Economic Assessment of Climate Mitigation Pathways (2015–2050) for the Brick Sector in India

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Abstract India is the second largest producer globally, of fired brick in traditional kiln technologies with 250 million bricks produced yearly. Amongst different sectors, brick production is an important contributor to several SLCPs like black carbon, and ozone precursors like non-methane volatile organic compound and carbon monoxide. This report presented develops and evaluates the evolution of SLCP emissions from India, during 2015–2050, from the brick sector, under two different scenarios of diffusion of cleaner technologies and practices, compared to that under a reference scenario. Net emissions of SLCPs from India in 2015 from the brick sector are estimated at 422.89 GT CO_2 eq. (using GWP-20). Total achievable mitigation of SLCPs in 2050 is 25% under a promulgated policies scenario, while it is 80% under a prospective policies scenario. Mitigation strategies of brick industry require shift from traditional burnt bricks to introducing higher use of unburnt bricks. A cost–benefit analysis shows that SLCP mitigation cost is as low as 59 Rs./tonne of CO_2 eq., which is significantly lower than those estimated for GHG mitigation in India. Actions reducing emissions from brick industry require shift towards manufacturing of unburnt bricks which also reduce warming of the atmosphere and benefit public health.

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Bottom-up approach

List of Abbreviation

AIM	Asia-Pacific integrated model
BTK	Bull's trench kiln
CBA	Cost–benefit analysis
CCAC	Climate and clean air coalition
CEA	Cost-effective analysis
CGE	Compound general equilibrium
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
GHGs	Greenhouse gases
GWP	Global warming potential
HFCs	Hydrofluorocarbons
LPG	Liquefied petroleum gas
NMVOC	Non-methane volatile organic compound
NOx	Nitrogen oxides
PM	Particulate matters
SLCPs	Short-lived climate pollutants
SO_2	Sulphur dioxide
VSBK	Vertical shaft brick kilns

1 SLCPs—An Underlying Opportunity for India

Global warming is a pressing issue in the current world, where the source of the problem is the greenhouse gases (GHGs) to be blamed. However, the recent research has found that there are two types of pollutants which cause warming of the atmosphere: one the GHGs and the other the short-lived climate pollutants (SLCPs) (Victor et al. 2015). As the name suggests, SLCPs have a shorter lifespan in the atmosphere compared to the GHGs. GHGs can be present in the atmosphere for as long as 100 s of years, whereas SLCPs have a lifetime in the range of days to weeks and maximum of 14 years for methane (CH_4). SLCPs are unique as they exert warming and cooling to the atmosphere, along with which they also cause health problems to humans.

SLCPs are a number of pollutants including, methane (CH_4), hydrofluorocarbons (HFCs), particulate matter (PM), sulphur dioxide (SO_2) and stratospheric ozone (UNEP 2014; Mass and Grennfelt 2016). Specific contents of particulate matter such as organic carbon and black carbon are of utmost importance as they exert negative and positive warming to the atmosphere, respectively. On the other hand, stratospheric ozone cannot be found directly in the atmosphere, and a combination of various other pollutants result in ozone formation. Such pollutants include, carbon monoxide (CO), volatile organic compounds (VOCs) and nitrous oxides (NOx) (Victor et al. 2015). The SCLPs exert higher warming or cooling than CO_2 for a shorter period, making them important to curb the temperature changes in the short run. Moreover, SO_2, PM and CO are the local air pollutants, impacting human health in various manners. Hence, SLCPs have double-fold effect and curbing them would not only clean the air, but also reduce warming of the atmosphere.

India is one of the prominent emitters of SLCP in the world, with emissions coming from residential cooking, agriculture burning, brick manufacturing and transport sector (CCAC 2015; Venkataraman et al. 2016). The mitigation strategies are being laid out by CCAC for SLCP mitigation; however, India is not an active partner in the coalition making it difficult to channelize the resources. Residential cooking stoves are inefficient and use fuelwood, instead of liquefied petroleum gas (LPG) and other energy-efficient fuels. However, the issue of residential cooking is diverse and concerns individual in every household, which makes it difficult to reach the extent of people to sensitize towards the same. Moreover, the economic cost for such a change may not be huge for a country, but an individual may not have the financial capacity to make the shift as India is a developing country with many living under poverty line.

Similarly, SLCPs from transport sector are being taken care of by advancements in vehicles efficiency improvements; however, they require monetary investment at the individual level. The personal choices are difficult to be restricted, especially in a country like India where the population is huge and the economic status of individuals are diverse. Moreover, initiating public transport and encouraging the use of the same has already been promoted by the government. Another scope for SLCP reduction lies in the agriculture waste burning, where the waste from current harvest is burned to prepare the soil for the next harvest. Similar to cooking practices, agricultural practices are part of the culture for individuals, requiring change which demands financial investments along with the habitual change. Various small-scale studies have been undertaken regarding the above-mentioned issues (Ramanathan and Parikh 1999; Reddy and Venkataraman 2002; Venkataraman et al. 2010; Sadavarte and Venkataraman 2014; Busby and Shidore 2017); however, a country-wide success story is difficult to find under the literature.

Brick manufacturing is one of the major SLCP emitting sectors considered for mitigation under SLCP literature (USEPA 2012; CCAC 2015; Ministry of Environment Forest and Climate Change Government of India 2015). The literature does not estimate the emissions or potential mitigation opportunities available in brick production; however, it is widely stated that the emissions from firing the fuel to bake bricks emit SLCPs. Hence, the study looks into the present emissions and mitigation potentials of the same in India. Firstly, brick manufacturing is an industry which is currently unregulated in India, where the industrial regulations do not apply except for a few with emission standards and technology upgradation (Ministry of Environment Forest and Climate Change Government of India 1986). The regulations have set emission standards restricting emissions of sulphur dioxide and particulate matter. Moreover, national brick mission has been launched to guide the progress of the industry (Bhushan et al. 2016). Such control over the industry gives room for policy guidelines and progress of the brick industry.

This section highlighted the importance of studying the brick industry, especially as a mitigation measure. Section 2 introduces brick industry in India, production technologies and current trends in the same. Section 3 is the tools of analysis, where the methodology adopted to develop the chapter is discussed along with the scenario description of each one of them. After which, the prospective futures of the brick industry are discussed in Sect. 4 along with the cost analysis. Finally, the implications of the chapter and its implications for the policy development are described under Sect. 5.

2 Brick Industry in India

The bricks have been one of the prominent building materials since the history of buildings. Along with the increasing building structures, brick production has also been growing in India, making India the second largest producers of bricks after China. With the production coming from about 100,000 kilns across the country, total production of bricks was 250 billion in 2015 (Lalchandani and Mithel 2013; Rajarathnam et al. 2014). The kilns are located in the large cities such as Delhi, Kolkata and Mumbai, with the spread across adjacent states. Moreover, the states of Assam, Karnataka and Tamil Nadu also have spread of kilns around the cities (Maithel 2003).

Bricks have traditionally been produced using sand moulds fired at a higher temperature to develop into a hard cake with the resistance power. However, the advancement in construction material has led to cement blocks which are produced from hardening cement into desired shape and size. The modern bricks do not require any firing and hence less energy consuming option for production of bricks. Fired and non-fired bricks such as cement blocks are the two market-available categories of bricks in the world. However, in India, non-fired bricks have not picked up yet due to unavailability of the bricks and lack of awareness about the option. In the megacities, the non-fired bricks are seen to have made an appearance in recent times; nevertheless, the extent of the same is negligible.

Looking at the fired bricks, they are produced in two types of kilns: one which runs intermittently and the others which are continuous. Intermittent kilns prearrange the bricks and fuel mix to be fired, which runs in a batch (Kumar and Maithel 2016). Once one batch of bricks is fired, the next one is arranged and fired and so on. Clamps are the prominent kilns which use this technique in India, with the share of 25% of total production. However, such arrangements are low in efficiency and lead to higher emissions. Moreover, as there is no structure required for this arrangement, control of emissions is also not possible, making it one of the dirtiest technologies.

The continuous kilns are the ones where the firing of bricks and staking of wet bricks is done simultaneously at different ends of the kiln. This type of kilns has a boundary wall in an oval shape that guides the flow of the currently firing, loading and unloading bricks. Such a kiln allows for a guided flow of flue gases, making it possible to provide a chimney and possible emission reduction measures. Bull's Trench Kiln (BTK), zigzag firing and Vertical Shaft Brick Kiln (VSBK) are the continuous type of kilns with the share of 66%, 8% and 1% of total production, respectively. The continuous kilns have higher fuel efficiency than clamps with varying emissions. BTK has the lowest fuel efficiency and higher emissions compared to other continuous kilns. Zigzag firing is a modified version of BTK, where the flow of firing and flue gases are guided. It is evident that zigzag firing is more efficient than BTK as well as less polluting. VSBK, on the other hand, is most efficient and lowest polluting technology amongst the continuous firing category (Kumar and Maithel 2016). Continuous firing kilns can install an air pollution reduction device in the chimney to reduce the pollution; however, for the GHG emission, no such measures are possible.

As mentioned earlier, the construction activities have been increasingly demanding more brick production year after year. The current trend shows an increase of 6.6% per annum of brick production since 2012, which is expected to continue in the near future (Bhushan et al. 2016). Such a growth rate is evident as the construction requirement in present and the future is going to increase with increasing population and income. Considering the fuel consumption, due to fired brick use, coal is used around 35 million tons (MT), which is 15% of the total industrial coal use. The emissions from coal have not been estimated; however, it is expected to be huge. CCAC is one of the coalitions working on SLCP emission mitigation opportunities, which identified brick production in South Asia as one of the key sectors (Valdés 2016). Specifically, in India, the brick manufacturing is expected to grow in the future at a similar rate. Hence, there is potential for SLCP mitigation by adopting various standards of emissions and technology shifts.

This chapter delves into brick production in the future, where similar growth rate of production is assumed. However, the technology distribution in the current state is not energy efficient and leads to emissions, which can be reduced by shifting to the better-fired technologies or non-fired technologies. Such trends are difficult to determine especially when the current government rules do not show encouragement towards non-fired bricks. A variety of future scenarios are possible in such cases, from which the best economically and environmentally friendly measure should be adopted while forming a policy. Hence, the next section explains a set of possible scenarios for brick manufacturing.

The mitigation of emissions requires investments in monetary terms from the producers. Hence, an economic analysis has also been proposed. The economic analysis has been performed in two ways under the existing literature, namely cost-effective analysis (CEA) and cost–benefit analysis (CBA). CEA values costs in monetary terms with benefits in 'physical' units, which is used to analyse a policy outcome in an economy. On the other hand, CBA calculates costs in monetary terms and benefits in economic terms where various market approaches with the broader definition is adopted. In CBA, benefits are called ecological benefits which incorporate environmental, health and livelihood improvements into account. However, CBA requires an empirical study on the quantification of the benefits achieved by the mitigation, which could be an extension of the current study. CEA analysis gives a cost which can also be called mitigation cost in the climate change analysis. The mitigation cost comparisons between the literatures determine the priority of an action/policy measure based on the cost minimization principle. Hence, in the present study, only the CEA approach is used for the economic analysis where costs are derived in monetary units and the benefits are derived in physical units of CO_2 equivalent.

3 Tools of Analysis

A sectoral analysis has been studied using various approaches such as top-down and bottom-up. Top-down approaches equate demand and supply of the product in the given economy. Such models base their assumptions on an economy where consumers and producers play a key role in achieving the future equilibrium. Computed general equilibrium (CGE) is one such model, which has been used widely for issues related to climate change with the aim to assess policy changes (Farmer and Steininger 1999; Xu and Masui 2009; Antimiani et al. 2015; Li and Jia 2016). On the other hand, bottom-up approach aggregates information at the plant level to project future emissions with the information such as the addition of new plants and capacity expansion in mind. Various application of the approach has been seen in the literature; however, the most popular models include MARKAL (Sulukan et al. 2010) and Asia-Pacific integrated model (AIM) (Wen et al. 2014).

In the current study, various information has been drawn at the national level such as total production and the share of each technology. Current emissions and future emissions are derived using technology-wise energy requirement and emission factors. Such an approach uses plant-level information of technology, energy used along with emissions to build it up to a national aggregate level, which signifies it as a bottom-up approach. The flow chart shown in Fig. 1 explains the methodology adopted for each scenario generation where firstly the yearly production of bricks is divided into the technology-wise production using a share of each one. From the number of bricks produced, the energy required for production is calculated using specific energy and calorific value of the fuel. The fuel used in India is assumed to be a mixture of coal and biofuels from the waste, as the primary survey of brick kilns signifies use of mixed fuels across the country (Weyant et al. 2014). Emissions of each type of pollutant are then calculated using emission factor of that pollutant for a particular technology. Total emission from brick industry has been derived by summing up the emissions from each individual technology for that year.

For the purpose of this study, 2015 is taken as a base year with the analysis period from 2015 to 2030 and then from 2030 to 2050. 2030 has been chosen as a mid-point of the analysis, where various policies would be revised and modified according to the requirement. Three scenarios have been developed: the first one being the reference scenario based on which the other two are assessed. Second is Promulgated Policies scenario where the existing policies are applied rigorously in the sector. Finally, the third is prospective policies scenario in which the targets of the current policies are

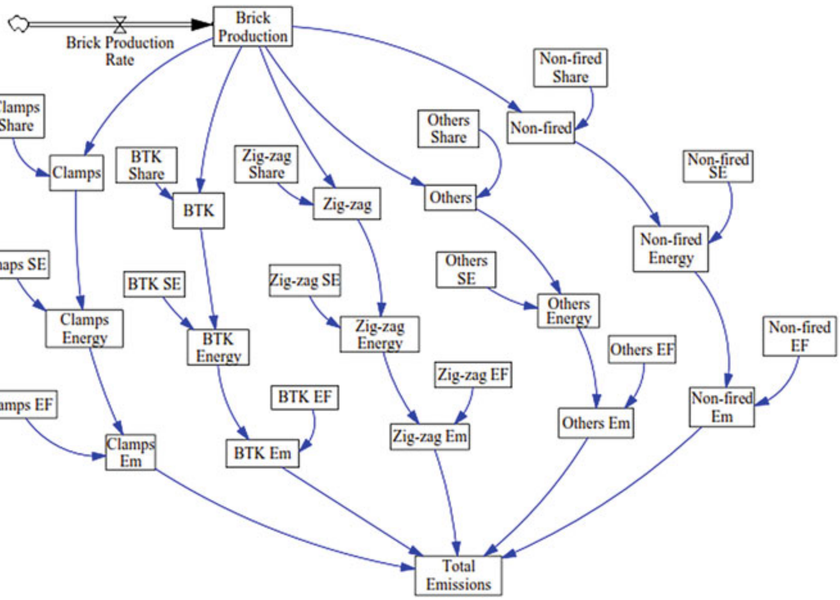

Fig. 1 Emissions calculations for brick manufacturing using specific energy (SE) and emission factor (EF)

achieved earlier and new policies are formed with even more commitment towards the emission reductions. Under each scenario, production growth rate is assumed to stay constant at 6.6% per annum following the current trend.

However, the technology share is assumed to change in each scenario, which is illustrated in Fig. 2. BTK and clamps contribute highest to the overall brick emissions in 2015, as the share of these technologies is highest. The cleaner technologies, such as zigzag, hollow bricks, and non-fired bricks only account for 3% of the total bricks production. The government of India has approached the issue of brick emissions by incorporating the shift from moving chimney BTK to fixed chimney BTK (CPCB 2017). Along with this, the producers are encouraged to convert from BTKs to zigzag, which are less polluting due to high energy efficiency acquired in the design. Hence, the reference scenario assumes pursuance of the similar trend with the highest share of production coming from clamps and BTK combined at 70% in 2030 and slowly reducing to 40% in 2050.

The other two scenarios have been inspired from the literature along with changes deemed required (Venkataraman et al. 2017). The Promulgated Policies have vouched towards high-efficiency fired kilns for the short term (2030) with effectively growing the share of non-fired bricks in the long run. The share of BTK and clamps reduce to 25% by 2050, whereas non-fired bricks would have 45% of share in total production. The high-efficiency fired bricks would have a moderate share of 30% by 2050. Lastly, prospective policies are assumed to promote non-fired bricks in the short term at a

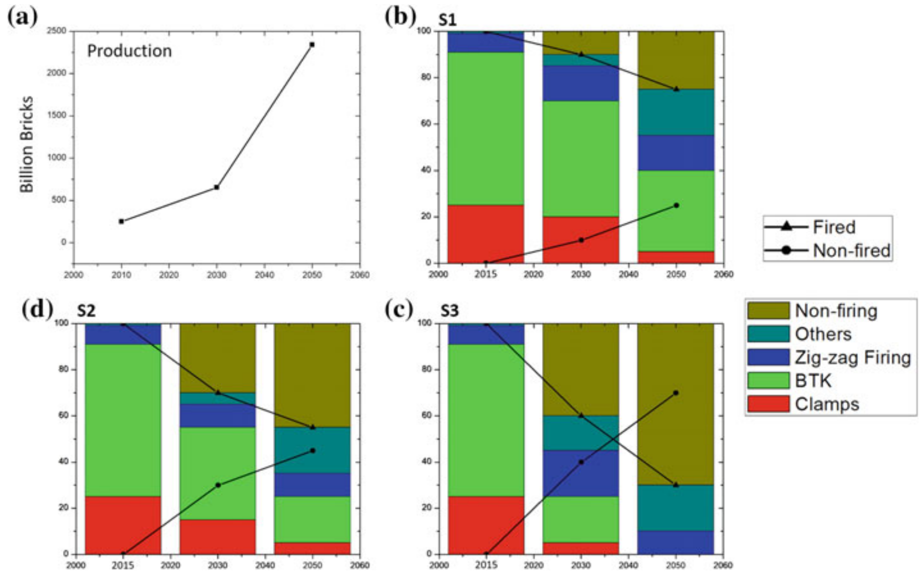

Fig. 2 Assumptions related to scenario formation **a** projected brick production in billion bricks; **b**, **c**, **d** technology shift and proportion of fired and non-fired brick production over 2015, 2030 and 2050 for S1, S2 and S3, respectively

Table 1 Operational and capital costs of brick manufacturing technology-wise, converted into Rs./1000 bricks

Operational cost (per 1000 bricks)	BTK	Clamps	Zig-zag firing	VSBK	AAC (non-fired)
Fuel	416	850	240	182	0
Electricity	0	0	12	9	133
Raw material cost	0	0	0	1855	980
Frieght in	115	370	137	137	90
Freight out	115	370	13.	137	90
Maintenance cost	37	8	54	52	9
Labour cost	20	48	24	1	3
Total Operational Cost	**705**	**1646**	**604**	**2374**	**1306**
Capital Cost					
Capital Cost	3250000	250000	3900000	20000000	10000000
Years of operation	25	25	25	25	25
Annualized capital cost	502773	38675	6d03328	3095975	1547988
Total Annualized Capital Cost (per 1000 bricks)	**84**	**19**	**121**	**619**	**103**
Total cost (per 1000 bricks)	**789**	**1665**	**725**	**2993**	**1409**

higher rate compared to the fired bricks. Awareness regarding the air pollution and emission standards is assumed to play a major role in the shifts, along with the climate change awareness. By 2030, the share of fired bricks is assumed to reduce drastically to 60% compared to 100% in 2015. Moreover, the trend is assumed to intensify with the share of non-fired bricks at 70% by 2050, where the dirty technologies such as clamps and BTK would have retired from the market.

A cost–benefit analysis of the scenario is undertaken where costs are availed from market place as well as from the information collected under primary survey. To manufacture bricks, the producer has to bear two types of costs, one which are upfront, capital costs required to establish the setting up of the kiln. The other cost is the operational cost, through which daily production is materialized. As capital cost is a one-time cost, it is converted into a daily cost using 15% interest rate, 25 years of operation period and average production capacity of each kiln type. The operational costs include fuel, electricity, raw material, freight in and freight out, maintenance and labour cost. For each type of kiln, total production cost per 1000 bricks is presented in Table 1.

CEA analysis is performed where the costs per scenario in the given year is calculated. The mitigation potential for the same year is acquired from the scenario analysis, wherein the global warming potential (GWP) 20 values are used to make the emissions comparable in CO_2 equivalent. GWP of 20 years is used as the maximum

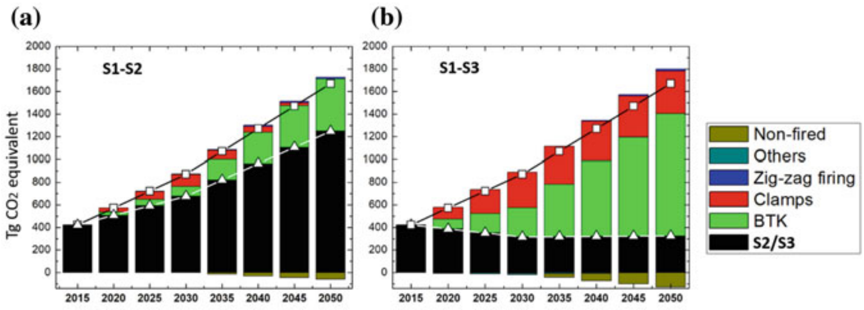

Fig. 3 SLCP emissions change in terms of Tg CO_2 equivalent **a** from promulgated policies (S2) to reference scenario (S1) **b** from prospective policies (S3) to reference scenario (S1)

residence time of SLCP is 10 years, making it impossible for the emissions to exert its warming capacity by 100 years. Moreover, to develop a policy, a reasonable timeframe of 20 years is considered, as in the rapidly changing world, a century becomes too long. Hence, the benefits are accounted in Tg CO_2 eq. for the given scenario in the given year. Finally, a mitigation cost is calculated by dividing cost with the emissions in the given year for the shift in the scenario from reference scenario towards promulgated policies (S2) or prospective policies (S3).

4 Future of Bricks

As production of bricks is expected to increase at 6.6% per annum growth rate throughout the study period, the total production of bricks increases up to 2.3 trillion bricks per year by the end of 2050. As per the technology distribution, reference scenario is the least developed with highest energy consumption leading to highest emissions. SLCPs are the focus of the study, specifically the ones which show positive GWP20 value, such as BC, CO, N_2O, CH_4 and NMVOC. The GWP20 values have been used from the IPCC fifth assessment report (Myhre et al. 2013). Promulgate policies scenario (S2) assumes moderate changes in the technology diversions from fired bricks, indicating lower penetration of non-fired bricks in the market, leading to a decrease of 195 GT and 421 GT CO_2 equivalent in 2030 and 2050, respectively (Fig. 3a). However, when all the SLCPs including OC, SO_2 and NOx are considered, the emission reduction observed is 219 GT and 3955 GT CO_2 equivalent in 2030 and 2050, respectively.

The prospective policies (S3) scenario moves towards the cleaner path, resulting in a reduction of emissions compared to S2. In 2030, as much as 555 GT CO_2 equivalent can be reduced, by adapting non-fired bricks into use. The emission reductions achieved could be as high as 1345 GT CO_2 equivalent by 2050, if the dependence on non-fired bricks is increased up to 70% (Fig. 3b). The reduction in emissions changes

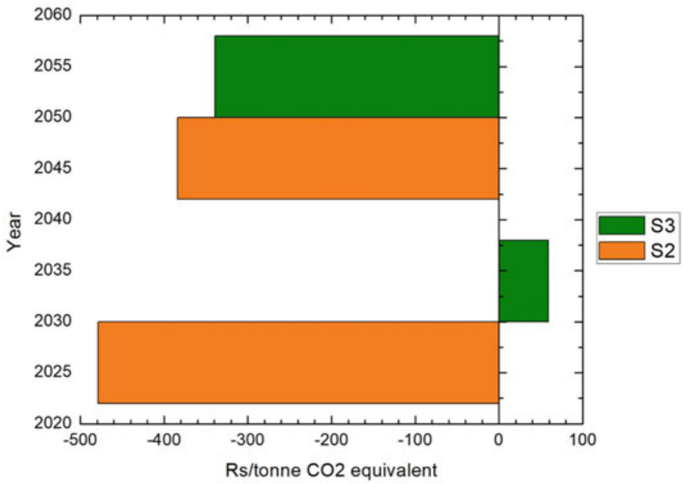

Fig. 4 Mitigation costs for 2030 and 2050 for S2 and S3 by achieving reductions compared to reference scenario in Rs./tonne CO_2 eq.

when negative SLCPs are included, the total emission reductions achieved in 2030 and 2050 amount up to 540 GT and 9227 GT CO_2 equivalent, respectively. The net reductions achieved are higher compared to the S2 scenario, even when compared with only positive SLCPs.

Production costs have been discussed earlier which indicate that operational and capital costs of VSBK are the highest amongst others. Even non-fired bricks have lower capital and operational costs, indicating that promoting the use of non-fired bricks is an economically and environmentally friendly option. As S3 promotes boosted use of non-fired bricks, the cost paid for shifting technology leads to reduced emissions at 300 billion Rs. in 2030 and 500 billion Rs. in 2050. On the other hand, to follow the path indicated under promulgated policies scenario, the costs paid are 50 billion Rs. and 220 billion Rs. in 2030 and 2050, respectively.

Even though the costs incurred in achieving the path under S3 is high, mitigation achieved is comparatively higher leading to mitigation costs of 59 Rs./tonne of CO_2 eq. in 2030 and −339 Rs./tonne of CO_2 eq. in 2050. The mitigation costs of S2, on the other hand, are negative in 2030 and 2050 at −479 Rs./tonne of CO_2 eq. and −384 Rs./tonne of CO_2 eq. due to reduced cost of production compared to S1 (which is indicated in Fig. 4). All the comparisons are based on the reference scenario (S1); where fired bricks are assumed to take up most part of the market demand. Even though, the cost of mitigation for the non-fired bricks is higher under S3, the long-term sustainability of the cement blocks is evident at similar cost in 2050.

5 Aggregate Economic Implications of Brick Industry

SLCP reductions of as much as 1345 GT CO_2 eq. can be achieved by technology shifts of the brick manufacturing alone by 2050. The modest change in technology could also achieve mitigation up to 22% and 25% reductions in the emissions by 2030 and 2050, respectively, compared to the reference scenario. Such a reduction suggests an immediate potential mitigation opportunity to be tapped by minimum efforts. However, the higher efforts could lead to emission reductions up to 60% in 2030 and up to 80% by 2050 under the prospective policy scenario (S3). To achieve reduction, the costs paid under promulgated policies (S2) are lower compared to prospective policy scenario (S3), where the additional costs required by 2030 is 11% and reduces to 8% by 2050. On the other hand, prospective scenario requires a much higher investment of 53% in 2030; however, the investment reduces with time to 20% by 2050.

Such investments are the addition over a period of time, making it possible for the producers to plan their strategy wisely. Moreover, investing 20% additional to the reference scenario may reap up to 80% of emission reductions is an attractive prospective for the cleaner future only from brick production. The mitigation potential of SLCP is huge compared to CO_2, as the recent study by McKinsey suggests that India has potential to mitigate 2.7 Gt CO_2 per year in 2030 which is 54% reduction from the business as usual scenario under the study (McKinsey 2009). The current study shows that the moderate efforts could lead to reductions of 219 Gt CO_2 per year by 2030. Moreover, the energy efficiency improvements are natural to an industry with time; however, they have not been considered as a function of time in this study. Considering the natural rate of efficiency improvement may lead to better emission reductions in the given cost.

It is evident from the above discussion that SLCP mitigation is an important aspect of climate change and mitigation debate with the additional benefits of local air pollution mitigation. Considering the modest mitigation may also lead to huge emission reductions compared to only GHG mitigation. The brick manufacturing industry is one such easy target, wherein the growth can be controlled and mitigations can be achieved. Technological standards should be set by the government in order to mitigate the emissions. To target the mitigation, costs paid by the industry is as low as 59 Rs./tonne CO_2 eq. compared to 1500 Rs./tonne CO_2 eq. required for reduction of GHGs (McKinsey 2009). A policy should be proposed for brick industry to reduce the emissions which will act as a bridge before the long-term actions are taken towards GHG mitigation.

The study has delved into the environmental and economic impact of mitigation from the brick industry for various scenarios in the given timeframe. The analysis suggests that policy should have a short-term and a long-term focus targets, the short term being from 2015 to 2030; 15 years of time span, and long term should extend up to 2050. It would be advisable to slowly reduce emissions by directly converting fired bricks manufacturing to non-fired bricks manufacturing. Such an approach would reap better results in the short run and long run, as non-fired bricks cost less and emissions are also less. The study recommends a mitigation strategy specifically designed for brick manufacturing with two sets of timelines and goals.

The study has comprehensively studied SLCP mitigation opportunities from brick industry in the future with a set of plausible scenarios. However, it is not certain that any of the scenario firmly represent the future of brick industry, rather combination of such scenarios are likely outcome of the brick emissions. The scenarios are developed based on the technologies that exists in the present, future innovation of technologies have not been taken into account. Moreover, the costs assumptions under the study are based on the current market prices, inflation over the future has not been taken into account. Lastly, the sole focus of the study is on SLCPs; GHGs have not been addressed in the study.

6 Summary

Global warming reductions would require actions against GHG mitigations; however, SLCPs can provide an opportunity to slow down the warming in the short run. Brick manufacturing is one such industry which can lead to potential mitigation for SLCPs as well as local air pollutants. The study estimates emissions from two policy scenarios: one promulgated and two prospective. The mitigation potentials are compared with the reference scenario which is an extension of the existing trends of brick production. The study extends to calculate mitigation cost per tonne of CO_2 eq. avoided using cost-effective analysis for which costs are assumed from the surveys performed.

Under brick productions, the major mitigations are a result of technology change from clamps to VSBK, and from fired bricks to non-fired bricks. The least polluting bricks are non-fired bricks, as the pollution from the same comes from energy use for the production process, which amounts to be almost null. On the other hand, the costliest technology is VSBK, due to higher capital cost requirements. Currently, promulgated policies advocate to use fired bricks manufactured from high-efficiency path such as zigzag firing and VSBK; however, the share of fired bricks in the market would remain higher at a total of 70 and 55% in 2030 and 2050, respectively. The prospective policies are expected to promote use of non-fired bricks with a total share of 40% in 2030 and 70% share in 2050. The resulting mitigation potentials are two times compared to S2 in 2030 and 2.5 times in 2050.

An economic analysis using CEA tool has been used to compare the mitigation costs for each scenario. As mentioned earlier, VSBK is the costliest technology amongst all; the overall mitigation cost under S3 is highest at 59 Rs./tonne CO_2 eq. in the short run (2030). The mitigation cost in 2050 reduces to −338 Rs./tonne CO_2 eq. due to proposed increase in non-fired bricks. On the other hand, S2 leads to negative costs due to lower investment requirement with reduced number of blocks required at −479 Rs./tonne CO_2 eq. and −383 Rs./tonne CO_2 eq. in 2030 and 2050, respectively.

From the above discussion, it is evident that in the long run, non-fired bricks are environmentally and economically friendly. However, promoting VSBK as an emission friendly option may not have economically sound effect on the country. The current directive by CPCB suggests that any brick kilns producing bricks using clamps or fixed chimney BTK has to convert the kiln into a natural draft zigzag kiln (CPCB 2017). The study presented here advocates in the short-term to continue with the zigzag firing technology and aim to slowly move towards the non-fired bricks as it is financially more viable. However, there is no substitute for non-fired bricks and must be promoted in the short as well as long run. Similarly, a policy should be designed that reaps maximum benefits by putting in short-term cost of 59 Rs./tonne CO_2 eq. with the potential reductions of 555 GT CO_2 eq. by 2030 by moving away from BTK and clamps. Whereas in the long term, non-fired bricks along with no dependence on clamps and BTK by 2050 should be promoted costing −338 Rs./tonne CO_2 eq. to mitigate 1345 GT CO_2 eq.

References

Antimiani A, Costantini V, Paglialunga E (2015) The sensitivity of climate-economy CGE models to energy-related elasticity parameters: implications for climate policy design. Econ Model 51:38–52. https://doi.org/10.1016/j.econmod.2015.07.015

Bhushan C, Basu D, Kumar Yadav N, Kumar R (2016) National brick mission—a scoping paper. Cent Sci Environ New Delhi:1–28

Busby JW, Shidore S (2017) When decarbonization meets development: the sectoral feasibility of greenhouse gas mitigation in India. Energy Res Soc Sci 23:60–73. https://doi.org/10.1016/j.erss.2016.11.011

CCAC (2015) 5-year strategic plan (2020)

CPCB (2017) Directions of Air (Prevention and Control of Pollution) Act, 1981 for brick kilns

Farmer K, Steininger KW (1999) Reducing CO2-emissions under fiscal retrenchment: a multi-cohort CGE-model for Austria. Environ Resour Econ 13:309–340. https://doi.org/10.1023/A:1008243611666

Kumar S, Maithel S (2016) Introduction to brick kilns & specific energy consumption protocol for brick kilns. https://breathelife2030.org/wp-content/uploads/2016/09/12.pdf

Lalchandani D, Mithel S (2013) Towards cleaner brick kilns in India

Li W, Jia Z (2016) The impact of emission trading scheme and the ratio of free quota: a dynamic recursive CGE model in China. Appl Energy 174:1–14. https://doi.org/10.1016/j.apenergy.2016.04.086

Maithel S (2003) Energy utilisation in brick kilns

Mass R, Grennfelt P (2016) Towards cleaner air. Scientific Assessment Report 2016

McKinsey (2009) Pathways to a low-carbon economy: Version 2 of the global greenhouse gas abatement cost curve

Ministry of Environment Forest and Climate Change Government of India (1986) The environment (protection) rules, 1986

Ministry of Environment Forest and Climate Change Government of India (2015) India first biennial update report to the United Nations framework convention on climate change

Myhre G, Shindell D, Bréon F-M et al (2013) Anthropogenic and natural radiative forcing. Clim Change 2

Rajarathnam U, Athalye V, Ragavan S et al (2014) Assessment of air pollutant emissions from brick kilns. Atmos Environ 98:549–553. https://doi.org/10.1016/j.atmosenv.2014.08.075

Ramanathan R, Parikh JK (1999) Transport sector in India: an analysis in the context of sustainable development. Transp Policy 6:35–45. https://doi.org/10.1016/S0967-070X(98)00030-4

Reddy MS, Venkataraman C (2002) Inventory of aerosol and sulphur dioxide emissions from India: I—fossil fuel combustion. Atmos Environ 36:677–697. https://doi.org/10.1016/S1352-2310(01)00463-0

Sadavarte P, Venkataraman C (2014) Trends in multi-pollutant emissions from a technology-linked inventory for India: I. Industry and transport sectors. Atmos Environ 99:353–364. https://doi.org/10.1016/j.atmosenv.2014.09.081

Sulukan E, Sağlam M, Uyar TS, Kirlidoğ M (2010) Determining optimum energy strategies for Turkey by MARKAL model. J Nav Sci Eng 6:27–38

UNEP (2014) The emissions gap report 2014: a UNEP synthesis report

USEPA (2012) Report to congress on black carbon

Valdés HM (2016) CCAC annual report 2015–16

Venkataraman C, Sagar AD, Habib G et al (2010) The Indian national initiative for advanced biomass cookstoves: the benefits of clean combustion. Energy Sustain Dev 14:63–72. https://doi.org/10.1016/j.esd.2010.04.005

Venkataraman C, Ghosh S, Kandlikar M (2016) Breaking out of the box: India and climate action on short-lived climate pollutants. Environ Sci Technol 50:12527–12529. https://doi.org/10.1021/acs.est.6b05246

Venkataraman C, Brauer M, Tibrewal K et al (2017) Source influence on emission pathways and ambient PM2.5 pollution over India (2015–2050). Atmos Chem Phys. https://doi.org/10.5194/acp-2017-1114

Victor DG, Zaelke D, Ramanathan V (2015) Soot and short-lived pollutants provide political opportunity, pp 1–3

Wen Z, Meng F, Chen M (2014) Estimates of the potential for energy conservation and CO_2 emissions mitigation based on Asian-Pacific integrated model (AIM): the case of the iron and steel industry in China. J Clean Prod 65:120–130. https://doi.org/10.1016/j.jclepro.2013.09.008

Weyant C et al. (2014) Emissions from South Asian brick production. Envir sci tech 48(11):6477–6483

Xu Y, Masui T (2009) Local air pollutant emission reduction and ancillary carbon benefits of SO_2 control policies: application of AIM/CGE model to China. Eur J Oper Res 198:315–325. https://doi.org/10.1016/j.ejor.2008.07.048