CHARITY ENTREPRENEURSHIP

Reducing Air Pollution by Improving Brick Kiln Energy Efficiency

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RECOMMENDED

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Ambitious Impact Research Report

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Ambitious Impact (AIM) *exists to enable more effective charities to exist worldwide. We strive to achieve this goal through our extensive research process and Incubator Program. We give talented potential entrepreneurs two months of cost-covered, intensive training designed by founders for founders. Our talented researchers and entrepreneurs identify evidence-based, high-impact interventions and help founders find a co-founder to launch the idea and reach scale.*

Note to readers: *Our research is geared toward AIM decision-makers and program participants. We attempt to find the best ideas for our incubation programs through these reports. Given our commitment to focusing on recommended ideas, reports on those not recommended for incubation can often be less polished.*

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Reducing Air Pollution by Improving Brick Kiln Energy Efficiency / Summary

Description

Artisanal brick kilns in South Asia are a major source of air pollution in the region, causing an estimated 60,000 premature deaths every year. To address the problem, multiple governments have pushed for a transition to less polluting so-called ‘zigzag’ kilns. While these physical conversions are underway, many kilns don’t follow the best operational practices, so emissions remain high. This charity would train brick kiln owners and workers to adopt a set of practices that, if correctly implemented, can reduce both particulate emissions and greenhouse gas emissions by about 20%.

Counterfactual impact

Cost-effectiveness analysis: We estimate that the intervention can avert one disability-adjusted life year (DALY) for $150–320 and avert one ton of carbon dioxide equivalent (tCO_2e) greenhouse gases (GHGs) for $1.50–2.10. While the health cost-effectiveness is mostly below AIM’s usual bar, the GHG cost-effectiveness makes this idea among the most cost-effective climate-oriented ideas globally. Overall, this makes the charity worth launching.

Scale this charity could reach: There are over 100,000 traditional brick kilns in the South Asia region, many of which have been converted to the zigzag design. We estimate that, at scale, this charity could train 500-1000 kilns per year, averting 1,750–3,500 DALYs and 232,000–463,000 tCO_2e per year.

Potential for success

Robustness of evidence: The evidence that brick kilns generate pollution that affects health and climate is strong. The evidence that improved operational practices reduce pollution primarily relies on one (high-quality) randomized controlled trial, though there is a broader evidence base of observational and anecdotal evidence supporting the idea that operational practices affect emissions.

Theory of Change: Identify areas with zigzag kilns with poor operational practices → get kiln owners to agree to training → conduct training (and follow-up support) → best practices implemented → more energy efficiency & better combustion → lower fuel use → lower emissions → health and climate benefits. Kiln owners are very likely to financially profit from this intervention, increasing our confidence in the uptake of these practices.

Neglectedness

Neglectedness: This intervention is being scaled in Bangladesh by the NGO icddr,b. In Pakistan, the International Centre for Integrated Mountain Development (ICIMOD) has developed training materials for the brick kiln sector and has extensively worked with the government to bring the sector to policy-level discourse; however, as a research organization, they have limited scaling plans for the delivery of training. The issue is much more neglected in India, and experts we spoke with all said there was space for another organization to focus on scaling up this kind of training.

Geographic assessment: We only considered India, Pakistan, Nepal, and Bangladesh, as these are the countries featuring this particular type of kiln. Four of our top five recommendations are Indian states, which receive comparatively less attention regarding training despite featuring a large burden. The other one is Punjab province, Pakistan. Nepal has a relatively minor burden, and Bangladesh is not as neglected.

Relevance

Strategic value to AIM: We see no special strategic value for AIM in this idea.

Fit for the CEIP: We expect this idea to be particularly attractive to founders who are keen to tackle one of the major sources of air pollution in a region that is badly affected by it. Brick kilns in the region often involve work that violates human rights, such as forced work or child labor; potential founders will have to be comfortable operating in such an environment. However, we expect some CEIP participants to be attracted to a topic that many other actors have shied away from but where they can achieve large counterfactual impact.

Other

Expert views: Experts agreed that there was space for an organization doing this work and that the intervention would be valuable. They cautioned that a new organization has to be aware of human rights violations at kilns and the challenge of gaining kiln owners' trust.

Implementation factors**:** Identifying kilns with suboptimal practices will likely require physical inspections. Engineering knowledge (among co-founders or early hires) will be useful for understanding local kiln-operation practices and designing locally tailored training modules – as well as for building credibility and trust with kiln owners. Kiln owners' associations can be helpful in making connections to skeptical kiln owners.

Reducing Air Pollution by Improving Brick Kiln Energy Efficiency / Crucial Considerations

Are there sufficient numbers of poorly operated zigzag kilns?

This intervention only works if the physical infrastructure exists simultaneously with opportunities for improvement via training. We are nearly certain that there are enough zigzag kilns in the countries we considered. It is likely that a significant proportion of them are operated in a way that can be improved and result in meaningful emission reductions.

Will zigzag kilns be around long enough for us to make an impact, or will market forces supplant them anyway?

It is nearly certain that zigzag kilns will stay relevant for at least another decade. Market incentives encourage buyers of bricks and brick kiln owners to persevere with traditionally-fired methods. Prior efforts to switch to more modern kiln types have failed, partially due to the high capital requirements. This assessment is backed by experts we interviewed.

Will there be a rebound effect?

If our training successfully reduces the amount of coal needed for each firing, these savings might enable producers to increase the number of production runs and offset some of the reductions in emissions. Our sense is that this rebound effect is likely real but small in magnitude (maybe ~10% of the effect size), as brick kilns have a hard limit on the number of production runs in any given year, and demand for bricks is not very responsive ('elastic') to their price.

Will rights issues turn away funders and/or other organizations?

Brick kilns are notorious for exploitative labor practices, ranging from unsafe work environments to indentured servitude and child labor. This factor will likely make receiving funding and/or cooperation from some actors more challenging.

How much will the training cost the charity, per kiln?

Our estimate of the variable cost of delivering the training is based on the costs observed by Brooks et al. (2025), reduced by 20%. However, some past AIM-incubated charities managed to reduce costs by more than 50% compared to prior actors. As such, we may be underestimating the potential cost-effectiveness of this charity. Moreover, given how profitable this training is for kiln owners, we suspect that the charity may be able to charge a fee for the training, thereby partly or fully offsetting its costs. However, this is currently an untested hypothesis.

How significant is the warming/cooling effect of reducing black carbon and sulfur dioxide emissions?

Aside from carbon dioxide, brick kilns emit other pollutants, including black carbon (BC) and sulfur dioxide (SO_2). BC is a strong GHG, though it only stays in the atmosphere for days to weeks. SO_2 has the opposite effect to GHGs, cooling down the atmosphere; though it too is very short-lived. We have significant uncertainty about the extent to which our training intervention will reduce BC emissions. Moreover, the climate effects of BC and SO_2 are uncertain and actively debated. Under our current estimates, it is likely that this intervention will cause temporary (<1 year) *warming*, followed by a long-term cooling effect on the climate. However, the exact extent and duration of these short-term effects are highly uncertain.

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1 Background

1.1 Context

Ambitious Impact (AIM) exists to increase the number and quality of effective nonprofits working to improve human and animal well-being. AIM connects talented individuals with high-impact ideas. We give potential entrepreneurs intensive training and ongoing support to launch ideas to scale. Our research team focuses on finding impactful opportunities.

As part of our 2025 research agenda, we reviewed interventions that have climate and human well-being co-benefits. In that context, we researched the benefits of training brick kiln workers on more efficient operational practices. This report provides an overview of our findings.

1.2 Air pollution from traditional brick kilns

Brick kilns are a type of oven used to bake or burn bricks.[1] They substantially contribute to emissions and air pollution in South Asia, the region with the worst air quality in the world. In the so-called "brick belt"—stretching across parts of Bangladesh, India, Nepal, and Pakistan—tens of thousands of open-air kilns operate during the dry season, producing hundreds of billions of bricks annually (Eil et al., 2020).

[1] The process begins with clay, often stripped from fertile topsoil, which is shaped and dried in the sun. Workers stack the dried bricks in kilns, where they are baked using coal or other fuels in a highly polluting process.

Figure 1: A zigzag kiln in operation. Bricks are covered with a layer of ash, and workers feed coal from above (Maithel et al., 2014b, p.9).

This process is highly polluting. Kilns emit large quantities of CO_2, carbon monoxide, and fine particulate matter, including black carbon.[2] Through these many emissions, kilns contribute to global warming and human health problems. Kilns have been estimated to represent 6% of India's CO_2 emissions, and more than a third of Nepal's (Eil et al. 2020, p.62).

Fine particulate matter, known as $PM_{2.5}$ particles (i.e., particles of 2.5 micrometers or smaller), **causes various health problems when inhaled.** It can penetrate deep into the lungs, enter the bloodstream, and reach the heart, the brain, and other organs. It has been linked to increased rates of respiratory illnesses, heart disease, and neurological conditions (Health Effects Institute, 2023). In South Asia, particulate air pollution is estimated to reduce average life expectancy by nearly six years (Lee & Greenstone, 2021). Because brick kilns are often spatially concentrated near population centers, they have an outsized effect on pollution in towns.

[2] Black carbon is essentially soot. Since it absorbs sunlight, it has an extremely high Global-Warming Potential (GWP), with one 1 kg of black carbon having an equivalent GWP to around 460kg of CO_2 (ICCT 2009, p.7). Its environmental impact may be especially severe in South Asia, as some of it may be carried to the Himalayas, settling on and melting the snow.

Efforts to date

To address this problem, governments and international agencies have promoted cleaner kiln designs for over a decade. Specifically, traditional fixed chimney (Bull's trench) kilns have been retrofitted to zigzag kilns. These physical changes result in an altered overall shape of the kiln, from oval to rectangular, making it possible to detect and validate which kilns have been retrofitted (Maithel et al., 2014). These changes have resulted in reduced emissions (Maithel et al., 2014).

We considered recommending an initiative to assist with the physical upgrades, but discarded this idea because the transformation is already well underway. For instance, in the "brick belt" states of India, at least 73% of kilns already have the zigzag design (94% in Haryana, 88% in Punjab, 83% in Bihar, 71% in West Bengal, and 55% in Uttar Pradesh; Mondal et al., 2024). In several nations and sub-national regions, laws have mandated a switch to zigzag kilns.[3]

However, much of the potential reduction in emissions depends on changes in operation. In a zigzag kiln, the bricks should be stacked so air can flow in a zig-zag pattern, increasing airflow and improving combustion. If fuel is fed continuously, combustion efficiency is further improved (Brooks et al., 2025, p.2). A properly operating zigzag kiln with a fan can emit 20% less CO_2 and 80% fewer $PM_{2.5}$ particles[4] (Maithel et al., 2014).

While progress is being made with physical upgrades, operational best practices are still inconsistently adhered to. In a pilot study of almost 30 kilns in Bangladesh, Brooks et al. (2024) found that very few kilns were following the two key practices that reduce emissions: improved zigzag stacking and continuous fuel

[3] A non-exhaustive list includes national policy in India and Nepal, as well as Punjab province in Pakistan (which is home to most kilns in the country).
[4] For an illustration of how a zigzag kiln works, see this video.

feeding.[5] An expert on the topic estimated that, in India, at least half of the zigzag kilns in the brick belt do not follow best practices (Sameer Maithel interview).

This report therefore explores the idea of launching a new charity that would train the owners, operators, and workers of zigzag brick kilns on adopting less polluting, energy-efficient operational practices. It closely follows the intervention tested in a randomized controlled trial (RCT) by Brooks et al. (2025), which increased the adoption of these practices in Bangladesh by 65 percentage points. Kilns that adopted improved zigzag stacking and continuous rather than intermittent feeding of coal—both of which improve combustion—significantly reduced their emissions (by up to 20%) of greenhouse gases and harmful $PM_{2.5}$ particles.

[5] These are only two possible improvements out of many. Brooks et al. (2025) suggested increasing heat retention by spreading a thicker layer of ash on top of the kiln and sealing access points more thoroughly, and encouraging combustion by using powdered biomass as fuel to encourage full combustion in the early stages of firing. While most kilns in the study did not implement these techniques, there are clearly many avenues for emissions reductions. The study team is coming up with even more improvements (Stephen Luby interview): an organization that is flexible, technically adept, and able to address the issues of a given kiln is likely to find a way to improve its efficiency.

2 Theories of change

2.1 Barriers

Before turning to the theory of change (ToC) of this charity, we explore the barriers to success that this new charity may face. The main barriers we have identified to training kiln owners and workers on improved practices are:

- **Information**: This charity's key activity will be identifying kilns that could benefit from operational improvements. This information can only be gathered on the ground; owners' associations might provide some support, but ultimately, it will require the difficult (and potentially expensive) work of visiting kilns individually.
- **Kiln owner cooperation:** The industry is informal, often breaking the law, and owners are wary of outsiders. Every expert we interviewed stressed that this would be a key challenge to overcome. Kiln owners are conservative about adopting new practices. A new organization must convincingly demonstrate that these changes will benefit owners.
- **Worker retention and turnover**: Many kiln workers are seasonal migrants, so there is significant turnover. This could mean a return to previous inefficient practices. However, the charity should be able to limit this risk by training the owners and supervisors in addition to the workers. While workers often change, supervisors are typically locals and do not turn over (Sameer Maithel interview). These supervisors can then train the future batches of temporary workers. The fact that Brooks et al. (2025) did not find evidence of a return to previous practices makes us optimistic that this barrier is surmountable.
- **Uncertain policy environment:** Governments in the region know that brick kilns are a key source of pollution. They have targeted them with extensive policies, including bans on Bull's type fixed chimney kilns. Since there are

less polluting ways of making bricks than in zigzag kilns,[6] governments could enact policies that only allow those. In most places, this issue has no clear institutional ‘owner’. This makes it more difficult to gather support for interventions like the one proposed here.

2.2 Theory of change of this charity

We decided to focus on the ToC depicted in Figure 2. The charity will begin by identifying geographic regions with high potential for the intervention. Working with local associations and other contacts, they will assess the extent of compliance with best practices, pilot an improvement program, and then train kiln owners and employees. If adopted, these best practices will significantly reduce coal usage and improve combustion efficiency, reducing CO_2 and particulate matter emissions.

[6] One example are fly ash bricks, which are bricks made of *fly ash*, a byproduct of coal combustion in thermal power plants (as opposed to clay). The emissions associated with using these bricks may be nearly an order of magnitude lower than emissions associated with clay bricks (Singh et al., 2024).

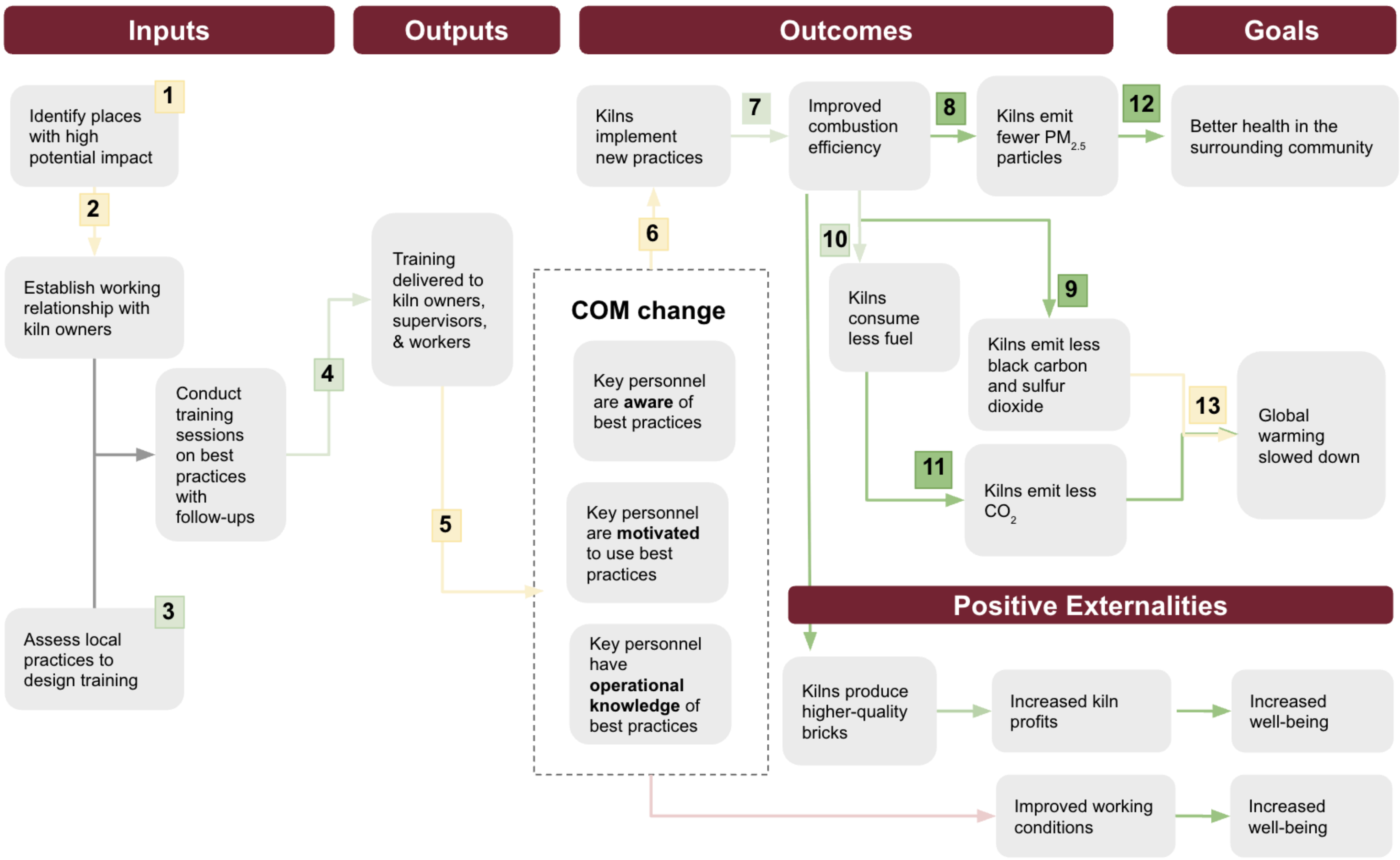

Figure 2: The theory of change of this charity. COM refers to capability, opportunity, and motivation, following the COM-B model.

2.3 Assumptions and key factors

Each step in the ToC is associated with one or more assumptions that must be satisfied for the causal relationship to hold. Below, we list these assumptions, highlighting them based on our assessed level of confidence:[7]

1. The charity can identify geographic locations with many zigzag kilns and widespread improper usage.
2. The charity can recruit kiln owners to participate in training (and make their employees available)
3. The charity can assess local conditions and design a training tailored to the context.
4. The charity can conduct training sessions and do follow-ups on-site at the kilns.
5. Training sessions are effective: key personnel are aware of best practices, have operational knowledge of how to implement them, and are motivated to do so.
6. Kilns implement the newly learned practices
7. Kilns that adopt the new practices have improved combustion efficiency
8. Kilns with improved combustion efficiency emit fewer $PM_{2.5}$ particles
9. Kilns with improved combustion efficiency emit less black carbon
10. Kilns that adopt the best practices have lower fuel consumption
11. Improved combustion efficiency and lower fuel consumption lead to a reduction in CO_2
12. Reduced $PM_{2.5}$ pollution improves the health of the surrounding community
13. Reduced CO_2, black carbon, and sulfur dioxide emissions overall result in a slowing down of global warming

We present the evidence for each step of the theory of change in more detail in Section 3.

[7] Very high confidence (>85%),High confidence (65–85%), Medium confidence (35–65%), Low confidence (15–35%), Very low confidence (<15%)

2.4 Additional theories of change

This charity would not have to restrict itself to teaching the twin improvements of continuous feeding and improved zigzag stacking. Indeed, Brooks et al. (2025) taught five interventions. While only continuous feeding and improved stacking found significant uptake in their context, it may be possible to increase their uptake in other contexts or via differently-designed training modules.

The authors of the study told us that the original team is developing more operational improvements. A charity with engineering expertise could follow new developments and develop an evolving arsenal of techniques that can be adapted to kiln owners' needs—while most kilns in the original study focused on techniques that improve combustion, a different area might adopt techniques that focus on insulation, for example.

It may be possible for the charity to spread beyond technical interventions and also address social components. Stephen Luby's team has found evidence that an information intervention that taught kiln owners about positively incentivizing their workers may have reduced the rates of child labor by 8.5pp (from a 30% baseline)—though there is some risk of bias in this result due to the outcome being survey-based (Miller et al., 2024).

Other potential improvements to the impacts of kilns include cleaner fuel sources (such as buying fuel made from crop stubble, preventing farmers from harmful burning), **and shifting to clay sources that do not involve scraping off fertile topsoil,** which leaves the land depleted and reduces agricultural yields (Nath et al., 2018).

Lastly, collaborating and aligning with governments may increase the likelihood of success and speed up scaling. For instance, the government of Bihar has mandated the use of cleaner bricks for government construction (Issar, 2018)[8]. If the charity training aligns with the government procurement standards, kiln owners will likely be more incentivized to adopt the new practices. Some states are also

[8] However, there are also reasons to believe that government would not be interested in collaborating: In Bihar, brick kilns have been completely banned (although the ban is scarcely enforced), making the brick kiln industry illegal. The government is unlikely to want to enage with an industry that it has been *de jure* banned.

considering mandating straw-based biomass as fuel for brick kilns to tackle air pollution associated with stubble burning (Nibber, 2025). Governments of multiple states have also mandated physical upgrades of kilns from FCBTK to the zigzag type, and some have partnered with non-profits[9] to deliver worker training, indicating their interest in this topic (Gupta et al., 2024; Mishra, 2024). Working with governments to implement these policies could therefore substantially increase the impact of this charity.

[9] Including Greentech Knowledge Solutions, of which our interviewee Sameer Maithel used to be a director.

3 Quality of evidence

The intervention is substantially based on two papers by the same authors. The studies are high-quality, and the mechanism of change is convincing. The most difficult (but not insurmountable) part lies in convincing kiln owners to participate in training sessions and implement the new practices.

3.1 Evidence that a charity can effect change in this space

We believe it is likely that the charity will be able to identify zigzag kilns with suboptimal operational practices. However, convincing kiln owners to participate in training and implement the new practices may be challenging.

Identifying geographic locations with many kilns operated suboptimally and designing training targeted to their needs

It is certain that there are a large number of operational zigzag kilns in the countries under consideration, and that a new charity could locate them. Past authors have been able to train machine learning models on satellite imagery data to identify and count zigzag kilns in India, Bangladesh, and Pakistan. These studies can form a starting point for the charity.[10]

It is highly probable that there are widespread poor practices in operating the kilns that a new charity could address. The current state of practices is impossible to establish with desk research, as no comprehensive studies or datasets capture this information. However, our interviews with experts in this space make us confident that a large percentage of kilns across the priority regions—possibly around 50%—are not following the best practices (Sameer Maithel interview).

[10] In all cases, papers describe the methodology and make code/models available. The paper on Pakistan even includes downloadable files with the exact location of all identified kilns.

To identify kilns that may benefit from the intervention, the charity will likely have to survey kiln owners and perhaps even personally inspect their practices (Sameer Maithel interview). In some places, local bricklayers' associations may be able to provide this information on their members. For instance, in Pakistan, International Centre for Integrated Mountain Development (ICIMOD) was able to report on district-level amounts and conversions to zigzag kilns thanks to information provided by the Brick Kiln Owners' Association of Pakistan (Shah et al., 2022, p.12).

Convincing kiln owners to participate in the training

A charity can likely convince kiln owners to participate in the training. Associations of brick kiln owners exist in all countries under review and tend to be active with training offerings. We are optimistic because implementing these practices is in the economic self-interest of the kiln owners: more efficient combustion leads to a higher proportion of higher-grade bricks, and to lower costs (Brooks et al., 2024). Indeed, out of 294 kilns that met eligibility criteria in the Brooks et al. (2025) study, only three refused participation and 18 dropped out. Additionally, a significant proportion of owners in the control condition sought information about new techniques despite not receiving it from the study team.

This buy-in, however, will not be automatic. As highlighted in our expert interviews, kiln owners tend to distrust people who do not speak their language, understand the industry, and are not confident in their understanding of the engineering aspects of kiln design and operation. For example, the program teams of professors Stephen Luby and Nina Brooks (authors of Brooks et al., 2025) included anthropologists and engineers. While no highly specialist knowledge or advanced degrees are needed, it may be necessary for the charity to have capable, well-trained local hires.

The training results in kiln owners shifting their practices

We think there is a roughly even chance that owners will shift their practices. In their study in Bangladesh, Brooks et al. (2025) report highly encouraging results: In the 2022–2023 firing season, the authors randomly assigned 276 kilns to the control group or one of two interventions. Both intervention groups taught the same five operational improvements[11] but one of them additionally provided information on the business benefits for improving worker conditions. Both intervention arms showed high rates of adoption of two of the taught practices—continuous fuel feeding and improved zigzag stacking—with around two-thirds of kilns adopting them.

These effects did not weaken afterwards: at follow-up in the following year, the percentage of kilns using proper techniques had increased to almost three-quarters. Even more encouraging is that several kilns in the control condition also switched practices and, by the second year, 56% of those who did not receive the training were using the improved methods (Brooks et al., 2025, p.3). The authors believe that this resulted from non-trained kilns adopting these practices from nearby trained kilns—a conclusion supported by the authors' analysis showing the proximity to intervention kilns was the most important predictor of spillovers (Nina Brooks interview). This could have resulted from non-trained kilns adopting these practices from nearby trained kilns. This reflects the fact that the intervention is in the best interest of the kiln owners, who are highly motivated to improve their methods. This logic makes us optimistic about the ability of the study to generalize to other areas. However, a pessimistic interpretation of these results would be that these changes were happening anyway and that the control group caught up due to counterfactual trends (which the authors could not observe).

The study conducted by Brooks and her coauthors substantially informed this report. The study, therefore, acts as a point of failure—if the study is incorrect, so may be our conclusions. However, we believe the study to be of high quality: it is an RCT, it is pre-registered, and it contains an extensive documentation of methods (analytical and on-the-ground) in its supplementary materials. In addition, it is based on careful groundwork. The intervention had been tested in a prior pilot

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[11] These were: continuous fuel feeding, (b) improved zigzag brick stacking (with two air paths rather than one), (c) a thicker ash layer top of the kiln to improve insulation, (d) closing the kiln gate with a cavity wall to improve insulation, and (e) complementary use of powdered biomass fuel.

RCT of 30 kilns (Brooks et al., 2024), following extensive engagements with kiln owners to understand what approach would be persuasive.

Kilns that adopt improved methods will have improved combustion efficiency

The improved operational methods taught by this charity are very likely to improve combustion efficiency.

1. Continuous fuel feeding: The ratio of air to fuel is the most important factor in combustion.[12] If large amounts of fuel are deposited simultaneously by multiple workers, there may not be enough air to efficiently combust the fuel. If, instead, a single worker feeds the fuel continuously (and more slowly), combustion efficiency increases (Brooks et al., 2025).

2. Improved zigzag stacking: A zigzag pattern has an air path about three times as long as a traditional 'straight line stack' (Adhikari and Pradhan, 2023). Such stacking results in better distribution of the hot air in the kiln, which improves the combustion of fuel (Brooks et al., 2025). The improved zigzag pattern further improves this by creating two or three different pathways for the air to travel through the brick stack. On top of higher combustion efficiency, this results in a more uniform heat distribution in the kiln and, consequently, higher brick quality (Brooks et al., 2025).

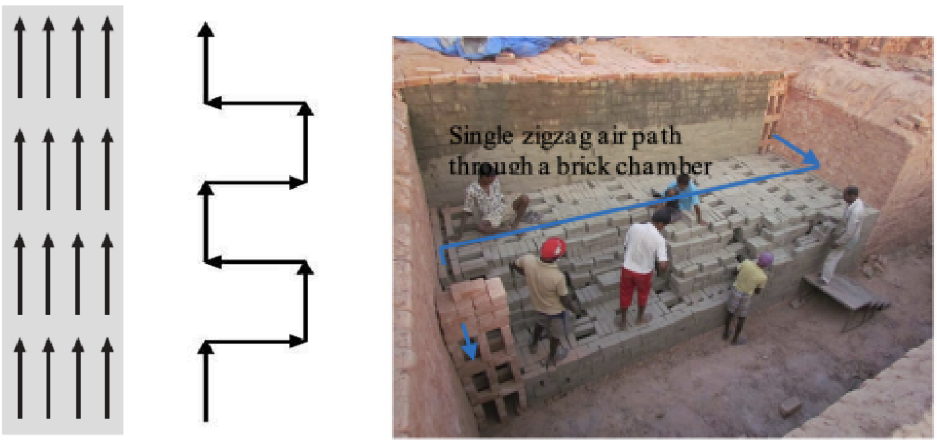

Figure 3: Left: straight vs zigzag air path. Right: Regular zigzag stacking, with one air path through the bricks (Brooks et al., 2025b).

[12] 1kg of coal needs 5-10kg of air to combust completely (Adhikari and Pradhan, 2023)

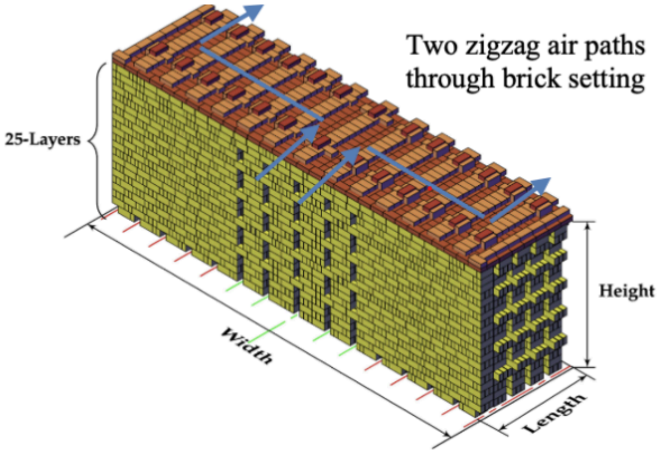

Figure 4: Improved zigzag stacking, with two paths for the air (Brooks et al., 2025b).

Kilns that adopt improved methods will have reduced fuel consumption.

Improved methods are highly likely to reduce fuel consumption. Improved zigzag stacking and continuous fuel firing are quite clearly linked to lower fuel *per run* due to the improvements to combustion noted above. Brooks et al. (2025) estimate that kilns in their study that adopted continuous firing and improved zigzag stacking reduced their fuel usage by around 25% (Table S18 of the paper).

Producers may react to the savings from lower fuel costs by producing more—a so-called "rebound effect". Such an effect could offset some of the benefits from the intervention. **We think that if there is a rebound effect, it is likely to be small in magnitude.** In the Bangladesh RCT, Brooks et al. found that kilns that adopted the improved practices, despite savings on fuel, did not engage in additional production runs (Brooks et al., 2025, p.4). However, since kiln owners purchase their clay supply in advance of a season, they may not have been able to react to reduced fuel expenses quickly enough for the rebound effect to be observable within the timeline of the study, and there is a possibility that a rebound effect may take place in subsequent years.

Despite this, there are more reasons to believe rebound effects might be limited: In practice, the number of production runs is limited by the weather, as these kilns only operate in the dry season. So, a natural limit exists to how many bricks a kiln can produce. In addition, demand for bricks is the primary driver of brick production, rather than kilns' ability to supply them. Recently, for example, there has been a low demand in many areas, which means kiln owners are not even at full capacity (interviews with Stephen Luby and Sameer Maithel). While a decrease in the cost of brick production could lowerthe price of bricks, potentially increasing demand for them, demand for bricks has relatively low price elasticity, so we expect this effect to be small.

Our best guess is that the rebound effect will reduce the intervention's effect size by 5–10%.

3.2 Evidence that the change has the expected effects

The mechanism behind reductions in greenhouse gases is clear and convincing — more efficient combustion leads to lower fuel usage and directly reduces the amount of $PM_{2.5}$ particles and black carbon emitted.

Reduced $PM_{2.5}$ emissions

We are highly confident that adoption of the target practices reduces $PM_{2.5}$ emissions. As noted above, the target practices improve combustion by improving airflow and the air/fuel ratio in the kiln. If there is not enough air, carbon does not combine with oxygen to create CO_2, but rather forms tiny particles, many of which are in the $PM_{2.5}$ range.

Brooks et al. (2025) estimate a 9% reduction among kilns that participated in the training (0.45 tons/kiln), and a 20% reduction among those that implemented the practices.

In addition, by reducing the use of coal, this intervention will reduce the emissions of sulfur dioxide (SO_2), which is an important source of $PM_{2.5}$. Coal typically contains a certain percentage of sulfur, which, when burned, turns into SO_2. This SO_2 (which is a gas) can then chemically react in the atmosphere to form so-called secondary $PM_{2.5}$ (i.e., PM pollution that is formed in the atmosphere rather than directly emitted; Van Zelm et al.,2021). This makes SO_2 emissions reduction an additional pathway through which increasing kilns' energy efficiency has a positive impact on health.

Improved combustion and reduced fuel usage reduce the emissions of CO_2, SO_2, and black carbon

Brick kilns have high energy requirements and most of this energy typically comes from burning coal in our target geographies. In India, the industry's energy consumption is comparable to that in the steel and cement industries in the country and 68% of fuel for brick kilns comes from coal (Tibrewal et al., 2023).[13]

Carbon dioxide (CO_2)

The brick industry is estimated to account for 3%–6% of CO_2 emissions in India, 3–7% in Nepal, and around 10% in Bangladesh (Eil et al., 2020; Shukla et al., 2023; Mondal et al., 2024). In their Bangladesh RCT, Brooks et al. (2025) estimated a 9% reduction in CO_2 emitted by kilns due to their intervention. Using an instrumental variable approach,[14] they estimate that kilns adopting the target practices reduced their CO_2 emissions by 20%. In our model, we use the intention-to-treat estimate of a 9% reduction, or 171 tons per kiln per year.

Black carbon

Coal burned with *insufficient* oxygen does not form CO_2. Instead, the process creates elemental carbon particles, carbon monoxide, and various hydrocarbon compounds. The carbon particles cluster together to form the dark, fine

[13] "With the revised estimate, the energy consumption of the brick sector (990 PJ yr^{-1}) is comparable to that of other formal construction sectors such as cement (~550 PJ yr^{-1}) and steel (~1,400 PJ yr^{-1})"

[14] An instrumental-variable (IV) analysis is a technique that allows estimating the effect of the treatment on those who actually took up the target practices as a result of the training. This contrasts with the intention-to-treat (ITT) estimate of the intervention, which is based on comparing average adoption rates in the treatment and control arms. Given that only around two-thirds of kilns in the treatment group adopted the target practices – and that some kilns in the control group also adopted these practices due to spillovers – the ITT estimate is much smaller than the IV estimate.

particulate matter called black carbon, or soot. Black carbon significantly contributes to global warming because the dark particles absorb sunlight (Center for Climate and Energy Solutions, 2010). While black carbon only stays in the atmosphere for about one week, its global warming potential[15] is 460 times higher than that of CO_2 over a 100-year period and 1600 times higher over a 20-year period (ICCT 2009, p.5-7).

The brick kiln industry is a significant source of black carbon emissions. In India, Bangladesh, and Nepal, it is responsible for 16%, 22%, and 6% of black carbon emissions, respectively (Eil et al., 2020, p.75).

In their RCT, Brooks et al. (2025) did not explicitly test whether black carbon emissions decreased.[16] However, we have reason to believe that they should. The main interventions promoted by the study team—continuous fuel and proper stacking—ensure that coal has enough air and therefore combusts better (Brooks et al., 2025, p.2). The difference between a traditional Bull's trench fixed chimney kiln and a well-operating zigzag kiln is striking: sources estimate a reduction in black carbon emissions of 90% (Maithel et al., 2014b; Ahmad et al., 2022). Our intervention would target kilns that have already completed the physical transformation to zigzag kilns, so reductions will likely be lower. However, black carbon production is driven by imperfect combustion, which will still occur without the proper practices that the training intervention teaches. Our best estimate is that the training reduces black carbon emissions by 36 kg per kiln per year—equivalent to 17 tons of CO_2 in terms of its 100-year global warming potential.

Sulfur dioxide (SO_2)

As noted in the previous section, coal contains sulfur and coal burning generates SO_2 emissions. By reducing fuel use, we expect SO_2 emissions to go

[15] The global warming potential (GWP) is a measure of how much heat a greenhouse gas traps in the atmosphere over a specific period compared to carbon dioxide (CO_2). It helps quantify the long-term impact of different gases on global warming. For example, methane has a GWP-20 of 81, meaning it is 25 times more potent than CO_2 in trapping heat over a 20-year period. It's GWP-100 is 28, which means that, over a 100-year period, a kilogram of methane is 28 times more potent at trapping heat than a kilogram of CO_2 (Smith et al., 2021).

[16] Black Carbon is a component of $PM_{2.5}$ pollution, which they did measure, and which decreased.

down. While Brooks et al. (2025) didn't directly measure SO_2 emissions, we expect them to reduce in line with the reduction of fuel use, i.e., by 11.5%.

The effect on SO_2 emissions is an important consideration due to their cooling effect on the atmosphere. When emitted, SO_2 reacts with water vapour and oxidants to form sulfuric acid (H_2SO_4), which condenses to form sulfate (SO_4^{2-}) aerosols. Sulfate aerosols are highly reflective (i.e., they have a high albedo). SO_2 emissions, therefore, have a cooling effect, potentially "masking" some of the warming caused by GHG emissions. This effect has been particularly well-studied from large volcanic eruptions, which release large amounts of SO_2 into the stratosphere. For example, the 1991 eruption of Mount Pinatubo has been widely cited as the cause for a drop in global mean surface air temperatures of 0.5 degrees Celsius in the following 15 months (Parker et al., 1996, Earth Observatory, NASA, 2001).

Reducing SO_2 emissions may therefore have an associated warming effect. A modelling study estimates a global warming of 0.07 degrees Celsius +/- 0.05 in response to the reduction in SO_2 emissions observed in the past two decades in East Asia (Samset et al., 2025). We note the wide error bars and the lack of certainty in the wider academic literature on the potential warming effect of reduced SO_2 emissions, particularly in the lower troposphere[17] as opposed to the stratosphere (e.g., Max Planck Gesellschaft, 2013; Takemura, 2020; MIT Climate Portal, 2025). Nevertheless, we still consider this necessary to account for in our model.

Health improvements from reduced $PM_{2.5}$ emissions

We are nearly certain that reducing $PM_{2.5}$ pollution would improve health outcomes. A major report on air pollution states that "$PM_{2.5}$ air pollution is the largest driver of air pollution's disease burden worldwide. Long-term exposure to $PM_{2.5}$ pollution is associated with illness and early death from diseases, including

[17] The lower troposphere is the layer of the atmosphere that emissions from brick kilns will reach. They wll not reach the stratosphere unlike SO_2 emissions from erupting volcanoes. The climate forcing effects of SO_2 in the troposphere are less well studied or conclusive in the literature.

heart disease, lung cancer, COPD, stroke, type 2 diabetes, lower respiratory infections (such as pneumonia), and adverse birth outcomes" (Health Effects Institute, 2024, p.15). It reduces the global average life expectancy at birth by around a year globally and by almost six years in South Asia (Apte et al., 2018; Lee & Greenstone, 2021, p.3).

Depending on the source, estimates of brick kilns' contribution to $PM_{2.5}$ pollution are between 2% and 8% in India, 11% in Bangladesh, and 3% in Nepal (Open Philanthropy, 2021). This pollution is often highly geographically concentrated: around 58% of fine particles in Dhaka can be attributed to brick kilns (Department of Environment Bangladesh, 2019)

The World Bank estimates that the $PM_{2.5}$ emissions by the brick sector account for approximately 60,000 deaths in India, Bangladesh, and Nepal (Eil et al., 2020, p.68). A set of quasi-experimental studies have directly quantified the effect of kilns on health. In Bangladesh, Brooks et al. (2023) find that 2 km downwind from a brick kiln, $PM_{2.5}$ levels are 72.3 µg/m3 higher, and there are significantly higher odds of respiratory symptoms in adults and children.[18] A study in Pakistan suggests cognitive effects on children within 3km of a kiln (Nasir et al., 2021).

Reducing emissions from brick kilns slows down global warming

We are certain that reducing GHG emissions will slow down global warming in the long term, but we are less confident about the short-term effects (on the scale of around a year).

Brick kilns emit multiple different pollutants. Among these, three stand out for their potential to affect global warming: carbon dioxide (CO_2), black carbon (BC), and sulfur dioxide (SO_2). As discussed above, CO_2 is a weak but persistent greenhouse gas, which is emitted from brick kilns in large quantities; BC is a strong

[18] "2.2 (95% CI: 1.2, 4.3) greater odds of [chronic obstructive pulmonary disease] symptoms among adults over 40 and 4.2 (95% CI: 2.7, 6.8) greater odds of respiratory symptoms among adults over 18. Among children under 5, we found greater odds of respiratory symptoms (2.1, 95% CI: 0.7, 6.0) and asthma symptoms (2.5, 95% CI: 0.1, 96.1)" (Brooks et al. 2023, p.1)

but short-lived greenhouse gas emitted in smaller quantities; and SO_2 is a short-lived pollutant that has a cooling effect on the climate.

In the long term (ten+ years), the effect of CO_2 dominates, so reducing the emissions from brick kilns reduces the total GHG emissions and contributes to slowing down global warming.

However, on shorter timescales, BC and SO_2 become more important. As we discuss in Section 6.1.2, depending on the exact amounts of BC and SO_2 emitted (which can vary significantly between kilns) and on their global warming/cooling potential (which isn't known with high precision), the overall effect of reducing brick-kiln emissions on timescales of around one year is uncertain, and it may even be overall warming (i.e., speeding up global warming).

While we find this somewhat concerning, it doesn't change our overall view of this charity idea. Firstly, the direct health effect of reducing $PM_{2.5}$ (and SO_2) emissions is clearly positive. Secondly, the climate-warming effect of reducing SO_2 emissions is transient and very likely inevitable: We expect that, sooner or later, SO_2 emissions from the brick kiln sector in South Asia will be reduced (by training, kiln conversions, switching to non-coal fuel, etc.). As such, we expect (and model) this intervention as only "bringing forward" a change that would happen in the future anyway.

3.3 Evidence on externalities/second-order effects/potential harm

The primary goal of this charity is to reduce brick kilns' emissions. However, the kiln industry has other negative impacts. Brick kilns in South Asia are often sites of human rights violations and unsafe labor practices, and can feature animal abuse. They also contribute to environmental degradation and reduce agricultural yields by using fertile topsoil as a raw material. **While this charity will be *associated with* this industry, we are nearly certain that it will not *increase* these types of harm.**

A range of human rights violations take place at brick kilns in South Asia (US Department of Labor, 2024). The ILO estimates that up to two thirds of brick kiln workers in the region are in bonded and forced labor, with ties often spanning generations. Meanwhile, over two million children are employed in the industry (Mitra and Valette, 2017). Many workers are migrants who live near the kilns in inadequate shelter, without access to basic services such as water, electricity, or schooling for children. The work is also dangerous: workers work up to 16 hours per day in extreme heat and harmful emissions, with little to no protective equipment (Mitra and Valette, 2017; Maithel et al., 2014a).

There is little evidence of sustained improvements to working conditions as a result of energy-efficiency training interventions. Brooks et al. (2025) include one treatment arm in which trainers informed kiln owners that incentivizing workers can be profitable, in addition to owners receiving technical advice. The authors find no effect on any measures of well-being. A separate study analyzing the data in more detail found no evidence that improved efficiency due to technical changes reduced labor trafficking or child labor, but found addition of an information intervention reduced child labor by 25–30% (Miller et al., 2024). However, their measure is imperfect,[19] so we consider this evidence promising but inconclusive. The authors told us they are optimistic about a new approach they are piloting (Stephen Luby interview).

Experts are optimistic that kiln owners can be persuaded to improve practices once trust has been established by demonstrating value via technical improvements. Interviewees stressed that it was essential to address issues at kilns holistically, including environmental and labor issues, and expressed optimism that this would be possible.

[19] Specifically, they survey adult workers at kilns at ask them whether they had observed child labor.

4 Expert views

Experts were very encouraging of our idea, stressing the urgency of addressing pollution. All cautioned that kiln owners would be skeptical of outsiders, and many raised the issue of worker welfare.

As part of our investigation, we consulted six people who are familiar with this space:[20]

- Sameer Maithel, technical expert on brick kilns and co-author of the Brooks et al. (2025) study.
- Nina Brooks, Assistant Professor in the Department of Global Health at the Boston University School of Public Health.
- Stephen Luby, Professor in the Department of Medicine at Stanford University.
- Two interviews with experts who have worked on brick kiln training in South Asia (anonymized).

Our findings from these conversations have influenced our decision-making across the reporting. This section summarises the key findings from the consultations not mentioned elsewhere.

4.1 Neglectedness

All experts agreed there would be space for a new organization doing this work. Luby noted that, even if the knowledge does diffuse among kiln owners naturally,[21] it could take many years, making it preferable to actively tackle the issue now to prevent negative effects in the interim.

[20] Some of the findings of our conversations have been deleted from the report as we had not received permission to speak about them publicly as of the date of publication. We may update a new version of the report if this changes.
[21] As they do in Brooks et al. (2025)'s study where more than half the kilns in the control condition, which received no training, were using improved practices in the firing season after the intervention.

4.2 Location

- Luby and coauthors have identified West Bengal as the next location for their work and think their previous implementation partner, icddr,b, can cover Bangladesh. He thought Punjab region, Pakistan might be promising due to its large number of kilns. His view was that training is currently neglected in India.
- However, other experts highlighted that there is ongoing work between the Brick Kiln Owners' Association of Pakistan (BKOAP) and the Pakistani government, suggesting that this work may not be neglected there.
- This contrasts with Sameer Maithel, who estimated that 50–60% of kilns have significant room for improvement in their operational methods (though we did not ask him about Punjab in particular).
- Sameer Maithel provided estimates of the proportion of kilns converted to zigzag: India (50–60%), Pakistan (50%), Nepal (50%), and Bangladesh (80%). In absolute terms, India has the highest number of zigzag kilns, followed by Pakistan, a factor we weigh in our advice on geographic prioritization.

4.3 Implementation

Gaining the trust of kiln owners will be crucial, and non-trivial. Several experts told us that the industry (which is informal, poorly regulated, and often in active violation of existing regulations) is distrustful of outsiders, and would only participate if they saw a clear benefit to themselves. Several experts agreed that brick kiln owners' associations will be useful contacts for establishing these relationships.

Luby noted that any founders would have to be able to stomach working with unsavory collaborators, as at least some kiln operators use exploitative labor practices (as discussed in section 3.3).

4.4 Worker Rights

Experts stressed the importance of this issue, and suggested addressing it together with energy efficiency could be beneficial. Multiple interviewees brought up this topic without prompting, stressing its importance and their belief that a holistic approach to improving kiln practices should include worker issues. Luby noted the lack of impact of their treatment arm in trying to improve worker conditions, but was positive about early results from a new pilot underway that aims to address child labor.

5 Additionality and geographic assessment

This section discusses our considerations of additionality and our review of locations where a charity could deliver this intervention in light of the burden, tractability, and potential additionality.

5.1 Neglectedness

Only a small number of actors have worked on this issue. Efforts are ongoing in Bangladesh and Pakistan, Nepal likely has less need than other areas, whilst Indian states have many kilns with poor practices and a lack of actors working on the issue.

Actors delivering this intervention

Experts think that Bangladesh, and potentially West Bengal, might be covered by a project growing out of the work in Brooks et al. (2025). While there has been a series of projects in India, Pakistan, and Nepal led by ICIMOD, most of these projects are now complete. Our expert interviewees thought there were few ongoing efforts, despite the low adoption of best practices.

ICIMOD and the Climate and Clean Air Coalation (CCAC) have conducted the bulk of kiln training (and advocacy work more broadly) in the region. ICIMOD has trained 'master trainers' from different countries who can teach others to train. In Pakistan, they have also brought brick kilns into national policy-level discussions, through their engagements over the past decade.[22]

Governments are keen to reduce emissions from kilns, but the effects of policy have been inconsistent. Policies have helped drive physical conversions to zigzag kilns, but there are many reports of practices lagging behind physical retrofitting. We sense that regional governments often lack the capacity to ensure kiln operations follow best practices. One expert told us about an exception from

[22] We are very grateful to ICIMOD staff for sharing these and other insights with us, which have shaped our understanding of the topic.

Punjab province in Pakistan, where the National Disaster Management Authority enforces a ban on non-zigzag kilns in smog season very strictly, physically shutting down kilns where proper stacking does not occur.

Table 1: Organizations active in this space

Organization	MANGO/ FoNGO[23]	Scale/Coverage	FTEs	Funding
ICIMOD	MANGO	Pakistan, Nepal, India	-	CCAC, usually
ILO	MANGO	Pakistan (we found one training program on the *conversion* to zigzag which included some operational training)	-	-
icddr,b	MANGO	Bangladesh	-	-
Greentech Knowledge Solution	MANGO	South Asia (primarily India)	-	-

Attention and Funding

The main organization working on this topic seems to be ICIMOD (the International Centre for Integrated Mountain Development), which is mostly funded by the Climate and Clean Air Coalition.[24] ICIMOD led a push to convert traditional fixed-chimney kilns to zigzag kilns, starting after the 2015 earthquake in Nepal, and has conducted training sessions in India and Pakistan in recent years, with training in the Sindh province of Pakistan ongoing.

The brick kiln industry causes multiple other harms (aside from worsening air quality and emitting GHGs) that have been the focus of some organizations' work:

[23] Multi-armed NGO (MANGO) and Focused NGO (FoNGO). See "Why household name NGOs are unlikely to offer the best value for money" from the Happier Lives Institute (2025)
[24] See a list of CCAC-funded projects on brick kilns here.

- The International Labor Organization (ILO) has worked on brick kilns from the perspective of workers' rights;
- Brooke, an animal rights organization, has focused on the conditions of working horses, mules, and donkeys.

5.2 Geographic assessment

We mostly recommend working Indian states, based on a combination of large scale and significant neglectedness.

Link to our model[25]

We created a weighted factor model to assess which geographic location might be the most promising for a new organization pursuing this intervention. We considered South Asian countries with significant amounts of zigzag kilns: Bangladesh, Nepal, India, and Pakistan, the latter two on a subnational level.

In this model, we try to balance the number of kilns in a location (and the damage to health they cause), whether other organizations are already working on similar projects, and how cost-effective the intervention would be.

Table 2: Top candidate states for this charity.

Location	DALY from Kilns (estimate)	Number of kilns (all types)	Cost-effectiveness ($/DALY)*	Cost-effectiveness ($/$CO_2$e)*	Neglectedness (subjective)
IND-Uttar Pradesh	397,117.52	17,335	316	2.16	1.00
IND-Bihar	218,811.23	6,048	308	2.11	1.00
PAK-Punjab	221,018.60	9,491	242	1.66	0.40
IND-Haryana	124,317.35	2,079	312	2.14	1.00
IND-Punjab	123,048.27	2,077	321	2.20	1.00

*These results are based on a model with 500 kilns per year and no revenue generation. See Section 6 for details on alternative models.

[25] Reported as of 28.07.2025—-note the models are live and may be subject to tweaks or (in rare occasions) large changes that may not be reflected in the text if carried out after publication.

We excluded Bangladesh from this list of top priority regions despite it scoring similarly to these choices. This is because experts were confident that icddr,b could scale up the program tested by Brooks et al. (2025) to the national level. **Pakistan may also eventually need to be excluded**, as our expert interviews suggest that ICIMOD has made significant progress there.

A significant driver of these overall rankings is scale; so it is not surprising that Indian states, with their dense populations and large numbers of kilns, would feature so prominently. However, we note that our province-level estimates of kiln numbers for Pakistan might be underestimated.[26] If this is the case, provinces such as Sindh may be more promising than our model currently suggests.

Table 3: Variables used in the weighted factor model.

Criteria	Data source & Manipulations	Strengths/Weaknesses	Weight
Population	Wikipedia This data was log transformed		5%
DALY from kilns	Own calculation from DALYs in region (source), proportion of DALY from kilns (estimates), and number of kilns (see below) This data was log transformed	Our estimates for the proportion of DALY from kilns is uncertain, and too coarse (country-level) given the clustering of kilns in certain geographic regions.	10%
Kiln numbers – zigzag (ZZ) kilns	India: satellite paper Pakistan: satellite paper Bangladesh: satellite paper Nepal: Emissions study This data was log transformed	While the models tend to perform well when tested against hand-validated images, this is not a count but an estimation. E.g. in Pakistan, while the numbers for Punjab match other sources, the overall kiln numbers for the country are drastically lower than claimed elsewhere.	10%
Kiln numbers – ZZ kilns and FCBTK	India: satellite paper Pakistan: satellite paper Bangladesh: satellite paper Nepal: Emissions study This data was log transformed		5%
Subjective neglectedness	Own assessment	Very subjective and based on limited information.	15%
Cost-effectiveness:	CEA	Depends on a somewhat	15%

[26] We get our estimates from a paper that uses satellite images to count kilns. This paper agrees with other sources on the number of kilns in Punjab province - around 10,000. But while other sources claim a further 10,000 kilns in the rest of Pakistan, this paper shows barely 2,000. We use this estimate because other sources on Pakistan do not have a province-level breakdown; and we use satellite papers for estimates in other geographic areas.

Criteria	Data source & Manipulations	Strengths/Weaknesses	Weight
DALY		uncertain estimate of the proportion of health DALYs caused by brick kilns.	
Cost-effectiveness: CO_2	CEA	+ Depends on physical measures of CO_2 rather than estimates. - Black carbon is estimated, and CO_2 from the study might be unrepresentative of other kilns.	15%
FSI - Security	Fragile States Index		10%
ZZ kiln density	Own calculation from kiln numbers (above) and various Wikipedia pages	Depends on the estimates above and thus comes with the same problems This indicator is a crude measure: a huge province with 100 kilns in one valley would have a worse density score than a small province with them spread out.	5%

6 Cost-effectiveness analysis

We model that this charity can avert a DALY for between USD 150 and 320 and avert one ton of CO_2 equivalent GHGs for USD 1.50–2.10.[27]

View our full model here.[28]

6.1 Results

Health Results

We modeled cost-effectiveness separately for each geographic location under consideration. **Depending on modeling assumptions, we calculate that this intervention could avert one DALY for $150–$320 in the top 5 geographies**.

We modeled three different scenarios:

1. The charity can reach 500 kilns per year at scale, about double the number reached by Brooks et al. (2025).
2. The charity can reach 1,000 kilns per year at scale. This scenario is more optimistic, but it may still be realistic.
3. The charity can reach 500 kilns per year, and it covers its variable costs by charging kiln owners for the training (see reasoning below).

Table 4: Health cost-effectiveness, depending on assumptions.

	500 kilns per year	1,000 kilns per year	500 kilns, variable cost covered
IND-Uttar Pradesh	$315/DALY	$232/DALY	$166/DALY
IND-Bihar	$308/DALY	$223/DALY	$162/DALY

[27] This is result is expresses global warming on a 100-year basis, which is our preferred calculation. On a 20-year basis, the cost-effectiveness is $3.20–4.40/t$CO_2$e.
[28] Reported as of 28.07.2025—-note the models are live and may be subject to tweaks or (in rare occasions) large changes that may not be reflected in the text if carried out after publication.

PAK-Punjab	$242/DALY	$165/DALY	$153/DALY
IND-Haryana	$312/DALY	$229/DALY	$164/DALY
IND-Punjab	$321/DALY	$236/DALY	$169/DALY

It may be possible for the charity to charge the kiln owners for its services. We are very uncertain about the kiln owners' willingness to pay and the extent to which asking for a fee would affect the take-up of the intervention (as this has, to our knowledge, never been tested). However, there seem to be good reasons to believe this should be feasible: Our calculations suggest that a typical brick kiln's annual revenue is around $300,000 (see here). Given that typical profit margins are around 25% and fuel costs account for ~30% of total costs (Kumar, 2021), we estimate that total fuel costs are around $66,000. Given that this intervention reduces fuel usage by 11.50% (Brooks et al., 2024), the savings generated for the kiln owners amount to $7,600 per year—more than ten times the charity's estimated variable cost per kiln, and more than seven times the total average cost per kiln.

Moreover, this $7,600 figure is likely an underestimate, for two reasons: (1) The 11.50% reduction in fuel usage is the intention-to-treat estimate from Brooks et al. (2024). Kilns that implemented the new practices ("compliers") experienced a 23.5% reduction in fuel costs. (2) The intervention also increased brick quality, increasing the percentage of "class 1" bricks by 7% (or 15% for compliers; Table S30), which Brooks et al. (2024) estimate increased the average value per brick by 1.3% (or 2.9% for compliers; Table S28).

These calculations make us optimistic that the charity could cover some of its costs by charging the kiln owners a fee. However, we are very uncertain about the potential value of this fee. It could be enough to cover only part of the charity's variable costs, all of its variable costs, or even all costs, including overheads. The charity must experiment with different values to find kiln owners' willingness to pay.

Climate Results

We calculate that this intervention could avert one tCO_2e[29] for $1.60 to $4.70. We model two different ways of accounting for black carbon (BC) and sulfur dioxide (SO_2) emissions, and model both of these under scenarios in which the charity trains 500 or 1000 kilns each year:

1. Accounting for CO_2, BC, and SO_2 under a 20-year timeframe (i.e. GWP-20)
2. Accounting for CO_2, BC, and SO_2 under a 100-year timeframe (i.e. GWP-100).

Standard reporting of the warming potential of GHGs is over a 100-year timeframe due to the long half-life of CO_2 and its cumulative global-warming effect over time. However, BC and SO_2 have very short lifetimes[30] in the lower troposphere, meaning their temperature effects are highly concentrated and occur entirely within the first year or so. Because of this, using a GWP-100 by averaging its effect over a 100-year period, could be viewed as "diluting" their strong climate effects that are concentrated within the first year. For example, BC has a GWP-20 of 1600 versus a GWP-100 of 460 (ICCT, 2009). Secondly, we place a higher value on warming in the next 20 years than the following 80 years because we discount impacts over time.

We model both the expected emissions averted and cost-effectiveness under both timeframes. We find that the intervention is highly cost-effective in both cases, though more so on the 100-year than the 20-year timeframe (Table 5).

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[29] A "ton of CO_2 equivalent" (tCO_2e) is a unit of measurement used to express the impact of various greenhouse gases in terms of the amount of carbon dioxide (CO_2) that would have the same global warming potential over a specific period. Here, we use 20 years and 100 years.
[30] SO_2 exists in the troposphre for ~1-2 days (Eliseev et al., 2019). BC has a lifetime of 4-12 days (CCAC, n.d.).

Table 5: Climate cost-effectiveness of this charity based on different scale assumptions and global-warming timelines

		20-year timeframe (i.e., GWP-20)	100-year timeframe (i.e., GWP-100)
Cost-effectiveness	Assuming 1000 kilns trained per year	\$3.19/tCO_2e	\$1.49/tCO_2e
	Assuming 500 kilns trained per year	\$4.38/tCO_2e	\$2.05/tCO_2e
Total net tCO_2e emissions averted per kiln per year		340 tCO_2e	479 tCO_2e
Isolated averted emissions per kiln per year	Sulfur dioxide (tCO_2e of the warming effect of averting SO_2 emissions)	-337 tCO_2e	-76 tCO_2e
	Black carbon (tCO_2e)	171 tCO_2e	49 tCO_2e
	Carbon dioxide (tCO_2)	506 tCO_2e	506 tCO_2e

We have also performed a supplementary analysis to estimate the effect of this intervention on even shorter timescales (see this model). This analysis indicates that, on a 4-year timescale, the intervention still significantly reduced GHG emissions, averting roughly 355 tCO_2e per kiln. However, **on a timescale of 0.8 years, the warming effect of SO_2 reduction more than offsets the cooling effect of CO_2 and BC reductions, resulting in an overall warming effect** (equivalent to -37 tCO_2e per kiln, in our model).

We would like to stress, however, that there is very large uncertainty in these estimates of short-term effects. These stem from a combination of (i) uncertainty about the BC emissions reduction as a result of this intervention,[31] (ii) the sulfur

[31] Different studies have found vastly different BC emissions across kilns. For instance, Weyant et al. (2016) say that "measurements in South Asian kilns show that about two thirds of the particulate matter was black carbon on average and but it could range from 1% to nearly 100% for different kilns." In our models, we use a conservative 8% figure for the baseline proportion of particulate pollution that is BC. If the baseline is much higher, then this intervention will have a much greater short-term cooling effect.

content of the coal used by the target kilns,[32] (iii) percentage of non-coal fuel used by the kilns, (iv) uncertainty in the literature about the global warming potential of BC and SO_2, and (v) very simplified modeling used in our analysis. This uncertainty means that, in the short term (especially on timescales <1 year), this intervention could both cause significant warming, but also not cause any warming at all.

We are, however, confident that, in the longer term, this intervention contributes to slowing down the rate of global warming (since it reduces the amount of long-lived CO_2 emissions) **and that it does so with very high cost-effectiveness.**

Other models

Brooks et al. (2025, p.5) provide a cost estimate of US$486 per kiln receiving treatment in the Bangladesh RCT, which includes the training venue, materials, and travel costs, as well as staff and travel costs for engineers providing ongoing assistance to kiln owners. Based on this cost, and the social cost of carbon of $185USD/MT, they calculate a benefit-cost ratio of 65:1 for a single season.[33]

6.2 Modeling choices

Costs

The costs we model consist of a fixed and a variable component.

For fixed costs, we use default AIM values of $130,000 in the first year and $280,000 annually in subsequent years. We are uncertain about the fixed costs this charity will require and suspect that, in reality, they may be lower than this.

We base our variable costs estimate on Brooks et al. (2025). The paper reports that the intervention (in Bangladesh) cost $486 per kiln. This included training materials, venue costs, engineers, travel and food for participants, training

[32] Typically less than 1% but can be up to 8% (Gopinathan et al., 2022; Baruah & Khare, 2007).
[33] Depending on assumptions about the measurement of CO_2 emissions, this benefit-cost ratio can be as low as 20 (Brooks et al. 2025, p.5)

sessions, and staff time to provide ongoing support. In our model, we assumed that 30% of this cost was for engineer salaries – which vary significantly between countries – and assumed, for simplicity, that the remainder stays roughly constant. We also applied a 20% discount to capture our belief that an AIM-incubated charity could reduce the variable cost per kiln. This adjustment is rather weak; some team members believed it should be 50% or more.

Effects

$PM_{2.5}$ pollution reduction → health effects

We assume that this charity will primarily achieve health benefits by reducing direct $PM_{2.5}$ emissions. We estimated the size of this effect the following way:

- We estimated the DALYs lost as a result of a year of operation of a typical brick kiln, in two ways (which we averaged):
    i. **Top-down:** We obtained estimates for DALYs caused by ambient particulate air pollution in Northern India, from the Global Burdens of Disease database. We combined these with estimates of kilns' share of $PM_{2.5}$ pollution and the estimated number of kilns in the area. The resulting estimate is 20.1 DALYs per kiln per year.
    ii. **Bottom-up:** We combined an estimate of how much $PM_{2.5}$ and SO_2 emissions a typical brick kiln emits per year (from Brooks et al., 2025) with estimates of the DALYs associated with a kg of $PM_{2.5}$ and SO_2 in India (from van Zelm, n.d.). The resulting estimate is 19.0 DALYs per kiln per year.
- Finally, we used Brooks et al.'s estimate of reduction in $PM_{2.5}$ pollution (9%)—combined with the assumption that we would counterfactually speed up the adoption of the target practices by five years—to estimate the DALYs averted by this intervention (3.2 DALYs/kiln). We use the intention-to-treat estimate, a conservative but more precise measure, and effects are likely to be higher.

CO_2 , BC, and SO_2 emission reduction → climate change effects

For CO_2, we begin with the amount of CO_2 emitted (in tons) by kilns in the Brooks et al. (2025) study that did not receive the intervention. We then take their estimate of the percentage reduction in CO_2 emissions caused by the intervention. We assumed a 9% reduction in CO_2 emissions, in line with Brooks et al.'s intention-to-treat estimate.

For BC, we assume that black carbon accounts for 8% of $PM_{2.5}$ emissions produced by a kiln (from a CCAC fact sheet). We use this figure, and Brooks et al.'s estimates of $PM_{2.5}$ emissions by kilns in the control conditions, to estimate the total tons of black carbon emitted by kilns operating imperfectly. We assumed that the reduction in BC is proportional to the reduction in $PM_{2.5}$ emissions, i.e., 9% (Brooks et al., 2025).

For SO_2, we estimated the potential "cooling" effect in two ways: (i) following the estimate for the cooling effect of SO_2 from a modeling paper on the effect of SO_2 emission reduction in East Asia (Samset et al., 2025), (ii) using the IPCC estimates for the global warming potential of SO_2 (ICCT, 2009). We assumed that the reduction in SO_2 emissions is proportional to the reduction in coal use, i.e., 11.5% (Brooks et al., 2025).

Finally, we estimated the total tons of CO_2-equivalent emissions for this warming effect. To get a single cost-effectiveness figure for all greenhouse gases, we converted BC and SO_2 to their CO_2 equivalent, using the global warming potential (GWP) on a 20- or 100-year scale.

Scaling

At present, we estimate reaching 500 kilns per year. This is roughly three times the number reached by Brooks et al. (2025). We also modeled reach at scale as 1000 kilns per year, which we think is optimistic but potentially achievable. The main difficulty in scaling up lies in recruiting and training enough skilled engineers who can train owners and workers, and provide technical assistance in the field (and potentially monitor emissions).

We assume the counterfactual duration of the effect is five years. It is highly unlikely that kiln owners revert to old practices on purpose: there is strong evidence that these practices increase the quality of the bricks they produce and lower fuel costs, which means it is in their interest to continue. Brooks et al. (2025) showed that adoption *had spread* in the second year after their study, rather than abating.

Sensitivity analysis and considerations

Estimates of attributable DALYs per kiln are highly uncertain.

- **Our estimates for DALY/kiln are very sensitive to estimates of the percentage of pollution in a country caused by brick kilns.** We used the conservative, lower-end estimate for India of 8% (whereas sources estimate 8–14%; Mondal et al., 2024). However, if 14% is correct, the health impact of brick kilns would be almost double what we modeled.
- **Another uncertainty is based on the total number of kilns in different regions.** Sources disagree about these numbers – though we hope that the remote-sensing data that we rely on are the most accurate source.
- **A major uncertainty is also associated with the effect size of $PM_{2.5}$ reduction.** While the point estimate is 9.0%, the 95% confidence interval is 2.7–15.3% (Brooks et al., 2025).
- **A major factor in our model is the duration of counterfactual impact** (i.e., for how many extra years each target kiln will adopt the taught practices). We assume that this will be five years, but it could be both much less and much longer.

When it comes to our GHG-reduction CEA, we are quite confident in our estimates of the long-term effects of the intervention. The two main sources of uncertainty are:

- **The effect size of the CO_2 reduction.** While the point estimate is 9.0%, the 95% confidence interval is 2.8–15.2% (Brooks et al., 2025).
- **The counterfactual duration of the impact.**

On short time scales, there are additional uncertainties stemming from (i) the size of the effect of BC on the climate (ii) the amount of BC in the emissions of target kilns (and how much the training intervention reduces them), and (iii) the size of the effect of SO_2 on the climate.

The table below lists other ways the CEA might under- or overestimate the cost-effectiveness for the intervention.

Table 6: CEA considerations.

Reasons this intervention could be more cost-effective than modeled, all else equal.	Reasons this intervention could be less cost-effective than modeled, all else equal.
• Brooks et al. (2025) found evidence of significant positive spillovers from this intervention (i.e., nearby untrained kilns learning the target practices from trained kilns). We do not model such spillovers. • We apply a 20% internal and 20% external validity discount on the effect size. These are subjectively chosen and could be overly large. • We assume fixed costs at scale of USD 280,000, in line with many other AIM CEAs. However, we suspect this may be an overestimate. • We rely on Brooks et al. (2025) for estimates of variable costs (USD 486 per kiln in Bangladesh), which we adjust down by 20%. However, we think that an AIM-incubated charity may be able to push down variable costs significantly lower. • We are not modeling effects on kiln workers, who may benefit from reduced pollution above and beyond the general population.	• Translating this intervention to a new location may require a significant time investment in intervention design – something we have not accounted for. • Scaling: If different kilns turn out to be highly heterogeneous – or kiln owners uncooperative – the charity may not be able to achieve the modeled 500 kilns reached per year. • Rebound effect: If the reduction in the cost of producing bricks results in an increase in brick supply, part of the benefit of this intervention could be offset. At the moment, we are only assuming a small, 5% rebound effect. • If the fuel mix of kilns changes in the future (e.g., by mixing in more non-coal fuels), their baseline emissions will reduce, and so will the effect of our intervention. • If other changes happen in the brick kiln market (e.g., significant policy changes or technological developments), the counterfactual

Reasons this intervention could be more cost-effective than modeled, all else equal.	Reasons this intervention could be less cost-effective than modeled, all else equal.
• We are not modeling the potential child-labor reduction benefits of this intervention. • Effects could be much larger if compliance was higher than assumed. • We are not accounting for other benefits of reduced pollution, such as cognitive, learning, or labor productivity impacts.	impact of training may go down. • Compliance rates may be lower than we assumed.

7 Implementation

This section discusses implementation factors that are relevant for: 1) deciding whether we should recommend the idea; and 2) the entrepreneurs considering taking the idea to scale.

7.1 What does working on this idea look like?

Figure 5 notes how we would characterize this proposed idea along an explore-exploit continuum.[34]

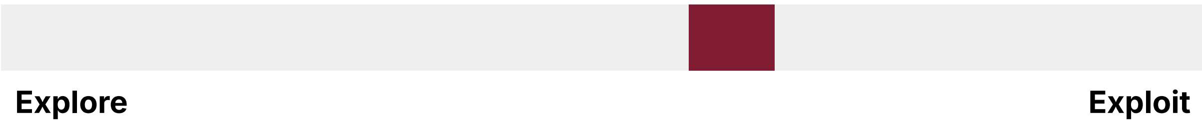

Figure 5: Where this charity lies on the explore-exploit continuum.

This intervention is substantially inspired by the RCT conducted by Brooks et al. (2025) in Bangladesh. The authors predict that this intervention cannot be transferred one-to-one to other contexts. They stress that the key to success lies in building relationships of trust with kiln owners, and in getting a thorough understanding of local practices and needs, a view corroborated by experts (e.g., Brooks et al., 2024). An organization in this space will always have to spend significant effort figuring out how to shape the intervention for a given context.

An organization will have to, among other tasks:

- Identify geographic areas featuring a significant amount/density of kilns that have the physical properties of a zigzag kiln but would benefit from operational gains
- Establish relationships with kiln owners (and their associations[35])

[34] Our recommendations can be characterized along a spectrum between exploration and exploitation: ideas closer to exploration require more research and design, and involve riskier bets and wider confidence intervals; ideas closer to the exploit side of things usually have narrower confidence intervals and rely more on replication/expansion of well-developed and concrete interventions.
[35] E.g., Bihar Int Nirmata Sangh (BINS) in Bihar

- Conduct a baseline survey of operational practices, to identify which improvements to push
- Identify potential early adopters who can demonstrate the success to other kiln owners and help the idea spread
- Convince kiln owners to not just attend themselves, but allow their employees to attend training sessions
- Conduct training sessions that transmit knowledge
- Travel to kilns to (i) provide follow-up support and (ii) monitor implementation (and emissions)

We also want to flag the issue of worker exploitation. The brick kiln industry is notorious for rights-violating practices such as child labor and indentured servitude (Boyd et al. 2018). The founders of this organization need to be open-eyed about this fact – they will have to make relationships and gain the trust of the people responsible for these rights violations.

We think the intervention is worth considering anyway. We do not think this intervention would *harm* any workers — counterfactually those practices would continue, but kilns would be more polluting. Second, there might be an opportunity to advocate for worker rights alongside efficiency improvements. Brooks et al. found no evidence of improvements in their RCT (Brooks et al., 2025, p.5) but Stephen Luby told us in conversation that they are hopeful about a current pilot.

7.2 Key factors

This section summarizes our concerns (or lack thereof) about different aspects of a new charity's implementation of this idea.

Table 8: Implementation concerns

Factor	Level of concern
Talent	Moderate
Access to information	Low

Factor	Level of concern
Access to relevant stakeholders	Moderate
Feedback loops/Monitoring and Evaluation	Moderate
Execution difficulty/Tractability	Moderate
Complexity of scaling	Moderate
Obtaining funding	Moderate
Risk of harm	Low

Talent

The following backgrounds, skills or profiles would likely be useful for the co-founders or early hires in this organization:

- Research skills - to identify promising regions, design baseline surveys etc.
- Engineering expertise - this can be an early hire but it would be useful to have someone in the team who understands the engineering principles behind kiln operation, can identify improvements, and stay up to date with new techniques
- Ability to make relationships with kiln owners
- Being from the target country

Access

Information

Information on the *location* of brick kilns is somewhat easily available. Some areas seem to have decent official records, while brick kiln owners' associations might also have detailed lists.[36] If those do not work, computer scientists have

[36] For an example, see the district-level breakdown of kilns provided by the Brick Kiln Owners Association for Punjab, Pakistan in this report.

designed models that identify zigzag kilns from satellite images with reasonable accuracy.

However, information about the kilns' practices is more limited. The charity will either have to try to obtain this data from the local associations or collect it itself.

Relevant stakeholders

Kilns are easy to identify, but their owners will require persuasion to cooperate. The kiln industry tends to be skeptical of outsiders. The industry is characterized by informality, and many kilns break environmental and/or labor laws.

Kiln owners' associations will be crucial in making connections. They exist at a national level in every country we looked at. There is a cross-national association, and often more localized ones at, for example, the district level. These organizations tend to publicize their contact details, and experts have told us they are open to collaboration.

Government actors can be useful, but are only sometimes keen to cooperate. In our conversations with experts, the lack of a clear institutional 'owner' of brick kilns was mentioned as a challenge. Regulators might assist in the research stage by providing information on kiln location and type. They can also be key in motivating a switch to better practices.

If the charity decides to address worker rights issues, potential partners exist. Bachpan Bachao Andolan has a multi-decade track record of rescuing children from bonded labor, including brick kilns. *Volunteers for Social Justice* have conducted research and intervened in some cases.

Feedback loops/Monitoring and Evaluation

Monitoring will require physical travel to the kilns. The ease of evaluation depends on the specific interventions, but many are easily visible in these open-air kilns. For example, a charity could monitor compliance with proper stacking practices by observing the kiln loading technique.

Measuring actual emissions is technically more difficult and will require more cooperation from kiln owners.

The best version of this charity would go beyond continuous firing and improved zigzag stacking and continuously test new methods that can improve efficiency. This would require conducting and analyzing RCTs, though academics working in development economics are often very willing contributors of that particular research expertise.

Tractability

As discussed above, gaining the trust of kiln owners will be challenging, a point several experts expressed. In addition, the charity will require a fairly large number of technical staff to support the kilns, certainly in the beginning as it identifies the optimal levels of support. These technical staff are needed to address another key issue: identifying which practices are lacking, and where improvement is possible, which will likely be an intensive process requiring on-the ground inspection and conversation.

Complexity of scaling

Scaling this program from one geographic area to another is not straightforward, because building relationships with kiln owners in new areas might take time. Practices might also differ slightly, requiring a change in the intervention.

That said, some geographic regions with many kilns fall into the same networks (e.g. kiln owners associations). There, scaling up will be easier, especially once success has been demonstrated. Because these interventions result in higher-quality bricks and fuel savings, there is an incentive for self-interested owners to not just accede to requests for change, but actively seek them out. (Recall that in the Brooks et al. 2025 study, over half of the kilns that did not receive the training adopted the improved practices the following year).

In other words, depending on the location chosen and the pace of enrolment, an organization can scale up significantly in a reasonable amount of time.

Obtaining funding

Experts cautioned that worker exploitation makes it more difficult to get funding, with some organizations outright refusing to fund programs that are associated with child labor (Stephen Luby interview). Some large institutions (like the Asian Development Bank) have funded investments in upgrading infrastructure, but that capital-lending approach does not fit this intervention.

Risk of harm

We are confident this intervention will not directly increase the risk of harm to kiln owners or workers. The reduction in particulate matter will likely benefit the workers near the kiln.[37] We think it is unlikely (though possible — ~20% chance) that the charity can adapt the intervention in the future to convince kiln owners to improve labor conditions.

We think it is highly unlikely that this intervention will harm the founders. However, founders should understand that their organization will be dealing with entrepreneurs in the informal sector.

[37] Reseach suggests that the majority of brick kiln workers have abnormal lung function, likely (though not conclusively) as the result of working in the kilns' polluted environment (Raza & Ali, 2021).

8 Conclusion

Brick kilns are one of the major contributors to the air pollution in South Asia, which is estimated to cause hundreds of thousands of premature deaths per year. Given the potential impact of scaling up energy-efficiency training, a known and tested playbook, and the neglectedness of this topic, we believe that this idea is worth recommending for incubation through the Charity Entrepreneurship Incubation Program.

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