BENEFIT-COST ANALYSIS

OUTDOOR AIR POLLUTION

Assessing social and private benefits and costs for improved brick production in RAJASTHAN

Authors
Souvik Bhattacharjya
Fellow
Centre for Resource Efficiency and Governance
The Energy and Resources Institute (TERI)
New Delhi

RAJASTHAN PRIORITIES
AN INDIA CONSENSUS PRIORITIZATION PROJECT

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info@copenhagenconsensus.com
www.copenhagenconsensus.com

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Rajasthan Priorities
An India Consensus Prioritization Project

Souvik Bhattacharjya

Fellow, Centre for Resource Efficiency and Governance

The Energy & Resources Institute, New Delhi

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Policy Abstract

India is the second largest producer of bricks in the world, after China with a global production share of nearly 14 percent. Brick is also a major contributor to environmental pollution as it depends heavily on natural resources, like soil (e.g. top fertilie alluvial soil in the Indo-gangetic plains), and coal. There are often applications of biomass including agricultural wastes like cotton straw, mustard straw, wood chips, etc for firing.

Although there are many technologies that can be used for brick manufacturing, two technologies that are largely predominant in India are Clamp Kilns and Fixed Chimney Bull's Trench Kiln (FCBTK). The main process of brick making practised in Northern and Eastern region of India is FCBTK. These regions account for majority of the annual brick production largely because of access to alluvial soil in the Indo-Gangetic plains. The remaining production is based primarily on Clamp Kiln methods used across the Central, Western and Southern parts of India. Over the last 40 years brick production has increased by more than 8 times, due to growing demand from the housing and infrastructure sectors. Since these technologies are old, they are inefficient and generate a lot of pollution. Around 35 million tonnes of coal is consumed in the sector and is the third largest consumer of coal in the economy after thermal power, iron and steel. The average estimated CO2 esmission from the sector is more than 60 million tonnes.

The economic and social benefit-cost assessment undertaken in this study looks at two options of cleaner kiln technologies in the state of Rajasthan. The two options involve improvement of existing Clamp Kilns and (and FCBTK technology) to the Zig-Zag Kilns, and Vertical Shaft Brick Kilns (VSBK) technology.

It is important to note that there may be marginal improvement in operating costs, but the biggest advantage of moving to these technologies is the increased production of class 1 bricks that will fetch substantial value from the market. Information on private benefits and costs of currently predominant and cleaner brick kiln technologies have been used based on review of recent literatures as well as interaction with selected experts. The key parameters for which information have been collected include investment, production value and operating costs, efficiency improvement and CO2 emissions. It has been found that the production of class 1 bricks can increase from 50 percent to 80 percent incase of Zig-Zag

technologies, while in VSBK, the production of class 1 bricks can be as high as 90 percent. Increased efficiency will reduce CO2 emission between 22 percent and 47 percent thereby reducing global warming potential. At the same time emission of particulate matter will come down thereby improving ambient air quality reducing disease burden and mortality across population of different age groups. Social benefits of cleaner technologies are estimated based on recent advances in health assessments of fine particulate matter (PM2.5) developed by Ostro (2004) as well as Global Burden of Disease (GBD). The recent estimates are for the state of Rajasthan. Table A1 presents the private benefits and costs as well as the environmental and social benefits from these technologies.

Table A1: Incremental present value (PV) of benefits and costs from shifting to proposed technologies

Rs million		Zig-Zag (VSL Approach)	VSBK (VSL Approach)	Zig-Zag (DALY Approach)	VSBK (DALY Approach)
Cost		15,600	24,000	15,600	24,000
Financial benefits					
	3%	102,024	134,640	102,024	134,640
	5%	89,114	11,7603	89,114	117,603
	8%	73,665	97,215	73,665	97,215
CO2 benefits	3%	24,764	52,905	24,764	52,905
	5%	7,439	15,892	7,439	15,892
	8%				
Health benefits					
	3%	58,091	88,375	35,998	54,765
	5%	49,724	75,645	27,237	41,436
	8%	39,905	60,708	18,610	28,311
Total benefits	3%	184,879	275,920	162,786	242,310
	5%	146,276	209,140	123,789	17,4931
	8%	113,570	157,923	92,275	125,527
BCR	3%	11.9	11.5	10.4	10.1
	5%	9.4	8.7	7.9	7.3
	8%	7.3	6.6	5.9	5.2

All cost and benefit in million INR
Source: Author's calculation

The studied options are financially (private costs and benefits) viable and economically (social costs and benefits) sustainable. As evident from the above table, the benfits costs ratios are relatively more for conversion or retrofitting of existing Clamp kilns to Zig-Zag kilns over VSBK. The BCR from conversion to Zig-Zag technology is in the range of 6 and 12 and for that of VSBK it is in the range of 5 and 10. The estimated incremental profits/kiln from shifting to Zig-Zag kiln is Rs 21 mn, Rs 18 mn and Rs 15 mn for three discount rates while for VSBK it is Rs 28, Rs 24 and Rs 20 mn under the three discount rate scenarios. The average number of lives to be saved per year is 362 in case of Zig-Zag technology and 551 in case of VSBK. The savings of carbon emission per year are 1.27 million tonnes CO_2 and 2.72 million tonnes CO_2 for these technologies. The total benefits due to conversion to Zig-Zag technology are Rs 184 billions (bn), Rs 146 bn, and Rs 113 bn using VSL approach and Rs 162 bn, Rs 123 bn and Rs 92 bn using DALY approach respectively. The total benefits due to conversion to VSBK technology are Rs 275 bn, Rs 209 bn, and Rs 157 bn using VSL approach while using DALY approach the total benefits are Rs 242 bn, Rs 174 bn and 125 bn using the three discount rates.

It is important to note that there are many impediments to this shift. Interactions with selected stakeholders have revealed that despite having a business case, poor awareness among entrepreneurs, lack of concessional finance for buying these technologies and hand holding are areas that need utmost attention. While there are various programs undertaken by ministry of micro small and medium enterprises to create awareness among producers, often the reach has been limited and focused at specific locations. This can be minimized by engaging with state level and/or district level institutions/ agencies particularly, industry associations, poly-techniques, Small Industries Development Bank of India, incubation centres of professional and technical institutions, etc. More importantly, such engagements need to focus on time adherence. Further delay in the transformation will put more people at risks thus jeopardizing some of the key development targets defined under the sustainable development goals (SDGs).

Academic Abstract

The analysis presented in this paper established that there are substantial financial, social and environmental benefits on account of reduced particulate matter (PM) and CO2 emissions through technology interventions in India's brick kiln sector using Rajasthan as a case study. Emissions largely arise from inefficient combustion of large quantities of coal, pet-coke and agri-residues that are used in brick kilns which has serious health and mortality implications. Improved brick manufacturing technologies like Zig-Zag can save 362 deaths per year till 2030. The total benefits due to conversion to Zig-Zag technology is estimated at Rs 184 bn, Rs 146 bn, and Rs 113 bn using VSL approach and Rs 162 bn, Rs 123 bn and 92 bn using DALY approach respectively using for the three discount rates (3%, 5% and 8%). Similarly, a shift to VSBK technology can save 551 deaths per year. The total benefits due to conversion to VSBK technology can be as high as Rs 275 bn, Rs 209 bn, and Rs 157 bn using VSL approach while using DALY approach the total benefits are and Rs 242 bn, Rs 174 bn and 125 bn using for the three discount rates (3%, 5% and 8%). Further, the estimated incremental profits/kiln in shifting to Zig-Zag kiln is Rs 21 mn, Rs 18 mn and Rs 15 mn for three discount rates while for VSBK it is Rs 28 mn, Rs 24 mn and Rs 20 mn under the three discount rate scenarios.

Introduction

Brick manufacturing is an extremely important economic activity in India. With an average annual production of 200 billion bricks per annum, India is the second largest producer of bricks in the world, after China. India's share is nearly 14 percent of the global brick production. Over the last forty years, brick production has increased by eight times, largely driven by growth in the housing and infrastructure sector (CSE, 2017). Fired clay bricks are still the first choice for building materials in the country. However, in recent years, alternate options are emerging largely in the form of fly ash hollow bricks that are used in various residential and commercial buildings and creation of public infrastructure. Nevertheless, with majority of the infrastructure development in India is expected to come up in the next 10 to 15 years, there would be a 3 to 4 times increase in demand for bricks in India. Clay fired bricks will continue to remain as the primary choice among consumers largely due cost and ease in their availability.

Brick is also a major contributor to environmental pollution as it depends heavily on natural resources, particularly soil (e.g. top fertilie alluvial soil in the Indo-gangetic plains), and coal as well as other agri residues for firing kilns, etc. Infact, 65 percent of India's bricks are produced from the fertile alluvial soil from the Indo-gangetic plain, while, it is the second largest consumer of coal in the industrial sector category, after iron and steel. Brick production operation is largely seasonal and is found to operate from 9 months of the year, particularly during the dry seasons. The brick manufacturing in most of the states starts after monsoons, from end of September/early October and continue till June/July, as clay extraction, moulding and drying are carried out in the open (Maithel, 2012). The brick kiln sector employs more than 10 million people, who are migrant labourers from eastern and south eastern states, working in more than 100000 bricks across different states in India. However, it is important to note that there are no official estimates on number of operating brick kilns in India, by state or region. Different studies have provided different estimates on the operating bricks which range from 1,00,000 to 1,50,000 kilns. The conditions under which these people work are extremely hazardous and they are often underpaid. There are also frequent reports on exploitation of child labour in major brick manufacturing states and clsuters.

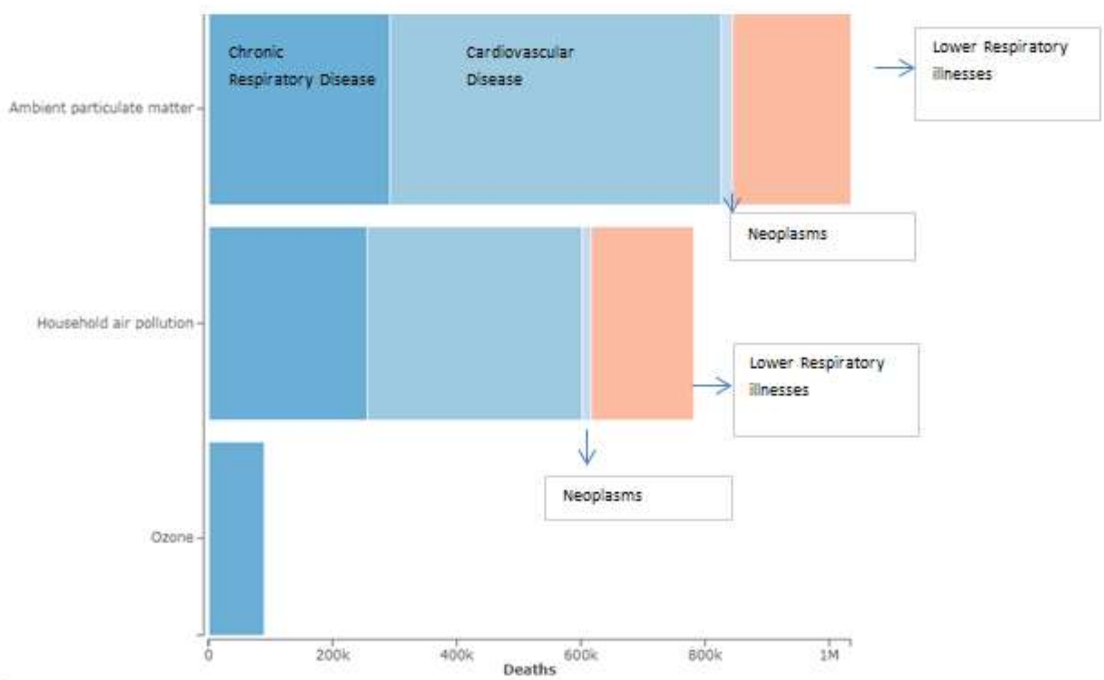
The predominant technology that is used for brick manufacturing in India is Fixed Chimney Bull's Trench Kiln (FBTK).This accounts for nearly 70 percent of the total brick produced in the country. However, other technologies that find application include Clamp Kilns, which produce bricks in batches where operation might be happening at relatively smaller scales, and are widely used in the peninsular region, contributing to about 25 percent of the total brick production. There are extremely fewer application of improved and environment friendly/cleaner brick kiln manufacturing technologies like Zig-Zag Kilns, Vertical Shaft Brick Kiln (VSBK), or Hoffmann Kiln, in India. Their share is around two to three percent of the total total brick manufacturing technologies currently operational in India, although official estimates are not available.

As mentioned above coal is the main source of energy for brick kilns. The use of large quantities of coal and petcoke in brick kilns contributes significantly to emissions of carbon dioxide (CO2), and particulate matter (PM). It is estimated that, around 35 million tonnes of coal is consumed in the sector and is eventually the third largest consumer of coal in the economy after thermal power, iron and steel. However, there is often application of biomass including agricultural wastes like cotton straw, mustard straw, wood chips, etc for firing. Because of these technologies, the poor and inefficient combustion of coal and other fuels lead to significant emission of particulate matter and CO2. The average estimated CO2 esmission from the sector is more than 60 million tonnes. In recent months, the growing emission from the brick manufacturing sector has drawn attention of the central pollution control board (CPCB), and as per the order received by the state pollution control boards, many of the brick kiln opertors have been ordered to convert to cleaner brick production methods as early as possible[i]. At the same time, there are emissions of other environmentally polluting substances like sulphur dioxide, various oxides of nitrogen, and more importantly carbon monoxide. The pollutants not only have an adverse effect on the health of workers, local population, and vegetation, but also contribute to global warming.

Air pollution and health impacts in India

Air pollution is now widely known to have impacts over human health, agriculture, ecology, buildings, and climate. In terms of health some of the common impacts reported are respiratory, cardiovascular, cardiopulmonary, and reproductive systems (Steinle et al. 2015). In a recent study by Indian Council of Medical Research (ICMR), air pollution was found as the second leading health risk factor in India after child and maternal malnutrition. This risk factor encompasses both outdoor air pollution from a variety of sources as well as household (indoor) air pollution that mainly results from burning solid fuels for cooking and domestic heating. While child and maternal malnutrition caused 14.6 percent of the country's total disability-adjusted life years (DALYs), air pollution was the second leading risk factor in India. Outdoor air pollution caused 6.4 percent of India's total DALYs in 2016, and DALY estimated from household air pollution was 4.8 percent. Air pollution was found to contribute significantly to India's burden of cardiovascular diseases, chronic respiratory diseases, and lower respiratory infections. Air Pollution led to over 2,750 cases of deaths or severe illnesses per lakh people in 2016. The key states that are most affected due to air pollution include Haryana, Delhi, Punjab, Bihar, Rajasthan, West Bengal and Uttar Pradesh. This is presented in figure 1. Around 41 deaths per 100000 population was estimated due to cardiovascular diseases arising from air pollution followed by chronic respiratory diseases (22 deaths) and other lower respiratory diseases (14 deaths) arising from ambiet air pollution. This indicates that chronic respiratory disease, largely caused due to air pollution, is the second largest cause of death after cardio-vascular diseases.

Figure 1: Deaths due to different diseases arising from air pollution in India



Source: ICMR, PHFI, IHM&E (2018)

Air quality in Rajasthan

Rajasthan Pollution Control Board is the agency responsible for collection and monitoring ambient air quality in the state. In 2017, the state had 32 ambient air quality monitoring stations and two continuous ambient air quality monitoring stations which were operating in six districts. These include, Alwar, Bharatpur, Jaipur, Jodhpur, Kota and Udaipur. The remaining 27 districts with a population of more than 47 million were out of the purview of air quality monitoring. This is nearly 70 percent of the total population in the state.

The brick kilns in the state are located in three major districts i.e. Jaipur, Hanumangarh and Sri Ganganagar as has emerged from review of literature and discussion with stakeholders. Interestingly, ambient air quality monitoring takes place only at Jaipur out of three key brick prodcing districts in the state. Reports suggest that Sri Ganganagar has the highest share of brick kilns in the state. Since, ambient PM 10 concentration is not available for Sri Ganganagar and Hanumangarh, hence for capturing the impact of brick production on health and environment in these two district, the ambient concentration of Jaipur (for which data is available) has been used.

Since brick production takes place during the dry seasons, the average concentration above the standard have been considered for all monitoring stations in Jaipur district. The contribution from the brick kiln sector in the ambient PM concentration is discussed in the subsequent sections. Figures 2 to 7 provide the scattered plot of PM 10 concentrations for the year 2015-2016 (CPCB, open gov data) recorded at six monitoring stations of the district. Monitoring of PM 2.5 has started very only in recent months. A quick assessment of share of PM 2.5 and PM 10 provides that an average estimate of nearly 0.5 for these districts. The central pollution control board has defined standards for PM10 ambient concentration for (industrial, Residential, Rural and Other Areas) at 60 microgram/m3 for (Annual arithmetic mean of minimum 104 measurements in a year at a particular site taken twice a week 24 hourly at uniform intervals), and 100 microgram/m3 (for 24 hourly or 8 hourly or 1 hourly monitored values, as applicable, shall be complied with 98% of the time, they may exceed the limits but not on two consecutive days of monitoring.)

Figure 2: Ambient PM 10 concentrations at Ajmeri gate in Jaipur District

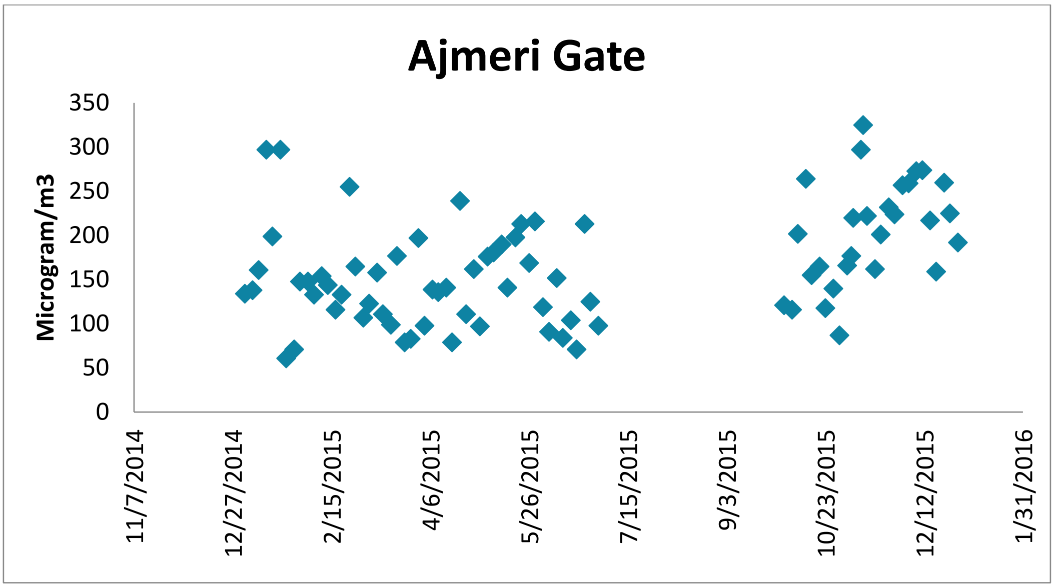


Figure 3: Ambient PM 10 concentrations at VKIA Jaipur

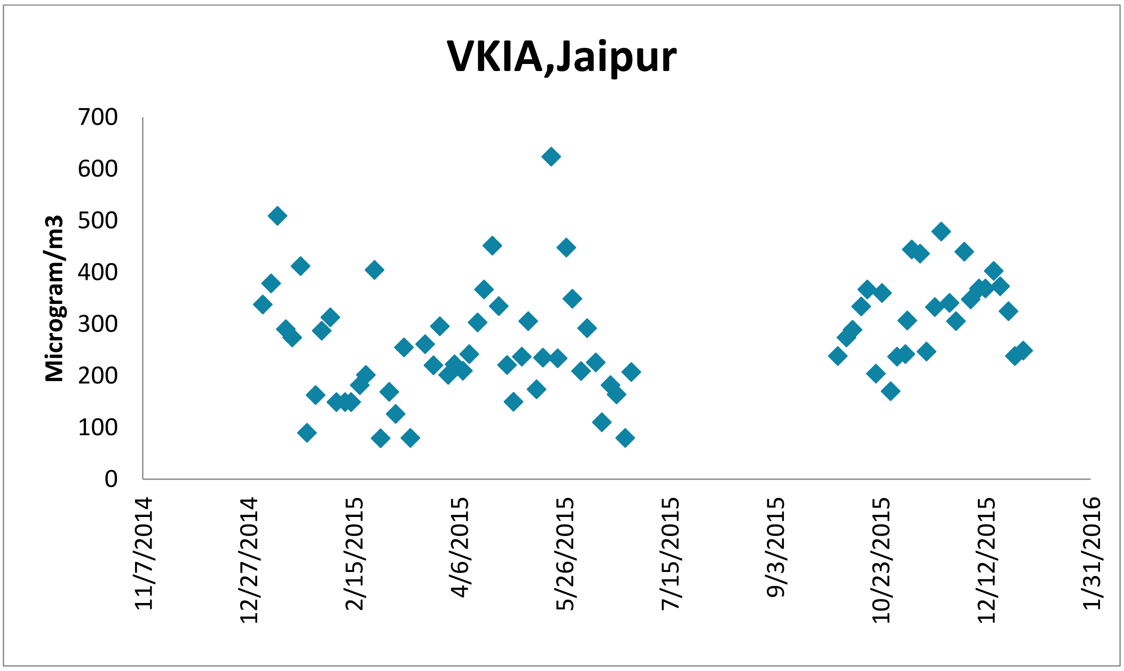


Figure 4: Ambient PM 10 concentrations at Jhalana Doongari

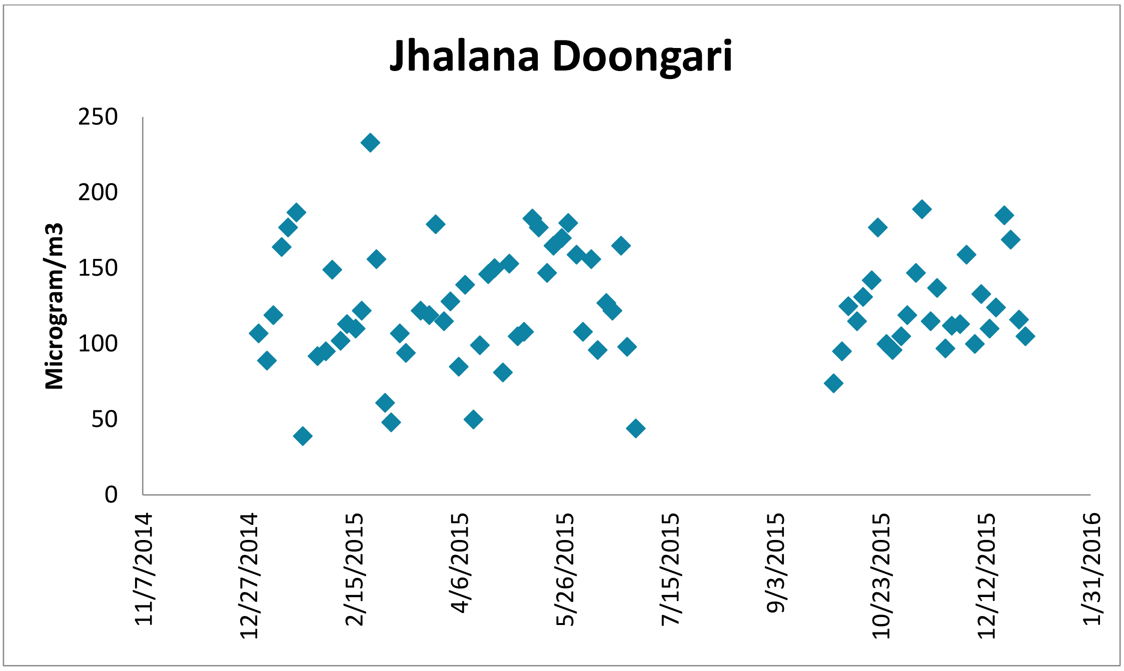


Figure 5: Ambient PM 10 concentrations at Chandpole

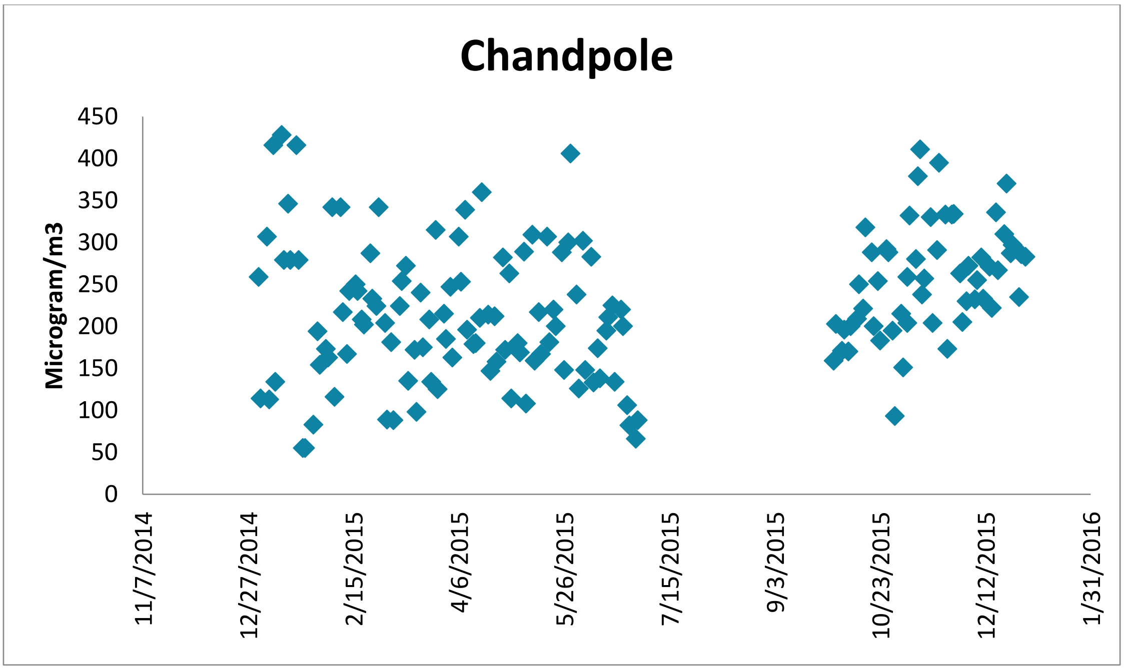


Figure 6: Ambient PM 10 concentrations at Vidyadhar Nagar

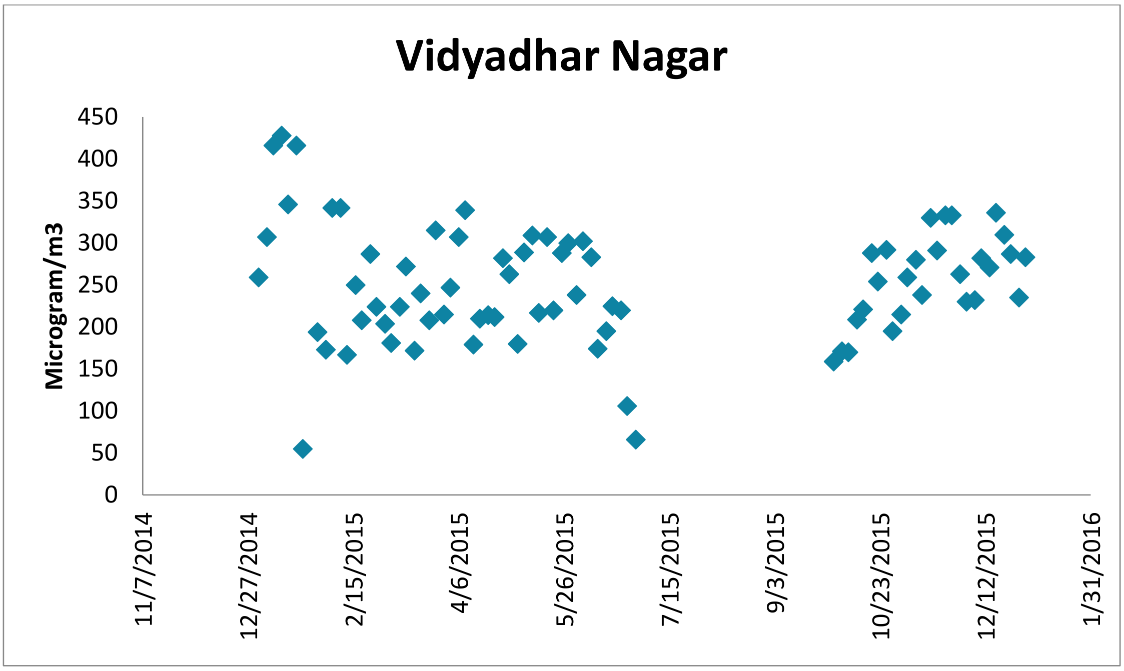
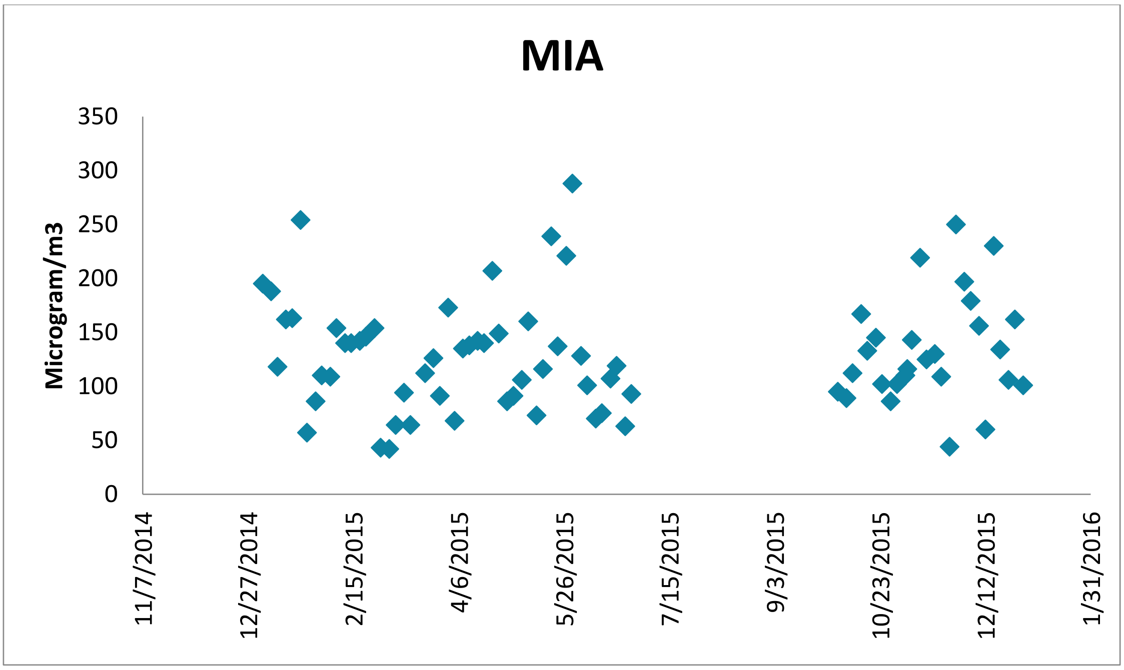


Figure 7: Ambient PM 10 concentrations at MIA



As observed from the above trend in ambient PM concentration, there are violations of PM 10 concentrations at most of the monitoring stations in the districts. Further, it is noted that there are variations in the average yearly concentration across these stations. For example, VKIA has the highest concentration, (>250 microgram/m3), while Jhalana Doongari has the least mean concentration of 125 microgram/m3 among all the locations where ambient air quality monitoring takes place and as recorded during the 9 months of a year when brick manufacturing takes place.

Source apportionment studies in India are limited and are largely available for regional/local level assessment. Among them, most of the studies are for key urban locations, like Delhi NCR, Mumbai, Bangalore, etc. Selected review of literatures suggest that the average contribution from the the brick kiln is in the range of 15 to 25 percent. Hence an average concentration of 20 percent of the monitored data has been apportioned for the emission from the brick kiln sector in the state of Rajasthan.

Brick Kiln sector in Rajasthan

Although there are quite a few technologies that can be used for brick manufacturing, in India two technologies that are largely predominant are FCBTK. The brick production methods and their geographic distribution are presented in the figure 8.

Figure 8: Brick Production Methods and Geographic Distribution (Maithel, 2012)

Kiln Type	Region	Brick production
Clamp/ Zig-Zag/Vertical Shaft Brick Kiln(VSBK)	Central, West and Southern India-Gujarat, Orissa, Madhya Pradesh, Maharashtra & Tamil Nadu	25%, 2-3%,1-2% (respectively)
Fixed Chimney Bull's Trench Kiln(FCBTK)	North and East India- Punjab Haryana, Uttar Pradesh, Bihar & West Bengal	70%

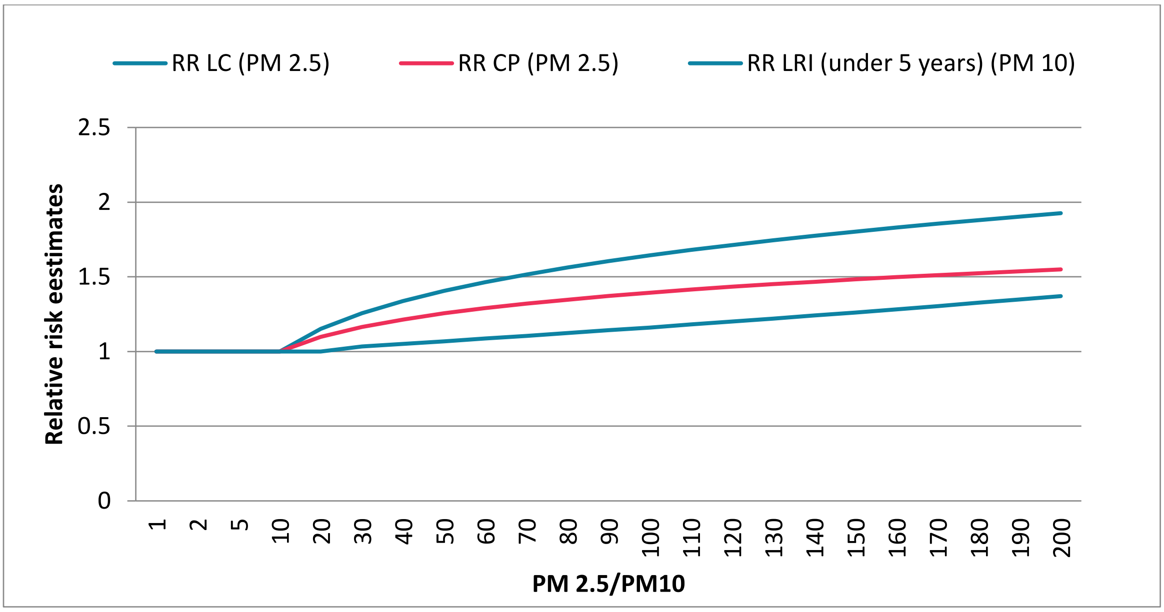
As evident from the above figure, the predominant technology in the Northern and Eastern region of India is FCBTK which is the most popular method of production, that account for majority of the annual brick production. The remaining production is based primarily on Clamp Kiln methods used across the Central, Western and Southern parts.

In Rajasthan there are no official estimates on the number of kilns in operating. According to an estimate of Ministry of New and Renewable Energy (MNRE, 2013), there are 3000 brick kilns operating in the state. However, a recent statement of a minister in the state indicated that there are nearly 1000 registered brick kilns in the state. Out of these 1000 brick kilns near the highest number of brick kilns registered, 321, are operating in Sri Ganganagar district, followed by Hanumangarh and Jaipur with 290 and 146 respectively. For the purpose of the study, the total number of brick producing units has been identified as 3000, howver there distribution of operations across different districts is based on the the registered kilns in these districts.

Health impacts of emissions of PM from the brick kilns

Exposure to air pollution is linked to a wide spectrum of health effects that can be acute or chronic in nature and will vary with concentration of pollutants. Particulate air pollution exposure can lead to lung cancer and other cardiopulmonary disease mortality. Health impacts of emissions of PM from brick kilns in Rajasthan has been analysed for cardiopulomonary disease (CP), lung cancer (LC) and lower respiratory tract infection (LRI) for children under the age of five years. The relative risks have been estimated based on Ostro (2004) for these health risks. The relationship between health risks and exposure to PM 10 or PM 2.5 is presented in figure 9.

Figure 9: Relative risks mortality due to lung cancer (LC), cardiopulmonary disease (CP) and lower respiratory infections (LRI) from exposure to PM 10 or PM2.5



RR (LC) = ((PM2.5+1)/(Threshold + 1))^(0.23218)
RR (CP) = ((PM2.5+1)/(Threshold + 1))^(0.15515)
RR (LRI (under 5 years) = EXP^(0.00166(PM10-threshold))*

Based on the estimates of the global burden of disease methrodolgy, Rajasthan recorded more than 65000 deaths due to exposure to PM 2.5. Further, an estimated around 801 deaths have been attributed due to brick kilns in the state. As mentioned above, there are limited source apportionments studies at the regional or local level. Review of selected studies (TERI, 2013, ICIMOD, 2016), reveal that PM 10 contribution from brick kilns to ambient PM concentration on an average ranges between 15 to 25 percent. Guttikunda et al. (2014) estimated share of PM 10 contribution from brick kiln in Patna city at 11 percent. A study by NRDC in Ahmedabad, estimated 6 to 15 percent contribution of PM in city's ambient concentration. However for the study a higer estimate of 20 percent has been used that was concluded based on discussion with experts. Table 1 presents the district wise population, average PM10 concentrations estimated during the brick manufacturing months and the estimated deaths arising from brick kilns in the state.

Table 1: District wise population, average PM concentration during the brick manufacturing months (above standards) and the estimated deaths arising from brick kilns

Sl. No	Name of Districts	Population (2016)*	Mean concentration (PM10)	Estimated deaths due to brick kilns
1	Ajmeri Gate	7,301,312	211	525
2	Hanumangarh	1,672,673	211	120
3	Sri Ganganagar	2,212,321	211	156

Estimated based on the annual population growth rate between 2001 and 2011 and calculated over 2011

Source: Author's estimation

Brick kiln interventions

The benefit-cost assessment undertaken in this study looks at two options of cleaner kiln technologies. One of the options involves an improvement of existing clamp kilns and FCK technology to the Improved Zig Zag Kilns, while the other option is Vertical Shaft Brick Kilns (VSBK) technology. The detailed benefits and costs of these technologies are presented in the following sections.

Intervention 1: Improved Zig-Zag Kiln

Clamp kilns and/or FCKs can be converted to Improved Zig-Zag Kilns at low costs in the low lands at the same site. This can be accomplished in less than half a year. Hence any intervention in 2018, will start reaping environmental benefits and social benefits from 2019. The production capacity is the same or higher compared to the Clamp kilns and/or FCBTKs. The brick quality is as good as or better than FCBTKs, and with energy savings and PM emission reductions. Brick Kiln owners find this technology the most attractive because they neither need to relocate nor having to look for high land (Guttikunda and Khaliquzzaman, 2014), and there is no need for large investment cost that requires commercial financing.

Needless to mention, for Zig-Zag brick kilns, conversions must meet technological and operational standards. It is important to note that Zig-Zag brick manufacturing leads to 22 percent lower CO2 emissions. A comparative assessment of key parameters for both the technologies in the context of Rajasthan is presented in table 2.

Table 2: Key technical, financial and environmental parameters of clamp kilns and /or FCBTK vis-à-vis Zig-Zag brick kiln technologies in the context of Rajasthan.

Category	Unit	Clamp kiln/Down draught kiln	Zig-zag
Total registered brick kilns in Rajasthan	No	3000	3000
Average brick production capacity/ clamp kiln	No (in million)	4.5	4.5
Average annual production of bricks in Rajasthan	No (in million)	13,500	13,500
Capital Cost/Kiln	Rs (in million)		5.2
Total capital cost	Rs (in million)	9750	15600
Percentage of Class 1 bricks produced (clamp brick kiln)	Percent	0.6	0.8
Percentage of Class II and other bricks	Percent	0.4	0.2
No of Class 1 Brick produced	No (in million)	8,100	10,800

No of Class II and other bricks produced	No (in million)	5,400	2,700
Selling Price of Class 1 brick	Rs	4	4
Total revenue from selling class 1 brick	Rs (in million)	32,400	43,200
Selling Price of Class II and other bricks produced	Rs	1.5	1.5
Total revenue from selling Class II and other bricks produced	Rs (in million)	8100	4050
Total Revenue	Rs (in million)	40,500	47,250
Operating Cost/Brick - INR	Rs	2.35	2.068
Total operating Cost	Rs (in million)	31,725	27,918
Operating Profit	Rs (in million)	8775	19,332
Emission factors/brick	Kg	0.43	0.15
Total Emission/year	Million tonne of CO2	5.78	4.51

Source: Maithel (2013); Guttikunda (2014), Greentech (2012)

* Since production capacity of brick kilns are not available, the average annual production capacity per kiln is assumed at 45,00,000.

As evident from the above table the Zig-Zag technology scores substantially over the conventional clamp kilns and/or FCBK brick kilns. Hence any intervention started in 2018 will start reaping environmental benefits and social benefits from 2019. It is important to note that there may be marginal improvement in operating costs, but the biggest advantage of moving to this technology is the increased production of class 1 bricks that will fetch substantial value from the market.

Finally, the financial benefits for Zig-Zag technology has been estimated for a period of 12 years (till 2030) using 3 discount rates viz. 3%, 5% and 8%. The incremental benefits and costs from shifting to Zig-Zag technology is presented in table in 3.

Table 3: Incremental present value (PV) of benfits (financial, health and environmental) achieved from shifting to Zig-Zag technology

Rs million		Zig-Zag (VSL Approach)	Zig-Zag (DALY Approach)
Cost		15600	15600
Financial benefits			
	3%	102024	102024
	5%	89114	89114
	8%	73665	73665
CO2 benefits	3%	24764	24764
	5%	7439	7439
	8%		
Health benefits			
	3%	58091	35998
	5%	49724	27237
	8%	39905	18610
Total benefits	3%	184879	162786
	5%	146276	123789
	8%	113570	92275
BCR	3%	11.9	10.4
	5%	9.4	7.9
	8%	7.3	5.9

Source: Author's calculation

The cost of technology has been used based on literature review and discussion with subject matter experts. Using the estimated average production per kiln (table 2), and the capital cost per kiln, the total capital cost of intervention has been esimated. The adoption of Zig-Zag technology not only reduces cost of production but also leads to increase in share of class 1 bricks. The total incremental financial benefits are Rs 102 bn, Rs 89 bn and Rs 73 bn till 2030, for 3%, 5% and 8% discount rates respectively. The incremental profit per kiln for these disount rates are Rs 21.25 mn, Rs 18.57 mn and Rs 15.35 mn.

The social benefits of cleaner brick kilns assessed in this study are health benefits of reduced PM 10 emissions and global benefits of carbon dioxide (CO2) emission reduction due to higher energy efficiency of Zig-Zag technology. Other social benefits of air emissions reductions - such as reduced material damage to buildings structures, reduced degradation of forest, soil and water, and reduced damage to agricultural crops – are not estimated as these benefits are found in most studies to be quite small compared to health benefits.

With regard to estimating the carbon benefits, the CO2 savings from Zig-Zag technology have been used along with the baseline estimates from the current technology. A retrofitting with a Zig-Zag technology is estiamated to reduce CO2 by 1.2 million tonnes. The social cost of carbon has been used from Tol (2018), in which Tol estimates the CO2 value at US$ 25.3/tCO2 for 3% discount rate and US$ 7.6 /tCO2 at 5% discount rate. Combining CO2 emission savings and cost of carbon, the present discounted value of carbon has been estimated at Rs 24 bn and Rs 7 bn respectively.

Finally, the health benefits have been estimated based on the risk function for cardiopulmonary disease, lung cancer and lower respiratory infection among children under 5 years. In the presence of Zig-Zag technology, an estimated 4346 deaths can be avoided (between 2019 and 2030), thereby improving quality of life. This leads to saving of 326 deaths per annum. The average PM concentration for each district alon with the risks parameter, as provided by Ostro (2004), the relative risk above the threshold has been estimated. Assuming that nearly 60 percent of the population is exposed to the ambient condition, and using the estimated decline in PM concentration of the district concerned due to intervention, the risk weigthed share of impacted population fraction for each disease is estimated. The decline in the risk weigthed share of impacted population fraction for each disease, arising due to technological intervention, when multiplied by the disease specific incidence of death, provides the avoided death due to technological intervention. Avoided deaths and associated illness from cleaner brick kilns can be monetized by using various benefit valuation measures. The Copenhagen Consensus Center (CCC) methodology suggest to apply a value of GDP per capita per avoided "disability adjusted life year" or DALY. VSL per averted death is equivalent to 56 times GDP per capita in Rajasthan, while DALYs are valued at 2 times GDP per capita in the state.

The benefits from the VSL approach provide estimated net present value of incremental health benefits of Rs 58 bn, Rs 49 bn and Rs 39 bn based on 3 discount rates 3%, 5%, 8% respectively. The estimated incremental benefits using the DALY based valuation approach provides benefits of Rs 35 bn, Rs 27 bn, and Rs 18 bn, using the same set of discount rates.

The total estimated benefits from VSL approach are Rs 184, Rs 146 and Rs 113 bn which is higher than the benefits obtained from DALY (i.e. Rs 162, Rs 123 and Rs 92 bn). The benefit costs ratio under these two approaches, for three discount rates are 11.9, 9, & 7 and 10, 7.9 and 5.9.

Intervention 2: Vertical Shaft Brick Kiln Technologies (VSBK)

The VSBK technology uses hot exhaust gases for the gradual preheating of the unfired bricks in a continuous process, thus reducing energy consumption and CO2 emissions compared to the more commonly used clamp kilns/FCBTK. There is no doubt that the VSBK technology is one of the most energy efficient and cost effective brick firing processes in the world, with the added benefit of providing a better working environment for staff members. The VSBK makes clay brick an even more sustainable building option by reducing the embodied energy of an average clay brick, at least by half. It is important to note that VSBK brick manufacturing leads to 53 percent lower CO2 emission than existing brick manufacturing process as per Guttikunda (2014).

A comparative assessment of key parameters for clamp kilns and VSBK is presented in table 4.

Table 4: Key technical, financial and environmental parameters of clamp kilns and /or FCBK vis-à-vis VSBK brick kiln technologies in the context of Rajasthan.

Category	Unit	Clamp kiln/Down draught kiln	VBSK
Total registered brick kilns in Rajasthan	No	3000	3000
Average brick production capacity/ clamp kiln	No (in million)	4.5	4.5
Average annual production of bricks in Rajasthan	No (in million)	13500	13500
Capital Cost/Kiln	Rs (in million)	3.25	8
Total capital cost	Rs (in million)	9750	24000
Percentage of Class 1 bricks produced (clamp brick kiln)	Percent	0.6	0.9
Percentage of Class II and other bricks	Percent	0.4	0.1
No of Class 1 Brick produced	No (in million)	8100	12150
No of Class II and other bricks produced	No (in million)	5400	1350
Selling Price of Class 1 brick	Rs	4	4
Total revenue from selling class 1 brick	Rs (in million)	32400	48600
Selling Price of Class II and other bricks produced	Rs	1.5	1.5
Total revenue from selling Class II and other bricks produced	Rs (in million)	8100	2025
Total Revenue	Rs (in million)	40500	50625
Operating Cost/Brick - INR	Rs	2.35	2.068
Total operating Cost	Rs (in million)	31725	27918
Operating Profit	Rs (in million)	8775	22707
Emission factors/brick	Kg	0.43	0.11
Total Emission/year	Million tonne of CO2	5.78	3.06

Source: Maithel (2013); Guttikunda (2014), Greentech (2012)

* Since production capacity of brick kilns are not available, the average annual production capacity per kiln is assumed at 4500000.

As evident from the above table the VSBK technology scores substantially over the conventional clamp kilns and/or FCBK brick kilns. It is important to note that there may be marginal improvement in operating costs, but the biggest advantage of moving to this technology is the increased production of class 1 bricks that will fetch substantial value from the market. While the number of class 1 bricks in Zig-Zag technology is approximtaly 80 percent, the share further increases to 90 percent in VSBK. With regard to financial benefit from VSBK technology, the increased revenue from selling additional class 1 bricks have been considered as the key benefit in the analysis.

The private financial benefits for VSBK technology has been estimated for a period of 12 years (till 2030) using 3 discount rates viz. 3%, 5% and 8%. The incremental benefits and costs from shifting to VSBK technology is presented in table 6.

Table 5: Incremental present value (PV) of benfits (financial, health and environmental) achieved from shifting to VSBK technology in Rajasthan

Rs million		VSBK (VSL Approach)	VSBK (DALY Approach)
Cost		24000	24000
Financial benefits			
	3%	134640	134640
	5%	117603	117603
	8%	97215	97215
CO2 benefits	3%	52905	52905
	5%	15892	15892
	8%		
Health benefits			
	3%	88375	54765
	5%	75645	41436
	8%	60708	28311
Total benefits	3%	275920	242310
	5%	209140	174931
	8%	157923	125527
BCR	3%	11.5	10.1
	5%	8.7	7.3
	8%	6.6	5.2

Source: Author's calculation

Use of VSBK can lead to an incremental financial benefit of Rs 134 bn, Rs 117 bn and Rs 97 bn for 3 discount rates. The incremental profit per kiln for these disount rates are Rs 28 mn, Rs 24 mn and Rs 20 mn. The social benefits of cleaner brick kilns assessed in this study are health benefits of reduced PM10 emissions and global benefits of carbon dioxide (CO2) emission reduction from improved energy efficiency. A retrofitting with a VSBK technology is estimated to reduce CO2 by 2.72 million tonnes.

Using the same approach discussed in the previous section the avoided CO2 costs have been estimated to be Rs 52 bn and Rs 15 bn for 3% and 5% discount rates. In the presence of VSBK technology, an estimated 6611 deaths can be avoided, thereby improving quality of life between 2019 and 2030. This is equivalent to 551 deaths saved per annum.

The incremental health benefits from the VSL approach provide estimated health benefits of Rs 88 bn, Rs 75 bn and Rs 60 bn based on 3 discount rates 3%, 5%, 8% respectively. The estimated benefits using the DALY based valuation approach provides benefits of Rs 54 bn, Rs 41 bn, and Rs 28 bn, using the same set of discount rates. The total estimated benefits benefits from VSL approach are Rs 275 bn, Rs 209 bn and Rs 175 bn which is higher than the benefits obtained from DALY based approach (i.e. Rs 242 bn, Rs 174 bn and Rs 125 bn). The benefit costs ratios under these two approaches for three discount rates are 10, 8, 6 and 9, 6 and 4.

Conclusion

The analysis presented in this paper confirms that there are substantial environmental benefits on account of reduced PM emission and the consequent health benefits through technology interventions.

Brick is also a major contributor to environmental pollution as it depends heavily on natural resources, like soil (e.g. top fertilie alluvial soil in the Indo-gangetic plains), and coal as well as other agri residues for firing kilns, etc. Infact, 65 percent of India's bricks are produced from the fertile alluvial soil from the Indo-gangetic plain, while, it is the second largest consumer of coal in the industrial sector category, after iron and steel. The use of large quantities of coal and petcoke in brick kilns contributes significantly to emissions of carbon dioxide (CO2), and particulate matter (PM).

The level of penetration of improved and environment friendly technologies in the brick kiln sector have been very slow. As per certain estimates there is 3 percent moving chimney BTK and 1 percent Holfmann kiln in India operating in India. Two technologies that are largely predominant are FCBTK, which are less efficient in terms of energy consumption and quality brick production, than other technologies. However, penetration of technologies like Zig-Zag and VSBK are are both financially (private costs and benefits) and economically (social costs and benefits) viable when appropriately adopted in the state of Rajasthan.

It is important to note that there may be marginal improvement in operating costs, but the biggest advantage of moving to these technologies is the increased production of class 1 bricks that will fetch substantial value from the market. It has been found that the production of class 1 bricks cen increase from 50 percent to 80 percent incase of Zig-Zag technologies, while in VSBK, the production of class 1 bricks can be as high as 90 percent. Increased efficiency will reduce CO2 emission thereby reducing global warming potential. At the same time emission of PM will also come down thereby improving ambient air quality.

The studied options are financially (private costs and benefits) viable and economically (social costs and benefits) viable. As evident from the above table, the benfits costs ratios are relatively more for conversion or retrofitting of existing Clamp kilns to Zig-Zag kilns over VSBK. As evident from the above table, the benfits costs ratios are relatively more for conversion or retrofitting of existing Clamp kilns to Zig-Zag kilns over VSBK. The BCR from conversion to Zig-Zag technology is in the range of 6 and 12 and for that of VSBK it is in the range of 5 and 10. The estimated incremental profits from shifting to Zig-Zag kiln is Rs 21 mn, Rs 18 mn and Rs 15 mn for three discount rates while for VSBK it is Rs 28, Rs 24 and Rs 20 mn under the three discount rate scenarios. The average number of lives to be saved per year is 362 in case of Zig-Zag technology and 551 in case of VSBK. The savings of carbon emission per year are 1.27 million tonnes CO2 and 2.72 million tonnes CO2 for these technologies. The total benefits due to conversion to Zig-Zag technology are Rs 184 bn, Rs 146 bn, and Rs 113 bn using VSL approach and Rs 162 bn, Rs 123 bn and 92 bn using DALY approach respectively. The total benefits due to conversion to VSBK technology are Rs 275 bn, Rs 209 bn, and Rs 157 bn using VSL approach and Rs 242 bn, Rs 174 bn and 125 bn using DALY approach respectively.

In the presence of Zig-Zag technology, an estimated 4346 deaths can be avoided (between 2019 and 2030), leading to saving of 326 deaths per annum. VSBK can lead to avoiding 6611 deaths (between 2019 and 2030), leading to saving of 551 deaths per annum.

However, there are many impediments to this shift. Interactions with selected stakeholders have revealed that despite having a business case, poor awareness among entrepreneurs, lack of concessional finance for buying these technologies and hand holding are areas that need utmost attention. While there are various programs undertaken by ministry of micro small and medium enterprises to create awareness among producers, often the reach has been limited and focused at specific locations. This can be minimized by engaging with state level and/or district level institutions/ agencies particularly, industry associations, polytechniques, Small Industries Development Bank of India, incubation centres of professional and technical institutions, etc. More importantly, such engagements need to focus on time adherence. Further delay in the transformation will put more people at risks thus jeopardizing some of the key development targets defined under the sustainable development goals (SDGs).

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Rajasthan is the largest Indian state. It has a diversified economy, with mining, agriculture and tourism. Rajasthan has shown significant progress in improving governance and tackling corruption. However, it continues to face acute social and economic development challenges, and poverty remains widespread. What should local, state and national policymakers, donors, NGOs and businesses focus on first, to improve development and overcome the state's remaining issues? With limited resources and time, it is crucial that priorities are informed by what can be achieved by each rupee spent. To fulfil the state vision of "a healthy, educated, gender sensitive, prosperous and smiling Rajasthan with a well-developed economic infrastructure", Rajasthan needs to focus on the areas where the most can be achieved. It needs to leverage its core competencies to accelerate growth and ensure people achieve higher living standards. Rajasthan Priorities, as part of the larger India Consensus – a partnership between Tata Trusts and the Copenhagen Consensus Center, will work with stakeholders across the state to identify, analyze, and prioritize the best solutions to state challenges. It will commission some of the best economists in India, Rajasthan, and the world to calculate the social, environmental and economic costs and benefits of proposals.

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