SMEP | Sustainable Manufacturing and Environmental Pollution Programme

Manufacturing pollution in sub-Saharan Africa and South Asia: Implications for the environment, health and future work

Executive Summary

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Acknowledgements

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Foreword

The manufacturing sector provides substantial opportunities for economic growth in developing countries but is often associated with high levels of pollution. This pollution can cause environmental degradation of air, water and soil that in turn can lead to poor occupational and public health. There are many reasons for these unwanted outcomes including limited resources and technological know-how to implement cleaner production methods as well as insufficient establishment and implementation of environmental regulations. As a consequence, high levels of pollution associated with the manufacturing industry have the potential to cause health problems, decreased levels of productivity and consequent economic losses.

The Sustainable Manufacturing and Environmental Pollution (SMEP) programme aims to reduce the impacts of manufacturing in developing countries by funding research activities and developing technical and behavioural solutions that will help reduce the levels of pollution and environmental degradation generated by manufacturing processes in sub-Saharan Africa (SSA) and South Asia (SA). SMEP target countries in SSA include: the Democratic Republic of the Congo, Ethiopia, Ghana, Kenya, Nigeria, Rwanda, Senegal, the United Republic of Tanzania and Zambia, and in SA include: Bangladesh, Nepal and Pakistan. The programme is funded by the UK government's Foreign, Commonwealth & Development Office (FCDO) and is implemented in partnership with the United Nations Conference on Trade and Development (UNCTAD).

To better understand the consequences of environmental degradation caused by manufacturing industries in these two regions, a scoping study was conducted that identified key manufacturing activities, the types of pollution associated with these industries, and the potential impact of this pollution on the environment and human health. This was achieved by collating and analysing data from a variety of sources including global trade and manufacturing data sets and international environmental data sets; peer-reviewed and grey literature sources; online surveys of regional stakeholders; and in-person interviews with key manufacturing actors in Kenya, Bangladesh and Nepal. The key findings from this scoping study are presented in this Executive Summary and will also be used to inform and further define the scope of research calls to be commissioned under the SMEP programme. To read the full report go to https://www.smepprogramme.org/s/files.

Polluting industries are increasingly prevalent in many developing countries

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This increase is partly due to expanding globalization of trade and manufacturing industries along with low labour costs and the spread of Western lifestyles. At the same time, environmental and public health protections are limited and there are few resources to implement cleaner methods of production in most developing countries. This has resulted in a sharp increase in various types and forms of pollution associated with industrial activities such as tanning, textile manufacturing, pharmaceutical production, chemical manufacturing (including lead battery and e-waste recycling) and food processing.

Pollution from manufacturing can adversely impact the environment and human health

As industrial activity has developed in lower-income countries, so too has the prevalence of pollution-related chronic conditions such as asthma, cardiovascular disease, stroke and cancer. Manufacturing processes are also affecting the health of the general population through contamination of air, drinking water, soil, crops, livestock, fish and other resources. Human health impacts associated with pollution, such as induced cognitive impairment, neurological diseases and endocrine disorders, can cause substantial economic costs by limiting the economic

productivity of entire generations and undermining the developmental trajectory of whole societies. Manufacturing pollution also impacts ecological functioning and related ecosystem services. The effects of pollutant exposure have also been found to be exacerbated by climate change causing increasing concentrations of many chemicals in the water, air and soil as well as enhanced sensitivity to pollution.

Economic structures in many developing countries may well be exacerbating pollution impacts from manufacturing

The impacts associated with pollution from manufacturing are likely to be exacerbated by the growth of the informal economy, which is typified by deregulation or lack of regulations, including those safeguarding against environmental pollution from any sectoral activities. The informal economy engages more than 60 per cent of the world's employed population and is more significant in developing countries. A significant amount of manufacturing activity that occurs in lower-income countries is conducted within this informal sector. Furthermore, labour markets are gender segregated, with women in mostly low-paying occupations.

The gender-based impacts of manufacturing pollution are important yet poorly understood

Although employment within the manufacturing industry can improve the economic and social status of women, narrowing the gender gap and reducing income poverty, this comes at a price. Gender norms and social structures that restrict women's mobility, free time and other employment opportunities can make them more vulnerable and more likely to work within poorly regulated, and hence polluted, manufacturing settings. Also, women are likely to be more at risk from certain pollution exposures due to lower body weight, with additional health risks during pregnancy. The impact of these (and other) issues that influence the role of gender in environmental exposure and morbidity related to pollution urgently requires further investigation.

….improving our understanding of these impacts will be crucial so that manufacturing can improve the socioeconomic status of women through enhanced employment opportunities without trade-offs

The share of female employment in manufacturing in lesser-developed countries rose from 41 per cent in 2000 to 43.7 per cent in 2017. Female employment in manufacturing tends to concentrate in particular industries, often due to the perceived higher productivity of women, and has been shown to improve their economic and social status while narrowing the gender gap and reducing income poverty. However, manufacturing work is often too poorly paid to overcome poverty or vulnerability. From a gender equity perspective, women are generally employed in low-skilled labour such as beverages, textiles and wearing apparel. Women may be more vulnerable to economic downturns because they are mostly engaged as temporary or casual low-skilled workers in labour-intensive roles. Further,

employment can intensify the burden of unpaid care work and cultural constraints on female mobility and sexual harassment may also physically bar women from employment if there are no jobs available in the vicinity at the appropriate skill level.

Existing initiatives that tackle manufacturing pollution are limited in scope and extent

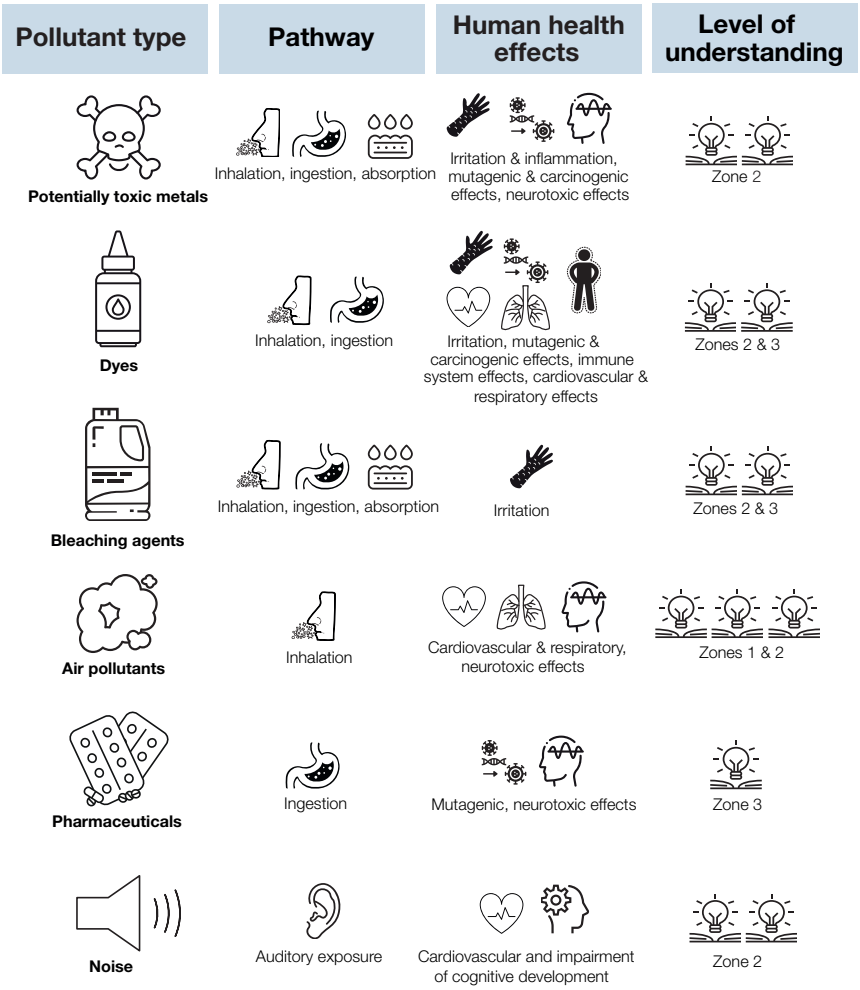
A number of existing initiatives provide information on the current state of pollution from manufacturing. These initiatives have tended to focus either on understanding pollution and health risks per se (e.g. the Global Burden of Disease study, the Lancet Commission on pollution and health, the Global Alliance on Health and Pollution [GAHP]) or on trying to quantify pollutant loads arising specifically from the manufacturing industry (e.g. the Toxic Sites Identification Programme [TSIP], the Industrial Pollution Projection System [IPPS]). The relevance of the TSIP in supporting sustainable manufacturing is limited by the fact that only one key pollutant (out of lead, chromium, mercury and radionuclides) and one exposure pathway (out of air, water or soil) are explored at sites identified as polluting. Estimates of pollution emissions by the IPPS are also complicated by lack of data on the size of manufacturing activities (often measured as number of employees and production output) and emission factors for particularly hazardous pollutants associated with manufacturing processes.

The holistic approach taken by the collaborative body of organizations that make up the GAHP will very likely play an important role in providing technical and financial resources to governments and communities to reduce the impacts of pollution on health in developing countries. Such endeavours can be supported by programmes such as the National Cleaner Production Centres (NCPCs) designed to support eco-efficient industrial development in key developing countries. Through assessment of these programmes and initiatives, in combination with a systematic review of the academic literature, it is possible to identify the key pollutant groups associated with the manufacturing industry that are most likely to have detrimental effects on human health (see Figure 1).

Identification of the key manufacturing industries causing pollution in SSA and SA is challenging due to knowledge gaps in international data

International data sets can provide information on the extent (e.g. number of establishments and employees) and economic value of different manufacturing industries. However, these data are limited in SMEP target countries. The importance of industries within each country varies depending on what metric is used. Though this can help to understand the prevalence of certain industries, there is very little data available on the level of pollution associated with these industries. Therefore, international data should be used in combination with information from the academic literature and knowledge of local and regional stakeholders to identify which manufacturing activities are most likely to be causing pollution that leads to environmental degradation and human health impacts.

Figure 1. Key pollutant groups associated with the manufacturing industry and their potential effects on human health



N.B. 'Level of understanding' refers to categories (zones) defined by the Lancet Commission on pollution and health with well-established pollution-disease pairs (Zone 1: high level of understanding) to those that are new and emerging pollutants (Zones 2 and 3: medium and low level of understanding, respectively). See main report for further detail.

There is far less information in the academic literature on manufacturing pollution and associated environmental and human health impacts for SSA compared to SA. Nevertheless, there is sufficient information to show that pollution from manufacturing industries can be associated with particular health outcomes. Reviewing the academic literature reveals the relative dearth of research on manufacturing pollution in SSA compared with SA, highlighting the need for increased research in this region. A systematic review of the academic literature that dealt with 'manufacturing' + 'pollution' + 'impact' (with 'impact' referring to environmental and/or human health) returned 175 articles for SA and only 38 for SSA. Information from international data sets, academic literature and stakeholder engagement can be used in combination to identify a number of manufacturing industries of concern that could be causing human health and well-being impacts (as well as degradation of ecosystem services) (see Figure 2). These pollution types can be classified according to a scheme developed by the Lancet Commission on pollution and health, which is affiliated with the GAHP in helping to assess the current level of knowledge of potential pollution effects.

Figure 2. Manufacturing industries, associated pollutants and health risks in SSA and SA

Industry	Number of articles	Pollutant type	Human health effects
Textiles & wearing apparel	94	Potentially toxic metals, dyes bleaching agents, air pollutants, noise	Cardiovascular & respiratory effects, irritation & inflammation, carcinogenic, neurotoxic effects
Leather & leather products	81	Potentially toxic metals, dyes bleaching agents, air pollutants, noise	Cardiovascular & respiratory effects, irritation & inflammation, carcinogenic, neurotoxic effects
Pharmaceuticals	34	Potentially toxic metals, dyes air pollutants, pharmaceuticals, noise	Cardiovascular & respiratory effects, carcinogenic, neurotoxic effects
Chemicals & chemical products	26	Potentially toxic metals, dyes bleaching agents, air pollutants, noise	Cardiovascular & respiratory effects, irritation & inflammation, carcinogenic, neurotoxic effects
Food and beverages	25	Potentially toxic metals, dyes bleaching agents, air pollutants, noise	Cardiovascular & respiratory effects, carcinogenic, neurotoxic effects
Non-metallic mineral products	20	Potentially toxic metals, dyes bleaching agents, air pollutants, noise	Cardiovascular & respiratory effects, irritation & inflammation, carcinogenic, neurotoxic effects
Electrical equipment	10	Potentially toxic metals, dyes	Cardiovascular & respiratory effects, carcinogenic effects

N.B. Number of articles refers to those retrieved from the systematic literature review that included mention of 'manufacturing' + 'pollution' + 'impact' for SA and SSA combined. See main report for further detail.

….but it is increasingly important to identify these polluting industries as the manufacturing industry is increasingly seen as pathway to greater economic growth

Efforts to grow the manufacturing sector in SSA and SA frequently form the cornerstone of national and regional development policy, as reflected in the African Union's Agenda 2063 and Sustainable Development Goal (SDG) 9. SDG 9 calls for member states to "Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation", with the assumption that manufacturing is the engine of economic growth. There is a long-term trend towards the relocation of manufacturing production from industrialized economies to the developing world, yet there is still some way to go before SDG 9 is realized for SMEP target countries in SSA and SA, especially with respect to sustainable production. It is also clear that global economic development processes such as trade and consumer demand have driven growth in manufacturing industries in SSA and SA.

Key manufacturing industries identified in SSA likely causing pollution detrimental to the environment and human health

Food and beverages is an extremely important and growing industry in the SSA region and the third-most important sector for export. Sub-sectors of the industry that have been associated with pollution include fishing, filleting, beverages, baking, sugar blending and packaging, wine making and coffee processing. Pollution from these sectors has been identified as likely to be hazardous to human health due to emissions of potentially toxic metals (e.g. chromium, lead and copper) and air pollutants (e.g. particulate matter, sulphur and nitrogen dioxides). These pollutants can cause cardiovascular and respiratory diseases, act as carcinogens and neurotoxins and can impair reproductive ability. Manufacturing industry stakeholders across the SSA region also identified this industry as particularly problematic as a source of water pollution; this is supported by the fact that the industry accounts for about 55 per cent of industrial wastewater pollution in SSA (see Figure 3). These wastewater discharges are often high in organic wastes (e.g. soil wastes such as food bits, blood, fat, skins, bones, pulp and husks) that alter the chemical and hence biological structure and functioning of the watercourses to which they are discharged.

Interventions – Physio-chemical effluent treatment is the most common intervention and includes anaerobic digestion (to treat organic waste), coagulation (removal of solids by sedimentation and filtration) and flocculation (removal of suspended solids through the addition of a clarifying agent. Emissions from boilers and furnaces could be reduced by improving energy efficiency through insulating boilers with glass wool, sheet and paper.

Textiles and Wearing apparel (the latter often referred to as the ready-made garment industry) are important industries, being the second- and fifth-largest manufacturing employers respectively across the SSA region. Textiles generally refer to factories involved in activities ranging from wet processes that include spinning, weaving, knitting, dyeing and finishing. Wearing apparel refers to dry processes that include sewing, knitting, printing and packaging; some factories span the entire

range of these processes. Wet processing is considered the more polluting of these industrial activities, using over 10,000 chemicals and 3,000 individual textile dyes, some of which are known to be harmful to human health (e.g. azo dye derivatives). Together, these processes cause the release of a number of pollutants, including organic substances such as dyes, bleaches, surfactants and potentially toxic metals (arsenic, copper, chromium and zinc). The use of dyes also releases a huge amount of coloured wastewater into ecosystems, a significant source of aesthetic pollution. It is estimated that 17–20 per cent of industrial water pollution comes from textile dyeing and finishing treatments given to fabrics. The industry also contributes to airborne pollution in the form of textile dust emissions of volatile organic compounds from solvent use and particulate matter, as well as sulphur and nitrogen oxides from energy provision for textile processing. These pollutants are associated with a number of human health impacts such as cancer, impaired reproductive activity and cardiovascular, respiratory and neurological disease; they have also been associated with skin irritations and inflammations.

Interventions – Effluent treatment plants (EFTs) use methods such as flocculation, coagulation and ozonation coupled with biological treatments that allow for the removal of nitrogen, organics, phosphorous and potentially toxic metals; chemical substitution approaches to replace especially toxic chemicals; innovative processes that increase operational efficiency, which can reduce water use and limit or eliminate the discharge of toxic waste; the use of personal protective equipment (PPE) to protect workers in the industry; and the use of pollution abatement technologies to reduce emissions, e.g. airborne pollutants.

> ***"SSA stakeholders identified upper respiratory health complications resulting from occupational exposure, and other non-communicable diseases such as cancers caused by carcinogens in water, food and air, as key health impacts associated with manufacturing pollution."***

Chemicals and chemical products is an economically important industry in SSA, being the second-highest ranked industry in terms of value added and the fourth-highest industry in terms of export value. It is also the third-fastest growing industry, with an annual average growth in value of exports of about 14 per cent. This diverse industry has a number of subsectors that have been specifically associated with pollution (including basic chemicals, agro-chemical products, plastics, paints, soaps and man-made fibres). The industry is particularly hard to evaluate in terms of potential impacts on human health due to new chemicals being constantly introduced and old chemicals frequently withdrawn, changing the chemical manufacturing market and making it difficult to monitor and evaluate. Pollutant emissions tend to take the form of gases, particulate matter and liquids, and are often associated with both organic and inorganic water pollution as well as the release of potentially toxic metals, lead compounds (especially from paint manufacturing) and air pollutants from fuel combustion. Industrial equipment such as compressors, pumps, and motors generate noise pollution that can cause stress as well as damage to hearing.

Interventions – Effluent treatments (often with permeable reactive barriers); PPE to minimize exposure to contaminated dust; training on minimizing occupational exposure. Technology exists for noise control in industry, but upgrading plants may be expensive.

Electrical equipment is an industry showing strong signs of growth, increasing within SSA at an average of 10 per cent annually by value of exports from 2005–2014, reflecting the proliferation of technology globally. Subsectors of this manufacturing industry (e.g. lead acid battery recycling and e-waste) are part of a circular economy since they provide opportunities for the recycling of existing materials. For example, vast quantities (75–80 per cent) of e-waste are exported to developing countries, mostly in Africa and Asia, for recycling and disposal. E-waste refers to discarded electrical and electronic equipment containing costly components that have economic value if recycled; health hazards arise from processes such as burning and dismantling that are used to recycle various components. Lead acid battery recycling has been identified as particularly hazardous due to emissions of airborne lead that can contaminate soil and dust and lead to elevated blood lead levels in both industry workers as well as adults and children in nearby residential communities and schools. E-waste recycling processes can lead to direct exposure via skin absorption, inhalation and ingestion of contaminated dust containing hazardous materials such as potentially toxic metals (in particular lead, cadmium and mercury) and other toxic fumes. Children may suffer exposure in schools, playgrounds and homes close to recycling sites via contamination of air, soil and water as well as by 'take-home' exposure from parents and household members working at e-waste sites.

Key manufacturing industries in SA likely causing pollution detrimental to environment and human health

Interventions – Regulations for performance measures for stack emissions, ambient air and occupational exposures (airborne and blood lead levels); minimum production capacities for new and existing plants to ensure industries have sufficient resources to install clean production; options to reduce the cost of lead soil remediation in local communities to battery recycling industries.

> ***"Between 6 million and 16 million people are exposed to dangerous concentrations of lead each year at used lead acid battery recycling sites,"*** **Lancet Commission on pollution and health.**

Key manufacturing industries in SA likely causing pollution detrimental to environment and human health

Textiles and wearing apparel are the top two industries in terms of number of employees, manufacturing value added and exports in SA. Textiles was the industry most commonly associated with pollution by stakeholders in Bangladesh and generated the greatest number of articles in the literature review overall. The industry generates the same types of pollutants as in SSA, with similar pollutant pathways leading to environmental degradation and human health impacts. However, the industry is more established in SA and hence the poor health outcomes might be expected to be more prevalent where cleaner production methods are not in operation.

Interventions – EFTs are most commonly adopted but not always maintained. Cleaner production techniques, such as efficient water usage, have proved successful but require knowledge transfer and technical assistance. An understanding of the business benefits of more sustainable practices could support increased uptake of cleaner production methods.

> ***"Textiles manufacturing has slowed in Bangladesh due to high levels of competition from other countries with higher capacity and pressures from high-income buyers demanding 'greener' production as well as cheaper prices,"*** **South Asian stakeholders.**

Leather and related products is the fourth-most important manufacturing industry for exports in SA. Leather manufacturing involves several sequential processes and a variety of chemicals. Raw hides are treated to prevent decomposition, soaked to remove hair and then undergo de-liming and pickling in preparation for the tanning process. After tanning, they are shaved, re-tanned, dyed and finally finished. Different chemicals and organic compounds are used to achieve each stage of the process but only a limited amount is chemically bound to the leather, so most is washed out as waste effluent. The resulting effluent can consist of potentially toxic metals, acids, sulfates and various organic pollutants (e.g. proteins, tannins, phthalates and many more). Most notably, effluent can contain high levels of chromium, which is a risk to humans (causing conditions such as cancers, skin problems, and brain, kidney and liver damage, as well as reproductive and neurological damage). Salts contained in the effluents can cause salinity, and high amounts of proteins, fatty matter, hair and other inorganic pollutants in discharges can impact the biological

function of water courses receiving effluent. Solid wastes dumped to land include hides, hairs, shavings and so on and can be a source of chromium pollution and noxious odours. Leather manufacturing also emits dust, hydrogen sulfide and ammonia, which are all sources of air pollution.

Interventions – EFTs, including biotechnology using enzymes to remove toxic metals; membrane technologies to reduce salinity along with reverse osmosis to remove solids and produce water that can then be reused in the manufacturing process. Effluent is a complex mixture that may require multiple treatment stages. Other interventions include alternative methods of preservation, such as chilling or drying to avoid the need for salt; chrome recycling or recovery; bioremediation of contaminated land and water through chemically enhanced phytoextraction using chelating agents to increase the capacity of plants to take up metals; and effective PPE to improve occupational health and safety.

> ***"Due to the complex nature of effluent from the leather industry it is difficult to attribute health risks to one component and the human health and ecosystem impacts of some pollutants are still not fully understood",*** **Yadav et al., 2019.**

Pharmaceuticals – The pharmaceuticals industry is growing in importance across SA and is currently ranked 13th out of 23 manufacturing industries in the region in terms of export value. Pollutants are produced throughout the production process, but emissions primarily take the form of wastewater effluent and sludge. A key pollutant group comprises active pharmaceutical ingredients (APIs). Over 1,900 APIs are used in human medicine around the globe and around 750 are used in veterinary medicine. These APIs are present in pharmaceutical wastewater, sediment, groundwater, sludge, soil and soil waste impacted by pharmaceutical manufacturing sites. APIs have been found to impact bird mortality, fish reproduction, wildlife behaviour and crop growth, and could potentially cause endocrine, gastrointestinal and liver function abnormalities, as well as musculoskeletal, neurological, reproductive and urinary impacts in humans. Pharmaceutical industry effluents can also be contaminated with other organics, such as benzene, polycyclic aromatic hydrocarbons and heterocyclic compounds, and with halides, nitrates, sulfates, cyanides and metals. These pollutants have been associated with impairments in growth, gene expression, neurotoxicity and endocrine disruption in aquatic species. Gaseous pollutants can also be released in the manufacture of pharmaceuticals (e.g. volatile organic compounds from storage tanks and reactors and through handling, as well as nitrogen and suphur oxides from combustion in boilers).

Interventions – Substitution for less toxic materials, process modification, recovery and recycling; treatment for waste and wastewater, including: biological treatment processes, advanced treatments, advanced oxidation processes and hybrid technologies involving a combination of approaches. The Sustainable Procurement in the Health Sector initiative or voluntary industry initiatives such as that of the antimicrobial resistance (AMR) Industry Alliance (a network of over 100 companies working in the pharmaceutical sector) encourage adoption and implementation of such interventions.

> ***"Elevated levels of antimicrobial-resistant organisms have been detected in surface waters and sediments receiving pharmaceutical wastewaters high in active pharmaceutical ingredients (APIs), the transfer of these resistant determinants back to the human population may be contributing to the global anti-microbial resistant (AMR) crisis,"*** **UNEP, 2017.**

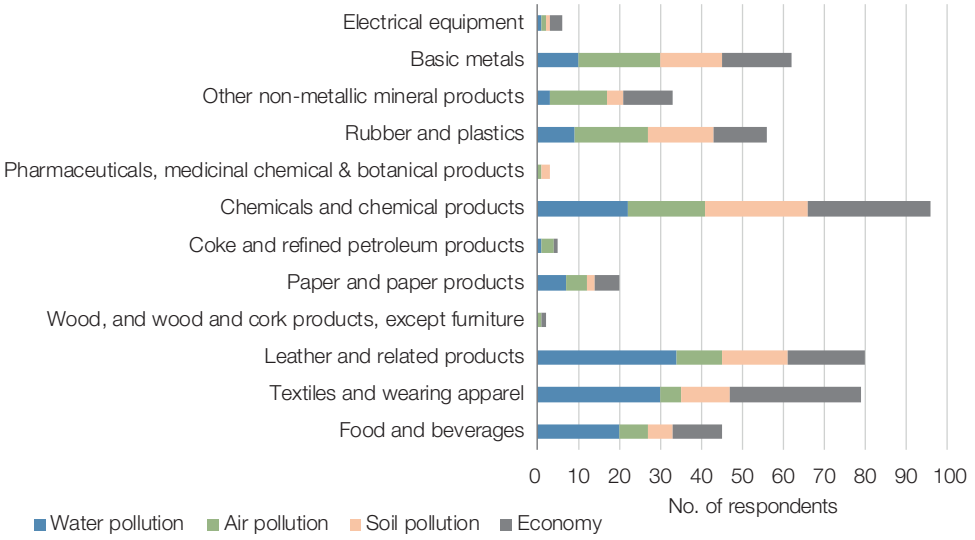
Non-metallic mineral products – These include ceramics, bricks, glass, concrete and cement manufacturing industries and the industry is the third-largest employer in the manufacturing sector in SA. Stakeholders in Bangladesh and Nepal identified brick kilns as the dominant source of industrial air pollution in their respective countries. Air pollutants are generated during the brick-baking process, where large volumes of fuel are consumed. The emissions produced are dependent on the fuel source but as fuel is typically low quality, production is energy intensive and highly polluting. Emissions include particulate matter and potentially hazardous gases such as sulphur and nitrogen oxides and carbon monoxide. Pollution is highest during the dry season when kilns are operating. Farmers sell soil for use in brick manufacturing, which contributes to soil degradation and reduces crop production. Air pollutants contribute to climate change and can also have serious health issues including inflammation in lung tissue, as well as short-term health impacts (coughing, wheezing, chest tightness) and long-term health impacts (reduced lung function, chronic bronchitis, lung cancer risk and even mortality). The health risk is particularly high for workers who endure occupational exposure. Children are also particularly vulnerable due to the high levels of child labour in brick manufacturing.

Interventions – Increase production efficiency in order to reduce fuel consumption by improved design of kilns (e.g. zigzag or Hoffman kilns that increase fuel efficiency by increasing air circulation).

SSA and SA manufacturing industry stakeholders responses generally corroborate the findings from the academic literature

Manufacturing stakeholders across SSA and SA (34 respondents) identified the chemicals, leather and textiles manufacturing industries as the most polluting, with water pollution acting as a key contaminant pathway to human health and ecosystem effects (see Figure 3).

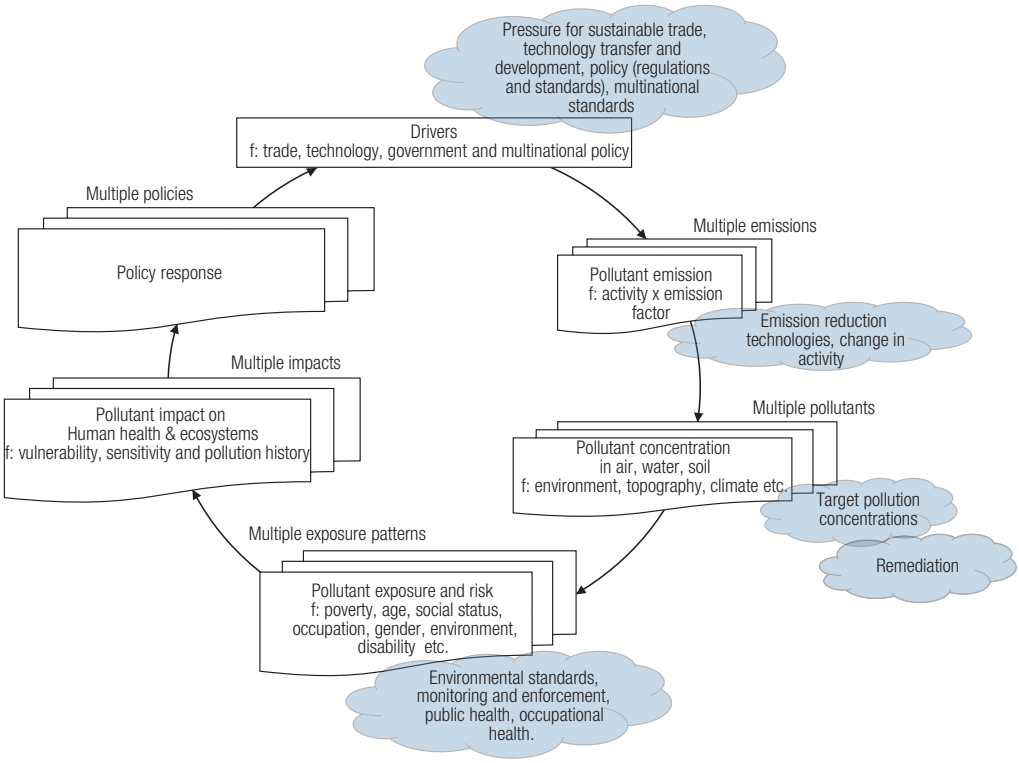
Figure 3. SSA and SA stakeholder responses identifying those manufacturing industries of most concern in terms of pollution (and the associated contaminant pathway) as well as of most economic importance



A DPSIR (Drivers, Pressure, State, Impact and Response) framework can be used to describe factors that determine the scale and extent of pollution and its impacts along a pollution chain

The DPSIR framework (see Figure 4) can be used to describe the drivers of manufacturing industries (trade, technology, government and multinational policy), the associated emissions (which are a function of manufacturing activity-related emission factor for each pollutant), the consequent pollutant concentrations in the environment (which will be determined by environmental factors, for example), the resulting pollution exposures (a function of factors such as poverty, occupation and gender) and the pollutant impact (which will depend on the sensitivity and vulnerability of the receptor). Policy responses can be developed to reduce pollution impacts along different parts of this pollution chain.

Figure 4. Key issues that influence the scale and extent of human health and ecosystem impacts from manufacturing industry pollution



Tackling pollution requires action along the entire pollution chain

Measures to reduce pollution should consider changes in the initial drivers of pollution (e.g. developing sustainable trading systems, improving and transferring technology, developing national and international regulations and standards), interventions that include emission reductions, remediation of toxic pollutant concentrations, and monitoring and enforcement of pollution standards. Identifying target pollutant concentrations is crucial to optimize emission reduction and remediation measures. The identification of target pollutant concentrations can also lead to a set of agreed environmental standards against which to develop monitoring and enforcement programmes and develop public and occupational health programmes.

> ***"The lack of enforcement of regulations, where they exist, is perhaps the single most important factor leading to high levels of pollution from manufacturing industries. Corruption and lack of resources for monitoring and enforcement are the main issues affecting the implementation of interventions".***

The multi-pollutant nature of emissions from manufacturing makes it difficult to prioritize actions to reduce pollution

This can result in both a single industry, as well as multiple, co-located industries (as is often the case in industrial zones) emitting a variety of toxic pollutants. The complexity caused by these multiple pollutant emissions, along with the potential transformations of pollutants as they are transported in air, water and soil, often leads to complex pollutant concentrations that vary with proximity to the emitting source as well as with prevailing environmental conditions (climate, season, etc.). These variable pollutant concentrations will be a component determining human exposure and ultimately the pollutant impacts on human health. This level of complexity highlights the difficulty in prioritizing action to reduce manufacturing pollution and determining which industries (or groups of industries) are most polluting.

The adoption rates of interventions to reduce emissions from manufacturing are often low, especially for smaller-scale industries

Larger manufacturing industries have sufficient resources and so are generally good at implementing environmental pollution control measures. However, the small-scale industries that make up most of the manufacturing sector have fewer control measures and tend to release polluting substances unabated. Pressure from international buyers towards cleaner production can be accommodated by the larger industries, so they are more likely to implement better pollution control measures.

….and the lack of enforcement of emission regulations exacerbates the problem

Accurate pollution monitoring data and regulatory pressure along with the need for law enforcement to reprimand non-compliant polluters have been identified as key factors for the success of interventions. These measures can be complemented by governmental support of industrial compliance using fiscal incentives such as subsidies and tax rebates.

Better pollution standards that consider multi-pollutants and associated exposures are needed

The trend in standard setting seems to be moving from a single, one-size-fits-all, pollutant concentration value approach to one that considers exposure scenarios, taking into account multiple exposure pathways in terms of exposure time and characteristics of the receptor such as age and body size. Such standards might also include a number of different factors, such as number of years of exposure and, for occupational exposures, time spent at work, time in the home environment, factors to predict dust generation, dietary intake of both contaminated and non-contaminated foods, different food types with different factors for uptake into different food types, and so on. This indicates the complexity involved in estimating

the impact on human health and ecosystems arising from manufacturing pollution: often, a complex mix of pollutants is emitted and transmitted via air, water and soil, and each of these pathways can lead to environmental and human health exposures.

…with the degree of exposure and risk being influenced by the vulnerability of different worker groups (e.g. migrant and child labour)

Some groups are more vulnerable to exposure. For example, for migrants working in the manufacturing industry, the immediate need to earn money means they are more willing to work in poorer conditions; they also have less access to trade organizations and unions. Children represent a particularly vulnerable labour class, as they consume more food, air and water per kilo of weight compared to adults, increasing their overall exposure. Moreover, early cognitive and physiological developmental processes are more prone to being disrupted in children. Workers often lack the power or capacity to demand PPE from their employers, and appropriate formal channels through which to lodge their demands or to protest. Lacking a voice, they are easily marginalized and because unemployment is often high, they are dispensable.

Local residents risk exposure to industry-associated pollutants

Polluting industries and human settlements are often co-located, meaning local populations are at a high risk of exposure and may not be aware of the risk. Even if they are aware of the risk, manufacturing attracts poorer people because it provides entry-level job opportunities and cheaper housing is often located in polluted areas. Residents who are malnourished are also more likely to be more affected by pollution. If pollution is reduced land and house prices go up, forcing low-income households to move elsewhere.

Improved industrial zoning can mitigate human exposure to pollutants

Certain clusters and industrial areas termed ‘industrial villages’ are being developed to move micro- and small-scale industries to specific locations. However, an important consideration for such industrial zones is that they provide residential areas supported by community facilities such as hospitals, schools or canteens for workers and their families.

Our understanding of the impact of pollution exposure on human health needs to be improved

Key health impacts associated with the manufacturing industry include: cardiovascular and respiratory diseases, carcinogenic effects, neurological conditions, reproductive toxicity, and irritants and inflammation. However, it is clear that knowledge of the causal links between pollutants, exposure and disease is limited. Understanding of

pollutant impacts is further complicated by the fact that receptors (both ecosystems and humans) can be more sensitive to pollutants if they are exposed to pollutant cocktails and if the environmental conditions of exposures vary, since this may influence pollutant uptake and detoxification. Other factors such as behavioural patterns, body weight, gender and underlying health conditions, geographical location, nutritional status and co-exposure to other pollutants will also influence the sensitivity of humans to a given pollutant concentration.

> ***"Further research is urgently needed to better understand differential toxicity to pollutants by gender and to train physicians and occupational health care workers in recognizing and managing pollution-induced diseases."***

…along with the socioeconomic costs of diseases caused by pollution

Diseases caused by pollution generate economic costs, including medical and opportunity costs from reduced productivity. It has been estimated that in rapidly developing countries seven per cent of health spending is on people made ill by pollution. At the same time, pollution that causes cognitive impairment can lower national intelligence levels and subsequently impact productivity.

A more transparent supply chain can enhance the sustainability of economic growth via production, but this must be reflected in retail prices

Transparent supply chains are essential if consumers are to make informed choices on which products to buy and encourage more sustainable production through purchasing power. However, it is also important to ensure a fair price is paid by consumers to support sustainable and equitable production in the manufacturing industries in SA and SSA. This is particularly important for the small- and medium-sized enterprises that comprise about 33 per cent of emerging markets and struggle to afford cleaner production processes due to their low economies of scale.

International and national trade systems can also play an important role in influencing standards of production and hence levels of pollution associated with manufacturing

Trade liberalization can also be an important driving factor of national and global contributions to pollution. Countries with more open economies tend to have a greater adoption of cleaner technologies, privatizing enterprises can reduce pollution, and energy subsidies can lower the cost of end-of-pipe treatment but also increase overall pollution due to increased processing of heavy raw materials and energy use in general. Governments' termination of subsidies and tax breaks for polluting industries could be used as a means to bear down hard on the worst-polluting manufacturers.

Future work

One of the key aims of the SMEP scoping study was to identify a set of recommendations for future work that could support the transition to more sustainable manufacturing in SSA and SA over the next five years. These recommendations are presented below, categorized according to different types of approaches that could lead to cleaner production in the manufacturing sector.

1. Linkages between manufacturing, pollution and sustainable development

Understanding how manufacturing can be developed to support global sustainability goals will be crucial to identifying the trade-offs and opportunities that continued growth in the manufacturing sector might play in SSA and SA.

Understanding the role of supply chains, consumer demand and multinational companies in encouraging more sustainable and cleaner production would be helpful to assess what works and what could be improved or adapted for the manufacturing industry in SSA and SA contexts. This would mean assessing existing initiatives that have established guidelines and frameworks to encourage cleaner production (e.g. via mechanisms such as emission standards, best practice guidelines, development of monitoring protocols and certification criteria).

Understanding the role the informal sector plays in pollution from manufacturing should also be an important focus given the growth in this sector and the difficulties in enforcing environmental law and regulations to control pollution in informal sector activities. This information could be used to prioritize targeted monitoring, the implementation of intervention measures, and future research in particular countries and country regions. Ideally, such activities would connect back to initiatives such as the TSIP and IPPS where data have already been collected and where efforts are underway to build capacity in the application of these approaches.

Understanding plastic pollution and manufacturing in terms of processes that create plastic pollution as well as plastic waste from product packaging means understanding that growth in the manufacturing industry (especially in the food and beverages sector) could increase the use and subsequent waste of plastics.

Understanding the role of poverty and gender in influencing vulnerabilities to pollution arising from the manufacturing sector is critical. It is apparent that little research has been done in this area, and most articles deal with the physical science of pollution (emissions, concentrations and impacts) with very little consideration of those socioeconomic factors that will influence risk and vulnerability.

2. Policy measures

Government policy to tackle manufacturing pollution includes the formation of industrial zones or industrial villages where polluting activities are moved away from urban or residential areas to reduce pollutant exposure. Such industrial zoning has been implemented in a number of areas in SSA and SA with seemingly positive and negative effects. Research to understand how effective such zoning is, and what policies and practices can be introduced to enhance its effectiveness from both the viewpoint of reducing physical pollution as well as improving socioeconomic conditions for workers and their families, could help governments decide the best conditions for the establishment of industrial zones. Additionally, governments should continue optimizing policy measures including command and control, and economic penalties and incentives applied to polluting industries.

3. Health effects

Engagement with the public health sector is needed for effective take-up of interventions. The use of exploratory, foresight type analysis to assess the likely extent of public health-related issues, challenges and impacts that may result from the continued growth and increase in scale of manufacturing activities will be crucial to identifying the most effective public health interventions. Working with public health authorities, local and national governments and other civil society bodies can help to ensure interventions are fit-for-purpose and context-specific.

Improving occupational health through interventions such as access to modern industrial processes, training on health and safety procedures in the workplace, improved education and awareness raising for employees working with hazardous materials, and provision of PPE will also be important interventions to improve health outcomes.

4. Data improvement and assessment of interventions

Developing and implementing rapid assessment methods building on methods such as those developed by the IPPS will be important to estimate the potential risk from manufacturing at the sub-national and national level. This could be based on manufacturing metrics (e.g. number of employees, female employees and establishments, production levels) collected at the national level along with knowledge of industry location (i.e. distribution models for manufacturing industries in the country, for example in industrial zones, industrial regions, urban areas and across scattered units of activity).

Developing and implementing methods to assess personal exposure for people working in the industry and living close by (or in proximal regions known to be affected by unsafe levels of pollution) will be crucial to improve pollution-related health assessments. These should build on recent research efforts that have focused on personal exposure rather than ambient pollution.

Improving exposure assessments will be crucial in determining the potential impact of manufacturing activities causing pollution. This work should focus on defining threshold pollutant concentrations for those pollutants considered most responsible for human health impacts. Thresholds should also take into account the potential effects of transformation products that can be formed in different treatment systems. Approaches for developing targets will need to reflect the fact that (eco)toxicity data are only available for a small proportion of active ingredients in use (this is particularly a problem for APIs from the pharmaceutical industry). This approach should provide better impact assessments that can be related back to pollutant emissions to identify those manufacturing activities that would benefit from targeted interventions. This could help to prioritize the uptake (and further development) of particular interventions that could be used as a focus for stakeholder activity.

Assessing the feasibility and effectiveness of the range of interventions that have been developed, and in some cases implemented by public and private sector actors, will help to reduce the level of pollutant emissions from manufacturing activities or to remediate pollution that has occurred as a result of manufacturing activities over time.

Assessment should not only consider how effective interventions might be from a physical point of view (i.e. the ease with which interventions could be adapted, transferred or repurposed for smaller-scale industries, and their effectiveness in reducing harmful emissions or cleaning up polluted sites in relation to target pollutant concentrations), but also how these interventions perform from a social and economic viewpoint.

It will be important to understand whether economies of scale are possible, especially where multiple manufacturing industries that have similar needs could be co-located. Further considerations include whether multi-industry measures benefit from coordinated government subsidies for the establishment, operation and maintenance of large-scale, multi-industry EFTs.

5. Collaboration among stakeholders

Collaborations should be established with existing initiatives that work at a range of geographical scales on issues relevant to pollution from the manufacturing industry. These collaborations should take place at the global level, with initiatives such as the GAHP and TSIP; at the regional and national level, with programmes that look to share best practice in cleaner production methods for particular manufacturing sectors; and at the national level, with government departments responsible for public and occupational health, manufacturing and environmental protection, and non-governmental organizations (NGOs) and civil groups.

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