.82	334.57	440.00	67.75	9.78
Total cost of Air Pollution to Health (SPM) (million BDT/kiln)	82.42	12.88	136.15	101.01	80.81	12.88	Not considered
Total cost of CO_2 (climate impact) (million BDT/kiln)	24.53	22.07	207.64	207.64	166.11	22.07	Not considered
Total external costs (million BDT/kiln)	106.95	34.95	343.79	308.65	246.92	34.95	Not considered
Net social profit [private profit minus costs (million BDT/kiln)]	-92.30	-15.38	-63.97	25.91	193.83	32.8	9.78
Project Payback period (number of years)	1	1	3	4	4	>1	5.5
Kiln project lifetime (number of years)	7	8	15	15	15	10	20
Project financial IRR	69.1%	68.5%	34.0%	25.0%	30.1%	125%	17%
Unit Profit & Cost Comparative Analysis	**FCK (Equity)**	**ZZK (Equity)**	**HHK**	**TK**	**TK-Hollow**	**FCK to ZZK Conversion**	**Alternate Building Material (Concrete**

[96] FCK to ZZK conversion cost benefit analysis is based on different input parameters and with an assumption of an annual production of 5'865'000 bricks and kiln lifetime of 10 years. Source: CASE Final Report: DoE-S08, World Bank.

[97] Cost benefit analysis of concrete block is based on different input parameters and with an assumption of an annual production of 2'031'955 blocks and plant life of 20 years. CASE Final Report: DoE-S08, World Bank.

							Block)
Net Private Profit (BDT/000 Bricks)	465	544	565	676	890	1155	241
Unit NP Cost of PM (BDT/000 Bricks)	2'616	358	275	204	163	358	0
Unit NP Cost of CO_2 (BDT/000 Bricks)	779	613	419	419	336	613	0
Net Social Profit (BDT/000 Bricks)	-2'930	-427	-129	52	392	184	241

Annex XII. Summary of key achievements of development projects in Bangladesh

	The CASE Project	HHK CDM Project	IKEBMI Project	FBKEI Project	BKEP Project
Timeline	*2009-2016*	*2009-2016*	*2010-2016*	*2012-2016*	*2014 onwards*
Implementing entity	*Department of Environment, Ministry of Environment and Forest*	*IIDFC*	*UNDP*	*Bangladesh Bank*	*IDCOL*
Business model	*Government led Technical Assistance Model*	*Carbon Finance Model*	*MBDO led Technical Assistance Grant Model*	*Credit Line (Reimbursement) Model*	*Credit Line (Direct Financing) Model*
Brick technologies supported	FCK to ZZK Conversion; Improved ZZK; VSBK	*HHK*	*HHK*	*TK; HK & HHK; FCK to ZZK Conversion; Improved ZZK; VSBK*	*TK; HHK*
No. of FCK to ZZK/Improved ZZK demonstrated	*9*	*0*	*0*	*0*	*0*
No. of VSBKs demonstrated	*1*	*0*	*0*	*0*	*0*
No. of HHKs demonstrated	*0*	*8*	*5*	*7*	*1*
No. of TKs demonstrated	*0*	*0*	*0*	*12*	*3*
Total number of projects demonstrated	*10*	*8*	*5*	*19*	*4*[98]
Total annual installed capacity of bricks (in	*36*	*150*	*45*[99]	*150*	*120*

98 Projects are still under construction.
99 Two HHKs have closed their operation.

millions)					
Total GHG emission reduction expected per annum (tons of CO_2[100])	*5058[101]*	*26400*	*9900*	*23100*	*13200*
Coal Savings	*25%*	*50%*	*50%*	*50%*	*50%*

[100]Assuming 60% capacity utilization factor and 5500 tCO_2 per HHK/TK of 15 million annual capacity.
[101]VSBK 698 tCO_2 and Zigzag 562 tCO_2 per annum.

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