Rebuilding Schools Destroyed in the 2018 Lombok Earthquakes Using Recycled Plastic Blocks

A Cost-Benefit Analysis

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CLASSROOM OF HOPE

BLOCK SOLUTIONS

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Executive Summary

This report conducts a cost-benefit analysis of accelerating the rebuild of 200 schools destroyed during the 2018 earthquakes in Lombok, Indonesia using a novel recycled plastic building technology. These 'Blocks', made from recycled plastic with or without organic material, are lighter and easier to assemble than traditional brick and mortar. This means that building costs and construction time are reduced, making it more feasible to shorten the reconstruction time from 8 years to 4 years.

The main policy implication of this report is that the governments of Nusa Tenggara Barat (NTB) and Indonesia should strongly consider rebuilding the destroyed schools as quickly as possible. The return on this investment is substantial with each rupiah invested yielding 15 rupiah in economic benefits. The costs of delay are large, while the marginal costs of speeding up the rebuild are relatively modest.

Children whose schools were destroyed in the earthquake have had to learn in makeshift environments, such as tents and temporary schools. In such environments, the evidence indicates that children learn half as much as they otherwise would in a permanent school. The analysis suggests that for every year in which students remain in these less-than-ideal conditions, the cost to the Indonesian economy, in terms of future lost productivity is around USD 180,000 per school. Given an estimated 200-400 schools that require rebuilding, **this implies an annual learning loss equivalent to USD 36,000,000 to 72,000,000 (0.7% to 1.4% of Lombok's current gross domestic product).**

Under business-as-usual, the reconstruction effort are assumed to take at least 8 years. The analysis shows that the cost of **accelerating school reconstruction efforts from 8 years to 4 years would cost USD 3,361,000**, with roughly a third of the cost for additional project management expenses, and the remainder the time value of bringing forward spending by 4 years. The intervention would improve the school environments of thousands of children, leading to better learning, which are estimated to increase the future income of beneficiaries by 5% for every extra year they learn in a permanent school. **Total benefits are valued at USD 50,150,000, with a central benefit-cost ratio (BCR) of 15 (range 7.5 to 25.6).** Additional benefits in terms of cost savings and reduced plastic waste increase the BCR by 9%.

This report also adds to the small but growing literature on the welfare impacts of plastic waste. Bringing together estimates of the costs of several different plastic pathways, including waste disposal, marine pollution and burning, the report notes that **each tonne of plastic waste that is not recycled has economic, social, and environmental costs equal to USD 190 to USD 360 per tonne**. Applied to the approximately 120,000 tonnes of non-recycled plastic waste generated in Lombok per year, the analysis in this report suggests **aggregate losses from plastic waste of USD 23,000,000 to 43,000,000 annually (0.4% to 0.8% of Lombok's domestic product),** a figure which will likely grow over time.

1. Introduction

In July and August 2018, a series of earthquakes struck off the coast of the Indonesian island of Lombok. The largest tremor on 5 August 2018 measured 6.9 on the Richter scale and was the strongest seismic event in the recorded history for the island. The quakes lead to 563 deaths, displacing hundreds of thousands and causing widespread damage to infrastructure. Hundreds of schools were destroyed or damaged, leaving thousands of children with no safe space to learn. Throughout the remainder of 2018 and 2019, displaced children learned in temporary facilities such as tents, pop-up schools and mosques, were forced to travel further to other undamaged schools or even dropped out altogether, with detrimental impacts on education attainment. These were further compounded by the COVID-19 pandemic which led to school closures in April 2020.
While schools have gradually reopened, discussions with stakeholders noted that as of April 2021, a vast majority of the destroyed schools had yet to be rebuilt. Continuing to operate in temporary facilities negatively impacts children's learning. Analysis conducted in this report suggests that for every year in which students remain in these sub-optimal learning environments, the cost to the Indonesian economy, in terms of future lost productivity is around USD 180,000 per school. Given an estimated 200-400 schools that require rebuilding, this implies an annual learning loss equivalent to USD 36,000,000 to USD 72,000,000 (0.7% to 1.4% of Lombok's gross product). While data on past and future reconstruction efforts remain unclear, it seems reasonable to expect that the rebuilding process will require at least eight more years beyond 2021.

This report outlines a cost-benefit analysis of accelerating the rebuild of Lombok schools using a novel recycled plastic technology developed by the Finnish company Block Solutions. Block Solutions recycles plastic to create a light weight, easy to assemble, low-cost alternative to traditional brick and mortar. The analysis considers a dedicated program to rebuild 200 schools in Lombok over a period of four years, compared to an assumed counterfactual of eight. Due to their light weight and low cost, the use of the recycled Blocks makes an accelerated timeline more feasible. At 10% of the weight of traditional bricks, the plastic Blocks can be transported and manipulated more easily, reducing build time from three weeks to one. The lower cost also means that more schools can be built with the same available resources. Consultations indicate that four years is an attainable milestone if there is sufficient focus and funding to rebuild the schools.

The base case scenario of the cost-benefit analysis, considers education impacts only, ignoring potential cost savings or recycling benefits. The marginal costs of this accelerated program are estimated at approximately USD 3,361,000. About one third of this cost is for increased management attention, assumed to be USD 300,000 per year for five years – one year of planning and four years of construction. The remaining cost represents the time value of bringing forward construction spending by four years. The intervention would result in a better learning environment for 10,000 extra children per year, on average, until 2028. This would mean that these children would learn more and end up being more productive as adults, generating productivity benefits of USD 50,150,000 in present value terms at a 10% discount rate. The benefit-cost ratio (BCR) is therefore 14.9, an excellent return on investment. The underlying economic rationale for this result is that accelerating the rebuild requires modest **additional** investment – these are resources that the government will spend eventually – and accelerating this spend prevents large aggregate learning losses for children. In sensitivity analyses, the impact of changing the counterfactual to a situation where schools are not built at all, is considered.

In subsequent scenarios, additional benefits in terms of cost savings and benefits resulting from recycling plastic are added to the base case scenario. Together these two additions increase the BCR by roughly 9%, for an estimated BCR of 16.2. To estimate the benefits of recycling plastic, this report assesses the economic, health and environmental savings from the various pathways that plastic can take once it becomes waste. Here the analysis assesses the avoided costs of landfill and waste management, avoided PM2.5 health impacts from burning plastic and avoided economic costs from plastic pollution. This framework extends the small but growing economic literature around the welfare impacts of plastic waste (UNEP, 2014; Beaumont et al., 2019; Deloitte, 2019). The framework suggests that on average, plastic waste that is not recycled in Lombok has environmental, economic, and health costs in the range of USD 190 to 360 per tonne.

The main policy implication of this report is that the governments of NTB and Indonesia should strongly consider rebuilding the destroyed schools as quickly as possible. The return on this investment is substantial at 15 rupiah for every rupiah spent. The costs of delay are large, while the marginal costs of speeding up the rebuild are relatively modest. The base case BCR holds even when considering Block Solutions or standard brick and mortar, though as mentioned above using recycled plastic Blocks makes the accelerated timeline more feasible due to weight and cost advantages.

The report also hints at the substantial absolute benefits of addressing the current and growing plastic challenge in Indonesia. Applied to the approximately 120,000 tonnes of plastic waste generated in Lombok per year, the analysis in this report suggests aggregate losses of USD 23,000,000 to 43,000,000 annually (equivalent to 0.4% to 0.8% of Lombok's gross product), a figure which will likely grow over time. Future research is needed to assess equivalent damages across Indonesia which will certainly be substantially larger on an aggregate basis, and very likely larger on per tonne basis.

The rest of this report is structured as follows. In the next section we describe the impacts of the 2018 earthquake on the education system in Lombok. Section 3 describes the recycled plastic technology. Section 4 reports the results of the cost-benefit analysis. Section 5 concludes.

2. The impacts of the 2018 earthquakes on education in Lombok

While not always consistent, media reports and official government announcements note that several hundred schools were damaged because of the earthquakes. On 12 August 2018, The National Disaster Management Authority (Badan Nasional Penanggulangan Bencana) announced that 3501 classrooms across 606 schools were damaged. More precisely, the announcement noted that 1,460 classrooms were heavily damaged and that 319 emergency schools were required.[1] Additional reporting, quoting Plan International, noted that more than 1,000 schools were damaged including 455 heavily damaged.[2] Classroom of Hope's internal analysis and consultations put the number of destroyed schools around 400.

Figure 1: A tent school erected after the earthquake. *Source: Classroom of Hope*

In the immediate aftermath of the earthquakes, tents were erected as temporary learning facilities (for example, see Figure 1).[3] Several months later, several 'pop-up' schools were constructed, including some by the Australian NGO Classroom of Hope. The pop-up schools, while sturdier than the tents, only have an expected lifespan of roughly 5 years. The use of other buildings, such as mosques and community halls, for schooling has also been reported. Additionally, it is likely that some children have stopped attending school altogether. Teachers have

1 BNPB: 606 Sekolah Rusak Akibat Gempa Lombok, Termasuk 3.051 Kelas, 12 August 2018 https://tirto.id/bnpb-606-sekolah-rusak-akibat-gempa-lombok-termasuk-3051-kelas-cR2T

2 Hundreds of schools damaged by earthquakes on Indonesian island of Lombok, 17 August 2018 https://theirworld.org/news/indonesia-earthquake-hundreds-schools-damaged-on-lombok

3 E.g. 6 Months On Lombok Earthquake: Introduction That Bring Blessing, 6 February 2019 https://www.wvi.org/indonesia/article/6-months-lombok-earthquake-introduction-bring-blessing

reported difficulties with using the temporary facilities, particularly the tents. Besides the obvious challenges associated with trauma recovery and concern about future shocks, the heat, exposure and discomfort of the tents has impeded student concentration.[4] One account notes:

"Fitria Kaplale… describes the difficulty in returning to learning post-earthquake, when children feel uneasy and the learning process must be carried out in tents which become hot when exposed to the sun. Student concentration was low, and teaching was challenging"

- INOVASI account of a primary school teacher affected by the earthquake[5]

The recent review by Barrett *et al.*, (2019), along with evidence across low-and-middle income countries, shows that learning outcomes are influenced by the quality of schooling infrastructure, and protection from heat, rain, dust and other elements (World Bank, 2010; Dunga, 2013; Bagby *et al.*, 2016; Mulera, Ndala and Nyirongo, 2017; Kazianga *et al.*, 2019; Levy *et al.*, 2019; Sawamoto and Marshall, 2020). Therefore, it is very likely that the sub-optimal schooling conditions reported above have impacted children's learning. Section 4.2 describes the literature in further detail, and from this review, the evidence indicates that children in temporary facilities plausibly learn only half as much as an equivalent child in a permanent school.

Some destroyed schools have been rebuilt,[6] though data on the reconstruction process are lacking. Consultations conducted with stakeholders in Lombok noted that most schools had yet to be rebuilt, with many children continuing to learn in the temporary facilities (or at home during the COVID pandemic). While timetables are uncertain, stakeholders suggested that the reconstruction process might take as long as 8-10 years.

An account from one teacher at a school accurately summarizes the challenges at hand, i.e. a slow bureaucratic rebuilding process, and a delay that impacts children:[7]

"I was stressed out of trying to ask for help to rebuild this school. Although there is a possibility of getting funding from the village office, there is no certainty of how much and when we will get the funds since there are many other things that must be prioritized by the local government. Meanwhile, our students have begun to have health problems since they have to study under a tent located on the roadside which makes them exposed to dust".

- Ms Pertiwi, a teacher at PAUD Permata Hidayah

Therefore, this analysis assumes the reconstruction process will take 8 years under 'business-as-usual', while a dedicated program with additional management attention to address the frictions in getting the schools rebuilt would shorten this to 4 years. The impact of these assumptions are also tested in sensitivity analyses.

3. Recycled Plastic Blocks

The recycled plastic Blocks are based on technology developed by Block Solutions, a Finnish company founded in 2017. The Blocks are a bio-composite made from some forms of plastic, in particular polyethylene terephthalate (PET), High-density polyethylene (HDPE) and Polypropylene (PP). The Blocks can also include organic wood fibre such as acacia, bamboo, or rice husk.

4 Strengthening education after the Lombok earthquake https://www.inovasi.or.id/en/story/strengthening-education-after-the-lombok-earthquake/
A Year in Progress: Lombok Post-earthquake Recovery, 5 August 2019, https://happyheartsindonesia.org/lombok-earthquake/

5 Strengthening education after the Lombok earthquake https://www.inovasi.or.id/en/story/strengthening-education-after-the-lombok-earthquake/

6 E.g. A Year in Progress: Lombok Post-earthquake Recovery, 5 August 2019, https://happyheartsindonesia.org/lombok-earthquake/

7 As above

The Blocks are standardized and modular so that structures are easy to assemble and pull apart (Figure 2). There are four different Block sizes measuring 100, 200, 400 and 600mm. Each Block has a height of 200mm and thickness of 100mm. The Blocks are lightweight, weighing approximately one tenth as much as traditional bricks. Lastly, Block Solutions reports that structures made from the blocks are earthquake and water resistant.

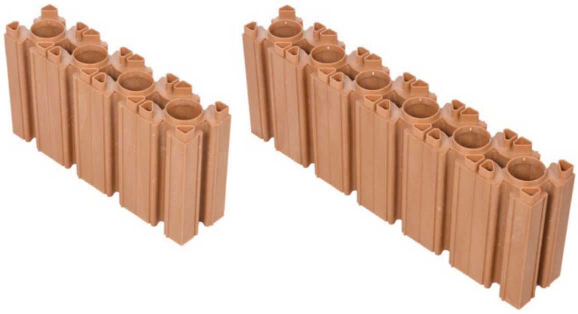


Figure 2: Close up of recycled plastic Blocks.
Source: Block Solutions

Due to these features, construction time can be significantly reduced.
A demonstration video shows a 5-person team erecting a 30 m^2 structure made of Blocks in 2 and half hours.[8] In June 2021, Classroom of Hope with support from the NTB government, built the first school in the world using this Block technology in the village of Taman Sari. The foundations, walls and roof were constructed in 5 days, with each classroom requiring 5 hours to build. The intervention considered in this report is a dedicated program to rebuild 200 more schools using the Block technology. A timelapse of the school construction can be seen at *https://classroomofhope.org/block-schools/*

Figure 3: The first Block School constructed in Taman Sari, Lombok

4. Cost-benefit Analysis

4.1 General parameters

Figures in this report are denominated in 2020 USD, the latest year for which most data are available. The intervention is assumed to start in 2021, with one year of planning before construction begins over a four-year period. The counterfactual scenario assumes construction also begins in 2022, but over an eight-year period. The number of schools that requiring rebuilding is not publicly available, though as described above, a reasonable, conservative estimate is 200 schools. The exchange rate used throughout this report is 1 USD to 14,500 IDR.

Estimates of Gross Provincial Product (GPP) per capita for provinces and cities in West Nusa Tenggara were downloaded from the Statistics Indonesia (Padan Busat Statistik) website. The regions specific to Lombok were then extracted to identify Lombok's Gross Product per capita, USD 1,398. This puts the island at roughly one third the gross product per capita as the entire country on average. The time series of future gross product per

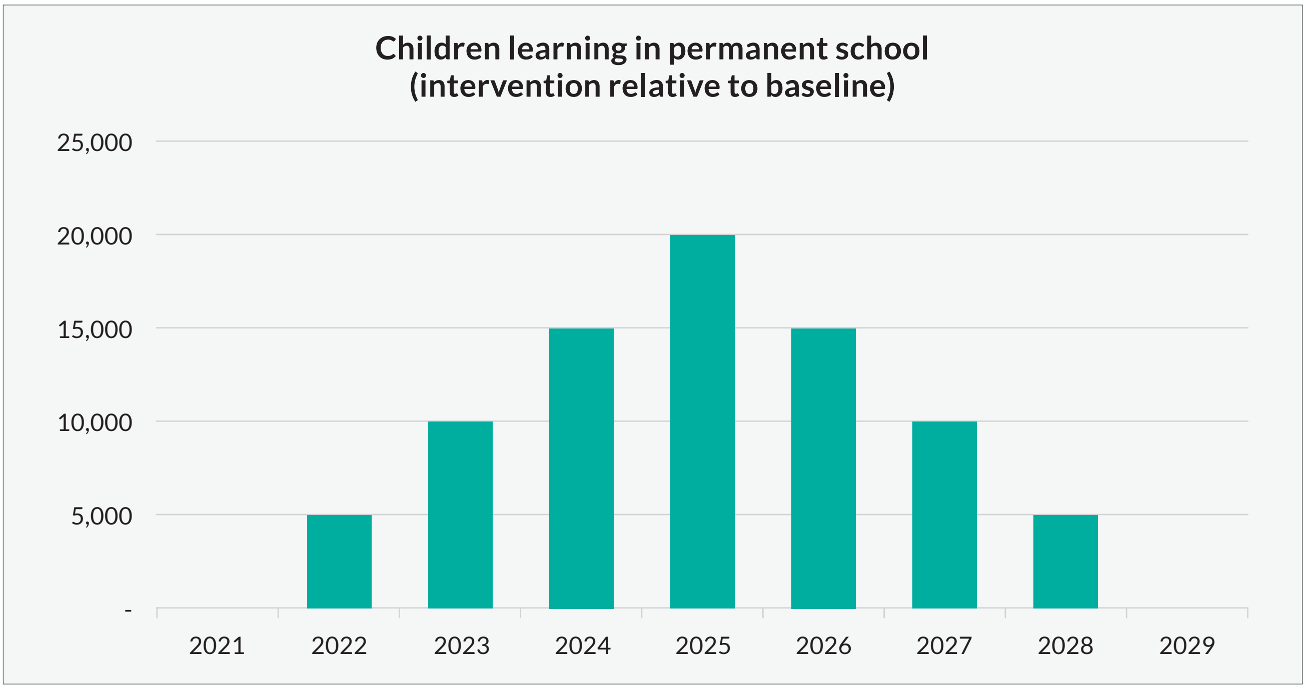
8 Block Solutions, easy and fun. https://www.youtube.com/watch?v=CQ3B9iOwyMg

capita figures is estimated by applying projected GDP per capita growth rates from the International Institute for Applied Systems Analysis (IIASA) Shared Socioeconomic Pathways database, middle-of-the-road scenario for Indonesia (Riahi *et al.* 2017). The assumption is that Lombok's gross product per capita will grow in line with national GDP per capita. This stream of gross product per capita is the assumed income levels of a typical worker in Lombok and is used for calculating education benefits of learning in non-temporary schools. Following Robinson *et al.*, (2019) we adopt discount rate equivalent to 2x short term per income capita growth rate, which yields 10%.

4.2 Base Case Scenario: Education impacts only

The base case scenario considers only education impacts from an accelerated rebuild. As discussed above, the intervention scenario assumes 200 schools are rebuilt in 4 years (50 schools per year), while the counterfactual is 200 schools in 8 years (25 schools per year). Each school is assumed to hold 200 children on average. The visual below depicts the number of children who benefit from a permanent school under the accelerated rebuild relative to counterfactual. The amount increases by 5,000 children per year, rising until 2025 when the gap between the intervention and counterfactual situations is the greatest – i.e. 100 schools (see Figure 4). This reduces as more schools are built in the counterfactual scenario, until 2029 when there are no further marginal benefits.

Figure 4: Children learning in permanent schools due to accelerated rebuild



Costs

There are two costs associated with the accelerated rebuild program. The first is the cost of additional management and program resources to ensure the schools are planned, rebuilt, and funded. The cost of additional management and administration is set at USD 1,500,000 spread over 5 years (i.e. 300,000 per year), approximately 9% of the total construction cost in the four-year program, a value reflective of typical project management costs in World Bank construction projects. Note that this 9% is additional to the usual management and program costs associated with school construction. In other words, the accelerated rebuild assumes twice the typical intensity of management and administrative resources. This USD 1,500,000 cost would be enough to cover at least one skilled project manager from the international market and support staff over 5 years. The present value of this cost is USD 1,251,000 at a 10% discount rate.

The other cost is the time value of investment associated with bringing forward construction by two years. The cost of a typical school of 6 classrooms capable of holding 200 students is estimated at USD 84,000 (personal communication, Classroom of Hope). Each year under the intervention USD 4,200,000 is spent on schools for four years, relative to USD 2,100,000 for eight years under counterfactual. The difference in net present value of these two time-series represents the time value of accelerating spending and equals USD 2,110,000. The total costs of the intervention are therefore USD 3,361,000 at a 10% discount rate.

Benefits

Schooling environments matter greatly for learning. The recent review by Barrett *et al.*, (2019) notes that characteristics such as appropriate lighting, airflow and temperature, plus design features that optimize the potential for learning influence education outcomes. Importantly in this context, the review also noted the importance of safe buildings for ensuring both children and teachers perform optimally in school. The review cites a range of literature, mostly from developed countries, that reinforces the broad point that physical schooling environments impact learning. For example, Earthman (2004) showed that US children in poorer buildings had 5 to 10 percentile points lower rank in standardized tests compared to children in better buildings.

For low-and-middle income countries, there is evidence demonstrating the importance of improved learning environments for better education outcomes. In an analysis of a school improvement, construction and upgrade program in Burkina Faso, researchers noted that having a higher quality school increased children's test scores in mathematics and language by 0.34 and 0.29 standard deviations of test scores respectively (Levy *et al.*, 2019), impacts that were sustained seven years later (Kazianga *et al.*, 2019). In Niger, schools that were provided with toilet facilities (including separate boys and girls toilets), playgrounds, and a potable water source improved learning levels in mathematics by 0.13 standard deviations, compared to control schools which mostly lacked these facilities (Bagby *et al.*, 2016). In Malawi, Mulera, Ndala and Nyirongo, (2017) note a positive correlation between the permanence of school buildings and pupil's test scores, while supporting research has shown learning outdoors reduces test scores by 0.093 standard deviations and reduces grade retention by 4 percentage points (World Bank, 2010; Dunga, 2013).

For Indonesia, the most recent and to the best of our knowledge, only evidence of the importance of infrastructure for learning comes from a study of madrasah schools across six provinces (Sawamoto and Marshall, 2020).[9] That study noted that the impact of improving an infrastructure index by 1 standard deviation[10] was associated with an increase in composite test scores by 0.09 standard deviations (Sawamoto and Marshall, 2020, Table 7 full model). The infrastructure index accounted for characteristics such as the presence of toilets and handwashing facilities, permanent rooms, corner libraries, electricity, internet connection and more.

Since no study has assessed the impacts of moving from temporary structures to more permanent ones in Lombok, for this analysis we adopt the same effect size for a 1 standard deviation improvement in infrastructure from Sawamoto and Marshall (2020) i.e. 0.09 standard deviations of test score improvement. To put this into context, across their entire sample, the difference between the worst and best schools in terms of infrastructure was 1.5 standard deviations. Given the fact that many of the temporary learning facilities in Lombok barely qualify as schools (e.g. tents and mosques) this does not seem an unreasonable assumption. The 0.09 s.d. test score improvement is also the lower end of effects noted in African contexts above suggesting that the assumption is not an overestimate.

To convert this learning improvement into a monetized value, we adopt the methodology described in Evans and Yuan, (2019). Specifically, the 0.09 s.d. effect size is converted into equivalent years of schooling, assuming that 1

9 The seminal study of Duflo (2004) examines the impacts of school construction on education outcomes in Indonesia. However, that study was based on large school expansion program that took place in the 1970s where the relevant counterfactual was the complete absence of a school. This is not an appropriate comparator to the situation in Lombok currently.

10 Across their entire sample, the difference between the worst and best schools in terms of infrastructure was 1.5 standard deviations.

standard deviation of test score improvement is attained in 5.75 years. This implies that being inside a temporary school instead of a permanent one, generates a learning loss equal to 0.5 years of normal schooling.

Multiple studies over several contexts note a rate of return of around 10% per year of education in Indonesia (see Yubilianto, 2020 for an overview). The impact of the intervention, is therefore avoiding this 5% drop in future income. We assume that the typical child benefitting from the intervention is 8 years old, and he or she starts working at age 15 to age 60. This is a conservative assumption since older children are closer to working age and therefore would have a higher net present value of income (since there is less discounting). The present value of the 5% avoided income loss is the benefit of the intervention, and averages around USD 915 per child when applied to the times series of gross product per capita described in Section 4.1. For a school of 200 children, this implies foregone future productivity of around USD 180,000 per school for each year children are learning in sub-optimal environments.

The total productivity benefits of the intervention are estimated at USD 50,150,000. The benefits are 14.9 times the size of the cost and therefore the BCR is 14.9

4.3 Sensitivity Analysis on Base Case Results

This section reports the results of additional sensitivity analyses on the base case results.

Sensitivity analysis 1: Changing baseline scenario

In the first sensitivity analysis, the assumption that schools will eventually be rebuilt is relaxed. Instead, it is assumed that schools will never be rebuilt (or not rebuilt within the next twenty years), and children will continue to learn in temporary facilities. While this is unlikely, it is nevertheless useful to assess results under such extreme scenarios. The effect of this change in assumptions is to increase marginal costs and benefits.

On the cost side, the total marginal costs equal the management costs (which are unchanged) and the full costs of schools, as opposed to the differences in present value from bringing school construction forward. This total cost is USD 14,564,000 at a 10% discount rate. This cost is a slight overestimate since replacing the temporary structures is not considered. If they were, then the marginal cost would be lower.

For benefits, this would mean a substantially larger number of children would experience better learning environments, 40,000 per year in steady state. In this case, total benefits are substantial, estimated at USD 301,368,000, assuming 20-year life span of the school. This is also potentially an under-estimate since it is likely that children would stop attending school, particularly in remote areas. In such cases the avoided education loss would be one whole year, instead of 0.5 years. In this extreme scenario, the BCR of the intervention is higher at 21.

Sensitivity analysis 2: Changing parameters

In the second sensitivity analysis, the original baseline and intervention scenarios are retained. However, the parameters of the model are altered. The table below documents the tested parameters.

Table 1: Parameters tested under one-way sensitivity analysis

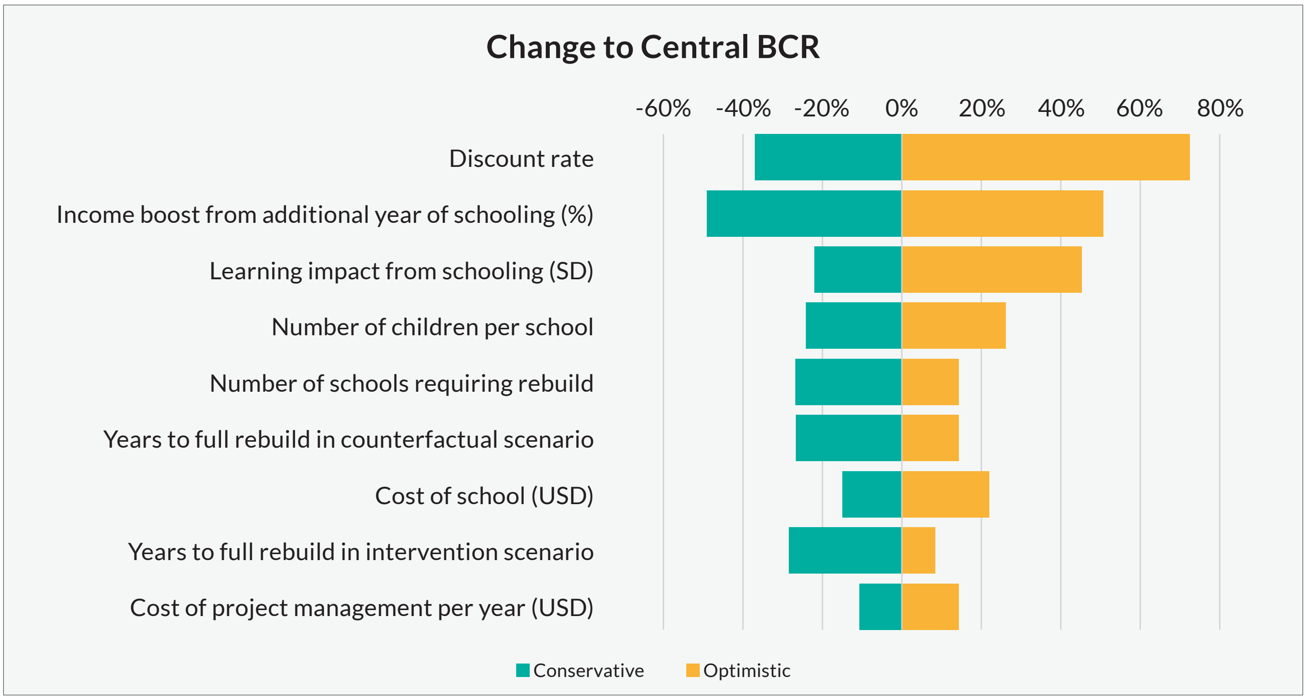
	Conservative	Base	Optimistic
Number of schools requiring rebuild	100	200	300
Years to full rebuild in counterfactual scenario	6	8	10
Years to full rebuild in intervention scenario	6	4	3
Number of children per school	150	200	250
Learning impact from intervention (SD)	0.07	0.09	0.13

	Conservative	Base	Optimistic
Income boost from additional year of schooling (%)	5%	10%	15%
Cost of project management per year (USD)	400,000	300,000	200,000
Cost of school (USD)	18,000	14,000	10,000
Discount rate	8%	10%	12%

Note: Conservative parameters decrease BCRs, optimistic parameters increase BCRs.

The results of the one-way sensitivity analysis are presented in Figure 2. The results are most sensitive to parameters that influence the present value of learning gains associated with the intervention. These are the discount rate, the income boost from additional schooling and the learning impacts from improved environments. For two of these parameters, the upside is larger than the downside suggesting the results are perhaps on the conservative side. The BCR is relatively stable for the remaining parameters with deviations altering results only +/- 10-20%.

Figure 5: One-way sensitivity analysis



4.4 Additional scenarios with cost savings and environmental benefits

In this section we present additional scenarios with cost savings and environmental benefits. These are reported separately because the evidence base for these benefits is not as firmly established as the education benefits of improved learning environments. Both benefits are predicated on the presence of a specialized privately owned plastic recycling factory in Lombok for which investment is currently being sought. The pro-rated cost of the factory, plus operating expenditure and a margin for profit of the private enterprise, are embedded into the retail price of the Blocks and therefore the costs of schools. As will become clear in the following section, these additional benefits only modestly increase the BCR.

Regarding cost savings, Block Solutions indicates that classrooms can be built at lower cost than using traditional brick and mortar. Estimates indicate that a typical school of six classrooms could be built for USD 60,000 rather than USD 84,000 – resulting in cost savings of USD 24,000 per structure. Spread over the four-year period of construction, these add USD 3,804,000 to the benefits at 10% discount rate.

The environmental benefits of recycling plastic are assessed as the avoided costs of alternative plastic pathways. Following the categorization described in the National Plastic Action Plan Partnership (World Economic Forum, 2020), these alternative pathways are i) collected and sent to semi-formal official dumpsites iii) burnt by households iv) improperly disposed, ending up as pollution on land and v) improperly disposed, ending up as pollution in waterways including oceans. The analysis indicates that one tonne of plastic recycled would avoid health, economic and environmental costs equivalent to USD 190 to 360 per tonne. Appendix A provides greater detail on the methodology used to estimate this figure. Each school built would lead to 12 tonnes of plastic being recycled or 600 tonnes of plastic for four years. At the midpoint value of the range USD 275, the additional benefits are USD 523,000 at a 10% discount rate.

Together the cost savings and environmental benefits add about USD 4,327,000 more to the benefit total, increasing gross benefits to USD 54,477,000 and the BCR to 16.2.

5. Conclusion and Future Research

This report conducted a cost-benefit analysis of rebuilding 200 schools destroyed by the 2018 Lombok earthquake. A summary of costs and benefits is presented in Table 2. The costs of the intervention are modest, estimated at USD 3,361,000. Focusing only on education benefits, the BCR is 14.9. Adding cost savings and recycled plastic benefits boosts the BCR to 16.2

Table 2: Summary of Costs and Benefits

Category	Value (USD)
COSTS	
Program management	1,250,960
Time value of accelerated spending	2,110,090
TOTAL COSTS	**3,361,049**
BENEFITS	
Increase in learning leading to higher adult productivity and income (Base case)	50,150,162
Cost savings (Additional scenario)	3,803,839
Recycled plastic (Additional scenario)	522,928
TOTAL BENEFITS (Base case + additional scenario)	**54,476,928**

Note: Reported costs and benefits are for a 4-year school construction program using recycled plastic Blocks, relative to an 8-year program. Figures are reported in 2020 USD and reflect a 10% discount rate.

The main policy implication of this report is that the governments of NTB and Indonesia should strongly consider rebuilding the destroyed schools as quickly as possible. The BCR is substantial at 15 rupiah for every rupiah spent. This is an excellent return on investment. Additional benefits in terms of costs savings are also substantial. In fact, the cost savings - if attainable – would outweigh the entire program cost by itself. The benefits of recycled plastic are valued at USD 522,928 for the entire program. These two benefits would increase the BCR to 16.2.

While recycled plastic waste benefits are relatively modest in this report, more research is required to ascertain the return-on-investment of additional and potentially more targeted plastic reduction programs. Indonesia has pledged to eliminate plastic pollution by 2040, and World Economic Forum (2020) estimates that USD 18.4 billion in capital investment and between USD 0.5 and 1.1 billion more in annual operations expenditure is required to reach this goal. Would these substantial investments be worth the cost? As a starting point, it is interesting to note that by 2040, the reduction in plastic pollution would be roughly 6 million tonnes less per year. Applying 2020 figures for Lombok for the benefit of avoiding one tonne of plastic - USD 190 to USD 360 – suggests benefits between USD 1.1 billion and USD 2.2 billion in 2040. This is against additional operating expenditure of USD 1.1 billion in 2040. Therefore, it seems that the annual benefits of avoided plastic would meet or exceed the operational expenditure, even when using benefit figures from 2020 for Lombok. The equivalent figures for the whole of Indonesia in 2040 would almost certainly generate higher benefits because the country as whole would be wealthier and willing-to-pay more for improved health and a cleaner environment. Calculating the exact magnitude of this benefit is left for future research.

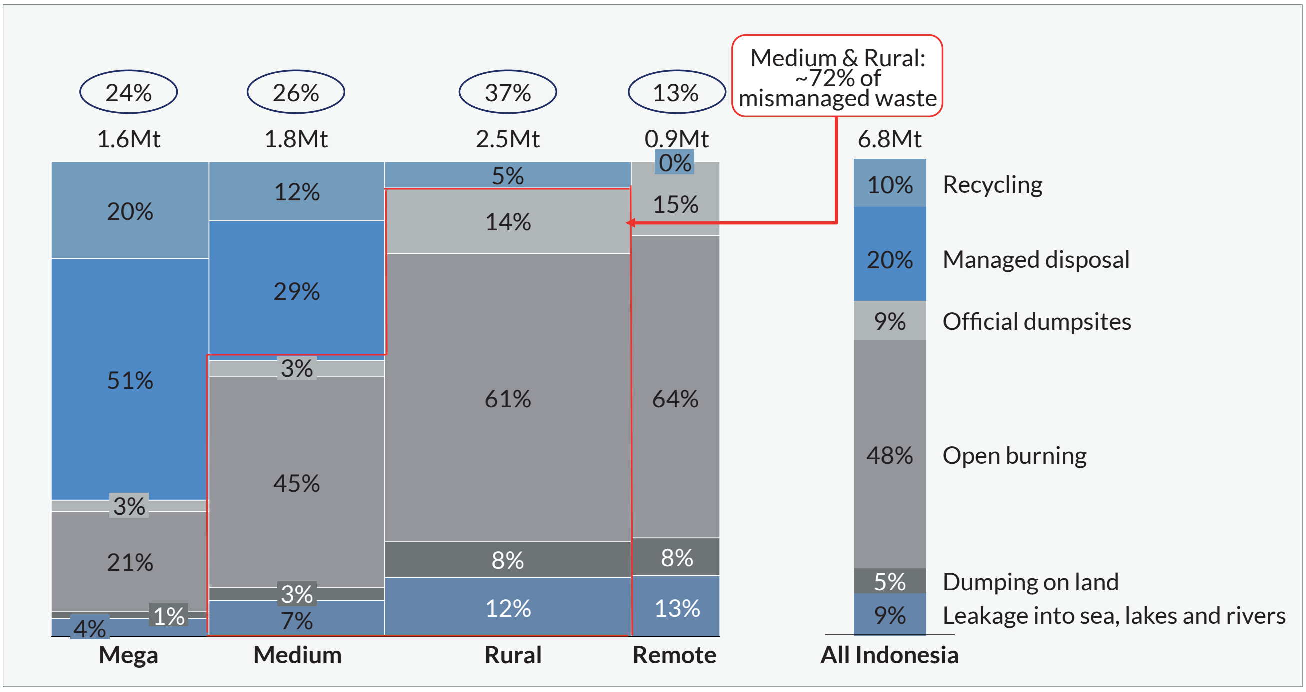
Appendix A
Framework for assessing the benefits of increasing plastic recycling

Brad Wong

Bjorn Larsen contributed the section on burning plastic

The National Plastic Action Partnership (NPAP), an initiative between the Government of Indonesia and the World Economic Forum, notes that 6.8 million tonnes of plastic waste are generated every year in Indonesia, a figure growing by 5% annually (World Economic Forum, 2020). NPAP identifies six different plastic-as-waste pathways – recycling, managed disposal, official dumpsites, open burning, dumping on land and leakage into waterways. Across Indonesia only 30% of waste is recycled or undergoes managed disposal to sanitary landfills. The remainder ends up being disposed in a way that generates negative environmental externalities, with almost half of plastic being openly burnt. As shown below, these averages mask substantial differences across four geographic archetypes in Indonesia, which NPAP names 'Mega', 'Medium', 'Rural' and 'Remote'. According to NPAP, Lombok is a mixture of rural and remote archetypes. Notably in rural and remote archetypes it is assumed there is no managed disposal to sanitary landfills, with waste instead ending up in semi-formal dumpsites with higher rates of runoff (called official dumpsites by NPAP). This is an appropriate characterization for Lombok since the largest landfill, Kebon Kongok, is already at capacity with significant challenges associated with liquid and solid waste runoff.

Figure 6: Plastic Waste in Indonesia



Source: National Plastic Action Partnership, World Economic Forum (2020)

For Lombok, the following breakdown is assumed across the plastic pathways broadly following the 'rural' geo-archetype and also noting that Lombok specific data indicates around 20% of waste is collected and ends up in landfill (KPMG, 2019; Abdullah, Hidayat and Sholehah, 2020):

- Recycled – 5%
- Managed disposal – 0%
- Official dumpsites – 20%
- Open burning – 55%
- Dumping on land – 8%
- Leakage into waterways – 12%

The excerpt below sets out the methodology for estimating the order-of-magnitude social, economic and environmental costs of these plastic pathways for Lombok. The benefits of increased recycling are simply the avoidance of these costs. The assumption is that plastic recycled under the Block Solutions model would have otherwise entered these plastic pathways proportionate to the current shares of each non-recycling pathway. This may not be a realistic assumption in the short run, where Block Solutions is likely to source plastic primarily from the nascent but growing system of local plastic recycling at waste banks (bank sampah). Nevertheless, in the medium and long run, should there be an increase in the demand for the low-cost building materials provided by Block Solutions, it will be necessary to increase the rate of plastic of recycling on the island.

The estimated weighted average cost of non-recycled plastic waste in Lombok is USD 190 to USD 360.

Table 3: Summary of welfare impacts of plastic waste by pathway

Pathway	Cost per tonne of plastic waste	Share of plastic (as a % of non-recycled plastic)	Estimation approach
Collected and sent to unsanitary landfill (official dumpsites)	• USD 30 to 60 for waste management • USD 3 to 10 for landfill operations • USD 20 to 50 for land value loss	21%	• Estimates of waste management from World Economic Forum, (2020). • Estimates of landfill operations cost from Kaza et al., (2018) and KPMG, (2019) • Estimates of landfill loss assume 6.7% reduction in land value for each 100m distance from land fill site, USD 25-50 per m^2 land values
Open burning	• USD 30 to 50 for those cooking with solid fuels (28% of the population) • USD 400 to 680 for those cooking with clean fuels (72% of the population) • USD 280 to USD 500	58%	Estimated the health effects associated with inhaled PM2.5 from plastic burning
Dumped on land	USD 60 to USD 150	8%	Triangulated based on values of land value loss and environmental costs from waterways
Leakage into waterways	USD 60 to USD 290	13%	Adopted costs from Deloitte (2019) which include revenue loss to tourism, aquaculture and fisheries plus cleanup costs
TOTAL	**USD 190 to USD 360**	**100%**	**Weighted average**

Note: All figures are in 2020 USD.

These figures can be used to give an approximate cost of plastic to the Lombok economy every year. To do this an estimate of total plastic waste generated in Lombok annually is required. Each person in Lombok generates 0.7kg of waste every day (KPMG, 2019). Across Indonesia, 13.1% of waste is plastic (World Bank, 2018). Applied to Lombok's 3.76 million people, this suggests annual plastic waste generation of 126,000 tonnes of which roughly 120,000 tonnes is not recycled. Therefore, the total welfare cost of non-recycled plastic to Lombok is USD 23,000,000 to 43,000,000 equivalent to 0.4% to 0.8% of Lombok's current gross product.

It is important to note that the evidence base for these impacts is incomplete and imprecise. Much is still to be learned for example, about the impact of plastic burning on human health and plastic pollution in oceans and land. Even less certain is the monetized costs of these impacts. Due to the nature of the uncertainty, **figures are rounded to the nearest USD 10 to avoid false precision** (except for landfill operations cost).

Recycling

Recycling is the reference against which all other plastic pathways are assessed, so is not included in the welfare impacts.

Collected and sent to semi-formal dumpsites (Cost per tonne of collection = USD 30 to 60; Cost per tonne for landfill operations = USD 3 to USD 10; Cost per tonne for landfill disamenity = USD 20 to 50)

Lombok has an incomplete and under-resourced waste management system. Waste is collected in village-level temporary collection sites before being transported to one of the landfill sites on the island. KPMG, (2019) notes that only 200,000 of the 900,000 tonnes of waste generated ends up in one of four of Lombok's landfills suggesting only 22% of waste is collected formally. Waste management is better in urban areas, with waste collection in Mataram estimated at ~60% (Macquarie Group, 2020). As mentioned above, landfills in Lombok are not considered sanitary with substantial waste leaching into the environment. While some plastic, especially high-grade plastic, is diverted to the waste banks, there is still much plastic that enters this waste management system. Increasing rates of recycling would reduce costs of waste management and landfill.

World Economic Forum, (2020) indicates that the 2017 cost of solid waste management for plastic and non-plastic in Indonesia was USD 0.5-1.0 billion annually. The component of this cost attributable to plastic is 30%, or USD 0.15 0.3 billion. The study notes that in the same year 29% of all plastic waste in Indonesia required collection (20% under managed disposal and 9% under official dumpsites) for a figure of 1,972,000 tonnes. Dividing cost of collection by number of tonnes generates a cost per tonne for management of plastic between USD 76 and 152 for Indonesia. Lombok has a GDP per capita around 37% of the Indonesian average. This means that costs, particularly for labour, are likely to be lower in Lombok. We therefore scale country level costs by 37% to account for lower costs. This suggests a collection cost of per tonne of plastic USD 30 to 60 for Lombok. This figure is consistent with the USD 30 to USD 75 range reported for lower-middle income countries[11] in Kaza *et al.*, (2018).

Land fill management costs are taken from Kaza et al. (2018) and suggest a range of USD 3 to USD 10 for developing countries. This is in line with USD 3 reported in KPMG, (2019) which is an estimate specifically for Lombok.

Landfills lower the value of surrounding land, due to their numerous dis-amenities such as odour, chemical leachate, and pests. By reducing the amount of waste that enters landfills, recycling reduces the need to create additional dumping grounds. To estimate this cost, we assess the land value reduction associated with creating a new landfill with the same specifications as the site at Kebon Kongok i.e. a size of 5.4 hectares and a capacity of 951,860 m^3 (Abdullah, Hidayat and Sholehah, 2020). An analysis of a different landfill site in Jatibarang, West Java, noted that land values increase by 6.7% for every 100m distance from the landfill (Dedi et al. no date). With an assumed land value range of USD 10 to 20 per m2 in rural Lombok, the above information can be used to estimate the land value loss associated with landfill. The cost by distance from the landfill is plotted below. While cost per m^2 is highest closest to the landfill the amount of affected area is lower. Increasing the distance away from the landfill reduces dis-amenity costs per m2 linearly but increases affected land by the square of the incremental distance giving the parabolic shape below. The total cost range is USD 25 million to USD 52 million depending on the assumed value of land.

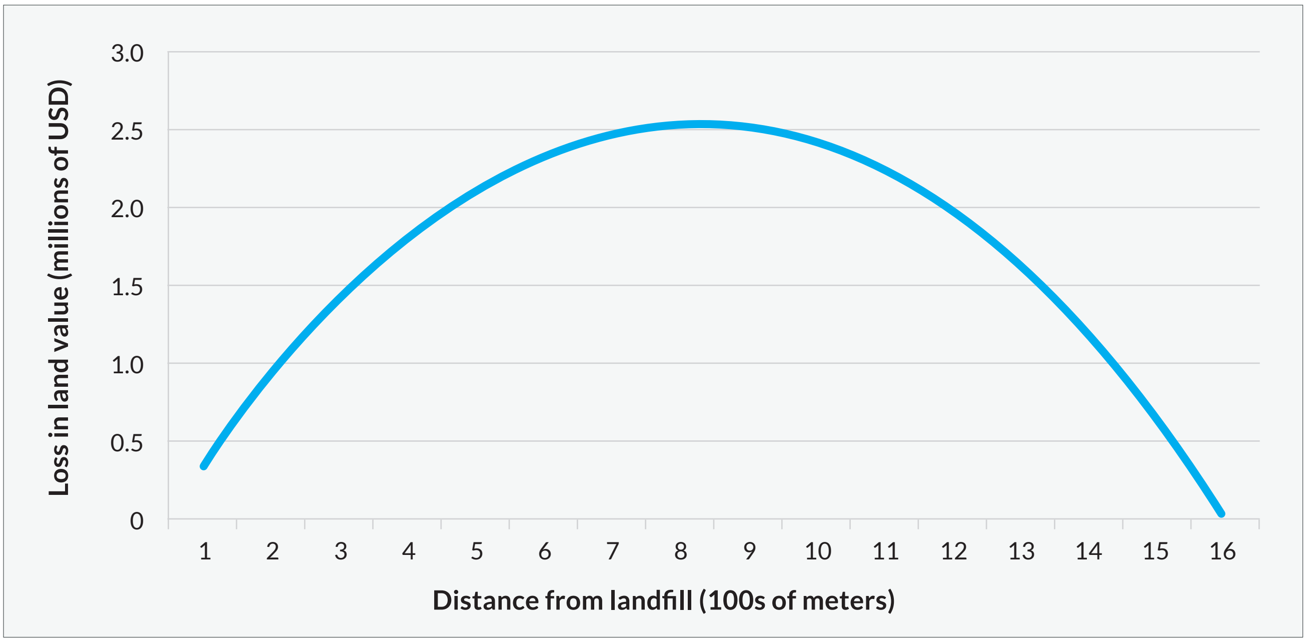
Given a capacity of 951,860 m^3 and an average density of plastic at 0.9 g / cm^3 a landfill the same size of Kebon Kongkok could hold 1,057,000 tonnes of plastic. The cost per tonne of plastic that enters landfill is therefore USD 20 to USD 50 (to the nearest USD 10).

11 While Indonesia is classified as an upper-middle income country, Lombok would be classified as lower-middle income if it were a country.

Open burning (Cost per tonne = USD 30 – 50 for those cooking with solid fuels; USD 400 – 680 for those cooking with clean sources)

Health damages from burning of plastic waste depend on how much of air emissions from burning are inhaled by the surrounding population. So-called intake fractions (iF) are often applied to estimate health damages of air emissions. Apte et al (2012) present intake fractions for ground level distributed emissions in cities worldwide with a population over 100 thousand. Intake fractions vary from less than 10 parts per million (ppm) in many small cities with good air circulation to 260 ppm in Dhaka, Bangladesh. For particulate matter (PM), this means that the population is inhaling 10-260 grams of PM per ton of PM emissions.

Figure 7: Land value loss by distance to landfill assuming land value of USD 20 per m2.



Source: Author's estimate

In Indonesia the intake fractions range from 10-30 ppm in many secondary cities to 90 ppm in Jakarta and 200 ppm in Pekanbaru (Apte et al, 2012). The size of the intake fractions depends largely on population density and air circulation or ventilation. An intake fraction of 20 ppm is applied to urban areas of Lombok and an intake fraction of 10 ppm is applied to rural areas due to the relatively high rural population density.

Emissions from the burning of plastic waste contains a variety of pollutants including PM. PM, and especially PM2.5, is the pollutant with the most established exposure-health response relationships. PM2.5 exposure-health response functions for six health outcomes (heart disease, stroke, COPD, lung cancer, lower respiratory infections (LRI), and diabetes type II) from the GBD 2019 are applied here (GBD 2019 Risk Factors Collaborators, 2020). This is likely to result in a conservative estimate of health damages from the burning of plastic waste as emissions from plastics also include many other toxic pollutants (Verma et al, 2016).

Health damages from PM2.5 do not only depend on the size of the intake fraction, but also on total PM2.5 exposure from all sources. This is because the PM2.5 exposure-health response functions in GBD are concave, i.e., incremental health effects are smaller at higher exposure levels than at lower exposure levels (GBD 2019 Risk Factors Collaborators, 2020). This means that households using solid fuels for cooking and other domestic purposes (thus facing a high PM2.5 exposure level) will experience less additional health effects from being exposed to PM2.5 emissions from burning of plastic than households that are not using solid fuels.

Therefore, based on differences in intake fractions and total PM2.5 exposure levels, health damages per ton of plastic burnt is estimated for four settings, i.e., two urban and two rural settings (Table 3). Ambient PM2.5 is set at 20 μg/m^3 in urban areas and 15 μg/m^3 in rural areas.[12] Total exposure for households using solid fuels for cooking is set at 150 μg/m^3.

Table 4: Population settings for estimation of health damages from burning of plastic waste

Setting where plastic is burned	Households cooking with solid fuels?	Intake fraction (ppm)	Total PM2.5 exposure (µg/m3)
Urban	No	20	20
Urban	Yes	20	150
Rural	No	10	15
Rural	Yes	10	150

The health damage cost ranges from USD400-680 per ton of plastic burned in rural and urban areas where household do not use solid fuels for cooking (Table 6). This is the case for the large majority of urban households and two thirds of rural households in West Nusa Tenggara (Table 5). The difference in health damage cost between the rural and urban areas is mainly due to the lower intake fraction in rural areas.

Table 5: Percentage of households using solid fuels for cooking in West Nusa Tenggara and Indonesia

Use solid fuel for cooking?	West Nusa Tenggara			Indonesia		
	Urban	Rural	Total	Urban	Rural	Total
Yes	18.9	34.7	28.5	7.6	38.0	23.1
No	81.1	65.3	71.5	92.4	62.0	76.9
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

Source: Demographic and Health Survey 2017 (National Population and Family Planning Board, et al. 2018). At Indonesia level, use of all types of solid fuels (coal, lignite, charcoal, wood, straw/shrubs/grass and agricultural crop) is reported. At West Nusa Tenggara level, use of only wood is reported in the data

The health damage cost ranges from USD 30-50 per ton of plastic burned in rural and urban areas where household use solid fuels for cooking (Table 6). The difference in health damage cost between the rural and urban areas is mainly due to the lower intake fraction in rural areas.

The large difference in damage cost between areas in which households use and do not use solid fuels is due to the concavity or flattening of the PM2.5 exposure-health response functions, i.e., households using solid fuels experience less additional health effects from being exposed to PM2.5 emissions from burning of plastic than households that are not using solid fuels.

In some urban and many rural areas, there will be some households that use and some households that do not use solid fuels for cooking. Average total exposure levels in these areas will therefore be somewhere between the ambient levels of 15-20 μg/m^3 and the level of 150 μg/m^3 in households using solid fuels. Health damage costs will therefore also be somewhere between the low and high presented in Table 6.

12 The GBD 2019 uses a nationwide urban and rural population weighted ambient PM2.5 of 19.4 μg/m^3 (HEI, 2020).

Table 6: Health damage cost of open burning of plastic waste

Setting where plastic is burned	Households cooking with solid fuels?	Health damage cost (US$ per ton of plastic)
Urban	No	680
Urban	Yes	50
Rural	No	400
Rural	Yes	30

Note: Health damages are estimated based on a PM2.5 emission coefficient of 20 kg/ton of plastic, as estimated by Yan et al (2016).

Health damage cost per ton of plastic burnt (C_P) is:

$C_P = I_P / I_T * C_T$

where I_P is PM2.5 inhaled from a ton of plastic burnt (g/ton); I_T is PM2.5 inhaled per 1 μg/m^3 of annual PM2.5 exposure (g/year); and C_T is the health damage cost per 1 μg/m^3 of annual PM2.5 exposure (US$/year). PM2.5 exposure can be outdoor ambient concentrations or household air pollution concentrations.

We also have:

$I_T = A * Q * P_T$

where *A* is an increment of annual PM2.5 exposure (here: 1 μg/m^3); *Q* breathing rate (365 days * 14.5 m^3/day/person)[13]; and P_T is population exposed to PM2.5. Furthermore,

$C_T = V_D * D_T = V_D * P_T * b_T * PAF$

where V_D is the cost of one death or value of averting one death (i.e., the value of statistical life (VSL); D_T is annual deaths associated with an increment of 1 μg/m^3 of annual PM2.5 exposure; b_T is baseline death rate in the population (thus $P_T * b_T$ is annual baseline deaths); and *PAF* is the population attributable fraction of annual baseline deaths associated with an increment of 1 μg/m^3 of annual PM2.5 exposure.

Health damage cost per ton of plastic burnt is then:

$C_P = V_D * I_P * b_T * PAF / (1 * Q)$

with C_P calculated for each type of health effect associated with PM2.5 exposure, i.e., using the six main health outcomes from GBD 2019. The V_D is calculated from World Bank (2016) at USD 343,505 for Indonesia in 2019. The b_T is from the GBD 2019 for West Nusa Tenggara.

Moreover, PM2.5 inhaled from a ton of plastic burnt (g/ton) is:

$I_P = iF * e * 1000$

where *iF* is a so-called intake fraction (ppm) and *e* is the emission coefficient (kg/ton of plastic).

The *PAF* is calculated based on the relative risks (RRs) of six major health effects from exposure to PM2.5 provided by the GBD 2019. The *PAF* and health damage cost is calculated for each of the four settings and for an incremental change in total PM2.5 exposure presented in Table 4.

Dumping on land (Cost per tonne = USD 60 to USD 150)

There is very little evidence of the impacts of dumping plastic on land outside of official dumpsites. As a proxy for the cost of dumping on land, the average of the low and high values for land value loss associated with landfill (USD 60 to 120) and the environmental costs of leakage into water (USD 60 to USD 290) are used. The rationale is that dumping on land would generate some combination of land value loss and eco-system loss. While this is the least precisely estimated of all the pathways, it generates the smallest impact by % of plastic waste, so it is not particularly consequential to the results.

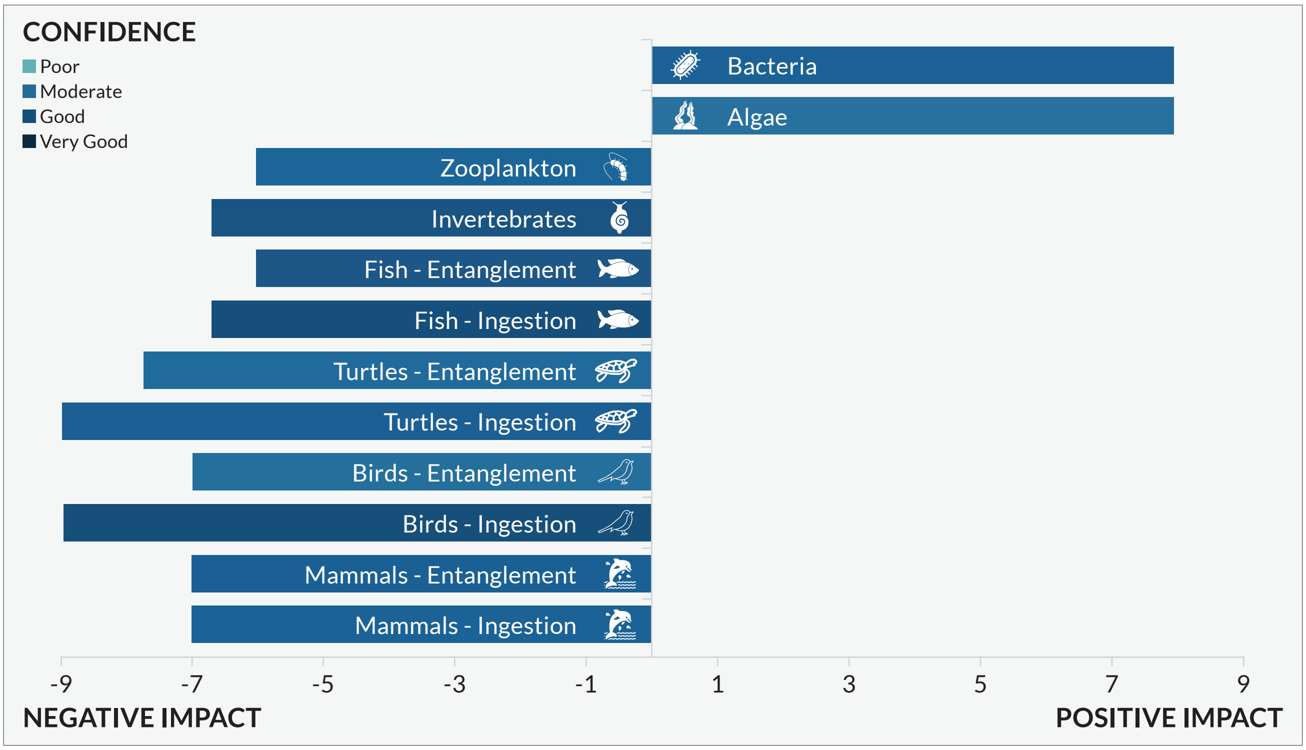
13 This is a commonly applied population breathing rate (see Apte et al. 2012).

Leakage into waterways (Cost per tonne = USD 60 to USD 290)

Plastic that ends up as pollution in waterways generates substantial ecological, social and economic costs (Macquarie Group, 2020). Plastic pollution harms marine animals (Galloway, Cole and Lewis, 2017). The review by Beaumont et al. (2019) shows that almost all marine animals, except for bacteria and algae, suffer frequent, irreversible, and wide-ranging impacts from plastic pollution through ingestion or entanglement. Plastic pollution reduces the value of water-based eco-system services, affecting the quantity and quality of animal source foods (Sussarellu et al., 2016; Galloway, Cole and Lewis, 2017), animals and environments of cultural importance (Beaumont et al., 2019), livelihoods of small and artisanal fishers (Phelan et al., 2020) and the demand for tourism (Ballance, 2000; Jang et al., 2014).

As described in Beaumont et al. (2019), the current state of knowledge on the welfare impacts of marine plastic pollution is limited. Relatedly, there are only a few estimates of cost of plastic pollution. Beaumont et al. (2019) speculates a 1-5% reduction in the value of marine ecosystem services, arriving at global cost per tonne of plastic pollution in the range of USD 3,300 to 33,000 (in 2007 figures) based on 2011 data. This particular figure is based on aggregate global ecosystem services for open oceans estimates presented in Costanza et al., (2014) divided by estimates of the stock of marine pollution in 2011. Adjusting to current context based on the ratio of GDP per capita (PPP) for Lombok to the world, the equivalent range for Lombok is USD 1,020 to USD 10,190 in current figures.

Deloitte, (2019) is another study estimating the economic costs of river plastic pollution. Focusing on loss of revenue for tourism and fisheries, as well as clean-up costs, the study identifies a cost of USD 6 to 19 billion for 87 coastal countries. The country level dashboard[14] accompanying the study notes a cost of USD 200 million to USD 900 million per year for Indonesia. Nurhati and Cordova, (2020) survey several studies and note a central estimate of 520,000 tonnes of plastic entering oceans from Indonesian rivers in 2019. Annual costs are a function of the *stock* of plastic in the ocean around Indonesia and not the flows. However, it is unclear what



Source: Beaumont et al. (2019) -9 impact indicates lethal or sub-lethal impact that is global, frequent and highly irreversible.

14 https://theoceancleanup.com/the-price-tag-of-plastic-pollution/

fraction of the plastic in the ocean would impact the three cost items mentioned in the Deloitte report. Some plastic that enters the ocean degrades into microplastic, some stays near the shore and some enters the deep ocean. Presumably only the plastic that stays undegraded near the shore would affect the costs mentioned in the Deloitte report, particularly noting that for Indonesia 90% of costs are associated with clean up. Lebreton, Egger and Slat, (2019) note that perhaps 50 million tonnes of the world's 130 million tonnes of plastic that has entered waters since 1950 remains as macro-plastic on shorelines with ages between 0-15 years old. This suggests that roughly 3.1 million tonnes of plastic is responsible for much of the costs near shorelines. In the case of Lombok this implies a cost per tonne of plastic of USD 60 to USD 290, two orders of magnitude less than the estimate from Beaumont *et al.* (2019).

Lastly, UNEP, (2014) estimate the cost of plastic litter entering the world's waters at USD 13 billion. This figure accounts for a variety of harms including higher greenhouse gas emissions, losses in revenue for fisheries, aquaculture and tourism, impacts on marine life and chemical leachate in the water. Given that this figure is close to the midpoint of the Deloitte report, the implied valuation for Lombok would be around USD 180 per tonne.

Given the uncertainty, this report adopts the figures reported in Deloitte (2019) and UNEP (2014), rather than the significantly higher values from Beaumont *et al.* (2019).

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