Exposure to Lead Paint in Low- and Middle-Income Countries

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Last updated: March 9, 2023 | Rethink Priorities

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    - In LMICs, the market share of solvent-based paints is roughly 30%-65% (80% CI) of all paints sold, which is higher than in HICs

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Historical basis: lead levels in the United States before the introduction of lead paint regulations
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    - Lead concentrations in paint historically used in US homes are roughly 6-12 times higher than lead concentration currently found in homes in LMICs

Speeding up lead paint bans across LMICs could lead to averted income losses of USD 18 billion to 155 billion (90% CI) and 150,000 to 5.9 million (90% CI) averted DALYs over the next 100 years

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Key takeaways

- Lead exposure is common across low- and middle-income countries (LMICs) and can lead to life-long health problems, a reduced IQ, and lower educational attainment. One important exposure pathway is lead-based paint (here defined as a paint to which lead compounds have been added), which is still unregulated in over 50% of countries globally. Yet, little is known about how much lead paint is being used in LMICs and to what extent it contributes to the health and economic burden of lead (link to section).

- Home-based assessment studies of lead paint levels provide evidence of current exposure to lead, but the evidence in LMICs is scarce and relatively low quality. Based on the few studies we found, our best guess is that the average lead concentration in paint in residential houses in LMICs is between 50 ppm and 4,500 ppm (90% confidence interval) (link to section).

- Shop-based assessment studies of lead-based paints provide evidence of future exposure to lead. Based on three

- review studies and expert interviews, we find that lead levels in solvent-based paints are roughly 20 times higher than in water-based paints. Our best guess is that average lead levels of paints currently sold in shops in LMICs are roughly 200-1,400 ppm (80% CI) for water-based paints and 5,000-30,000 ppm (80% CI) for solvent-based paints (link to section).

- Based on market analyses and small, informal seller surveys, we estimate that market share of solvent-based paints in LMICs is roughly 30%-65% of all residential paints sold (the rest being water-based paints), which is higher than in high-income countries (~20%-30%) (link to section).

- There is also evidence that lead-based paints are frequently being used in public spaces, such as playgrounds, (pre)schools, hospitals, and daycare centers. However, we do not know the relative importance of exposure from lead paint in homes vs. outside the home (link to section).

- As many studies on the exposure and the health effects of lead paint are based on historical US-data, we investigated whether current lead paint levels in LMICs are comparable to lead paint levels in the US before regulations were in place. We find that historical US-based lead concentrations in homes were about 6-12 times higher than those in recently studied homes in some LMICs (70% confidence) (link to section).

- We estimate that doubling the speed of the introduction of lead paint bans across LMICs could prevent 31 to 101 million (90 % CI) children from exposure to lead paint, and lead to total averted income losses of USD 68 to 585 billion (90% CI) and

150,000 to 5.9 million (90% CI) DALYs over the next 100 years. Building on previous analyses done by LEEP (Hu, 2022; LEEP, 2021) and Attina and Trasande (2013), we estimate that lead paint accounts for ~7.5% (with a 90% confidence interval of 2-15%) of the total economic burden of lead. We would like to emphasize that these estimates are highly uncertain, as our model is based on many inputs for which data availability is scarce or even non-existent. This uncertainty could be reduced with more data on the use of paints in LMICs (e.g. frequency of re-painting homes) and on the average dose-response relationship between residential lead paint levels and blood lead levels (link to section).

Editorial note

This report is a "shallow" investigation, as described here, and was commissioned by GiveWell and produced by Rethink Priorities from November 2021 to January 2022. We updated and revised this report for publication. GiveWell does not necessarily endorse our conclusions.

The primary focus of the report is to provide an overview of what is currently known about the exposure to lead paints in low- and middle-income countries. We reviewed the scientific and gray literature and spoke to 12 experts on lead paint. We mainly focus on decorative lead paints for residential use, but we also include and discuss information on lead paints for use outside the home, such as (pre)schools, daycare centers, and playgrounds.

We don't intend this report to be Rethink Priorities' final word on lead paint, and we have tried to flag major sources of uncertainty in the report. We hope this report galvanizes a productive conversation within the effective altruism community about exposure to lead paint. We are open to revising our views as more information is uncovered.

Lead exposure is toxic and comes partly from the use of lead-based paint across many low- and middle-income countries (LMICs)

Lead is a toxic metal that can accumulate in the body and increase the risk of life-long health problems. Low levels of exposure can increase the risk of mental disorders, kidney disease and cardiovascular diseases, and high levels can even lead to a coma or death. Moreover, lead can impair brain development and result in a reduced IQ, lower educational attainment, and increased antisocial behavior. **Children are especially vulnerable to neurological damage due to lead exposure** (WHO, 2022). Despite the knowledge about the damaging effects, **lead exposure is still common in low- and middle-income countries** (LMICs) (Schukraft and Bernard, 2021).

Lead-based paint is one of the major sources of lead exposure.[1] The main issue with lead paint in a domestic setting (e.g., on walls, windows, doors, or furniture) is that, as painted surfaces age and degrade with time, it can lead to ingestion of paint particles containing lead. Small children, who are most harmed by lead exposure, can ingest lead through normal hand-to-mouth behavior by playing and touching lead-contaminated house dust, soil, or in some cases paint chips (IPEN, 2020, p. 11). Yet, **lead-based paint is still unregulated in more than 50% of countries worldwide** (UNEP & Lead Paint Alliance, 2020, p. 1). Moreover, little is known about how much lead paint is being used and to what extent it contributes to the health and economic burdens of lead.

This report aims to determine the residential exposure to lead-based paints in LMICs by summarizing the results of existing studies in the literature and expert interviews, and by providing a very rough estimate of the economic and health benefits of speeding up the introduction of lead paint bans for residential use in countries where it is currently unregulated.

We would like to point out that lead-based paint only becomes a problem when it starts to peel, flake, chip, or crack (US EPA website). This means that the mere presence of lead paint constitutes a hazard, but not automatically a risk.[2] **The majority of this report is focused on hazard analysis, i.e., assessing the lead levels in paints in LMIC homes or shops**. An exception to this is our estimation of the benefits of speeding up the introduction of lead paint bans in LMICs, where we explicitly estimate the risks associated with lead exposure.

Types of paint

Paints form a large part of the coatings industry, which is generally differentiated into industrial and decorative categories.[3] "Decorative paint" refers to paints for the interior or exterior of homes and other buildings, such as schools and commercial buildings (IPEN,

[1] Other sources of lead exposure are, for example, lead-adulterated foodstuffs (especially spices), the use of improperly sealed aluminum-lead alloy cookware, and informal recycling of lead-acid batteries (UNICEF, 2020, p. 2).
[2] In the context of lead exposure, "hazard" and "risk" should be considered as disparate concepts. Hazard refers to the existence of the substance in question – in this case, the presence of lead in relevant contexts. Researchers only describe the presence of a "risk" when the hazard appears to lead to measurable effects in those exposed. For example, one might denote the effect that lead paint exposure has on blood lead levels as a risk. If we had more time, we would be interested to look into what conclusions can be drawn regarding the relationship between hazards and risks. To our knowledge, only a small set of studies exist which attempt to measure the contribution of various exposure sources to blood lead levels (e.g., Lanphear et al, 1995; Ericson et al, 2020; and Forsyth et al., 2018).
[3] These categories are not clearly defined. According to Gottesfeld (2015, p. 1), "there is no regulation or universal definition to differentiate "industrial" coatings from "architectural/decorative" coatings."

2017, p. 11). "Industrial paint" refers to "powder coatings, high performance coating, and automotive and marine paints" (IPEN, 2009, p. 10).

This report focuses primarily on decorative paints, which can be either water-based or oil-based depending on the solvent base. Plastic, acrylic, latex, and emulsion paints are water-based (IPEN, 2009, p. 10). Oil-based paints are sometimes also referred to as solvent-based paints (PG Paint & Design, 2020). In the following, we use these two terms interchangeably.

Paints can also be described by their final appearance. For example, "enamel paints" refer to paints with a hard, glossy finish (Lead Paint Alliance, 2021). Enamel paints are typically oil-based, but can also be water-based (Wikipedia).

In line with the Lead Paint Alliance, we define "lead-based paint" or "lead paint" as "a paint or a similar coating material to which one or more lead compounds have been added." Lead compounds can be added to paints for various reasons, e.g., to produce bright colors or to improve the drying or corrosion-resistance of paints. Both water-based and oil-based paints can contain lead, but lead compounds are mainly added to solvent-based paints (UNEP website).

Methods to measure lead in paint

Broadly, there are two main approaches to measuring lead content in paint: laboratory methods and X-ray fluorescence (XRF) spectrometry (WHO, 2020, pp. 2-10).[4] We outline these two approaches in the following.

Depending on the methodology, the lead content in new or existing paints is typically reported as a mass concentration (in %, mg/kg, or ppm [parts per million by weight]) or as a concentration per unit area on a surface (in mg/cm^2; also referred to as lead loading) (ibid, p. 3). For ease of exposition, we convert mass concentrations to ppm whenever possible.[5]

Unfortunately, lead loading measurements (in mg/cm^2) cannot be converted to ppm without knowing the total mass per unit area of the sample (see US HUD, 2012, App 1-3, for a more detailed explanation).[6] According to US HUD (2012, App 1-4), "on average 1 mg/cm^2

[4] Chemical test kits are another approach described in WHO (2020, pp. 2-10). We omit this approach as it is the least accurate method to measure lead in paint, and we have not encountered any studies that use chemical test kits.
[5] According to WHO (2020, p. 4), "0.009% = 90 ppm = 90 mg/kg."
[6] We learned in a conversation with Elsbeth Geldhof, a paint expert, that the thickness of a paint layer can differ enormously. For instance, a layer is thinner when the brush runs out of paint. According to US HUD (2012, App 1-3), it is theoretically possible that a lead loading below 1 mg/cm^2 corresponds to a very high mass concentration of more than 100,000 ppm.

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is about equal to 1% lead," that is, 10,000 ppm. Thus, in the following, we assume that 1 mg/cm^2 = 10,000 ppm as a very rough conversion to facilitate the comparison of results across studies. However, we urge you not to take this conversion literally, as there is possibly a very large error margin.

The same measurement methods can be used for both new paints purchased in stores (e.g., paint in a can), as well as already dried paint on walls and other surfaces. The only difference lies in the sampling method: New paints typically need to be applied onto swatches and allowed to dry before they can be analyzed, either in situ via specialty equipment, or as paint chips in the laboratory (WHO, 2020, p. 4).[7]

Different thresholds of lead levels exist above which a paint is considered lead-based. Importantly, **there is no known safe level of lead exposure** (UNEP & Lead Paint Alliance, 2020, p. 2). Many countries have regulatory limits for the concentration of lead in paint. The recommended concentration limit by the "Model Law and Guidance for Regulating Lead Paint" is 90 ppm. It is the lowest legal limit that has been set in countries (Lead Paint Alliance, 2018, p. 5). Some countries use higher legal limits, such as 600 ppm, or no legal limits. Other commonly used thresholds we found in the literature are those by the US Environmental Protection Agency (US EPA), which are 1 mg/cm^2 or 5,000 ppm (US EPA, 2001, p. 1207). These thresholds are not risk-based limits, but rather administrative thresholds for the purpose of addressing legacy paint on walls.[8] **In this report, we choose the lowest commonly used threshold (i.e., 90 ppm) to define a tested paint as lead-based.** We choose this threshold as it is the most protective limit and also "technically feasible for manufacturers to achieve by avoiding the addition of lead compounds and taking into account residual (unintentional) lead content in certain paint ingredients" (UNEP & Lead Paint Alliance, 2018, p. 5).

Laboratory methods are precise but expensive

Laboratory methods[9] typically require the researcher to collect dried paint samples from a prepared sample on a swatch or from the surface in question. See WHO (2020, pp. 5-6) for a more detailed description of these methods.

[7] According to WHO (2020, p. 4), one method exists where lead paint can be measured in a liquid paint sample using a special sampling cup. We have not seen any study that used this method, and it seems rather controversial among the lead paint experts we talked to.
[8] The US EPA thresholds have been criticized for being insufficiently protective (e.g., Neltner, 2018).
[9] The most commonly used laboratory methods are flame atomic absorption spectrometry (FAAS), electrothermal atomic absorption spectrometry (ETAAS), and inductively coupled plasma atomic emission spectrometry (ICP-AES) (WHO, 2020, pp. 5-6).

Two advantages of these methods are that they can measure lead content in paint at low detection limits and generally produce more accurate results than the other measurement methods (WHO, 2020, p. 12). Two downsides are that they can be quite expensive and require skilled laboratory technicians. Moreover, these methods require collecting paint chips and flakes from walls and other surfaces, which is rather invasive and requires a repainting of a surface to cover exposed layers of potential lead paint (WHO, 2020, p. 10).

We encountered relatively few studies using laboratory methods to measure lead content in existing paint on walls, which we suspect might be due to their relatively high cost and invasive nature. Our impression from reading the literature is that results from lab digestion methods are most frequently reported in terms of ppm or mg/kg.

X-ray fluorescence (XRF) spectrometry is useful for screening whether paint contains high levels of lead

Most studies we found that measure the lead content on painted surfaces use an XRF spectrometer. XRF devices can broadly be grouped into laboratory XRF devices and portable and hand-held XRF devices (often referred to as pXRF). Laboratory devices are generally more accurate and have lower detection limits than portable devices. Portable devices have the advantage of being non-invasive and can be used for in situ testing (WHO, 2020, p. 6-8).

We learned in a conversation with the US EPA that their understanding is that XRF spectrometry has a larger margin of error in determining the exact lead content in paints compared to laboratory methods. It is their understanding that XRF devices are more useful for screening to determine whether paint contains high levels of lead. They are less accurate in determining exact lead contents compared to laboratory methods.[10]

In most XRF analyses we encountered, the lead content is reported in terms of lead loading (mg/cm^2). We also found some studies in which XRF results are reported in terms of ppm. According to WHO (2020, p. 4), "some XRF devices have an option to calculate and display units in ppm, but the density and thickness of the paint must be entered to enable this

[10] This has been confirmed by paint expert Elsbeth Geldhof and by a UNEP Lead in Paint Community of Practice (LiP CoP) discussion on testing (see LiP CoP, 2021).

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calculation." We learned in conversations with the US EPA and Elsbeth Geldhof that this typically yields less accurate results.[11,12]

Residential lead paint exposure in LMICs

Home-based assessments provide evidence of current lead paint exposure, while shop-based assessments help gauge future exposure

Lead exposure in LMICs is still a nascent research topic, and "the wide availability of lead paint on the market in LMICs was mostly unknown until 2009" (Brosché, 2022, p. 10). Thus, studies on lead exposure in LMICs are scarce and not available for all countries. Moreover, as the "awareness of lead paint as a source of lead exposure is still very low in many countries," lead paint is often not investigated in studies that analyze different lead exposure sources (Brosché, 2022, p. 10). Thus, caution must be applied when drawing any population-wide conclusions on lead exposure in LMICs.

To our knowledge, **there are broadly two strands of literature that speak to the residential lead paint exposure in LMICs: home-based assessments and shop-based assessments**. Home-based assessment studies measure lead contents in existing paints on walls and other surfaces. In most cases, these studies rely on XRF spectrometry as a non-invasive means to gauge lead levels in residential areas. In our view, the **key strengths of home-based assessments are that they provide direct evidence of the lead levels people are exposed to in their homes and insights into current exposure to lead paint**. Even if lead paints are no longer sold, it is not uncommon to find lead-based paints in older houses and structures.

Shop-based assessment studies measure lead contents in new paints sold in shops. These studies either rely on laboratory methods or on XRF spectrometry. The **key strength of shop-based assessments is that they help gauge future exposure to lead paint. However, they provide only indirect evidence of exposure, as it is not clear how much paint really ends up being used in homes**. Even in countries that ban lead-based paints, the bans are

[11] To be more precise, the US EPA explained to us that some XRF devices use an algorithm to convert from mg/cm^2 to ppm, which is based on predefined parameters and therefore yields less accurate results (see LiP CoP, 2021). Moreover, Elsbeth Geldhof explained that some elements in a surface absorb and/or block the X-rays from an XRF unit more than others, resulting in slight variations in the penetration rate of the X-rays. It is therefore not feasible to make accurate statements on the thickness of the paint layer in the location, because of the small surface where an XRF unit is reading (around 0.8cm^2 or even smaller, depending on the type of XRF unit used) and the varying thickness of a single paint layer.

[12] According to Sara Brosché, "there is also a consumer product measurement program that provides results in ppm (not only a specific lead paint program). The consumer product assumes a homogeneous sample so it is important to only measure the top layer if used on paint."

not always enforced (IPEN, 2020, p. 9). Thus, shop-based assessments can also help us understand in which countries lead-based paints are still being sold and used despite existing lead paint regulations.

However, a major caveat of both home-based and shop-based assessment studies is that they are often undertaken to investigate whether lead paint in LMICs exists at all, and not with the goal of estimating population-wide exposure levels. Thus, the results of these studies are difficult to generalize.

Another noteworthy study that does not fit in the aforementioned categories is Ericson et al. (2021), which we review in more detail in Appendix 1. Ericson et al. (2021) identified probable sources of lead exposure based on a systematic review of previous studies and concluded that "lead-based paint does not appear to be a major source of lead exposure in LMICs" (p. e151). We are very skeptical about the conclusion of this study and therefore put little weight on its results.

Several other types of studies exist that speak to lead paint exposure which we decided not to review as part of this report. For example, a number of studies measure lead levels in dust in homes or other buildings. As lead in dust can not only come from lead-based paint but also from other lead sources, such as lead-contaminated soil or from industrial pollution, it does not provide direct evidence on lead-paint levels. Hence, we do not focus on dust lead levels in this report. Moreover, isotopic ratio analysis studies are a means of "assessing contributing factors if lead sources to elevated blood lead levels" (Jaeger et al., 2009, p. 693), that is, they are useful to gauge the extent to which elevated blood lead levels are a result of lead-based paint. Unfortunately, isotopic ratio studies that take lead paint into account are very scarce, even in high-income countries (HICs), and we have not encountered any isotopic ratio analysis studies carried out in LMICs.[13]

In the following, we first review the literature on lead paint levels in existing residential paints in LMICs to gauge current exposure to lead. We then review the literature on lead levels in new paints sold in shops in LMICs and combine it with information on market shares of different paint types to gauge future exposure hazards.

Home-based assessments show lead paint levels in the range of 50 ppm to 4,500 ppm in several LMICs

[Confidence: relatively low. We found only a handful of home-based assessment studies on residential lead paint levels in LMICs, most of which have a relatively low quality and are likely prone to

[13] This is likely because this type of analysis is expensive and time-consuming, as we learned in a conversation with Sara Brosché from IPEN.

selection bias. It is unlikely that a more extensive literature review would change our view, but the publication of more home-based assessment studies in LMICs might alter our conclusions.]

While many assessments of residential lead paint exposure in HICs have been conducted, few such studies have been undertaken in LMICs (Ericson et al., 2019, p. 1383). In the following, we first review the most prominent recent study on residential lead paint exposure we came across by Ericson et al. (2019) in Indonesia and outline some major critique points. This study has the largest sample size and (in our view) the overall highest quality among the studies we found. We then briefly outline the results of six other home-based assessment studies carried out in LMICs in recent decades.

In the following, we focus on lead levels found on walls and other surfaces in residential houses. However, we would like to note that recent studies also found lead in other types of paint used in homes, such as face paints, finger paints, and paint on toys (e.g., Erbas et al., 2017; Mateus-García and Ramos-Bonilla, 2014; Shen et al., 2018).

Ericson et al. (2019):
The most prominent and most frequently mentioned[14] recent study that features home-based lead paint assessments is Ericson et al. (2019), which assessed the prevalence of lead-based paint exposure in Jakarta, Indonesia. Using a field portable XRF device, the team assessed 1,244 painted surfaces for the presence of lead (in mg/cm^2) from 103 homes in 13 different neighborhoods of Jakarta.[15] Using the US EPA guideline value for paint (1 mg/cm^2) (EPA, 2001, p. 1207), they found that 11% of the assessed homes had at least one measurement above the threshold. Moreover, 1.5% of the 1,244 XRF measurements in homes showed lead levels higher than 1 mg/cm^2. Ericson et al. (2019) concluded that in Greater Jakarta, "exposure risk to lead-based paint appears low" (p. 1382).

The conclusion drawn by Ericson et al. (2019) is contested by several experts in the field, some of which we outline in the following. We would like to emphasize that we may lack sufficient technical knowledge on measuring and reporting lead in paint to thoroughly evaluate the validity of those critiques, so we recommend taking our impressions with a pinch of salt.

In separate conversations, Sara Brosché at IPEN and staff at the US EPA raised several concerns about Ericson et al.'s (2019) analysis and conclusions. For instance, Brosché criticized Ericson et al. (2019) for equating a 90 ppm lead limit in new paint with the US EPA cut-off limits for lead loading (1 mg/cm^2) to define lead paint (UNEP & Lead Paint

[14] This article was frequently mentioned in many of our expert interviews.
[15] The authors also assessed the prevalence of lead-based paint in preschools, which we describe here. Moreover, besides measuring lead in paint, they also assessed the presence of lead in dust. We do not describe those results here.

Alliance, 2018, p. 5). The EPA limit is an "administrative trigger" for interventions in the US and not a health-based standard, whereas the 90 ppm limit is the current internationally recommended regulatory lead limit for new paint. The EPA threshold defines the usage of the phrase "lead-based paint," but it does not indicate whether a lead hazard exists. Similarly, the US EPA emphasized that it is important to understand that this limit is an "action level" for landlords and others for remediation or other action to address lead in paint on walls, and is not a risk-based limit.

As we mentioned here, on average, a lead loading of 1 mg/cm^2 corresponds to a mass concentration of 10,000 ppm and can theoretically even correspond to a very high mass concentration above 100,000 ppm (US HUD, 2012, App 1-3, 1-4). Thus, relying on the 1 mg/cm^2 threshold could potentially lead to an underestimation of the number of houses in which people are exposed to paint with unhealthy concentrations of lead. However, we do not know how likely this scenario is.

Based on the critique of the threshold choice of (1 mg/cm^2), we used Ericson et al.'s (2019) supplementary data to calculate how many samples had lead levels above the instrument limit of detection (0.02 mg/cm^2).[16] We found that ~14% of the 1,244 XRF samples taken in homes had lead levels above the limit of detection. Moreover, ~47% of the homes had at least one XRF measurement (wall or other surface) above the detection limit.[17] Thus, given that all experts we talked to asserted that there is no known safe level of lead exposure, we find it more plausible to focus on the samples that exceeded the instrument limit of detection rather than the administrative threshold. These numbers paint quite a different picture than the conclusion Ericson et al. (2019) draw, implying that almost half of the houses (instead of 11%) had at least one positive XRF measurement.

For the sake of comparison of Ericson et al. 's (2019) findings to other studies, we tried to make a rough conversion from lead loadings into ppm. Using the highly uncertain assumption that 1 mg/cm^2 = 10,000 ppm and the assumption that samples below the instrument limit of detection had a lead loading of 0 mg/cm^2, we find an average lead concentration of ~700 ppm.[18]

Overall, we tentatively conclude that the study conducted by Ericson et al. (2019) provides more reasons to believe that there may be considerable lead exposure from lead paints in Jakarta than not. We are not convinced that Ericson et al. 's (2019, p. 1) conclusion that "[e]xposure from lead-based paint in Greater Jakarta appears to be limited" is fully warranted.

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[16] The limit of detection of 0.02 mg/cm^2 would correspond to 200 ppm under our assumption that 1 mg/cm^2 = 10,000 ppm.
[17] Our calculations are available upon request.
[18] This is a simple average of all 1,244 home-based XRF samples in Ericson et al. (2019). Our calculations are available upon request.

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Other home-based assessment studies:
In the following, we briefly summarize six other home-based assessment studies of lead paint that were conducted in LMICs. All of the below studies are subject to two major limitations, albeit to different degrees. First, the sample sizes are generally low, and very few samples were collected per home, in some cases only one per dwelling. This might lead to an underestimation of the true proportion of houses with lead-based paint. Second, the houses were generally not selected randomly, but chosen based on either being in a state of degeneration with visibly peeling or flaking of paint, or selected based on high blood lead levels of their inhabitants. This likely leads to an overestimation of the presence of lead paint in typical homes.

- **South Africa:** Montgomery and Mathee (2005) collected 316 residential paint samples from 60 homes in randomly selected suburbs in Johannesburg, South Africa. Using laboratory analysis of paint chips, they found lead concentrations ≥ 90 ppm in 100% of samples, and ≥ 5,000 ppm in 17% of samples. They found an average paint concentration of 4,470 ppm and a maximum concentration of 290,000 ppm for interior paints and 57,000 ppm for exterior paints. The authors only sampled dwellings in a state of degeneration with visible flaking of paints.

- **Nigeria:** Nduka et al. (2008) collected flake paint samples in 168 residential and non-residential buildings in four large cities in Eastern Nigeria. Using laboratory analysis, they found paints containing between 40 and 70 ppm of lead, with little variation across sectors. The highest lead levels were found in residential buildings. Only buildings in a state of degeneration were included.

- **India:** Clark et al. (2005) measured lead contents with XRF in the residential environments of children with very high blood lead levels in two Indian regions. They found that in 5 out of 10 homes of the children with elevated blood lead levels, three or more locations in or around the home showed lead paint levels of 1 mg/cm^2 or higher, with a median level of 0.4 mg/cm^2.

- **Kenya:** Ogilo et al. (2017) collected paint chips from the interior walls of 12 randomly picked residential houses in Nairobi County, Kenya. They found an average lead concentration of 290 ppm using laboratory analysis. Moreover, they found lead concentrations above 90 ppm in 50% of the sampling points. The authors only collected one sample per house.

- **The Philippines:** Riddell et al. (2007) tested paints for lead in the homes of a convenience sample of 26 children with a high blood lead level (> 35.7 µg/dL) in the rural Philippines. Using a laboratory analysis of paint chip samples, they found that 12% of the paint chip samples had lead levels exceeding 5,000 ppm.

- **Nepal:** Dhimal et al. (2017) ran a household survey in Kathmandu Valley, Nepal, and found that 81% of homes of 201 children with a blood lead level > 5 µg/dL "had some parts of their house painted with lead-containing paints." Our understanding is that they did not measure lead levels in paints, but determined the presence of enamel paints in homes by visual inspection.

Thus, using the very rough assumption that 1 mg/cm^2 = 10,000 ppm, as we explained here, we find that the **home-based assessment studies we summarized reported average lead paint concentrations between roughly 50 ppm in the lowest and 4,500 ppm in the highest cases**. Based on these studies, our intuitive best guess is that the average lead concentration in paint in residential houses in LMICs falls into this range (with an 80% confidence interval). Nonetheless, we would like to emphasize that this guess is based on few studies and relatively low-quality evidence that is hard to summarize and extrapolate due to differences in study design and major study limitations. All of the home-based assessments in LMICs we came across found traces of lead paint, but that might be due to publication bias. As lead-based paint is still being sold in shops in many LMICs, we find it plausible that many more LMICs than listed above have non-negligible lead paint levels present in houses. **Overall, we tentatively conclude that the rather scarce evidence from home-based assessments provides a reason for concern about lead-based paint exposure in at least some LMICs.**

Shop-based assessments show that new paints sold in LMICs are frequently in the range of tens of thousands of ppm of lead

[Confidence: medium. Many shop-based sampling studies on lead paints in LMICs exist, though these are mostly based on small sample sizes and are likely prone to selection bias, potentially leading to an overestimation of lead paint levels in LMICs. A more thorough review of the methodologies used in these studies might help us gauge to what extent the tested paints are representative of typical paints sold in LMICs.]

Due to differences in chemical properties, solvent-based paints are more likely to contain lead compounds than water-based paints

As explained in Types of paint, there are water-based paints and solvent-based paints. We learned in conversations with two experts (Elsbeth Geldhof, paint expert, and Sara Brosché at IPEN) that these two types of paint differ in their suitability to contain lead.

From talking to these two experts, we learned that **it is more likely to find lead compounds in solvent-based paints than in water-based paints** for two reasons:

1. **Lead compounds have chemical properties that make them usable and beneficial for solvent-based paints**. For example, lead-based pigments are added to solvent-based paints to give the paint its color, make it opaque, and provide corrosion resistance, whereas other lead compounds contribute to better drying properties (IPEN, 2017, p. 13).

2. There are many lead-free pigments for use in both solvent-based and water-based paint available on the market. However, finding the right replacement formulation may take some time and may come with a certain cost for some colors. Moreover, it is **easier to find a substitute for lead in water-based paints than in solvent-based paints**.

However, Geldhof also emphasized that it is definitely not impossible to find lead-based pigments in water-based paints and that this depends on various factors, such as the availability of paint materials, the culture, and the type of object. Brosché seconded this and explained that **there are cases in which water-based paints can contain lead**, such as when emulsion paints and latex paints have been mixed with a solvent-based color. Moreover, she pointed out that lead compounds can also unintentionally end up in water-based paints due to contamination between different production lines.

Our best guess is that average lead levels of paints currently sold in shops in LMICs are roughly 200-1,400 ppm (80% CI) for water-based paints and 5,000-30,000 ppm (80% CI) for solvent-based paints

We reviewed the literature for shop-based assessments of lead contents in different types of paint in LMICs and found three reviews of shop-based sampling studies. These shop-based assessments provide indirect evidence of the levels of lead paints in the homes of people, as they are not informative on exactly which types and what quantities of paints people buy and use in their homes. We would like to emphasize that shop-based studies are a better proxy for future rather than current and past exposure to lead in paint. We summarize these three reviews in the following.

O'Connor et al. (2018):

O'Connor et al. (2018) undertook the most comprehensive review of recent shop-based assessments of paints in LMICs that we came across. According to their findings, "**lead concentrations in home paints, particularly enamel paints, are often above 10,000 mg/kg, in countries such as India, most south-east Asian, African, and Latin American countries, as well as many east European countries**. The percentage of sampled paints exceeding 600 mg/kg, a commonly used regulatory threshold, reaches nearly 50% in many countries" (p. 98). Table 1 below shows an example of their findings for new paints in African countries. As can be seen in the table, new paints in African countries frequently reach maximum lead concentrations in the hundreds of thousands of mg/kg (= ppm).

Table 1 - Lead content of new paints in African countries (O'Connor et al., 2018, p. 91)

Table 6
Lead content of new paints in African countries.

Location	Year[a]	Product type	n[b]	Average (mg/kg)	Geometric mean (mg/kg)	Median (mg/kg)	Max (mg/kg)	> 600 mg/kg (%)	Reference
Benin	2017	Home paints	28	N/A	N/A	N/A	180,000	N/A	(IPEN, 2017b)
Cameroon	2013	Paint	61	N/A	N/A	2150	500,000	64%	(Gottesfeld et al., 2013)
Cameroon	2015	EP	35	N/A	N/A	N/A	N/A	51%	(CREPD, 2015)
Cameroon	2017	Home paints	65	N/A	N/A	N/A	220,000	N/A	(IPEN, 2017b)
Egypt	2009	EP	20	26,200	1338	4717	N/A	65%	(Clark et al., 2009)
Egypt	2014	EP	52	14,300	N/A	N/A	122,000	48%	(Clark et al., 2014b)
Egypt	2017	Home paints	58	N/A	N/A	N/A	43,000	N/A	(IPEN, 2017b)
Ethiopia	2013	EP	23	18,500	N/A	N/A	130,000	83%	(UNEP, 2013)
Ethiopia	2015	EP	36	N/A	N/A	N/A	110,000	78%	(PAN, 2015)
Ethiopia	2017	Home paints	36	N/A	N/A	N/A	100,000	N/A	(PAN, 2017)
Ghana	2013	EP	18	5030	N/A	N/A	42,000	28%	(UNEP, 2013)
Guinea	2017	Home paints	18	N/A	N/A	N/A	9700	N/A	(IPEN, 2017b)
Ivory Coast	2013	EP	20	8700	N/A	N/A	42,000	65%	(UNEP, 2013)
Ivory Coast	2015	EP	44	N/A	N/A	N/A	190,000	75%	(JVE, 2015)
Ivory Coast	2017	Home paints	51	N/A	N/A	N/A	470,000	N/A	(JVE, 2017)
Kenya	2012	EP	31	14,900	N/A	N/A	69,000	81%	(iLima, 2012)
Kenya	2017	Home paints	51	N/A	N/A	N/A	160,000	N/A	(CEJAD, 2017)
Morocco	2017	Home paints	33	N/A	N/A	N/A	140,000	N/A	(SMTCA, 2017)
Mozambique	2017	Home paints	32	N/A	N/A	N/A	25,000	N/A	(IPEN, 2017b)
Nigeria	2007	Home paints	21	14,500	N/A	N/A	50,000	96%	(Adebamowo et al., 2007)
Nigeria	2009	EP	25	15,750	7341	N/A	N/A	96%	(Clark et al., 2009)
Nigeria	2009	EP	23	36,989	N/A	23,866	129,837	100%	(Kumar, 2009)
Nigeria	2017	Home paints	54	N/A	N/A	N/A	160,000	N/A	(IPEN, 2017b)
Senegal	2009	EP	21	5866	N/A	2771	29,717	76%	(Kumar, 2009)
Seychelles	2009	EP	28	24,880	1167	2527	N/A	61%	(Clark et al., 2009)
South Africa	2009	EP	29	19,862	N/A	11	195,289	62%	(Kumar, 2009)
Sudan	2017	Home paints	25	N/A	N/A	N/A	71,000		(IPEN, 2017b)
Tanzania	2009	EP	20	14,537	N/A	4130	120,862	95%	(Kumar, 2009)
Tanzania	2015	EP	56	12,541	N/A	N/A	99,000	57%	(AGENDA, 2015)
Tanzania	2017	Home paints	46	N/A	N/A	N/A	84,000	N/A	(IPEN, 2017b)
Togo	2017	Home paints	27	N/A	N/A	N/A	42,000	N/A	(IPEN, 2017b)
Tunisia	2013	EP	30	17,900	N/A	N/A	170,000	63%	(UNEP, 2013)
Uganda	2017	Home paints	30	31,694	2106	1450	150,000	57%	(NAPE, 2017)
Zambia	2017	Home paints	39	14,500	N/A	15,800	50,000	N/A	(CEHF, 2017)
Average	2014	N/A	35	17,839	N/A	N/A	132,480	68%	N/A
Average (weighted by n[b])	2015	N/A	40	17,784	N/A	N/A	154,940	66%	N/A

Abbreviations: EP = Enamel paint.
[a] The year of publication.
[b] n = number of samples.

According to our own calculations, the sample-size weighted average lead content found in the studies in Asia, Africa and Latin America reviewed by O'Connor (2018) et al. is 18,778 ppm. Table 2 below shows the weighted average per region, based on the data in the paper.[19]

Table 2 - Sample-size weighted average lead content of new paints in different regions based on data from O'Connor et al. (2018)

Region (table in O' Connor et al. (2018))	**Average lead content weighted by sample size (ppm)**	**Total number of samples used to calculate this average**
China (Table 3)	20,284	277
India (Table 4)	23,008	441
Other Asian countries (Table 5)	18,050	1,545

[19] Our calculations can be found here.

Africa (Table 6)	17,306	486
Latin America (Table 9)	16,476	192
Total (weighted by sample size)	18,778	2,941

Unfortunately, the authors did not explain the methodology their review is based on. Thus, we don't know how representative their review of shop-based sampling studies is. Moreover, their study does not allow for a distinction between water-based and solvent-based paints in most cases.[20] Thus, we cannot use this review to confirm whether solvent-based paints are indeed more likely to contain high levels of lead than water-based paints.

Apanpa-Qasim et a. (2016):

Apanpa-Qasim et al. (2016) reviewed nine sampling studies that measured the lead contents of water-based and oil-based (i.e., solvent-based) paints in 14 different LMICs (results shown in Appendix 2). The average concentrations found in oil-based paints range from low (< 50 ppm) to extremely high (~500,000 ppm), with a weighted average of 21,613 ppm.[21] The highest concentrations in oil-based paints were found in Cameroon and Thailand. The lead contents of water-based paints also varied widely across studies, ranging from very low (< 5 ppm) to very high (~140,000 ppm), with an average of 953 ppm. The highest concentrations in water-based paints were found in India. All paints combined had a weighted average of 13,100 ppm.

We would like to emphasize that these summary statistics should be treated with caution, as there is substantial variation in the lead concentrations found across countries and studies, with some studies finding no paint samples with lead concentrations ≥ 90 ppm. Moreover, the studies vary substantially in terms of their sample size, ranging from 5 to 174 samples. Thus, the sample-size weighted averages we calculated are highly driven by the study with the largest sample size, which we describe in the following.

Besides providing this review of previous studies, Apanpa-Qasim et al. (2016) also presented results from their own analysis of lead contents in 174 water-based paint samples in Nigeria and found an average lead concentration of ~800 ppm. We are not sure how representative these selected paints are, but according to the authors, the paints were selected "based on color availability and the most commonly used water-based paints" from 14 different manufacturers (p. 44). Despite regulations in place stipulating that paints

[20] O'Connor et al. (2018) distinguish between different types of paints, such as enamel paints, oil-based and decorative enamel paints, decorative paints, and home paints. We have not been able to find out how they define those types and whether they are typically water-based or solvent-based. We contacted the authors but have not received a reply.

[21] We weighted the average by sample sizes. The calculations can be found here in the columns on the right. Note that these calculations are based on Table 2 in Apanpa-Qasim et al. (2016, p. 46) and not on the full underlying data, which we didn't have access to.

should contain less than 90 ppm of lead, all of the 174 water-based paint samples showed lead levels above this permissible limit, showing clearly that these limits have yet to be enforced in Nigeria. We included the results of this study in the average calculations above.

Like O'Connor et al. (2018), Apanpa-Qasim et al. (2016) also did not explain the methodology of their review of sampling studies. We have not thoroughly reviewed the underlying studies, and thus, cannot evaluate the quality of the evidence.

IPEN Global Lead Paint Elimination Report (2020):
Another extensive review of sampling studies is in IPEN's (2020) Global Lead Paint Elimination Report. According to IPEN's website, IPEN-affiliated organizations have collected and analyzed over 4,000 solvent-based paints in 59 countries. IPEN presents the results of the most recent publicly available paint studies since 2009 on this map. The data this map is based on can be found in a table format in IPEN (2022a).[22] Based on this table, we calculated the sample size-weighted average percentages of paints with lead contents exceeding different ppm thresholds: 54% of sampled paints contain lead contents above 90 ppm, 45% above 600 ppm, and 22% above 10,000 ppm.[23] For comparison, in Apanpa-Qasim et al. (2016), 73% of solvent-based paints have a lead content above 90 ppm and 65% above 600 ppm, based on sample size-weighted averages of percentages. Unfortunately for our analysis, IPEN studies do not state average lead levels.

Besides IPEN's findings on solvent-based paints, IPEN also included 63 water-based paints in their paint sampling studies in recent years (IPEN, 2022b). They found that 10% of water-based paints had lead concentrations above 90 ppm, 5% above 600 ppm, and 2% above 10,000 ppm. These figures are much lower than Apanpa-Qasim et al.'s (2016) findings on water-based paints, who found that 66% of tested water-based paints had lead levels above 90 ppm and 51% above 600 ppm.[24]

The sampling studies in IPEN (2020) and IPEN (2022b) have one important caveat. Due to IPEN's sampling procedure, the sampled paints are likely not fully representative of the typical paints used in households. More precisely, IPEN's general sampling methodology explicitly mentions that in most cases, one white paint and one or more bright-colored paint, such as red, orange, or yellow are selected (e.g., IPEN, 2016, p. 49). These colors were included in the sampling since a previous study had shown that they were likely to contain high lead concentrations (IPEN, 2015, p. 1). This makes sense given that IPEN is an advocacy network that aims to eliminate the use of lead paint. Thus, IPEN's findings on lead levels in paints might potentially be higher than the typical lead levels in new paints consumers purchase.

[22] IPEN also shared with us some testing data they obtained on spray paints and industrial paints. However, we decided not to include this data here as we are not aware what those paints are typically used for and whether they are water-based or solvent-based.
[23] We included these calculations in this table.
[24] The calculations can be found here.

Table 3 below gives a summary of the results from different studies described above. It shows that there are quite some discrepancies between the studies, which we believe are partly driven by differences in study design (e.g., sample selection, measurement techniques, choice of countries).

Table 3 - Overview of the results of different studies of paint above different thresholds of lead concentration, as well as the number of samples each percentage is based upon

Study	**Type of paint**	**> 90 ppm**	**> 600 ppm**	**> 10,000 ppm**	**Number of samples**
IPEN (2022a)	solvent-based	54%	45%	22%	2,609 [25]
IPEN (2022b)	water-based	10%	5%	2%	63
Apanpa-Qasim et al. (2016)	solvent-based	73%	65%	NA	603 [26]
Apanpa-Qasim et al. (2016)	water-based	66%	51%	NA	298

Overall, based on the three review studies we described and the expert interviews we conducted, we have four main takeaways on shop-based assessments:

1. Due to differences in chemical composition, **solvent-based paints are more suited to carrying large levels of lead than water-based paints**. They also have more reason to do so, as it is more difficult to substitute lead compounds in solvent-based paints.

2. **Shop-based sampling studies in LMICs show that paints can vary hugely in their lead content**, ranging from negligible levels up to more than 500,000 ppm for solvent-based paints and 140,000 ppm for water-based paints in some cases.

3. Lead concentrations in solvent-based paints are generally higher than in water-based paints. Based on the average (water-based: 953 ppm; solvent-based: 21,613 ppm)[27] lead levels of studies included in Apanpa-Qasim et al. (2016), as a

[25] For some countries in the study, it was not recorded how many paints were above the 10.000 ppm, so that percentage is based on a lower sample size of 2,589.
[26] For some studies within this paper, it was not recorded how many paints were above the 600 ppm threshold, so that percentage is based on a lower sample size of 432.
[27] These are averages weighted by sample sizes, as detailed in this document.

rough estimate, **oil-based paints contain about 20x more lead than water-based paints**.

4. **A majority of the solvent-based paints tested in shops in LMICs well exceed the recommended limit of 90 ppm**. The tested solvent-based paints often contain levels of lead ranging into the tens of thousands ppm (usually 5,000-40,000 ppm, rarely higher than 100,000 ppm).

An important caveat is that many of the sampling studies (at least those carried out by IPEN-affiliated organizations, but likely also some of the other studies) were not meant to provide nationally representative estimates on the prevalence of lead in paints on the market, but were carried out to show that lead paint exists.[28] Thus, we expect there to be a selection bias which leads to an overestimation of the lead paint levels.

Thus, given our aforementioned findings and a likely selection bias, **our best guess is that, average lead levels in paints currently sold in shops in LMICs are roughly 200-1,400 ppm (70% CI) for water-based paints and 5,000-30,000 ppm (70% CI) for solvent-based paints.**[29]

In LMICs, the market share of solvent-based paints is roughly 30%-65% (80% CI) of all paints sold, which is higher than in HICs

[Confidence: High that the relative market share of solvent-based paints is higher in LMICs than in HICs, but low on the exact shares. Further investigation of the literature on this topic is unlikely to lead to a more precise figure, as no good market data on paints sold in LMICs seems to exist.]

The previous section provides indirect evidence of the amounts of lead paints in the homes of people. To get a better sense of the extent to which people in LMICs are exposed to lead paints in their homes, this section aims to establish what types of paints people typically buy and use and in what quantities.

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[28] We also reviewed the sampling approaches of the two largest studies reviewed by Apanpa-Qasim et al. (2016), namely Mohanty et al. (2012) and Gottesfeld et al. (2013). We could not evaluate how representative these studies are, as they do not state why they selected certain samples and brands. For example, in both studies, it is unclear whether they sampled the most popular paints and/or the largest brands.

[29] These best guesses are based on the following steps: (1) We rounded the average lead paint levels in Apanpa-Qasim et al. (2016), i.e., water-based: ~1,000 ppm, solvent-based: ~22,000 ppm. (2) We then deducted 20% from both figures to account for selection bias. (3) We used symmetrical ranges of 75% around the estimates from step (2) to create our confidence intervals, i.e., water-based: 800 +/- 600 ppm, solvent-based: 17,600 +/- 13,200 (which we rounded again).

While reasonably good market data seems to exist for HICs, we found little market information on paints in LMICs. This section is largely based on estimated market shares and small, informal paint seller surveys, which provide only a very rough and highly uncertain indication of the extent to which different paints sold on the market actually end up in homes. Moreover, it only covers the supply side of paints, as we did not find information on the demand side.

In HICs, it seems clear that various factors (e.g., concerns about odors and hazards to health, technological developments) have reduced solvent-based paints to a small fraction of the paint market in recent decades. According to a large US-based paint dealer, the proportion of solvent-based paints has drastically decreased and water-based paints now account for about 80% of paint sold for home use (JC Licht, 2015).[30]

However, we have reason to believe that this trend does not hold in LMICs. Cultural and environmental factors make solvent paints more practical than water-based in many environments in LMICs. For example, according to the Solvent Based Coatings Global Market Report 2020, "solvent based coatings are beneficial in humid environments. The time required to dry for solvent based coatings is very less when compared to the water-based coatings which are less efficient in humid environments" (Newswire Press Release, 2020).[31] Moreover, **small, informal seller and consumer surveys carried out by LEEP indicate that solvent-based paints are a popular choice in tropical, warm, and humid regions that are prone to a fast degradation of paints** (LEEP research notes).

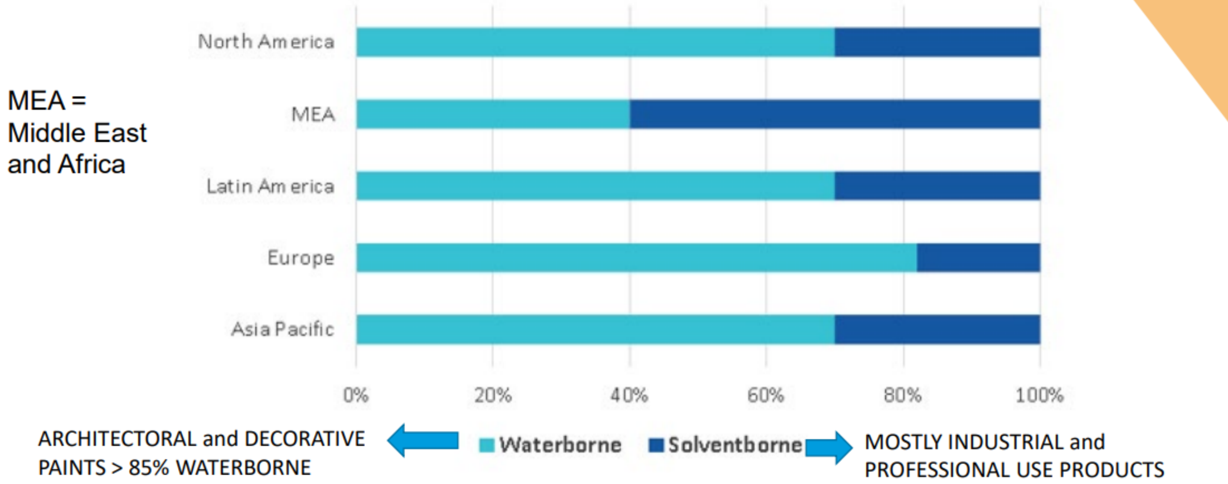
This observation is consistent with current market shares of solvent-based and water-based paints in different regions of the world. According to the World Coatings Council (2021, p. 11), the market shares of solvent-based paints are relatively low in HICs (~18-30% in Europe and North America) and higher in some LMICs - 60% for the Middle East and Africa, 30% for Latin America and the Caribbean, and 30% in Asia (see Figure 1 below). An important caveat is that this data is based on all applications of paint, not only residential.[32]

[30] According to JC Licht (2015), "[f]ifty years ago, virtually all paint was solvent-based. [...] These solvents or compounds facilitate application, drying and the formation of a durable, regular paint film. [...] Today, advances in paint technology mean that water-based paints, typically referred to as waterborne acrylics, are in many ways equal, or superior to their solvent-based counterparts. High quality waterborne acrylic emulsions offer excellent durability, quick dry time, and the emission of far less odor. Currently, water-based coatings account for approximately 80% of paint sold in the residential marketplace. Additionally, this class of paint has moved into all sorts of industrial applications, including maintenance coatings for steel and concrete."

[31] Unfortunately, we have only been able to access a press release, not the actual report.

[32] Brosché also pointed us to paint market analyses conducted by IPEN partners for Indonesia and Nigeria and to reports from additional countries in the list here. However, these do not provide concrete sales figures for solvent- or water-based paints (or lead-based paints, for that matter) in LMICs.

Figure 1 - Percent market share by region of water-based and solvent-based paints ([World Coatings Council, 2021](), p. 11)



Unfortunately, we have not been able to find high-quality data on the respective shares for decorative paints only. Nonetheless, small, informal paint seller surveys carried out by LEEP in Malawi and Pakistan (described in more detail in LEEP [2022]) are consistent with the thesis that the market shares of solvent-based paints in LMICs are higher than in HICs. LEEP surveyed 4-7 paint sellers per country and found that sellers in Malawi reported that solvent-based paints are sold in greater quantities than water-based paints for home use. Sellers in Pakistan did not report that solvent-based or water-based paints are sold for home use in significantly different proportions. No seller had quantitative data on sales, and most were not willing to give quantitative estimates.

Based on these seller surveys, LEEP came up with the following estimates of the shares of solvent-based paints vs. water-based paints for home use (see Table 4 below). These results should be treated with caution as they are based on very small sample sizes and informal interviews. Moreover, the confidence intervals stated below are based on LEEP's intuitions rather than quantitative data.

Table 4 - LEEP's estimated shares of solvent-based paints for home use based on seller surveys (LEEP, 2022)

Country	**Estimated share of solvent-based paints for home use**	**90% confidence interval**
Malawi	60%	40-80%
Pakistan	50%	30-70%

These **highly uncertain findings from interviews with paint sellers indicate that water-based and solvent-based paint sales for home use are approximately equal in the studied countries, with slightly more market share going to solvent-based paints**. LEEP's estimates are also roughly in line with the aforementioned figures from the World Coatings Council 2021.

There is reason to believe that the shares of solvent-based paints for residential use might potentially be even higher than the above figures suggest. Sara Brosché from IPEN pointed out to us that most so-called **industrial paint in LMICs is solvent-based and frequently ends up on the home use market despite their legal prohibition**, but it is not included in statistics for home use paint. Brosché cited recent IPEN studies in the Philippines (IPEN, 2021a) and in Indonesia (IPEN, 2021b) as examples for this, showing that these paints can contain very high lead contents. We have not reviewed these studies, so we do not know how frequently this issue occurs and whether this observation extends beyond the two countries.

Overall, our best guess is that solvent-based paints have a market share of roughly 30% to 65% (80% confidence interval) in LMICs. Given that in some cases, industrial solvent-based paints are also sold for residential use but do not appear in home use statistics, the market shares of solvent-based paints for residential use in LMICs might be even higher than these numbers suggest. Due to the paucity of data, we are very uncertain about these numbers. However, we believe that it is reasonable to assume that in many LMICs, solvent-based paints have a significantly larger market share compared to HICs. Moreover, while these numbers and insights provide only indirect information on the types and quantities of paints used in homes in LMICs, **we think it is plausible to conclude that solvent-based paints are widely used in or outside homes and environments around children in LMICs**.

Lead paint in public spaces contributes to lead exposure

[Confidence: fairly high that lead paint is used in public spaces in LMICs and that this contributes to exposure. However, we do not have enough information to say what the relative importance of exposure from lead paint in homes vs. outside the home is, and we are unsure whether such information currently exists.]

Lead paint is not only used in homes but has also been found in various other settings that may put children at risk of exposure, such as schools, daycare centers, playgrounds, and toys (Mathee et al., 2007, p. 321). In this section, we summarize the evidence we found in literature for lead exposure in public spaces.

High lead levels in public areas, particularly in playgrounds, constitute a hazard for children. Playgrounds are generally outdoors and exposed to the elements, plausibly leading to more degradation and faster flaking of paints, and thus higher lead concentrations in the soil and dust surrounding playground equipment. Paints tend to degrade faster in warmer and more humid weather conditions, leading to an increased exposure to lead.[33] Moreover, playground equipment is frequently painted in bright, glossy colors and solvent-based paints, which on average contain higher levels of lead than matt and muted colors.[34]

In the following, we summarize the evidence we found on lead paint exposure in (pre)schools, daycare centers, playgrounds, and hospitals in LMICs.

- **Indonesia, Malaysia, Mexico, the Philippines, & Thailand:** In 2019, IPEN-affiliated organizations measured the lead content on playground equipment in Indonesia, Malaysia, Mexico, the Philippines, and Thailand using a portable XRF device. Table 5 below shows an overview of the results. They found that 85% of the equipment tested in the five countries exceeded 90 ppm. The Philippines stands out as having the highest share (75%) of equipment with lead levels above 10,000 ppm and the highest detected lead concentration of more than 600,000 ppm. None of the studies mentioned how the analyzed playgrounds and equipment pieces were selected.

Table 5 - Summary of IPEN playground sampling studies

Country	**Number of playgrounds sampled**	**Number of playground equipment pieces analyzed**	**% of analyzed equipment > 90 ppm**	**% of analyzed equipment > 10,000 ppm**	**Highest lead concentration detected in ppm**
Indonesia	32	119	69%	0%	4,170
Malaysia	10	17	76%	64%	620,000
Mexico	8	Not stated	81%	48%	Not stated
The Philippines	14	55	91%	75%	663,000
Thailand	2	24	83%	58%	72,300

- **Indonesia:** Ericson et al. (2019) (which we have previously summarized in the context of home-based assessments) assessed the prevalence of lead-based paint,

[33] Bodeau-Livinec et al. (2016, p. 14) measured blood lead levels in Benin and made environmental assessments in households. They concluded that “in this hot and humid climate, children’s hands may be likely covered with dust and therefore their BLLs may be higher than children from high-income countries for a given concentration of lead in dust.” We haven’t reviewed whether this is an actual finding of the study or merely a hypothesis.
[34] This is a general observation we noted from talking to several experts.

taking 330 XRF measurements in 19 preschools in Jakarta, Indonesia. Of these measurements, 52 were taken from playground equipment. The authors found that 26% of preschools had at least one positive measurement when using the threshold of 1 mg/cm². Using the same threshold, 7% of all 330 XRF measurements in preschools were positive. Using the data the authors shared with us, we find that 63% of preschools in the sample had at least one measurement that exceeded the XRF instrument limit of detection (0.02 mg/cm²).[35] Of all measurements taken in preschools, 37% were above the limit of detection. For the playground equipment, 25% of measurements showed lead contents above the limit of detection.

- **Brazil:** Da Rocha Silva et al. (2018) measured blood lead levels of Brazilian children and tested four daycare centers, including the playground equipment, for lead-based paint using an XRF device. They found that, respectively, 34% and 22% of measurements in two of the daycare centers contained lead levels above 600 ppm. In the same two daycare centers, respectively, 77% and 23% of playground measurements yielded lead levels above 600 ppm. Moreover, there was a significant association between blood lead and lead levels in daycare centers. The authors concluded that "lead exposure estimated from the DCCs [daycare centers], where children spend about 10 h/day, can be as relevant as their household exposure."

- **South Africa:** Mathee et al. (2009) measured lead levels in paint on playground equipment in 49 public children's parks in South Africa (Johannesburg, Tshwane and Ekurhuleni) using a portable XRF device. Playground lead levels ranged from 'too low to detect' to 10.4 mg/cm². The mean and median concentrations were 1.9 mg/cm² and 0.9 mg/cm², respectively. 48% of lead paint measurements exceeded the reference level of 1 mg/cm². In 96% of the parks, at least one measurement was found above this reference level.

- **The Philippines:** Riddell et al. (2007) tested paints for lead in two schools and three hospitals in the rural Philippines. Using laboratory analysis of paint chip samples, they found lead-based paint on interior and exterior walls in one of the schools, and on walls and various other surfaces (e.g., beds) in all three hospitals (> 5,000 ppm). Riddell et al. (2007) also undertook home-based lead paint assessments, as we summarized here.

Overall, we found **evidence that various surfaces outside the home, as we have shown for playgrounds, (pre)schools, hospitals, and daycare centers, can also contain significant, and in some cases high, levels of lead and might therefore also be an important source of exposure. Moreover, a positive correlation was found between lead levels in public spaces and blood lead levels.** However, we have not seen sufficient data to say anything reliable on the relative importance of exposure from lead paint in homes vs. outside the home. We

[35] We can share our calculations on request.

have not seen any lead paint assessments of public spaces that did not detect any lead, but it is possible that this is due to publication or selection bias. We think that there is reason to expect that the aforementioned results may extend to other countries.

These studies are subject to a number of limitations. First of all, it is unclear whether the studies' findings are representative at the national, or even subnational level. For some studies, it is not clear how the study sites and surfaces to be tested were selected (e.g., IPEN playground studies). It is possible that lead paint testing was specifically focused on areas with visible paint chipping, where a high lead exposure is more likely. Second, we have concerns about the use of ppm as the unit of measurement for the XRF-based studies (e.g., Da Rocha Silva et al., 2018). As we explained here, this might lead to less accurate results, but we are not able to quantify the error margin. Third, according to Bret Ericson (personal communication), it is possible that XRF measurements pick up on the metallic substrate on which a coating is painted, thereby skewing the readings upward. We have not had time to pursue this line of thought.[36]

It is also important to note that **lead paint has not only been found in public spaces in LMICs, but also in HICs**. For example, studies in Canada (Moore et al., 1995), Israel (Berman et al., 2018), England (Turner et al., 2006), and Japan (Takaoka et al., 2006) found lead levels that exceeded 90 ppm on a variety of structures and equipment in playgrounds, or in the soil surrounding playground equipment.[37] Moreover, we find it plausible to assume that lead can also be found in other places outside the home, such as supermarkets and office buildings, but we have not investigated whether this is in fact the case.

Historical basis: lead levels in the United States before the introduction of lead paint regulations

During conversations with experts, we learned that views on the importance of lead paint as a source of exposure are highly influenced by the history in developed countries, especially in the US, about the situation before lead paint regulations were introduced in the 1970s. In these conversations, we also learned that many studies on the exposure and the health effects of lead paint were carried out with US data. Thus, to get a better sense of

[36] Sara Brosché responded to this: "In our studies, we have several measurements from different parts of each piece of playground equipment. That means that any background levels of lead from the meta itself would at the most be the lowest level of lead detected. For example, in our study in the Philippines, we have levels from the same slide that were: yellow: 4,290, orange: 13,100, blue, 63,400; so the max background level from the metal can only be 4,290 (IPEN, 2019b)."

[37] We would also like to emphasize that paint may not be the only source of exposure on playgrounds. As they are outdoor environments, playgrounds can collect dust from a wide variety of sources, some of which may contain lead, for example, leaded gasoline (e.g., Ren et al., 2006). We have not reviewed this literature as it was out of scope for this report.

the current exposure and health impacts of lead paint in LMICs, it would be helpful to know whether typical lead levels in paints used currently in LMICs are comparable to historical levels in the US. In this section, we try to answer this question.

In the US, the majority of houses built before 1980 have paint containing more than 1 mg/cm²

[Confidence: high. Although our findings are largely based on one study on lead paint levels in the pre-war US, we find its results highly reliable due to its very large sample size, national representativeness and methodological rigor. Further research is unlikely to change our conclusions, as we do not expect to find more studies of comparable quality.]

Many experts we talked to pointed out to us that lead paint exposure in US houses was generally high before the manufacture of lead-based house paint was banned in 1978 (Wikipedia). According to Dignam et al. (2019, p. 4),

> "Use of lead in paint in the United States expanded in the early 1900s, when the paint industry burgeoned and the first pigments produced on a large commercial scale were made of lead. For many years, white lead was the principal opaque pigment used for interior and exterior paints and, on average, interior paints used before 1940 contained about 50% lead."

We saw this 50% lead figure, which we interpret as 500,000 ppm,[38] mentioned by several sources (e.g., the US Lead-based paint poisoning and prevention act of 1975 [p. 100]),[39] but haven't been able to access the original source of this claim. Thus, we do not know how this figure was calculated and how reliable it is. Given that the first commercial field portable XRF device was not available before 1967, we think it is unlikely that the 50% figure is based on measurements undertaken in a representative set of houses in the US, but it might simply be based on commonly used paint recipes. Moreover, we find it intuitively hard to believe that this figure really represents the average,[40] and we think it is more likely that the

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[38] According to the 2012 Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing in the US (Appendix 1, p. App 1-3), a common unit of measure used in the lead-based paint field is a weight to weight ratio (%w/w), also called "weight per cent" or "% by weight." The same source also explains that a lead concentration of 50% w/w corresponds to 500,000 ppm. In theory, the % can also refer to the weight to volume or the volume to volume ratio, which would yield different ppm figures, but our general sense from reading the literature is that these interpretations are less commonly used than the weight to weight ratio.

[39] According to the US Lead-based paint poisoning and prevention act of 1975 (p. 100), "old paint manufactured and applied 20 to 30 years ago contained as much as 50% lead by weight on the average."

[40] This would imply that lead levels even (potentially much) higher than 500,000 ppm were frequently used. We have not encountered evidence or even traditional recipes on house paints with lead contents substantially higher than 500,000 ppm.

figure represents an upper bound. Similarly, ~500,000 ppm seems to be an upper bound for current paints sold in some LMICs, as we explained here. We have not come across any evidence on how frequently paints with such high lead levels were used in the US pre-war era.

When looking for studies that show evidence of typical lead levels of paints in pre-war US houses, we found relatively little data. This scarcity of data might be because the "handheld" XRF machine, which made testing of lead levels easier and more affordable, was not invented until 1982. This was after US consumers had reduced their access to lead paint for use in the home, according to several experts we talked to. In this section, we outline the results of two studies that provide evidence on lead paint exposure in old US houses, a US EPA (1995) report and a study by Lanphear et al. (1998). We then compare these data points with contemporaneous studies from LMICs.

US EPA report (1995):
A US EPA (1995) report randomly sampled more than 77,000 houses in the US and measured lead levels on painted surfaces using an XRF device. According to this study, a painted surface was defined as containing lead if an XRF reading was 1 mg/cm^2 or higher. The study found that an estimated 83% (± 9%) of private housing units in the US built before 1980 have lead-based paint on either interior painted surfaces, exterior surfaces, or both. Approximately 86% (± 8%) of pre-1980 public housing units also have lead-based paint on their surfaces. Even more houses built before 1940 (88% ± 9%) exceeded the threshold (p. 2-3).

Interesting results can also be found in Appendix II of the report. For example, Table 6 below shows that the **estimated average interior wall lead concentration found in privately owned houses was 1.4 mg/cm^2 for houses built before 1940 and 4.6 mg/cm^2 for exterior surfaces. The figures for all occupied housing units built before 1980 were 0.7 mg/cm^2 (interior) and 1.9 mg/cm^2 (exterior).** Thus, the younger the house, the lower the found lead concentrations in walls according to XRF readings.

Table 6 - Mean paint lead loadings in residential houses built before 1980 in the United States (US EPA, 1995, Appendix II, p. 2-17)

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TABLE 2-13

ARITHMETIC MEAN PAINT LEAD LOADINGS IN PRIVATELY OWNED OCCUPIED HOUSING UNITS BUILT BEFORE 1980, BY SELECTED CHARACTERISTICS (Paint Lead Concentration >= 1.0 mg/sq cm)

Characteristic	Interior Surfaces (mg/sq. cm.)	Exterior Surfaces (mg/sq. cm.)
Total Occupied Housing Units Built Before 1980	0.7 (0.4 , 0.9)	1.9 (1.3 , 2.5)
Construction Year:		
1960-1979	0.3 (0.2 , 0.4)	0.6 (0.3 , 0.8)
1940-1959	0.5 (0.3 , 0.7)	1.5 (0.9 , 2.1)
Before 1940	1.4 (0.7 , 2.2)	4.6 (2.6 , 6.5)
Housing Type		
Single Family	0.7 (0.4 , 0.9)	2.0 (1.3 , 2.7)
Multifamily	0.4 (0.2 , 0.7)	1.0 (0.3 , 1.6)
One or More Children Under Age 7	0.7 (0.3 , 1.0)	1.6 (0.5 , 2.7)
Census Region		
Northeast	1.5 (0.6 , 2.5)	2.4 (1.4 , 3.4)
Midwest	0.5 (0.2 , 0.8)	2.1 (1.2 , 3.0)
South	0.3 (0.2 , 0.5)	1.7 (0.4 , 2.9)
West	0.4 (0.2 , 0.6)	1.2 (0.4 , 2.0)

Note: Numbers in parentheses are 95% confidence intervals for the respective arithmetic means.

Lanphear et al. (1998):
The Lanphear et al. (1998) study is a pooled analysis that was mainly conducted to estimate the contributions of lead-contaminated house dust and soil to children's blood lead levels. It also contains some data on lead levels in paints in US houses pre-1998 based on 12 studies conducted between 1982 and 1997. In all underlying studies, lead levels were measured using XRF spectrometry.

Table 7 below shows the most relevant information from this report, the **maximum interior paint XRF reading within a home (maximum paint XRF) in mg/cm^2. It ranged from 0.28 to 7.12 mg/cm^2 with an (unweighted) average of 2.46 mg/cm^2.**

There are a number of limitations to this study. First of all, there is no information on how old the sampled houses are and when paint was applied, so it may not be a good indicator of the lead content of interior house paints in the pre-war era. Second, as the stated numbers are maximum XRF readings, they are likely an overestimate of the overall lead levels in interior paints. Third, while the study also shows data on dust lead loadings and exterior lead exposure, it is not clear how much of this lead exposure is from paint versus from other sources. Overall, we think this study is not very informative on historic lead levels in US interior paints, and we would put little weight on this information. Nonetheless, it confirms the existence of high lead levels in paints in older US houses.

Table 7 - Descriptive statistics of the key variables in the blood lead-environmental lead analysis ([Lanphear et al., 1998](), p. 56)

TABLE 3
Descriptive Statistics of the Key Variables in the Blood Lead–Environmental Lead Analysis

				Geometric Means for Observations used in Analyses						
Study	Study sample size	Number of observations used	Percentage blood lead ≥ 10 μg/dL	Blood lead (μg/dL)	Dust lead loading (μg/dL)	Exterior lead exposure (ppm)	Maximum paint XRF (mg/sm^2)	Percentage max XRF on damaged paint	Mean age (months)	Mean SES level
Boston Longitudinal Study	175	40	28%	4.29	2.29	247.01	0.83	30%	13.5	1.7
Cincinnati Longitudinal Study	285	250	54%	11.17	293.40	472.36	3.12	43%	13.6	1.7
Cincinnati Soil Study	99	52	62%	10.44	20.37	965.51	0.75	0%	20.0	1.9
Rochester Longitudinal Study	274	264	2%	2.86	8.30	914.19	5.36	10%	6.1	2.9
Rochester LID Study	205	195	22%	6.33	17.79	689.67	7.12	54%	20.4	2.4
Butte, MT Study	118	110	6%	3.60	2.50	519.61	2.45	1%	21.1	2.9
Bingham Creek, UT Study	335	100	2%	3.20	1.92	96.91	0.58	0%	23.7	3.4
Leadville, CO Study	108	84	12%	4.92	4.73	755.01	1.62	1%	20.2	2.8
Magna, UT Study	64	54	11%	4.45	8.87	247.43	2.97	4%	21.3	2.5
Sandy, UT Study	46	40	0%	3.15	6.11	415.97	1.58	3%	22.3	3.0
Midvale, UT Study	86	65	12%	4.62	3.68	326.96	0.99	0%	19.6	2.5
Palmerton, PA Study	45	43	7%	4.74	5.91	581.87	0.28	2%	20.8	3.0
All studies	1,861	1,297	20%	5.07	13.52	508.61	2.46	20%	16.3	2.5

Lead concentrations in paint historically used in US homes are roughly 6-12 times higher than lead concentration currently found in homes in LMICs

[*Confidence: medium. Due to low data availability and methodological differences in studies in LMICs, it is difficult to compare historical US-based lead paint levels with current lead paint levels in LMICs. The publication of more high-quality home-based assessment studies in LMICs might alter our views.*]

How do the results from the US EPA (1995) and the Lanphear et al. (1998) studies compare to recent XRF readings in LMICs? In this section, we compare the results of both studies from the US with findings from home-based assessments in LMICs we describe here. We would like to emphasize that methodological differences across studies and a relatively low data availability in LMICs render this comparison difficult. Thus, we advise taking our comparison very lightly.

As we explained before, according to the US EPA (1995), the estimated average interior wall lead concentration in US homes built before 1980 was 0.7 mg/cm^2, and 1.4 mg/cm^2 for homes built before 1940. If we use the rough conversion that 1 mg/cm^2 = 10,000 ppm, these figures correspond to 7,000 ppm for US homes built before 1980 and 14,000 ppm for homes before 1940. For comparison, the home-based assessment studies in LMICs showed average lead paint concentrations between roughly 50 ppm and 4,500 ppm. As a rough point estimate, we assume the midpoint of this range, i.e., 2,275 ppm. Among the studies in LMICs, we put most weight on the results from Ericson et al. (2019), whose findings on average lead concentrations were roughly converted to ~700 ppm. Thus, assuming that average lead concentrations in LMICs are most likely roughly somewhere between 700 ppm and 2275 ppm, and taking the US-based figures of 7,000 ppm - 14,000 ppm, we find that historical lead concentrations in US houses were roughly 3 - 20 times larger than in current houses in LMICs. We assume the midpoint of this range, i.e., ~12.

Lanphear et al. (1998) reported XRF wall paint readings in a way that we have not seen in any other study, i.e., in terms of maximum XRF readings.[41] Most other (contemporaneous) studies we came across reported their results in terms of average XRF readings or XRF readings above a certain threshold. Thus, there are not many other studies to compare it to. Nonetheless, we looked at the data from Ericson et al. (2019) and calculated the average of the maximum XRF wall readings per structure.[42] We obtain an average of max readings of 0.42 mg/cm^2, when assuming that walls below the detection limit had 0 mg/cm^2. These numbers are clearly lower than the average of max readings of 2.46 mg/cm^2 found in Lanphear et al. (1998). This would suggest that the historical US-based figures are about six times higher than those in recent LMIC studies.

Taking both comparisons together, **historical US-based lead concentrations in homes were very roughly about 6-12 times higher than those in recently studied homes in some LMICs**. We are about 70% confident that the true figure lies somewhere in this range.

[41] Angela Bandemehr (US EPA) suggested in a comment on this report that this might be because, at the time of the study, XRF device detection limits were not as low as they are today.

[42] We can share our calculations upon request.

Speeding up lead paint bans across LMICs could lead to averted income losses of USD 68 billion to 585 billion (90% CI) and 150,000 to 5.9 million (90% CI) averted DALYs over the next 100 years

[Confidence: medium. We tried to rely on estimates from the literature for the various inputs to our model as much as possible. Nonetheless, we have not found estimates for all of our parameters and are highly uncertain about some inputs. Our uncertainty could be reduced with more data on the use of paints in LMICs (e.g. frequency of re-painting homes) and on the average dose-response relationship between residential lead paint levels and blood lead levels.]

This report has so far focused on the lead levels of paints typically used and sold in LMICs. In this section, we use our findings to provide a rough estimate of the economic and health benefits of speeding up the introduction of lead paint bans for residential use in LMICs. To do so, we estimate the economic benefits in terms of lifetime earnings, and the health benefits in terms of DALYs (disability-adjusted life years) over the next 100 years.

To estimate the benefits of speeding up lead paint bans, we consider the difference between two scenarios over a time horizon of 100 years:

1. **Counterfactual scenario:** This scenario assumes that the share of the population in LMICs who live in countries without a lead paint ban drops by one percentage point each year.
2. **Intervention scenario:** This scenario assumes that the speed of introducing lead paint bans in LMICs doubles to two percentage points each year.

We would like to point out that our model considers only a part of the likely social and economic benefits to speeding up lead paint bans and could thus be considered a **lower bound of the returns to investing in lead hazard control**. There are various other benefits to reducing lead paint exposure, such as reduced healthcare costs, reduced costs of providing special education due to a decreased average IQ, and lower costs of crime.[43]

We did the calculations in Causal; the model can be viewed here (see Appendix 3 for the inputs and assumptions). Considering the cumulative effects over the next 100 years, our key findings are:

- Doubling the speed of the introduction of lead paint bans in LMICs could **prevent 31 to 101 million (90 % CI) children from exposure to lead paint** (see Figure 2 below).

[43] See Gould (2008) for an estimate of these benefits of reducing lead exposure in the United States.

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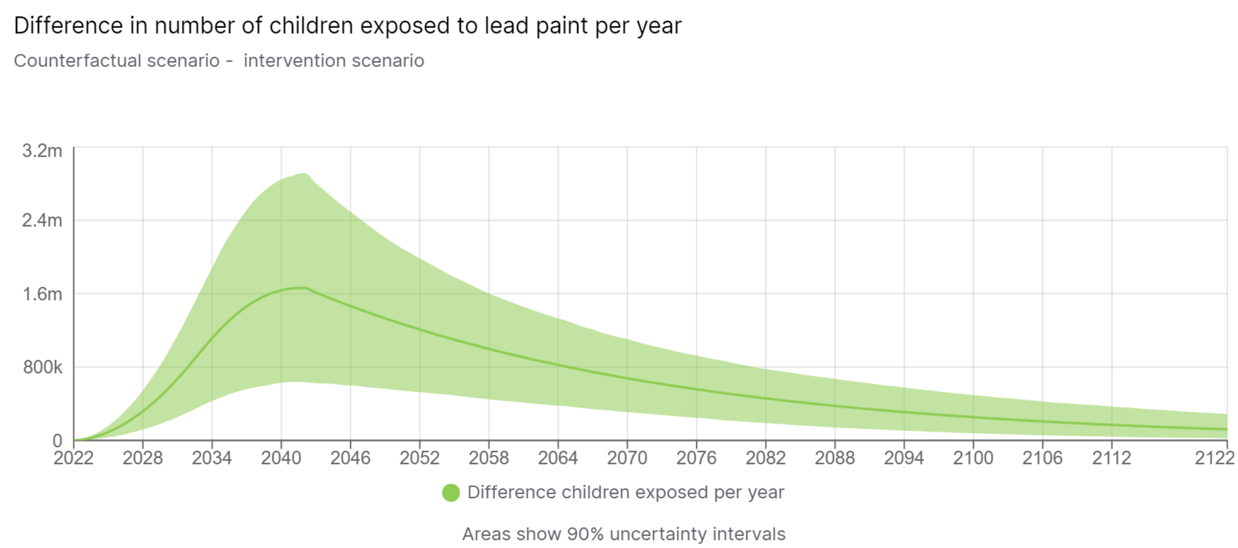
- This could lead to **averted income losses of USD 68 to 585 billion (90 % CI) and 150,000 to 5.9 million (90% CI) averted DALYS** (see Figure 3 below).
- Converting averted income losses into DALY-equivalents (using an assumption about the 'moral weight' of one DALY vs. one year of income), we find that **~89% of the benefits are due to higher incomes and the remaining ~11% of the benefits are due to health improvements** (see Figure 4 below). For comparison, LEEP estimated that ~80% of the benefits of LEEP's Malawi program was due to income benefits and the remainder was due to health benefits.

Our analysis builds on previous work done by LEEP and Attina and Trasande (2013). LEEP replicated and extended the methodology used by Attina and Trasande (2013) and found that total lead exposure (from any source) reduces average per capita lifetime earnings in LMICs by ~4% (Hu, 2022). Our estimates suggest a reduction of ~0.3% (with a 90% confidence interval of 0.08-0.6%) in lifetime earnings due to lead paint exposure. Combining both results, this would suggest that **lead paint accounts for ~7.5% of the total economic burden of lead paint exposure (with a 90% confidence interval of 2-15%)**. This finding complements LEEP's analysis, which is based on the assumption that 20% (with a 90% confidence interval of 4-60%) of lead exposure in Malawi is due to lead paint (LEEP, 2021).

Figure 2 - Difference in number of children exposed to lead paint per year (counterfactual scenario - intervention scenario)



Our main assumptions are the following (see Appendix 3 for a more detailed overview of our model inputs and assumptions):

- We assume that any child that is born into a home painted with lead paint gets exposed to lead and experiences lifelong economic and health consequences due to exposure in their first year of life. This means that even if no new lead paint is sold because of new regulations, there is still a group of children that gets exposed each year due to the fact that houses have already been painted with lead paint before the lead paint regulations took effect.

- We assume that a home contains lead paint if lead paint was used at the most recent time it was painted. This means we also assume that a house is 'free' of lead paint if the most recent layer of paint does not contain lead.[44]

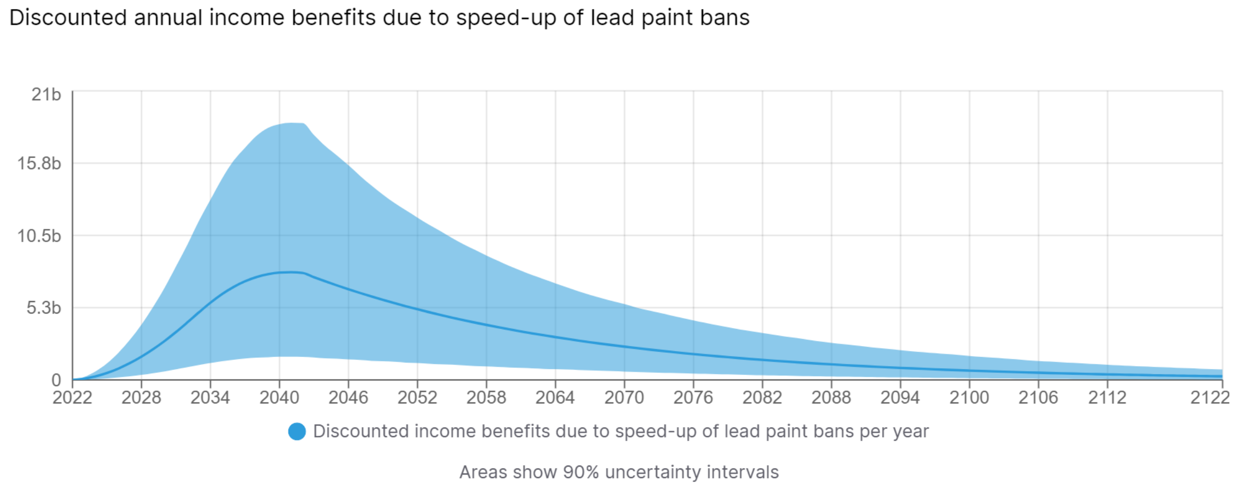
- We assume that lead paint exposure increases blood lead levels via increasing lead in dust, which is ingested and enters the bloodstream. Higher blood lead levels are associated with a reduced IQ, which then negatively affects lifetime earnings.

- We estimate the health effects of lead paint exposure in DALYs. For simplicity reasons, we assume that some proportion of the lead exposure DALYs is due to lead paint. We assume that the estimated DALYs that occur each year are proportionate to the number of children newly exposed to lead paint.

Due to limited or no available data for many of our key inputs, our estimates are highly uncertain. Our model serves to give a sense of the rough order of magnitude of the effects of speeding up lead paint bans rather than scientifically precise estimates. To reflect some of our uncertainty, we use confidence intervals rather than point estimates for most model inputs.

Figure 3 - Discounted annual income benefits due to speed up of lead paint bans

[44] The reality is more nuanced than this - many houses will have a combination of some paints without lead and some with different concentrations of lead. Moreover, painting over lead paint with regular store-bought paint is technically not a proper way of "encapsulating" lead paint (see O'Connor et al. (2018) for a discussion of the abatement of residential lead paint).



Our **main uncertainties** are:

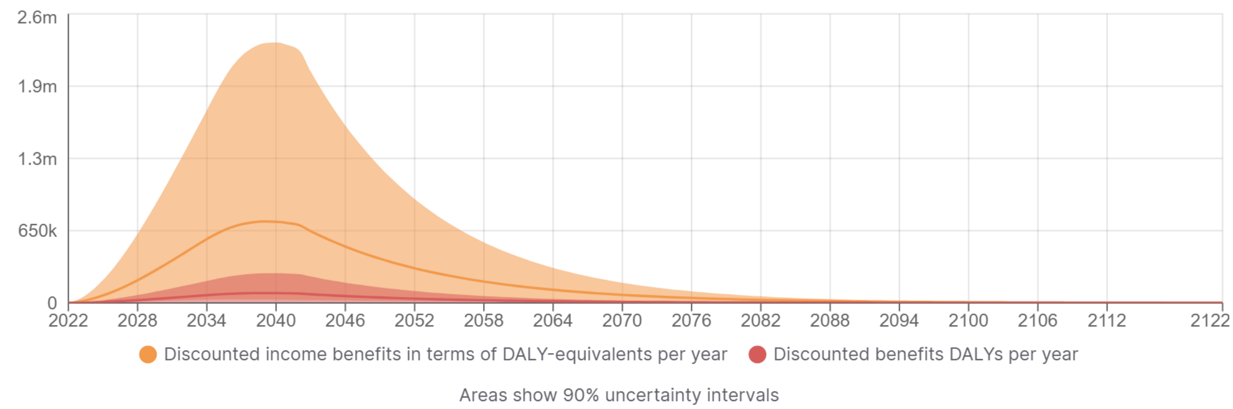
- Our estimated effect on the number of children newly exposed to lead paint depends on the **probability that an average home is (re)painted each year**. As very limited market data is available on the sale and usage of paints in LMICs, we have not found any estimates on this. We assume a 2-5% (80% CI) probability that a home is repainted in any given year, which is slightly higher compared to LEEP's (2021) assumption of 2%.

- Our estimated income benefits rely on the **relationship between lead paint levels and blood lead levels**, for which we found relatively few correlational and no causal estimates. Based on two studies, we assume that increasing lead paint levels by a factor X leads to an increase in blood lead levels of $X^{0.005}$-$X^{0.015}$ (90% CI). Intuitively, this means that, for example, increasing lead paint levels by 50% leads to a 4% increase in blood lead levels (if we use the point estimate of $X^{0.01}$).

- Our estimated DALY benefits rely on an estimate for the **proportion of lead exposure that is from lead paint in LMICs**. Combining our findings on income benefits with previous findings by LEEP (Hu, 2022), we find that this proportion is roughly 7.5% for income. We assume that this also holds for DALY benefits and use a 90% confidence interval of 5-10% to reflect our uncertainty.

We share an interactive version of our model here, so that users can see the effect of changing inputs.

Figure 4 - Discounted annual DALY benefits & annual income benefits in terms of DALY-equivalents



Acknowledgements

Jenny Kudymowa and Ruby Dickson jointly researched and wrote this report. Carmen van Schoubroeck assisted in revising the report for the public-facing version. Jason Schukfraft and Tom Hird supervised the report. Thanks to David Reinstein, William McAuliffe, Greer Gosnell, and James Hu for helpful comments on drafts. Further thanks to Bruce Lanphear, Lucia Coulter, Clare Donaldson, Sara Brosché, Bret Ericson, Elsbeth Geldhof, Angela Bandemehr, Ashley Fisseha, Steve Wolfson, Drew McCartor, Richard Fuller, Emily Nash, Adam Kiefer, and Perry Gottesfeld for taking the time to speak with us. GiveWell provided funding for this report, and we use their general frameworks for evaluating cause areas, but they do not necessarily endorse its conclusions.

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Appendix

Appendix 1 - Ericson et al. (2021) review on probable sources of lead exposure

Ericson et al. (2021) conducted a systematic review to assess blood lead levels in LMICs. More relevant for our report is that they also identified probable sources of lead exposure from 478 subsamples (out of a total of 1,100 subsamples). The probable sources of exposure were taken from the underlying studies. They found lead-based paint as a probable source of exposure in only 7 out of 478 samples and thus concluded that "lead-based paint does not appear to be a major source of lead exposure in LMICs" (p. e151).

We have heard differing views on the conclusions of this study by some experts in the field. In the following, we outline a few key views we came across and provide our general impression on this issue. We would like to emphasize that due to limitations in our knowledge and experience, we are not very confident in our own assessment.

For example, an opinion piece by Gottesfeld and Ismawati (2021) published in the Lancet stated that although "probable sources" of exposure were listed,

> "[...] Lead exposures generally come from multiple sources. A single dominant source might be of the greatest concern for an individual, among a specific subpopulation, or within a specific geographical area. However, as we become increasingly concerned with lower exposures, every source contributing to an incremental increase in blood lead level is of greater importance in contributing to the body's lead burden."

They wrote that "we feel that it is premature to conclude that sources of lead exposure in LMICs are different from those in high-income countries and that 'lead-based paint does not appear to be a major source of lead exposure in LMICs.'" Moreover, "we certainly don't have sufficient data to rank or draw conclusions on the relative weight of lead exposure sources globally." Ericson et al. (2021b) issued a reply stating that "it is possible that other lead applications (including paint) are considerable sources of lead exposure in some LMICs. However, to our knowledge, research illuminating this issue by quantifying dose (i.e., blood lead levels) does not appear in the literature."

Brosché (2022) from IPEN conducted an analysis of the scientific evidence for claims that lead paint is not a significant source of lead exposure in LMICs and pointed out some specific concerns regarding the Ericson et al. (2021) systematic review. In particular, Brosché (2022, p. 14) claimed that Ericson et al. 's (2021) conclusion "disregards the underlying factor that many studies of blood lead levels in LMICs are conducted in response to suspected cases of lead poisoning or to investigate point sources of exposure. It is therefore expected that well-known sources of exposure would top the list. It does not mean that lead [paint] exposure is not a significant source of exposure, especially noting the estimates that point to widespread low-level exposure in children. It also misses contributing sources of exposure."

In a similar vein, LEEP wrote in its research notes that in Ericson et al. (2021),

> "The smaller 'background' subgroup (90) is more relevant when considering general exposure. In this group the 'probable' sources of exposure are more evenly distributed, with paint and batteries listed as the 'probable' source in the same number of studies. However, even in this subgroup many (possibly the majority) of the studies do not actually investigate sources of exposure or only investigate one source. Many others do not seem to include a population representative of general exposure. If only studies that investigated multiple sources of exposure and a more general population were included, a significantly higher proportion would identify paint as a primary source."

To better evaluate the validity of these critical analyses, we looked at some of the reviewed studies in Ericson et al. (2021) ourselves. Online Appendix 1 of the article contains a spreadsheet with all the included studies along with information on their probable exposure sources and other data. We picked two studies at random and reviewed how they identified likely sources of lead exposure:

1. The first study we reviewed is Carpenter et al. (2019), who aimed to measure the prevalence of elevated blood lead levels among healthy Haitian children. Using a small household survey, they also tried to identify likely sources of lead exposure. One question on lead paint is included: "Does your home, your child's school, or any place where your child spends more than one hour per day contain lead-based paint?" as well as other questions on exposure sources, like: "Are there batteries discarded in or around your home, your child's school, or any place where your child spends more than one hour per day?"

Carpenter et al. (2019) calculated prevalence ratios in Haiti to investigate whether elevated blood lead levels are more likely for children exposed to different lead sources. They found that BLLs were elevated in 180 (65.9%) children. When looking at possible sources for the elevated BLLs (EBLLs), they concluded: "We did not find that exposure to leaded paint predicted EBLLs in children, despite ample literature documenting this association. However, nearly half of the parents and guardians we interviewed were unaware of their child's exposure to lead-based paint, and, thus, we could not draw a definitive conclusion about this important potential risk factor." We do not find it surprising that many parents are unaware of their child's exposure to lead-based paint, and we suspect that there is some measurement error in the reply to this question,[45] making it statistically less likely[46] to detect a correlation between stated exposure to lead-paint and blood lead levels. Overall, we believe that the design of this particular study made it difficult and rather unlikely to detect lead-based paint as an important exposure source.

2. The second study we reviewed is Ngoc Hai et al. (2018), who measured blood lead levels in children living near a mining site in Vietnam. Lead paint exposure has not been measured in any way in this study, making it impossible to find lead paint as an important exposure source. Our general impression from reading the lead paint literature and from talking to experts is that, compared to other exposure sources, such as living near a battery or mining site, lead paint exposure is less likely to cause acute poisoning.[47] Thus, lead paint may not frequently be the most important source of exposure for those with very high blood lead levels at an individual level. However, it is possible that, at population level, more low exposure to lead paint exists than high exposure to lead from, e.g., mining that might result in an overall higher exposure burden from lead paint.[48]

[45] We ourselves are not sure whether lead-based paint has possibly been used in the houses we live in and other places we spend a lot of time at, despite having spent 150 hours researching lead paint for this report.
[46] Lead exposure was stated for a relatively small subsample of 146 children and might thus have been lacking sufficient statistical power to detect differences in blood lead levels among children that were statedly exposed or unexposed to lead paint. Moreover, random measurement error in the stated exposure to lead paint would render regression coefficients and standard hypothesis tests invalid. We are aware that Carpenter et al. (2019) used a slightly different methodology, but we are fairly convinced that our general reasoning nonetheless applies to the methodology used in the paper.
[47] Nonetheless, acute lead poisoning can certainly result from lead-based paint, particularly in cases where hazards are significant and children exhibit pica behavior. See Moore et al. (1995) for a prominent example.
[48] Our intuition tells us that more individuals live in (potentially lead-) painted houses than individuals who live near mining sites. We have not significantly explored this line of reasoning.

Moreover, LEEP briefly reviewed several other studies that were included in the systematic review in their research notes. For example, they found that Ericson et al. (2021) mentioned 'diet' as the probable exposure source for one study in Tanzania (Bisanz et al., 2014). However, in their understanding, the study was not investigating sources of exposure and did not conclude that diet was more important than any other source of lead exposure. We have not reviewed this study ourselves.

Given the analyses we outlined by Brosché, Gottesfeld and Ismawati, LEEP, and the handful of studies included in Ericson et al. (2021) that we reviewed, we have a strong tendency to agree with the aforementioned views in that Ericson et al. (2021) excessively downplayed the potential lead paint hazard, based on the results presented. Overall, the reviewed studies did not appear to be designed to give a meaningful picture of the relative importance of different lead exposure sources.

Appendix 2 - Shop-based assessment studies in Apanpa-Qasim et al. (2016)

Table 8 - Lead in paint samples of water-based and oil-based paints in low and middle income countries (Apanpa-Qasim et al., 2016, p. 46)

Countries	Samples	Number of Samples	Average concentration	Maximum concentration	Percentage of samples with concentrations ≥ 90 ppm[a]	Percentage of samples with concentrations ≥ 600 ppm[b]	Reference number
Nigeria	water-based	174	811	3231	100	72	This study
Nigeria	water-based	8	86	516	5	none	46
	oil-based	11	45	159	11	none	
Nigeria	oil-based	25	14500	50000	NA	96	47
Cameroon	oil-based	61	NA	500000	66	64	48
Brazil	oil-based	20	5600	5900	35	30	41
Sri Lanka	water-based	11	4177	45743	10	10	38
	oil-based	19	25210	137325	68	68	
Philippines	water-based	10	11	40	none	none	38
	oil-based	15	28354	189163	67	60	
Thailand	water-based	10	3	15	none	none	38
	oil-based	17	61893	505716	47	47	
Tanzania	water-based	6	22	40	none	none	38
	oil-based	20	14537	120862	100	95	
South Africa	oil-based	29	19862	195289	65	62	38
Nigeria	water-based	7	8458	34598	100	100	38
	oil-based	23	36989.5	129837	100	100	
Senegal	water-based	9	5.5	29	none	none	38
	oil-based	21	5866	29717	86	76	
Belarus	water-based	8	58	418	none	none	38
	oil-based	22	5558	59387	82	68	
Mexico	water-based	10	6	16	none	none	38
	oil-based	20	51860	163812	100	100	
Brazil	water-based	7	10	14	none	none	38
	oil-based	24	15004	170258	42	37	
India	oil-based	22	9411	49593	36	36	38
India	oil-based	26	16600	134000	42	35	41
India	oil-based	5	106000	290000	100	100	49
India	water-based	38	NA	140000	38	49	50
	oil-based	31	NA	NA	84	NA	
India	oil-based	17	NA	NA	100	NA	51
India	oil-based	148	NA	80350	85	NA	52
Armenia	oil-based	26	25000	130000	77	77	41
Kazakhstan	oil-based	26	15700	71000	81	77	41

Table 2 — Comparison of the Present Study with Other Studies Reported in the Literature for Lead in Paint Samples

Note: NA-not available; [a] Present permissible limit of 90 ppm for Pb and [b] previous permissible limit of 600 ppm for Pb by the US Consumer Product Safety Commission.

Appendix 3 - Estimating the benefits of speeding up lead paint bans in LMICs

Table 9 below provides a detailed overview of our model inputs and assumptions. The details of our calculations can be viewed here. Note that we assumed normal distributions for most inputs, unless stated otherwise.

Table 9 - Overview of inputs for estimation of benefits of speeding up lead paint bans in LMICs

Input	Value	Source / Explanation
Population in LMICs in 2022	6.62 billion	2021 population estimate from World Bank Data (most recent estimate).
Annual population growth rate	Starts at 1% per year (decreasing by 0.015 percentage points annually)	We assume a population growth in LMICs based on projections by the UN population division. We assume the population grows at 1% in the first year, and then 0.15 percentage points less each year until it eventually stops growing. The calculations of how we get from UN projections to this relation can be found here.
Birth rate per 1000	14 - 19 (99%CI)	The birth rate in LMICs was 19 in 2020. In 2000 it was 23, so we assume a similar trend and use 19-5=14 as lower bound. Source: World Bank Data.
Percent of paints solvent-based	30% - 65% (80% CI)	Based on estimated market-shares of paint sales in LMICs, as explained here. We assume all paints to be water-based.
Percent of paints containing lead without bans by type	Water-based: 8%- 53%; Solvent-based: 43% - 58% (both 80% CI)	We use the upper and lower bounds for % of paints > 90 ppm according to shop-based assessment studies in Table 3 and reduce these bounds by 20% to account for a potential selection bias (as some shop-based assessment studies sampled paints that were expected to contain lead).
Lead levels of paints without bans by type	Water-based: 200-1,400 ppm; Solvent-based: 5,000-30,000 ppm (both 80% CI)	Based on findings from shop-based assessment studies, as explained here.
Lead levels of paints under enforced bans	0 ppm - 90 ppm (uniform distribution)	For the upper bound, we use the lowest commonly used threshold to define a tested paint as lead-based, as explained here.
Percent of homes repainted each year	2% - 5% (80% CI)	We assume that houses in LMICs get repainted typically every 20-50 years, so that each year 2-5% of the houses get repainted. LEEP (2021) assumes 2% in its cost-effectiveness

		analysis, but we think this number is likely to be higher, hence we take 5% as an upper bound.
Base blood lead level (BLL) in µg/dL	5	Assumed blood lead level of children who are not exposed to lead paint in their home, taken from Lanphear et al. (2002, Table IV). Note that this is not a 'safe' level of blood lead, but it reflects our expectation that children are also exposed to other sources of lead, even if paint is lead-free.
Relation lead paint level and BLL	0.005-0.015 (90% CI)	We assume that this relationship is mediated via dust lead loading and obtained this input in two steps: (1) Lead paint level ➜ dust lead loading: We assume that a rise in lead paint levels by a factor X increases dust lead loading by a factor $X^{0.119}$. This is a highly uncertain estimate based on the association between window paint lead and floor dust lead found in Dixon et al. (2007, Table III). (2) Dust lead loading ➜ BLL: We assume that a rise in dust lead loading by a factor X increases BLLs by a factor $X^{0.052}$, based on an estimate from Wilson et al. (2022). Thus, combining those two steps, a rise in lead paint levels by a factor X increases BLLs by a factor ~$X^{0.006}$, which we round up to $X^{0.01}$. This means that, for example, increasing lead paint levels by 50% is associated with an increase in BLLs by 0.4%. To express our uncertainty around this estimate, we use a subjective confidence interval instead of the point estimate.
Percent of population in LMICs without lead paint bans in 2022	19% - 27% (90% CI)	This was calculated as the percentage of LMICs that do not have lead paint bans and weighted by population size. See here for our calculations, based on World Bank Data for population estimates from 2021 and the World Health Organization on lead paint regulations (2023). For simplicity reasons, we do not distinguish between different types of bans (i.e., different thresholds for lead in paint).
IQ loss per µg/dL of blood lead	0.30 - 0.70 IQ points (95% CI)	Lanphear et al. (2019): "The estimated IQ point decrements associated with an increase in blood lead from 2.4 to 10µg/dL [...] [was] 3.8 (95% CI, 2.3–5.3)." We divided the upper and lower bound by 7.6 (=10 - 2.4) to get the estimated effect per µg/dL.
Income loss per IQ point loss	1.8%-2.4% (90% CI)	Based on Attina and Trasande (2013, p. 1099).
Per capita income in 2022	USD 13,776	As income data is not available for many countries, we estimate per capita earnings as (GDP per capita) * (labor share of income) / (labor force participation rate). We use World Bank Data from 2021 for the GDP per capita (PPP,

		current international dollar) in LMICs (USD 11,847) and assume 50% as the labor share of income, in line with previous studies (e.g., Tong et al., 2022, p. 3). We estimate the labor force participation rate as a percentage of the total population using World Bank estimates for the labor force participation rate among individuals aged 15+ and the percentage of the total population aged 0-14 (see Tong et al., 2022, p. 3). Our estimate is 43%.
Lifetime earnings per child born in 2022	USD 2,049,706	We calculate lifetime earnings as follows: (1) We calculate yearly per capita income using per capita income in 2022 (UDF 13,776) and the growth rate (3%). (2) Following Tong et al. (2022, p. 3), we assume that the average individual starts working for 44 years at age 16. (3) For a child born in year X, we calculate the sum of their yearly per capita income starting from year X+16 for 44 years. This is our estimate of lifetime earnings per capita.
Annual per capita income growth rate	3%	According to World Bank Data, GDP per capita in LMICs has grown by an average of ~3% each year since 1961. See here for our calculations of the average.
DALYs due to lead exposure in LMICs in 2022	13,263,664 - 28,534,748 (95% CI)	Global Burden of Disease Results Tool (2019)
Percent of DALYS due to lead exposure attributable to lead paint	5%-10% (80% CI)	Combining our findings for the income effects with LEEP's findings from a previous analysis (see Hu, 2022), we find that lead paint accounts for ~7.5% of the total economic burden of lead paint exposure. We assume that this relationship also holds for the DALY burden and use a confidence interval to reflect our uncertainty.
Years of income equivalent to 1 DALY	2.8	We use this assumption based on GiveWell's and IDinsight's research on how people make trade-offs between income and health. GiveWell assumes that 2.8 years of income is equivalent to one DALY in its cost-effectiveness analysis for Fortify Health.
Discount rate	4%	We use GiveWell's assumed discount rate for cost-effectiveness analyses.
Counterfactual speed of introducing lead paint bans per year	1 percentage point	Counterfactual scenario: We assume that the share of people in LMICs without lead paint bans decreases by 1 percentage point each year until it reaches 0%.

Speed-up factor of introducing lead paint bans under intervention	2	Intervention scenario: We assume that an intervention could double the speed of introducing lead paint bans in LMICs each year.

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