SMEP | Sustainable Manufacturing and Environmental Pollution Programme

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

Main Report



UKaid from the British people

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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 and environmental degradation. There are many reasons for this, including limited resources and technological know-how to implement cleaner production methods. High levels of pollution are also linked to chronic health problems and decreased levels of productivity that can cause economic losses as high as 2 per cent of Gross Domestic Product (GDP) per year.

The Sustainable Manufacturing and Environmental Pollution (SMEP) programme is funded by FCDO and is implemented in partnership with UNCTAD. The programme aims to improve upon the existing knowledge of the environmental and health impacts of trade-exposed manufacturing across sub-Saharan Africa (SSA) and South Asia (SA) and to develop solutions that address complex technical challenges in this area.

To better understand the consequences of environmental degradation caused by manufacturing industries in these two regions, and aware of limitations in existing data, the present report identifies and maps manufacturing activity, the types of pollution associated with key manufacturing industries and the potential impact of this pollution on the environment and human health. This is done in three steps: a literature review on manufacturing pollution and its consequences, a regional mapping exercise for the SSA and SA regions and an in-depth examination of selected country cases. The results from this scoping study will be used to inform and further define the scope of research calls to be commissioned under the SMEP programme.

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Acronyms

AMR	antimicrobial resistance
API	active pharmaceutical ingredient
B2B	business-to-business
BOD	biological oxygen demand
CCAC	Climate and Clean Air Coalition
CHP	combined heat and power
COD	chemical oxygen demand
EDGAR	Emissions Database for Global Atmospheric Research
ETP	effluent treatment plant
EU	European Union
FCDO	Foreign Commonwealth & Development Office (United Kingdom)
GAHP	Global Alliance on Health and Pollution
GBD	Global Burden of Disease
GDP	gross domestic product
Gg	gigagram
GHG	greenhouse gas
GIZ	Gesellschaft für Internationale Zusammenarbeit (Germany)
ICIMOD	International Centre for Integrated Mountain Development
IEA	International Energy Agency
ILO	International Labour Organization
ISIC	International Standard Industrial Classification
IPCC	Intergovernmental Panel on Climate Change
IPEN	International Pollutants Elimination Network
IPPS	Industrial Pollution Projection System
LEED	Leadership in Energy and Environmental Design
LMIC	lower- and middle-income countries
LWG	Leather Working Group
MVA	manufacturing value added
MRV	monitoring, reporting and verification
NCPCs	National Cleaner Production Centres
NGO	non-governmental organization
NMVOCs	no-methane volatile organic compounds
NOx	nitrogen oxides
OECD	Organisation for Economic Co-operation and Development
PaCT	Partnership for Cleaner Textile
PM	particulate matter
PPE	personal protective equipment
RECP	resource efficient and cleaner production
SA	South Asia
SAICM	Strategic Approach to International Chemicals Management
SDG	Sustainable Development Goal
SMEP	Sustainable Management and Environmental Pollution
SSA	Sub-Saharan Africa
TDS	total dissolved solids
TSIP	Toxic Sites Identification Program
TSS	total suspended solids
UNCTAD	United Nations Conference on Trade and Development
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNIDO	United Nations Industrial Development Organization
USEPA	United States Environmental Protection Agency
VOC	volatile organic compound
YLD	year lived with disability
WHO	World Health Organization

1. INTRODUCTION

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). To better understand the consequences of environmental degradation caused by manufacturing industries in these two regions, this scoping study identifies and maps manufacturing activity, the types of pollution associated with key manufacturing 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. These include global trade and manufacturing datasets, international environmental datasets; peer-reviewed and grey literature sources; online surveys of regional stakeholders; and in three countries – Kenya, Bangladesh and Nepal – in-person interviews were conducted with key actors across policy, practice, and industry. The results from this scoping study will be used to inform and further define the scope of research calls to be commissioned under the SMEP programme.

1.1 Background: Trends in manufacturing and pollution

Polluting industries are increasingly prevalent in lower- and middle-income countries (LMICs), due in part to the globalization of trade and manufacturing industries along with low labour costs and the spread of Western lifestyles (Suk et al., 2016). At the same time, environmental and public health protections are limited (Kearsley and Riddel, 2010) and there are few resources to implement cleaner methods of production in most LMICs. This has resulted in a sharp increase in various types and forms of pollution associated with industrial activities such as mining (Hilson, 2012), tanneries (Jenkins et al., 2004), oil extraction and transport (Adedeji and Ako, 2009), chemical manufacturing (including lead battery recycling) (Suk et al., 2016; Gottesfeld and Pokhrel, 2011), and food processing (Oguttu et al., 2008). This surge has contributed to a variety of impacts on human health and well-being, socioeconomic inequalities in communities, injustice and poverty, as well as on ecological functioning and related ecosystem services (Hilson, 2012; Emberson, 2013; Landrigan et al., 2018). As industrial activity has augmented in developing countries, so too has the prevalence of pollution-related chronic conditions such as asthma, cardiovascular disease, cerebrovascular accident and cancer (Landrigan et al., 2018). Manufacturing processes are also affecting the health of the general population through contamination of air, drinking water, soil, crops, livestock, fish, and other resources. The human health impacts associated with pollution, such as induced cognitive impairment, can cause substantial economic costs by limiting the economic productivity of entire generations and undermining the developmental trajectory of whole societies (Landrigan and Fuller, 2014). Climate change has also been found to exacerbate the effects of pollutant exposure in developing countries by increasing concentrations of many chemicals in the water, air and soil (Noyes et al., 2009) as well as sensitivity to pollution (Hooper et al., 2013).

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 (Elgin and Oztunali, 2014). The informal economy engages more than 60 per cent of the world's employed population and is more significant in developing countries. Much of the manufacturing activity that occurs in LMICs is conducted within this informal sector. However, it is not represented adequately in international statistics (ILO, 2018a).

Furthermore, labour markets are gender-segregated, with women in mostly low-paying occupations (UNDP, 2016). SSA also has the highest labour participation for women over 15 years of age, at an average of 65 per cent (ILO, 2018a) with many of these women being engaged in the informal sector. In Africa, about 90 per cent of employed women work in the informal sector in contrast to about 83 per cent of men (ibid.). Furthermore, women in SSA earn lower wages in the manufacturing, services and trade sectors, at 70 cents for every dollar earned by men (UNDP, 2016). Gender

also plays an important yet poorly researched role in determining the impacts of manufacturing pollution. 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. Women are likely to be more at risk from certain pollution exposures due to lower body weight, with additional health risks during pregnancy (Butter, 2006). Gender norms and social structures that restrict women's mobility, free time and other employment opportunities can also make them more vulnerable and more likely to work within poorly regulated, and hence polluted, manufacturing settings (Nazneen et al., 2019). 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 and will be explored in this study.

Over the past decade, several initiatives have tried to gain a better understanding of approaches taken to tackle manufacturing pollution and its consequences in developing countries. The 'Greening Industry' review (World Bank, 1999) was an important and wide-ranging assessment of the challenges faced by developing countries in increasing activity in the industrial sector. Importantly, this review focused on the role that communities, markets and governments could play in overcoming problems and assessed the effectiveness of a variety of pollution control options that included 'command and control' as well as more informal regulatory approaches. The review found substantial advantages in the latter but identified limitations in implementation in both approaches. Key limitations were data scarcity (e.g. inadequate monitoring of pollution and exposure), limited knowledge and communication of impacts, limited training for health care providers in identification and treatment of diseases, and insufficient community cohesion to champion informal controls. More recent reviews have identified additional aspects of industrial pollution that require further consideration. These include, notably, relationships with poverty (Hilson, 2012), gender, social equity, and vulnerability (Muradian et al., 2012; Butter, 2006), as well as a greater role for global responsibility to support sustainable trade and share technology and knowledge for pollution prevention.

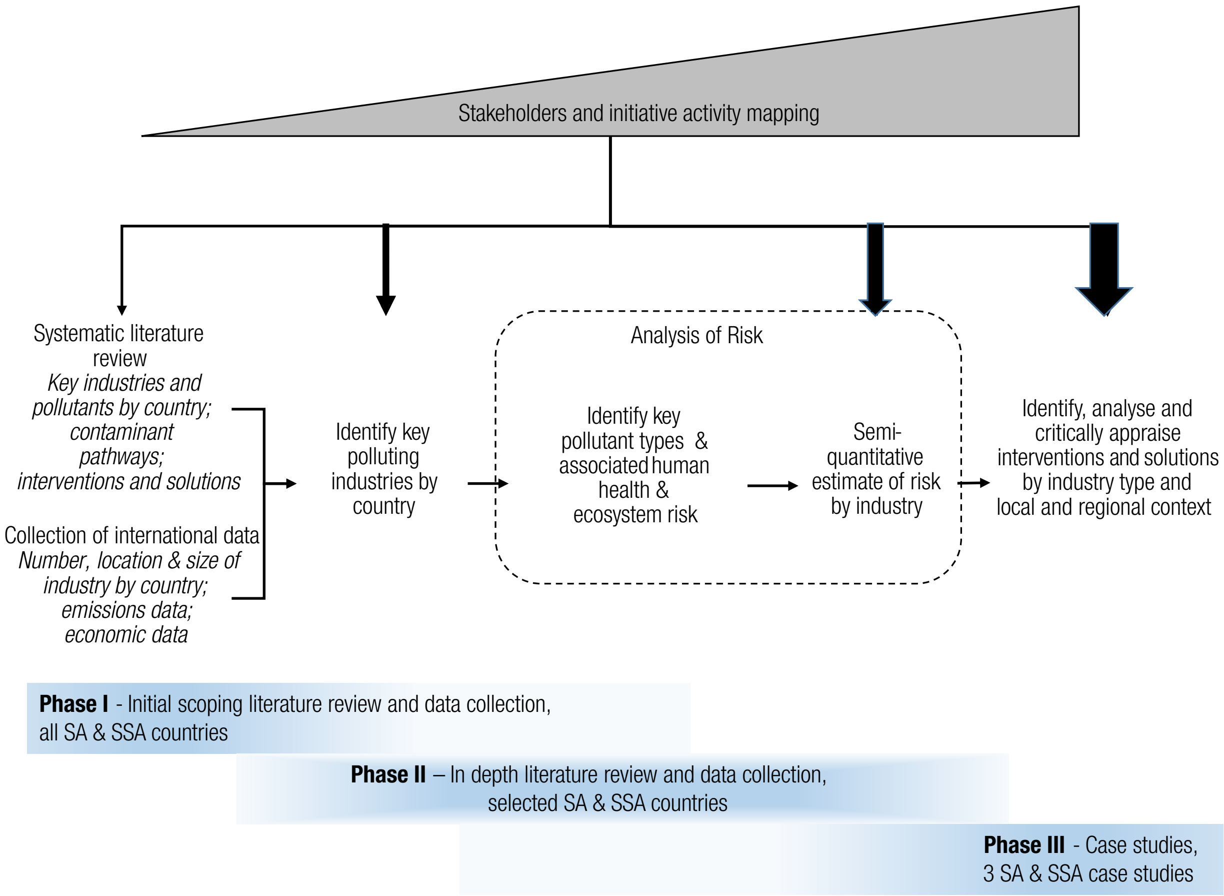
This scoping study describes how pollution from the manufacturing industry in SSA and SA impacts on the environment and human health and how these impacts will interact with economic, social and governance constructs within these regions. This results in the identification of countries, regions and industries where problems are likely to be greatest, an understanding of the most important knowledge gaps that limit the effectiveness and design of interventions, and provides suggestions for future programmes of work that will allow industrial activities to move more effectively towards sustainable methods of industrial production in developing countries.

1.2 Study scope: Rationale and coverage

The approach adopted to collate and analyse the information provided in this study is described in figure 1. Key stakeholders were identified and engaged in increasing levels of dialogue (indicated by the increasing depth of the 'wedge' and width of arrows) as the key polluting industries were defined for the countries. This approach was adopted to ensure methods were relevant to SSA and SA contexts. An evidence-based approach was adopted and used accredited methods to review the academic and grey literature for selected countries in SA and SSA to identify key polluting industrial activities known to be causing risk and damage to human health and the environment. The evidence-based review underpins all three data-collection phases (indicated by the blue shaded bars in figure 1) and goes into increasing levels of detail in terms of data collation and analysis, focusing efforts on key countries identified as particularly vulnerable to increasing levels of industrial pollution. This review process was coupled with data available from international datasets to understand the scale, frequency, spatial extent, emissions and environmental impacts associated with industrial activities as well as the economic and societal implications of such industries and how these change over time. This enabled the identification of industries (e.g. textiles, tanneries, chemical manufacturing and food processing) that are either important now, or likely to become important in the future as industrial activities expand, as well as their geographical location. The purpose here was to guard against bias that might be introduced in the assessment by only exploring the published literature.

To assess the risk posed by different manufacturing industries, key pollutant types commonly associated

Figure 1. Overarching data collection, review and analysis of industrial pollution to identify interventions and solutions for sustainable manufacturing in this scoping study

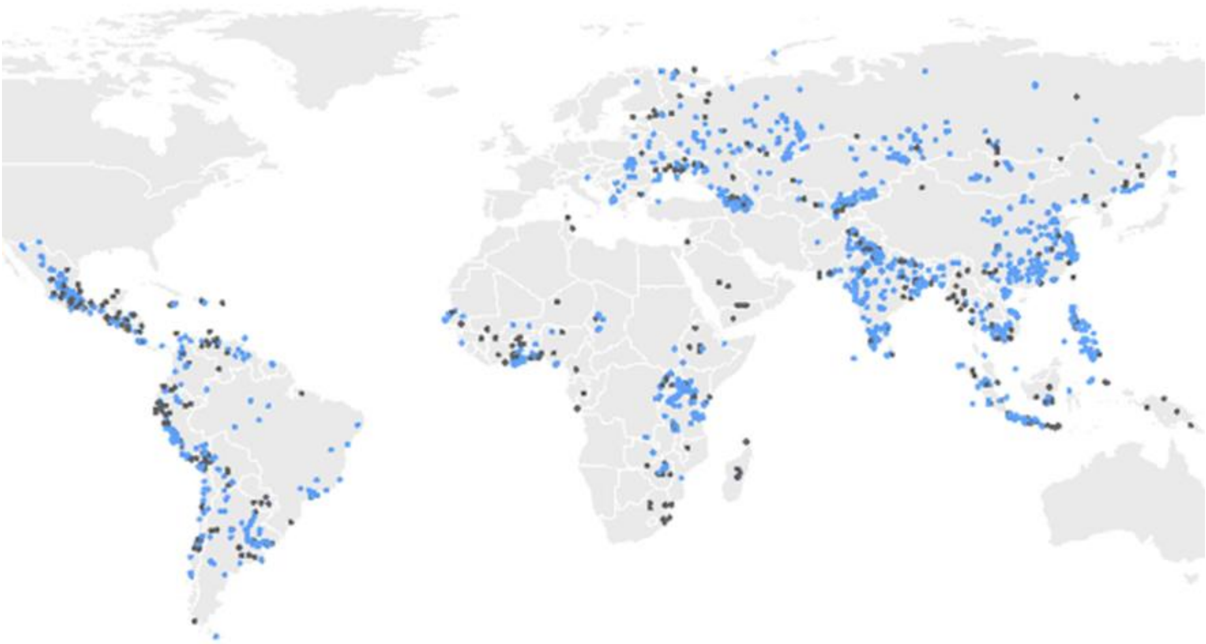


with these industries are linked to important human health impacts using a matrix form. To understand the likely exposure of humans to these pollutants, information was extracted (from both stakeholders and the literature) that described the 'contaminant pathways' by which industrial activities lead to pollution emissions, exposure and consequent impacts. Structured informant interviews with key stakeholders were held to gather their views on the main polluting industries, pollutant pathways, potential interventions and solutions, the benefits and disbenefits of these interventions from the national and subnational perspective, and barriers to implementation. The data gathered from these structured interviews complement the data extracted from the literature review on interventions and solutions, options and mechanisms to prevent, mitigate and remediate manufacturing pollution. Finally, these data were analysed and synthesized to identify important knowledge gaps and make suggestions for future research programmes that would most effectively lead to an enhanced understanding of how to move towards more sustainable manufacturing activities.

1.3 Other initiatives

It is important to set the information presented in this study in the broader context of other initiatives and activities that explore pollution, hazard and risk to the environment and human health. These initiatives have tended to focus either on understanding pollution and health risks or on trying to quantify pollutant loads arising specifically from the manufacturing industry. The most important activities and initiatives that take a holistic approach to tackle different forms of pollution from a variety of sources are reviewed below. There are also initiatives (working at a range of scales from

Figure 2. Identified and screened contaminated sites, Toxic Site Identification Programme



Source: Pure Earth (2016).

local, national, regional to international levels) that deal with particular manufacturing industries and pollution sources. These are covered in more detail within sections 3.4 and 4.4, which map them according to generic value chains for key industries.

1.3.1 Toxic Sites Identification Programme

The Toxic Sites Identification Program (TSIP)[1] (Pure Earth and Green Cross, 2016) has been documenting environmental chemical exposures due to hazardous waste sites globally over the past decade. The TSIP is not intended to be a comprehensive inventory of such sites, but rather an assessment that helps to understand the scope of the problem worldwide. Due to the programme's focus on chemical exposures, many of the sites identified are related to manufacturing activities, categorized as follows: chemical manufacturing; dye industry; electronic and electrical waste (e-waste) recycling; fertilizer manufacturing; food processing; heavy industry; battery manufacture, repair and recycling; pesticide manufacturing; pharmaceuticals; tannery operations; and product manufacturing (electronics, equipment and clothing). The programme uses an Initial Site Screening rapid assessment protocol (Pure Earth, 2019) to identify sites of concern, which includes the training of a network of investigators to collect data. Three key elements are assessed for each site: the primary pollutant and its source; the pathway of the pollutant to humans; and the estimated population at risk of exposure to the pollutant (Ericson et al., 2013). To date, more than 5,000 sites have been identified in over 50 countries, with an estimated population at risk of 80 million people (see figure 2). The relevance of this programme in supporting sustainable manufacturing is limited by the fact that only one key pollutant (out of a limited range of lead (Pb), chromium (Cr), mercury (Hg) and radionucleides) and one key exposure pathway (from air, water and soil) are identified per site.

1.3.2 Industrial Pollution Projection System

The World Bank developed the Industrial Pollution Projection System (IPPS), which is a rapid assessment tool to estimate pollution loads, to support policy formulation for industrial pollution control (Oketola and Osibanjo, 2007; Hettige et al., 1994). The IPPS is a modelling system that uses industry data (e.g. on employment, production) to estimate profiles of industrial pollution intensities (e.g. pollution per unit of output,

1 See https://www.pureearth.org/projects/toxic-sites-identification-program-tsip/

pollution per unit of employment) for countries, regions, urban areas and proposed new industrial areas. Three key metrics are explored – output, value-added and employment. The IPPS has been used, among other places, in Bangladesh, Brazil, India, Latvia, Nigeria, the Philippines, Thailand and Viet Nam (Oketola and Osibanjo, 2007). The IPPS model provides regulators and monitoring agencies in developing countries with knowledge about the most polluting industrial sectors. However, a key issue is the availability of reliable data from which to estimate pollution loads. The system also lacks a fuller understanding of the contaminant pathways, pollutant transformations and human behavioural patterns that will determine pollutant exposures and ultimately, risk, from these hazards.

1.3.3 Global Burden of Disease

The Global Burden of Disease (GBD) is the most comprehensive observational epidemiological study describing mortality and morbidity from major diseases, injuries and risk factors to health at global, national, and regional levels (GBD, 2017). The series examines trends from 1990 to the present and allows comparisons across populations to understand the changing health challenges facing people across the world in the twenty-first century. As an example of the type of data available from the GBD dataset, figure 3 provides an overview of the main occupational health hazards facing SSA and SA in terms of Years Lived with Disability (YLDs). These occupational health data should be considered with the knowledge that the manufacturing industry employs only about 6 per cent and 12 per cent of the total SSA and SA workforce, respectively. In addition, other members of the public (i.e. local residents), as well as the workers themselves, often experience human health impacts resulting from manufacturing pollution. Figure 3 shows that respiratory diseases, neurological conditions as well as hearing, blindness and irritation or inflammation issues are all substantially affecting occupational health in both SSA and SA. These human health impacts are frequently associated with pollution from the manufacturing industry.

Data on trends in hazards are also available from the study (ibid.). For example, airborne pollution is often associated with manufacturing activities and can cause both chronic and acute respiratory diseases when exposures are high over continued periods. Figure 4 shows an increase in YLDs per 100,000 of the population for chronic respiratory diseases attributable to occupational health risk from around 2005 onwards to 2017 for Bangladesh, Nepal and Pakistan, and SA as a whole. Interpretation of these data again should consider that manufacturing employs only about 12 per cent of the working population in SA. By contrast, increases in occupational health chronic respiratory diseases are also found in SSA SMEP target countries, but only since 2011 and generally only amounting to 30 to 40 YLDs per 100,000 people.

1.3.4 The Lancet Commission on pollution and health

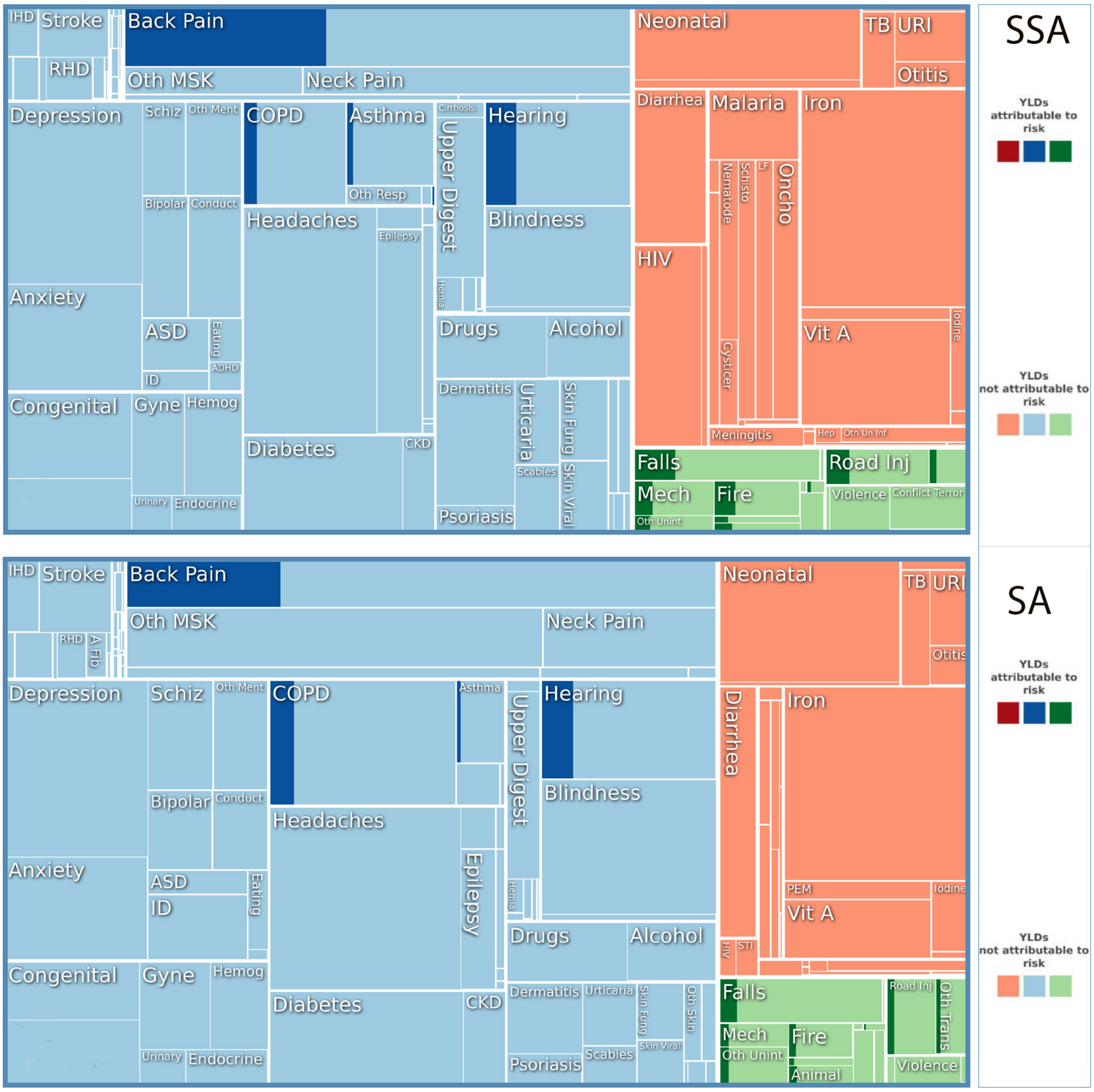
The aim of the Lancet Commission on pollution and health was established to “raise global awareness of pollution, end neglect of pollution-related diseases, and mobilize the resources and the political will needed to effectively confront pollution”.[2] The findings from the Commission are provided in a review paper (Landrigan et al., 2018). The study explored all sector pollution (i.e. from many sectors including the manufacturing sector) and estimated the consequences of total pollution loads on human health. Chemical pollution (one of the categories of pollution that most strongly relates to the manufacturing sector) was identified as a great and growing problem but one that is poorly defined, and for which estimates of contribution to the global burden of disease are very likely underestimated. Important for this scoping study is the definition developed by the Commission to assess the current level of knowledge and characterization of the harmful effects of pollutants. The Commission identified three Zones within which different pollutant types could be categorized, these Zones range from those that have well-established pollution-disease pairs (Zone 1) to those that are new and emerging pollutants (Zones 2 and 3). Many of the pollutants that are emitted by the manufacturing industry fall into Zones 2 and 3, which has important implications for understanding impacts on human health (see section 2.5).

1.3.5 Global Alliance on Health and Pollution

The Global Alliance on Health and Pollution (GAHP) is a collaborative body that facilitates the provision of technical and financial resources to governments and communities to reduce the impacts of pollution

2 See https://www.thelancet.com/commissions/pollution-and-health

Figure 3. Percentage of total YLDs attributable to occupational risks for SSA and SA

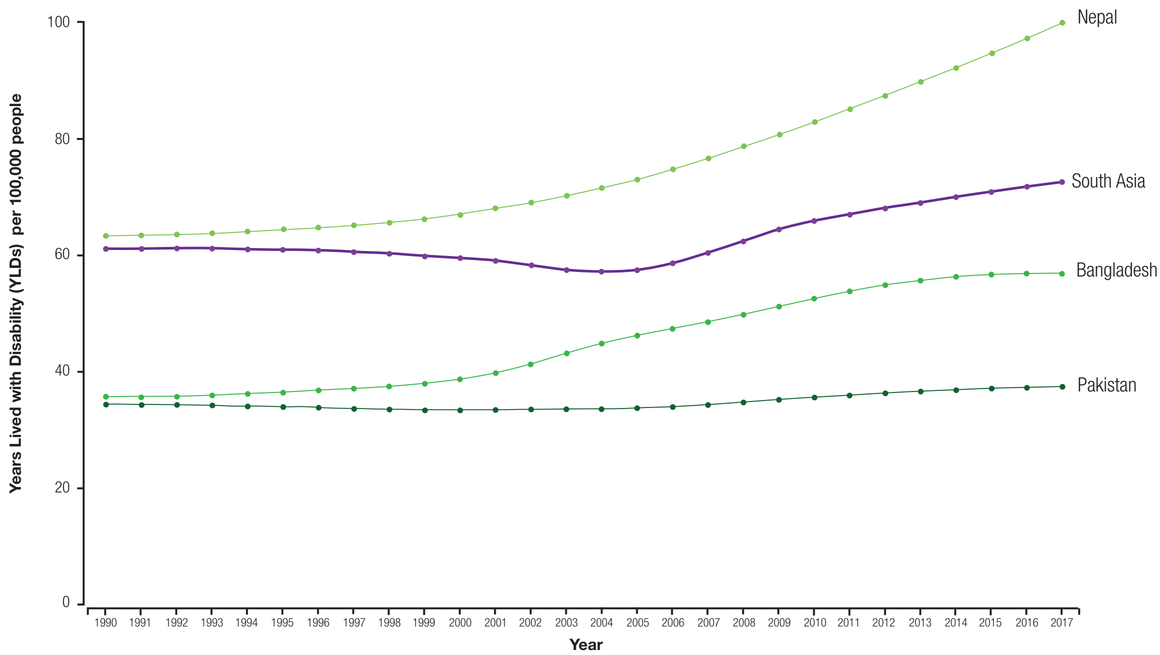


Source: GBD (2017).

on health in LMICs. The GAHP was established in 2012 and is comprised of more than 60 members and dozens of observers that advocate for resources and solutions to pollution problems[3]. The work of the GAHP is supported by the World Bank, the United Nations Environment Programme (UNEP), the United Nations Development Programme (UNDP), the United Nations Industrial Development Organization (UNIDO), the Asian Development Bank, the European Commission, and the ministries of environment and health of many LMICs. The GAHP was formed to provide a collaborative, multi-stakeholder, multi-sectoral approach to deal with the global pollution crisis and resulting health and economic impacts and provides a supporting framework for the broad array of pollution reduction initiatives, activities and programmes that exist around the world. Specifically, the GAHP aims to: i. advocate for solutions that address pollution more broadly (i.e. indoor and outdoor air, wastewater, and contaminated soils and

3 See https://gahp.net/about-gahp/

Figure 4. Chronic respiratory diseases attributable to occupational risks in SA and in Bangladesh, Nepal and Pakistan



Source: GBD (2017).

water); ii. initiate activities that reduce adverse health impacts caused by contaminated sites; iii. work to help actively polluting small-scale industries and activities move to cleaner production practices; and iv. measure project performance based on health and economic outcomes. Initially, the GAHP played an important role in the TSIP (see section 1.3.1) supporting a range of activities including the revision of the Initial Site Screening protocol, the expansion of the number of TSIP sites, and the development of national government reports. It has also supported the hosting of training workshops for investigators and government representatives to help them identify toxic sites and has supported the development of National Toxic Action Planning processes. The GAHP has also been successful in raising awareness of the threat from pollution through the publication of a number of accessible reports. A good example is the Lancet Commission report (see section 1.3.4) which was an initiative of the GAHP in collaboration with The Lancet and the Icahn School of Medicine at Mount Sinai with additional coordination and input from UNEP, UNIDO and the World Bank. In the future, the GAHP will be a key player in focussing international efforts to tackle the problems associated with the emerging agenda on pollution and health. Important roles that can be provided by the GAHP include supporting project work to plug knowledge gaps, particularly on international chemicals and waste agendas; expanding data collection on toxic pollution, and continuing to raise awareness on the issues of pollution and health.

1.3.6 National Cleaner Production Centres Programme

The National Cleaner Production Centres (NCPCs) Programme was a joint initiative between UNEP and UNIDO established in 1994 to support eco-efficient industrial development in key developing countries. The programme was reoriented in 2009 to cover the sustainability dimensions of more efficient use of natural resources, reduction of waste generation and improved protection of human health and well-being. By 2014, the programme has been active 58 NCPCs located across 56 countries (with 13 and 11 centres in Africa and Asia respectively). The programme aims to: i. raise awareness of the benefits and advantages of resource efficient and cleaner production (RECP); ii. demonstrate the environmental, financial and social benefits of resource efficient cleaner production; iii. provide support in obtaining financing for RECP investments; iv. provide policy advice to national and local governments; and v. disseminate technical

information on RECP. A review of the NCPC programme conducted by (Luken et al., 2016) assessed how the expectations of the programme had played out over the past 20 years. They found that NCPCs exceeded expectations of the programme operating in countries that collectively accounted for 80 per cent of manufacturing value added (MVA) and in the provision of four core services (information dissemination, training, technical assistance and in-plant assessments and policy advice). Programme expectations were met in that: i. revenues were sufficient to provide cleaner production core services; ii. implementation of many cleaner production measures generated significant financial savings; iii. implementation of cleaner production measures resulted in significant reductions of industrial pollutants and wastes; iv. centres became leaders in cleaner production expertise in their countries; and v. centres became institutionally and financially sustainable based on capacities built to provide core cleaner production services. Partially met expectations included that: i. the host institutions for centres were mostly industry-related organizations; ii. some centres decentralized core cleaner production services to state governments and research institutions; and iii. some enterprises were transformed with assistance from the centres into greener and larger operations. Finally, the key areas where the programme had not succeeded were in the greening of entire industrial sectors and the lack of measurable improvements in environmental quality from the implementation of cleaner production options along with the installation of pollution control technology. (Luken et al., 2016) identified the need for NCPCs to have a catalytic role in a national strategy for greening industry to achieve the comprehensive and integrated strategy for resource efficiency and environmental management that is required to clean up the industrial sector.

1.4 Aims of the study

The overarching aim of this scoping study is to provide an overview of the key manufacturing industries that are causing environmental degradation and subsequent impacts on human health in SSA and SA. This analysis considers emerging, established and declining industries within the regions, the key pollutants and pollutant pathways associated with particular manufacturing industries that have been identified as likely to result in exposure to harmful levels of pollution, and the interventions (both hard and soft) that have been developed to reduce or remediate pollutant exposure. Finally, the study identifies key knowledge gaps and provides recommendations for future work to support a move towards sustainable manufacturing in SSA and SA.

2. METHODOLOGICAL APPROACH

2.1 Overview

To achieve the aims of this study, three different approaches were used to identify, collect and analyse data used to identify key manufacturing industries and their associated impacts. Data from a range of international datasets were collated and analysed, published literature was systematically searched for information that described pollution from manufacturing industries that have resulted in impacts on ecosystems and human health and stakeholders relevant to the manufacturing industry were surveyed. Throughout this study, SSA and SA have been defined using the United Nations geographic regions (United Nations, 2020). To enable more in-depth analysis, the study focused on SMEP target countries in SSA (Democratic Republic of the Congo, Ethiopia, Ghana, Kenya, Nigeria, Rwanda, Senegal, United Republic of Tanzania and Zambia) and SA (Bangladesh, Nepal and Pakistan).

Three country case studies, Kenya in SSA and Bangladesh and Nepal in SA, were selected for more detailed data analysis on consideration of information collected from face-to-face stakeholder interviews conducted with key actors related to the manufacturing sector in these countries. These case study countries were selected in consultation with UNCTAD and FCDO, considering the scale and extent of manufacturing activities and associated hazardous pollution and their importance as SMEP target countries.

The International Standard Industrial Classification (ISIC) was used to categorize the manufacturing industries explored in this study, manufacturing is covered by divisions 10 to 33 of ISIC Rev. 4 (United Nations, 2008). It is important to note that sub-divisions of these classifications can vary between ISIC revisions, for example ISIC Rev. 3 (used in the INDSTAT2 dataset described in this study) classifies 'food and beverages' in a single division whilst ISIC Rev. 4. classifies 'food' and 'beverages' in two separate divisions.

2.2 International data sources

International datasets provide quantification of a range of metrics that allow an assessment of the relative size, importance and trends of different manufacturing industries within and between countries in SSA and SA. These data can help identify those existing and emerging industries that are especially important both nationally and regionally which, when coupled with data describing the polluting nature of industries and the harm that such pollution causes, can identify key manufacturing industries that the SMEP programme should focus on in the future. Relevant international datasets were identified using information gathered from literature reviews, web searches and stakeholder dialogues. International datasets describing some aspect of manufacturing activity that were considered to provide useful information for this study (i.e. they were available at the national level, included variables related to manufacturing that were consistent across countries, and were unique to the dataset from which they were derived), are described in table 1. It should be noted that the metrics provided by these datasets do not give any indication of the direct relationship between the level of manufacturing activity and any consequent pollution and impact. Therefore, analyses of these datasets only allowed patterns and trends in manufacturing activity to be identified, however, such data could be related to pollution levels where information on pollution intensity for different activities exist (e.g. the IPPS pollution load metric is estimated according to the number of employees and an associated pollution intensity parameter, see section 5.1.1 for further details). The patterns and trends in manufacturing activities are described in sections 3.2 and 4.2, which provide regional descriptions for SSA and SA respectively with the express purpose of identifying important existing and emerging industries in the regions, and SMEP target countries in particular.

International environment datasets were also explored to assess whether they could provide additional information on the pollution associated with manufacturing and the impact of this pollution on the environment and human health. These datasets could be divided into the following three groups:

Table 1. International datasets with information on manufacturing activities

Sectoral level	Dataset and source	Metrics	Comments	Reference
Manufacturing sector	World Bank: World Development Indicators[4]	MVA as a per cent of gross domestic product (GDP)	Manufacturing is not broken down into subsectors Data are available from 2000 to 2018	World Bank (2018)
	International Labour Organization (ILO)[5]	Employment by economic activity (ILO-modelled estimates) Per cent of population employed in the manufacturing industry	Manufacturing is not broken down into subsectors Data are available from 2000 to 2018	ILO (2020)
Manufacturing subsectors	UNIDO: INDSTAT2[6]	Eight metrics relevant to manufacturing: Number of establishments Number of employees Wages and salaries Output Value added Gross fixed capital formation Number of female employees Index numbers of industrial production	Manufacturing is broken down into ISIC divisions (Rev. 3) More comprehensive data coverage than later INDSTAT3 and INDSTAT4 versions Data are available for 38 countries in SSA and SA Data are available from 2000 to 2017	UNIDO (2020)
	Organisation for Economic Co-operation and Development (OECD)[7]: Bilateral trade in goods by industry and end-use	Value (in US$) of exports by industry	Manufacturing is broken down into ISIC divisions (Rev. 4) Note: OECD data use the ISIC classification scheme used by the INDSTAT data. Therefore, for comparability OECD data are used in this study even though the underlying dataset is the United Nations COMTRADE data Data are available from 2000 to 2018	OECD (2018)

i. Emissions datasets (predominantly of greenhouse gas (GHG) emissions) that provide data describing emissions associated with different manufacturing activities. The level of manufacturing subsectors to which these emissions are disaggregated varies by dataset as does the source of emissions data provided (e.g. emissions resulting for the combustion of fuels used to power manufacturing processes or emissions from the manufacturing processes themselves). These datasets were deemed the most useful environmental datasets and are further described in table 2.

ii. Pollution datasets that provide data describing the concentrations of pollutants or parameters that reflect the quality of air, water and soil. These datasets mostly focus on air quality (e.g the World Health Organization (WHO)) global ambient air

4 See https://datacatalog.worldbank.org/dataset/world-development-indicators

5 See https://ilostat.ilo.org/data

6 See https://stat.unido.org/

7 See https://stats.oecd.org/index.aspx?queryid=64755

quality database[8] with the more robust datasets combining ground level monitoring data with satellite observation and modelled data to estimate pollutant exposure data. These datasets tend to focus on particulate matter (PM) with a diameter less than 2.5 μm ($PM_{2.5}$) or 10 μm (PM_{10}). The WHO dataset has been used to further estimate consequent disease burdens. There are a far more limited number of datasets that focus on water quality. A good example of the type of data available is the GEMstat database[9] which collates water quality monitoring data from a global water quality monitoring network. Finally, the Harmonized World Soil Database[10] of the Food and Agriculture Organization of the United Nations (FAO) provides data on soil quality for crop production. Unfortunately, all of these datasets have very limited use since they do not relate air, water or soil quality to sectoral emissions, therefore it is not possible to attribute pollution, and any potential impacts, to activities such as manufacturing.

iii. Finally, data platforms (e.g. the United Nations environmental statistics[11], UNEP GEO data[12], World Resource Institute's Climate-Watch[13] and World Development Indicators from the World Bank[14] provide environmental data. These are mostly collations of data from other sources (e.g. data on CO_2 emissions in the World Resource Institute Climate Watch database are based on International Energy Agency (IEA) data, data on CO_2 emissions in UNEP GEO are based on United Nations Framework Convention on Climate Change (UNFCCC) data; both these core underlying datasets are described in table 2). These platforms rarely disaggregate emissions by sector (with the exception being GHG emissions data), use rather generic metrics (i.e. that are not specific to the types of impacts associated with manufacturing pollution), are very often incomplete in terms of the years for which data are available, and also tend to have very few, if any, data available for the SMEP target countries. The derivation method of individual metrics can also vary by country. For example, the UNSD environmental statistics provide data on non-treated wastewater but the only SMEP target country for which data are available is Senegal and the metric provides the total volume of wastewater generated by economic activities; this does include manufacturing but also includes agriculture, forestry and fishing, electricity industry and other economic activities.

Table 2 describes the international environment datasets that were deemed useful to provide some additional information on the impact of manufacturing activities on the environment. This information is presented for SSA and SA in sections 3.2.3 and 4.2.3 respectively. It should be stressed that these data only provide information on atmospheric emissions (and only on GHG emissions rather than air pollution) and hence only provide environmental data on one component of air, soil and water quality that is known to be affected by manufacturing activities. The mechanisms underlying these environmental impacts are described in more detail for specific industries in sections 3.4 and 4.4 for SSA and SA respectively. This scoping study shows that international datasets are not yet able to capture the environmental pollution associated with specific manufacturing activities.

2.3 National data sources

Due to the limited availability and inadequacies of international environmental data (discussed in sections 3.1, 3.2, 4.1 and 4.2) nationally reported data were also analysed to assess their usefulness in identifying pollution from manufacturing activities. National datasets describing GHG emissions are required to be submitted as part of the UNFCCC Monitoring, Reporting and Verification (MRV) of systems to provide emission inventories. These datasets could in the future be useful for the identification of pollution from manufacturing activities since they are prepared using a common methodology described in the emission inventory guidebooks (IPCC, 2019) developed by the Intergovernmental Panel on Climate Change

8 See https://www.who.int/airpollution/data/cities/en/

9 See https://gemstat.org/

10 See http://www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/harmonized-world-soil-database-v12/en/

11 See https://unstats.un.org/unsd/envstats/index.cshtml

12 See https://geodata.grid.unep.ch/

13 See https://www.wri.org/our-work/project/climate-watch

14 See https://databank.worldbank.org/source/world-development-indicators

Table 2. International datasets with information on environmental impacts of manufacturing activities

Sectoral level	Dataset and source	Metrics	Comments	Reference
AIR				
Manufacturing (and limited number of sub-manufacturing sectors)	European Union (EU): Atmospheric emissions Database for Global Atmospheric Research[15] (EDGAR)	GHG emissions from (as Gg of substance) for: carbon dioxide (CO_2), methane (CH_4) and nitrogen oxide (N_2O)	Country-level data broken down by the following manufacturing relevant categories: Combustion for manufacturing Non-metallic mineral production Chemical processes Iron and steel production Non-ferrous metal production Data are incomplete for SSA and SA countries. Data are available from 2000 to 2018	EU (2018)
Manufacturing (and limited number of sub-manufacturing sectors)	United Nations Framework Convention on Climate Change (UNFCCC): GHG data[16]	GHG emissions (as Gg CO_2 equivalent) for: CO_2, CH_4, hydroflurocarbons (HFCs), perflurocarbons (PFCs), sulphur hexafluoride (SF_6), aggregated fluorinated gases	Country level data broken down by the following manufacturing relevant categories: i. fuel combustion (which combines manufacturing industries and construction); ii. industrial processes (which is divided into mineral products, chemical industry, metal production) iii. industrial wastewater. More up to date and disaggregated data can be obtained from the National Communications (see Section 2.3) though these are not standardised across countries. Data available from 1990 to 2010	UNFCCC (2020a)
Manufacturing subsectors	International Energy Agency (IEA)[17]	CO_2 emissions from fuel combustion (as kt of CO_2)	Country level data broken down by the following manufacturing categories (using ISIC Rev. 4) • Iron and Steel • Chemical and petrochemical • Non-ferrous metals • Non-metallic minerals • Transport equipment • Food and tobacco • Wood and wood products • Textile and leather • Not elsewhere specified (industry) Data are available from 1971 to 2018 for non-OECD countries and regions Data not freely available. Data only provides emissions of CO_2 from fuel combustion.	IEA (2020)

15 See https://edgar.jrc.ec.europa.eu/overview.php?v=50_GHG#

16 See https://unfccc.int/process-and-meetings/transparency-and-reporting/greenhouse-gas-data/ghg-data-unfccc/ghg-data-from-unfccc

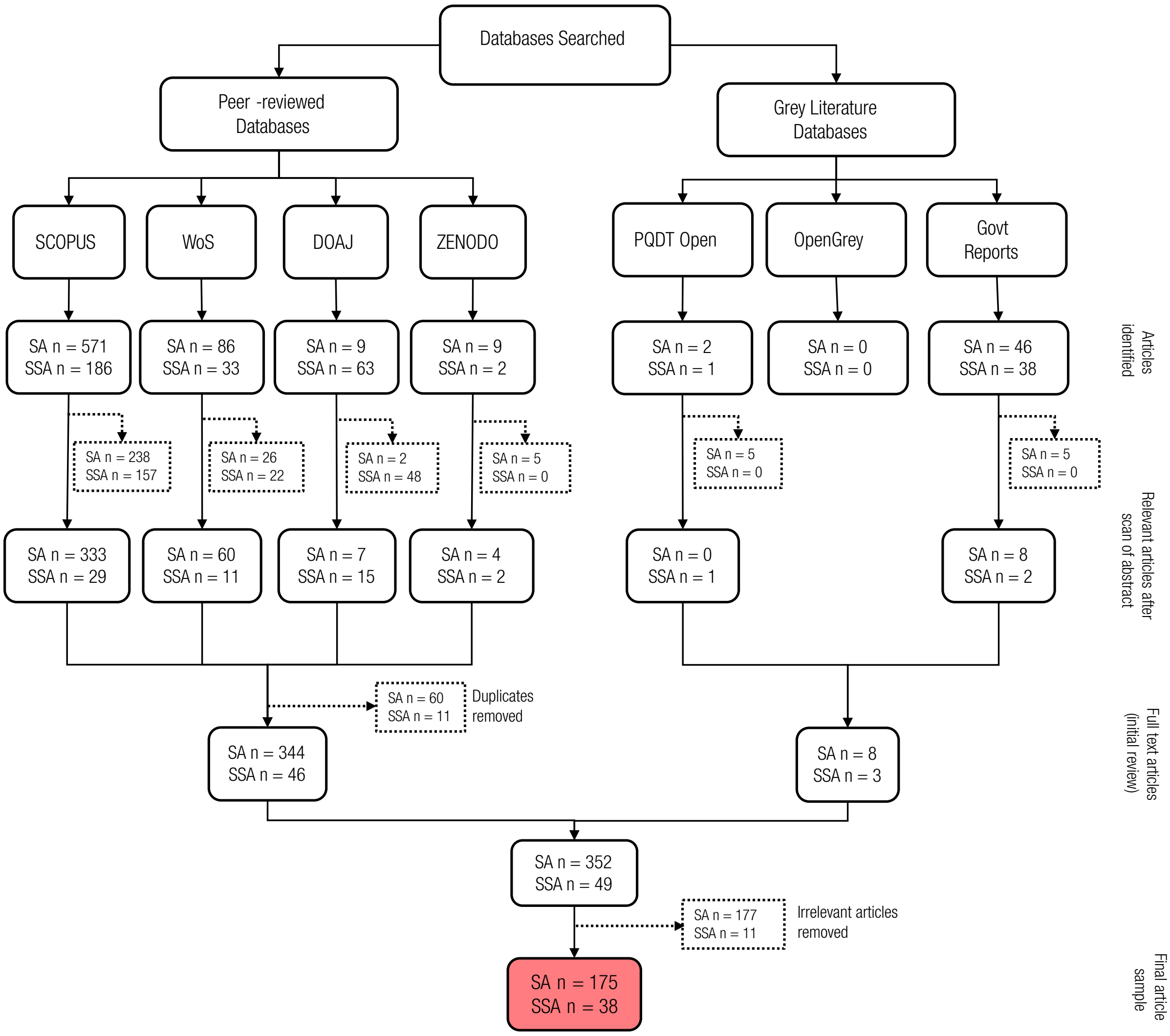
17 See https://www.iea.org/subscribe-to-data-services/co2-emissions-statistics

(IPCC). Application of the IPCCs emission inventory methodology sees national institutions collecting activity data for different emission sectors and sources (which include energy consumption, solid and liquid waste generation), and quantifying a range of atmospheric emissions that include air pollutants as well as GHGs. These data are increasingly becoming available due to the regular reporting requirements of countries under the UNFCCC MRV systems. Non-Annex 1 countries (i.e. developing countries) are required to report GHG emissions within National Communications and Biennial Update Reports. The usefulness of these datasets are discussed in sections 3.2.4 and 4.2.4 for SSA and SA respectively.

2.4 Systematic literature review

A systematic review of peer-reviewed and grey literature was undertaken using several search engine databases. This was conducted following a review protocol, which defined the scope: geography (region of interest), language, time period, databases to be searched, inclusion and exclusion criteria, search strings and strategies for extracting information. In brief, relevant target literature was identified using pre-defined search strings to capture those papers that explored the manufacturing sector in relation to pollution and consequent ecosystem and human health impacts in SSA and SA. The review focused

Figure 5. Prisma flow diagram showing the number of articles retrieved from different search engines for SSA and SA



Note: Dotted lines denote removal of articles after scanning of abstracts, scanning full text and checking for duplicates.

on the period 1990 to the present. Specific searches were conducted in the following databases: Scopus, Web of Science, Directory of Open Access Journals, OpenGrey, ProQuest Dissertations and Theses Open and Zenodo. In addition, other relevant published materials were identified through government department websites. Retrieved publications were screened against a series of inclusion and exclusion criteria to judge the merits and relevance of their content. From an initial number of 323 and 723 articles for SSA and SA respectively, 38 and 175 respectively were identified as relevant (see figure 5). A codebook (a spreadsheet allowing data extraction to be recorded following a systematic list of key variables) was developed to ensure consistency during the data extraction process and to allow easy analysis of key aspects of data associated with each article such as the manufacturing industry, country, pollutant type, and ecosystem and health impacts. As such, the codebook acts as a reference database as well as an analytic tool and is used to assess the number of articles associated with different manufacturing industries by region (i.e. SSA and SA) and country (i.e. Bangladesh, Kenya and Nepal).

2.5 Pollutant categories and impacts

An important application of the information collected from the systematic literature review is to identify those manufacturing industries that are emitting pollutants that are hazardous to human health, either directly or indirectly via environmental degradation. This is achieved by grouping pollutants into pollutant types and assessing the threat they pose to human health. Table 3 describes the pollutant type groupings used in this study, along with their likely pollution pathways (and hence environmental route to human health impact). Table 3 also describes what form these human health impacts take and indicates how well these effects are understood and gives references to useful reviews that provide further details of these pollutant types and their impacts. This information is used to define the key categories of human health impacts that this study will focus on (acknowledging that 'other' health impacts may also occur):

- Cardiovascular and respiratory diseases (e.g. heart disease, stroke, chronic obstructive pulmonary disease, lung cancer and acute respiratory infections in children);
- Carcinogenic effects (i.e. pollutants that promote carcinogenesis, the initiation of cancer formation) ;
- Neurotoxin effects (i.e. pollutants that alter the structure or function of the nervous system causing symptoms such as loss of cognitive function, behavioural problems, depression);
- Endocrine disruption (i.e. pollutants that alter normal hormone action);
- Reproductive toxicity (i.e. pollutants that affect sexual function and fertility in adult males and females, as well as developmental toxicity in offspring);
- Irritants and inflammation (e.g. skin irritation, itchy or blocked noses, sneezing and sore eyes).

Having defined these pollutant types and likely health consequences, these groupings are used to assess the potential hazard associated with each manufacturing industry. The results of this assessment are shown in table 5 and table 8 for each of the manufacturing industries identified as causing pollution and impacts from the systematic literature review for SSA and SA respectively. There are two important limitations to this approach. The first relates to the limited knowledge of pollution impacts on human health, and the second to the limited understanding of the pollutant levels (and hence exposures) that are likely to result from manufacturing activities and that will lead to these impacts. The Lancet Commission's Zone categories used in table 3 classify pollutant types according to how well characterized and quantified the knowledge is of their impacts (Landrigan et al., 2018). Zone 1 includes well-established pollution–disease pairs; Zone 2 includes emerging pollutants, where evidence of causation is building, but associations between exposures and disease are not yet fully characterized; and Zone 3 includes new and emerging pollutants whose effects on human health are only beginning to be recognized and are not yet quantified. Unfortunately, most of these manufacturing industry pollutant types fall under Zones 2 and 3. The information provided later on in this study describing key manufacturing industries and their associated pollutant pathways gives some indication of the level of pollution that might be caused by particular manufacturing activities (see sections 3.4 and 4.4).

Table 3. Key pollutant groups associated with the manufacturing industry and potential effects on human health

Pollutant type	Potential pathways to human uptake	Human health impacts	Knowledge of effects (following the Lancet Commission on pollution and health)	Key references (providing reviews of additional information)
Potentially toxic metals (e.g. cadmium [Cd], lead [Pb], arsenic [As], mercury [Hg])	*Inhalation* of airborne particles and vaporized metals; *Ingestion* of contaminated drinking water and foodstuff (within which metals can bioaccumulate); *Absorption* from contact with contaminated soils, sediment and water.	Some metals are necessary for metabolic functioning (e.g. iron [Fe], copper [Cu]) but in excess concentrations can be toxic. **Pollutants have been identified as causing**: irritation and inflammation, mutagenic effects, carcinogenic effects, neurotoxic effects and associated neurological diseases.	Zone 2	Mudgal et al., 2010; Landrigan et al., 2018; Järup, 2003
Synthetic dyes (e.g. Azo dyes)	*Inhalation* of airborne dye particles; *Ingestion* of contaminated drinking water.	**Pollutants have been identified as causing**: cardiovascular and respiratory problems (e.g. itching, watery eyes, sneezing and symptoms of asthma such as coughing and wheezing); immune system effects, irritation (e.g. skin irritation, itchy or blocked noses, sneezing and sore eyes); carcinogenic effects, mutagenic effects.	Zones 2 and 3	Hassaan and Nemr, 2017; Chung, 2016
Bleaching agents (e.g. chlorine-based bleaches such as hypochlorite, hydrogen peroxide [H_2O_2])	*Inhalation* of vapours; *Ingestion* of contaminated drinking water; *Absorption* from contact with contaminated water.	**Pollutants have been identified as causing**: irritation (e.g. burns to mouth and throat, gastrointestinal irritation, eye and nose irritation, chest tightness, coughing and sore throat).	Zones 2 and 3	Walters et al., 2005
Air pollutants (e.g. Particulate Matter [PM], sulfur dioxide [SO_2])	*Inhalation* of airborne particles and gases.	**Pollutants have been identified as causing**: cardiovascular and respiratory disease (Zone 1) and neurotoxic effects as well as other diseases (diabetes, pre-term birth, dementia in the elderly).	Zones 1 and 2	Landrigan et al., 2018
Pharmaceuticals (e.g. antimicrobial compounds)	*Ingestion* of contaminated drinking water or foodstuff (within which active pharmaceutical ingredients [APIs] can occur).	**Pollutants have been identified as causing**: neurotoxic effects, mutagenic effects, antimicrobial resistance (AMR).	Zone 3	Carter et al., 2019; Williams-Nguyen et al., 2016
Noise	*Exposure* to continuous noise of 85–90 dBA[18]. Intensity, frequency spectrum and duration of noise will determine effects.	**Pollutants have been identified as causing**: loss of hearing, contributions to cardiovascular problems, impairment of cognitive development in children, sleep disturbance, stress.	Zone 2 (Note: noise was not included in the Lancet Commission report)	Omari et al., 2013

18 dBA stands for A-weighted decibel scale to account for differences in how people respond to sound.

2.6 Stakeholder engagement

2.6.1 Stakeholder online survey

A stakeholder database was developed for SSA and SA by contacting various non-governmental organizations (NGOs), trade associations, public health bodies, government departments, industrial managers, and researchers and academics. These stakeholders were identified through a combination of existing institutional contacts, web searches, reviews of the academic literature and network investigation. They were invited to complete an online survey to generate an initial understanding of how they saw the manufacturing industry contributing to pollution, and damage to the environment and human health, as well as the economic importance of these industries.

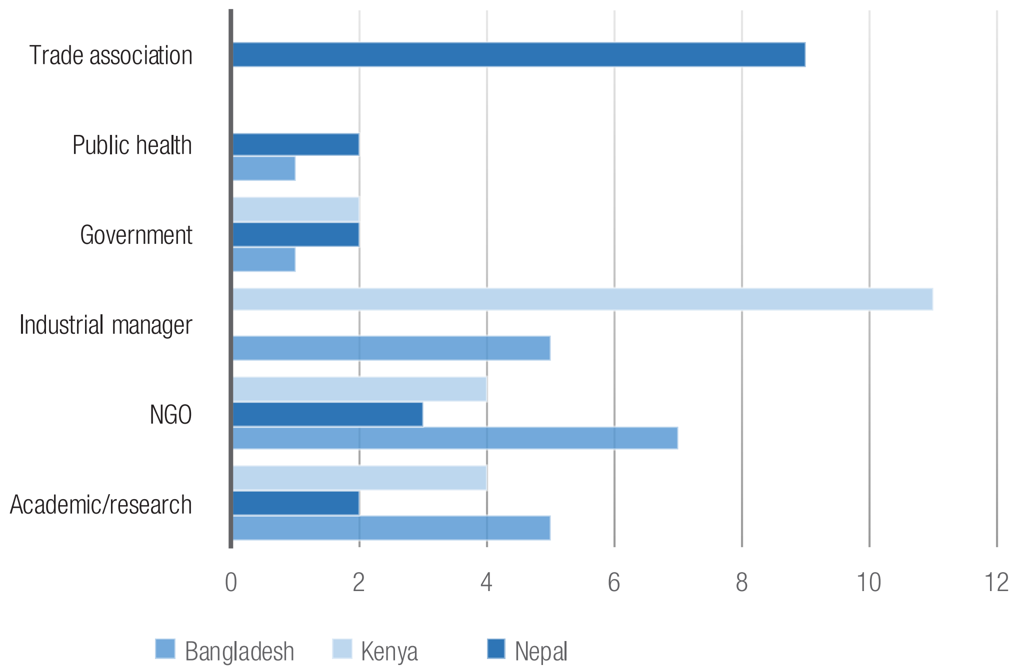
2.6.2 Stakeholder interviews

A semi-structured interview methodology was developed to gain further insight on the local context of manufacturing activities and their relation to pollution, impacts and interventions. To ensure consistency between the different interview facilitators, a topic guide was developed outlining the overall structure and themes for the interviews. Training on applying the topic guide in an interview setting was held both in-person and via video conference.

The topic guide interview structure included the following elements:

- Participant details, including background and level of experience;
- Identification of the importance of a specific industrial sector from an economic, social and political perspective;
- Identification of the pollution profile of the industry in relation to air, water, soil or other pollution pathways;
- Identification of resulting ecosystem and human health impacts;
- Discussion of existing mitigation measures and their local enforcement;
- Brainstorming of additional measures that could be usefully taken locally;
- Snowballing of the literature capturing additional local documents for the study;

Figure 6. Stakeholder groups by country (respondents to semi-structured interviews)



- The topic guide and the studies informed consent form gained ethical approval from the University of York.

These semi-structured interviews were undertaken with key stakeholders in the three case study countries (Bangladesh, Kenya and Nepal) (figure 6). In total, 20 semi-structured interviews were conducted in Bangladesh, 25 in Kenya, and 17 in Nepal. Interviews were recorded and transcribed, and these transcripts were uploaded into NViVO qualitative social research software for further coding and analysis.

2.7 Summary of methodological approach

The overall aim of this scoping study it to explore the interventions that might prove most effective in reducing harmful levels of pollution from manufacturing in the SMEP target countries in SSA and SA. An important first step is to identify those manufacturing industries that are causing pollution at scale across the regions. This is complicated by the fact that the different metrics collected by international data do not readily translate into pollution emissions. In addition, the level of pollution emissions are not necessarily related to the harmful impacts of the pollutants (since impacts depend on e.g. pollution toxicity, exposure and sensitivity of the receptor) and that the data are not comprehensive (e.g. in terms of coverage of data for each metric both within and between countries over the years for which data collection has occurred).

To overcome these challenges three different sources of information are used and described previously in this chapter: international data, peer reviewed literature and stakeholder surveys, to support identification of the manufacturing industries that are important in causing harmful pollution at scale in the regions. This requires the development of an approach that can combine these information sources and identify harmful levels of pollution. To achieve this, data from these different sources are ranked to provide an assessment of the most important manufacturing industries according to each information source. These rankings are then combined to semi-quantitatively identify the most important industries that are likely to be causing harmful pollution in the regions. Industries most likely to be releasing harmful pollution are also identified via an analysis of the peer reviewed literature to determine the pollutant types released by different industries and their ecosystem and human health impacts. This allows the identification of the most important industries within the region that are likely to be causing the most harmful pollution. Pollutant pathways for each industry are then explored in detail in section 3.4 and 4.4. These sections investigate different types of pollutant arising from each industry, the pathways that lead to exposure (via air, water and soil) and the likely impacts of exposure to these pollutants on human health and ecosystems. Interventions that have been proposed to tackle pollution from these industries are assessed and described in relation to key stakeholders of the industry and existing initiatives to control and prevent pollution and its impacts.

3. MANUFACTURING IN SSA: KEY SECTORS, POLLUTION PATHWAYS, INTERVENTIONS AND STAKEHOLDERS

The aim of this chapter is to identify the key polluting manufacturing industries in SSA. This is achieved by assessing and ranking information contained in international datasets (with supporting information from national datasets) that describe the scale and activity of manufacturing across the SSA region (described in section 3.1). To provide context for this ranking, key features of these data are described for the SMEP target countries and for the Kenyan case-study country where stakeholder interviews were also conducted (section 3.2). Other sources of information (i.e. peer reviewed literature and stakeholder survey information) were ranked and combined, on consideration of the toxicity of pollutants from key SSA manufacturing activities, to identify the most harmful polluting manufacturing industries across SSA (section 3.3). Section 3.4 then takes these key identified industries (i.e. food and beverages; textiles and wearing apparel; electrical equipment and chemicals and chemical products) and investigates their respective pollutant pathways and consequent human health and ecosystem impacts using information retrieved from the peer reviewed literature. Section 3.4 also describes interventions that have been used to reduce pollution and its impacts and provide a mapping, by stakeholders along the value chain of each manufacturing industry, of existing activities and initiatives that have been implemented to date.

3.1 Identification of key manufacturing industries across SSA

This section uses international data on manufacturing activity (described previously in section 2.2 and summarised in table 1) to identify the most important manufacturing industries across the SSA region by ranking relevant manufacturing metrics. It is first useful to understand the type of metrics available in these datasets and their ability to demonstrate the variability in physical scale and economic importance of manufacturing across the SSA region as a whole. The datasets and their associated metrics are: i. INDSTAT2 data (UNIDO, 2020) which describe a. number of establishments, b. number of employees and c. value added, each broken down into manufacturing subsectors (defined according to ISIC division Rev. 3) and ii. Organisation for Economic Co-operation and Development (OECD) data (OECD, 2018) which describe value of exports (in US$), again broken down into manufacturing subsectors (but here defined according to ISIC division Rev. 4). The rankings were calculated by averaging each of these metrics across the years for which data were available for each manufacturing subsector and for each country and then summing the results for each country of the SSA region; each manufacturing subsector is then ranked separately for each metric. For example, table 4 shows the top five manufacturing subsectors ranked according to each of the four metrics. The full rankings (i.e. for all manufacturing subsectors) are provided in table 6 along with similar rankings of data obtained from the peer reviewed literature and stakeholder surveys (see section 3.3 for a description of how these other rankings are performed). Together these rankings allow the key polluting industries across the SSA region to be identified for further investigation of their pollutant pathways and impacts in section 3.4).

This ranking exercise shows that food and beverages is an important industry across SSA according to the metrics examined. The other industries that frequently occur in the top ranking are basic metals, fabricated metal products, textiles and wearing apparel, non-metallic mineral products and chemicals and chemical products and pharmaceuticals.

It is also crucial to conduct further analysis of these international datasets to better understand the physical scale, economic importance and temporal trends in manufacturing across the SSA region. In this analysis it is important to understand the limitations in using these datasets to assess various aspects of manufacturing across the region, which largely result from the datasets being incomplete (i.e. there are many gaps in the data with incomplete

Table 4. The top five ranked industries according to each of four manufacturing relevant metrics for the SSA region

Ranking	INDSTAT2 data (UNIDO, 2020)			OECD data (OECD, 2020)
	Number of establishments	Number of employees	Value added	Exports
1	Food and beverages	Food and beverages	Food and beverages	Basic metals
2	Wearing apparel, fur	Textiles	Chemicals and chemical products (including pharmaceuticals)	Coke, petroleum products, nuclear fuel
3	Furniture	Wood products (excl. furniture)	Fabricated metal products	Food
4	Fabricated metal products	Rubber and plastic products	Basic metals	Chemicals and chemical products
5	Non-metallic mineral products	Wearing apparel, fur	Non-metallic mineral products	Other transport equipment

records of different metrics for different countries and across different years). Other problems with the data relate to the fact that the metrics collected are not targeted towards assessing the polluting nature of manufacturing activities. To discuss this further, data provided from a number of environmental datasets are analysed (described in section 2.2 and 2.3) to identify the limitations in using these datasets to identify key manufacturing activities causing pollution. A key issue with these international datasets is that often they do not define the required level of manufacturing subcategories that could support identification of activities that are particularly polluting (e.g. chemicals and chemical products are a large category that comprise a number of different manufacturing activities with very different levels of pollution).

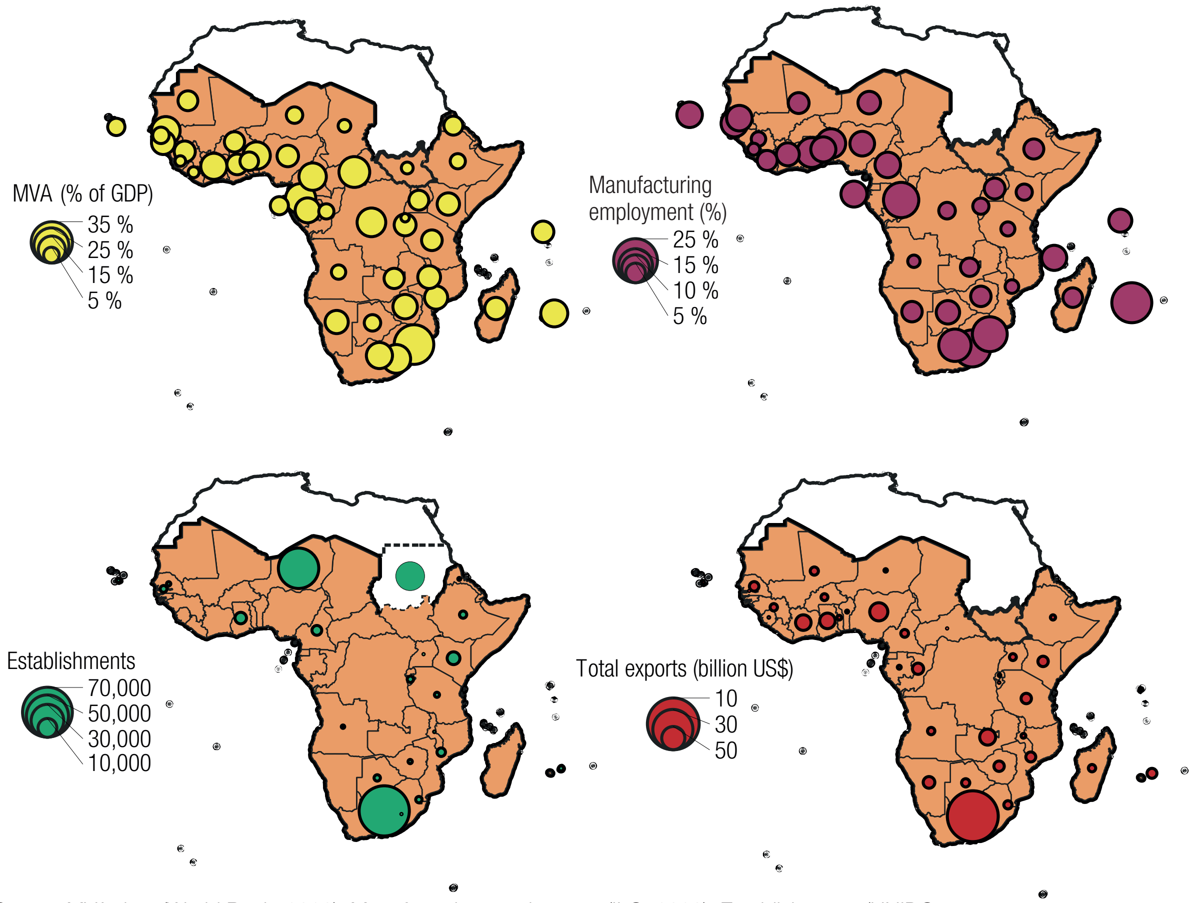
In the following sections, the additional information that can be derived from these, and other international and national datasets, is reviewed to support and critique the assessment of the scale and economic importance of manufacturing in the SSA region. This analysis is predominantly used to identify some of the key concerns in using these data to define and identify key polluting industries in the SSA SMEP target countries that should be considered in future research.

3.2 Manufacturing across SSA and in SMEP target countries

3.2.1 Analysing international manufacturing data for SSA

Figure 7 illustrates the geographical variability in five different manufacturing relevant metrics that are available from established international datasets that include the INDSTAT2 and OECD data used in the ranking analysis described in section 3.1, but which also include International Labour Organization (ILO) and World Bank datasets. The metrics from each dataset are: MVA as a percentage of GDP (World Bank, 2018); percentage of employment in manufacturing (ILO, 2020); the number of manufacturing establishments (UNIDO, 2020); and total export value in US$ (OECD, 2020). Figure 7 shows that the level of manufacturing as defined by these different metrics varies greatly across the SSA region, as does the completeness of the data availability by country. The ILO and World Bank datasets are most complete with good data coverage across all SSA countries, however these datasets only define metrics for ‘manufacturing’ as a whole rather than to the subsector manufacturing level so are not suitable for the analysis of the most important industries (conducted in section 3.3).

Figure 7. Geographical distribution of manufacturing activities across SSA



Source: MVA data (World Bank, 2020); Manufacturing employment (ILO, 2020); Establishments (UNIDO, 2020); Total exports (OECD, 2018).

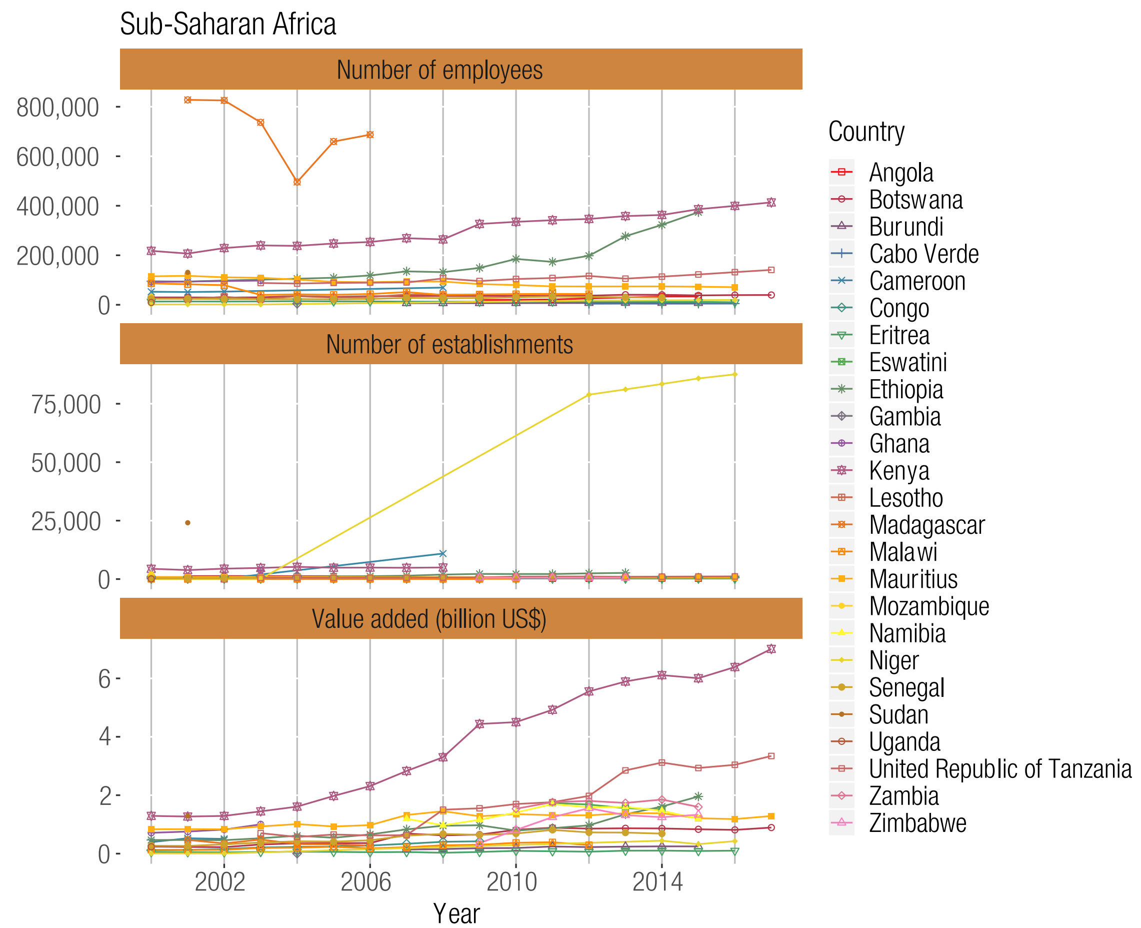
Note: Country data for each metric are averaged across available years.

It should also be noted that the data in figure 7 are averaged over years for which data are available. This allows better comparison between countries but may be misleading as the coverage over time varies significantly both within datasets and between countries. For example, in Mozambique data describing MVA as a percentage of GDP are available from 2000 to 2018 (World Bank, 2018), by contrast INDSTAT2 data describing the number of establishments are only available for the year 2000. Similarly, in Kenya, the percentage employment in manufacturing is only available for 2005 (ILO, 2020), whereas INDSTAT2 data on the number of establishments are available from 2000 to 2008 (UNIDO, 2020). This highlights the lack of consistent historical data within these international datasets.

Further analysis of INDSTAT2 data (UNIDO, 2020) reveals the variability (and inconsistencies) between countries in the manufacturing relevant metrics. Figure 8 demonstrates the trend in the number of employees, the number of establishments and the value added of manufacturing within SSA over time. These data show that manufacturing is tending to increase, particularly in Kenya, Ethiopia, Niger and the United Republic of Tanzania but also reiterate the large variation in scale across the region. Some countries may have experienced a manufacturing increase over time but at a much lower level; these individual country trends are masked when considering the region as a whole.

Analysis of data at this coarse scale provides only limited insight into the physical and economic scale of the manufacturing sector within countries. Therefore, international data at the subsector level for SMEP target countries are analysed in the following section.

Figure 8. Trends in manufacturing metrics from INDSTAT2 data (number of employees, number of establishments, value added) from 2000 to 2017 by SSA country



Source: UNIDO (2020).

Note: South Africa has been excluded. Value added is measured in current prices.

3.2.2 Analysing international manufacturing data for SSA SMEP target countries

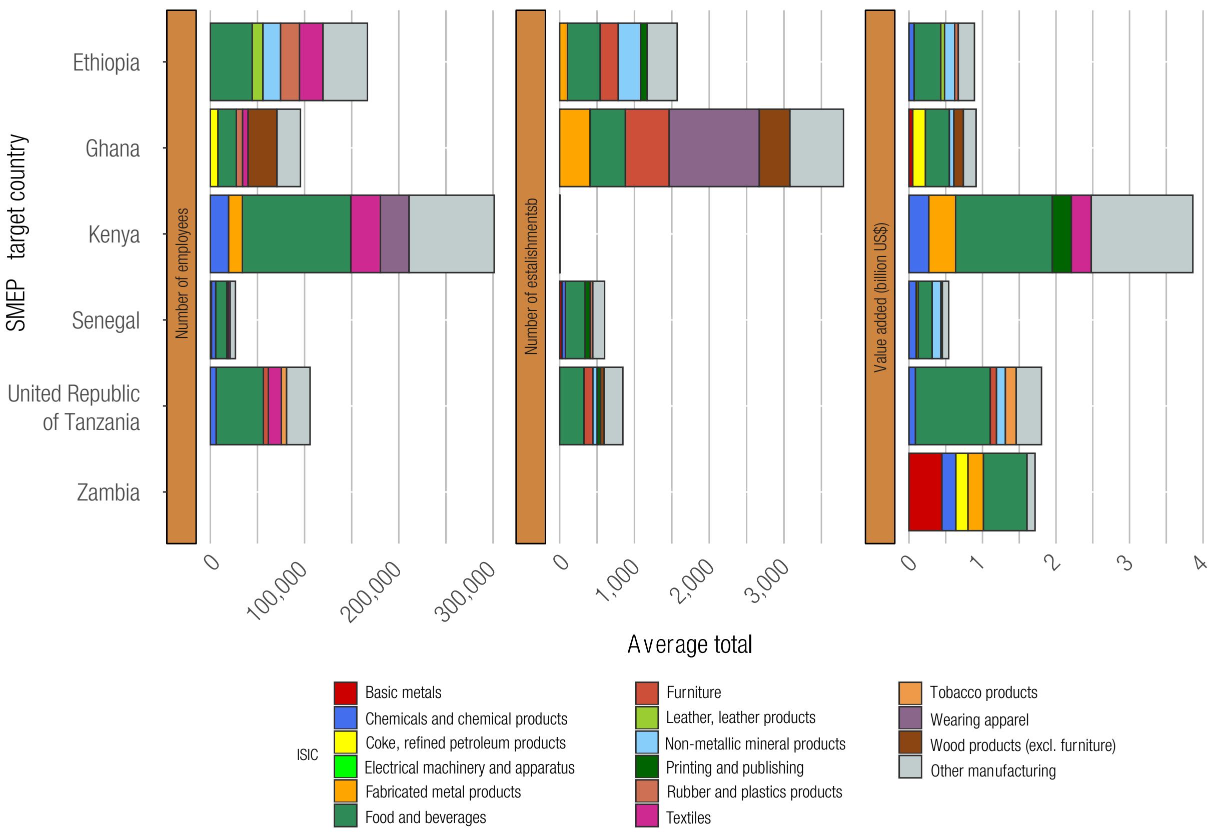
This section analyses the INDSAT2 (UNIDO, 2020) and OECD (OECD, 2018) international dataset metrics that describe manufacturing subsectors activities for the SMEP target countries. This analysis is intended to identify the most important industries in terms of the number of establishments, the number of employees and economic importance.

Figure 9 summarizes the top five manufacturing industries according to the number of establishments, number of employees and value added (using the method described previously in section 3.1). Data are averaged from data available from the year 2000 up to 2017) as provided by INDSTAT2 (UNIDO, 2020); the remaining industries are grouped as 'other manufacturing' to show the proportion of these top five industries to all industries. Figure 9 shows the variation in scale of manufacturing across the SSA SMEP target countries with Senegal consistently lowest in the three metrics presented. Figure 9 also demonstrates that different industries are important in different countries and that the importance changes depending on which metric is considered. For example, in Ghana, wearing apparel is the largest industry in terms of number of establishments but this is not one of the top five industries in terms of the number of employees or value added. Food and beverages is one of the top five industries under each metric for all countries making it the most significant industry according to INDSTAT2 data.

The integrity of this analysis is weakened by inconsistencies in data availability. For example, United Republic of Tanzania INDSTAT2 data are available from 2003 to 2016 for all three metrics presented in figure 9, whereas for Ghana they are only available for 2000 to 2003. For the Democratic Republic of the Congo, Nigeria and Rwanda, there are no data available for any of these relevant manufacturing metrics. The OECD export data (OECD, 2020) can be used to identify the largest manufacturing subsectors. Figure 10 shows the average total export value of each manufacturing type. When comparing with other data it should be noted that this economic metric identifies the high value products as the most important industries, such as basic metals and petroleum products; it also excludes production for domestic consumption.

An important limitation of these international datasets is that they do not account for the informal sector which is significant in SSA. In Zambia, where there are no employment data in INDSTAT2, it is estimated that 37 per cent of the employed population are engaged in the informal sector (Central Statistical Office of Zambia, 2019). The informal sector produces a variety of simple manufactured goods (including metals fabrication and products for agribusiness) and caters largely to a domestic market (Dinh et al., 2012). These activities are not captured in international datasets and may account for some of the discrepancies between different metrics and countries due to the variation in informal sector activity. Future research to understand the relative size of the informal vs formal manufacturing sector by country would be useful to assess the potential

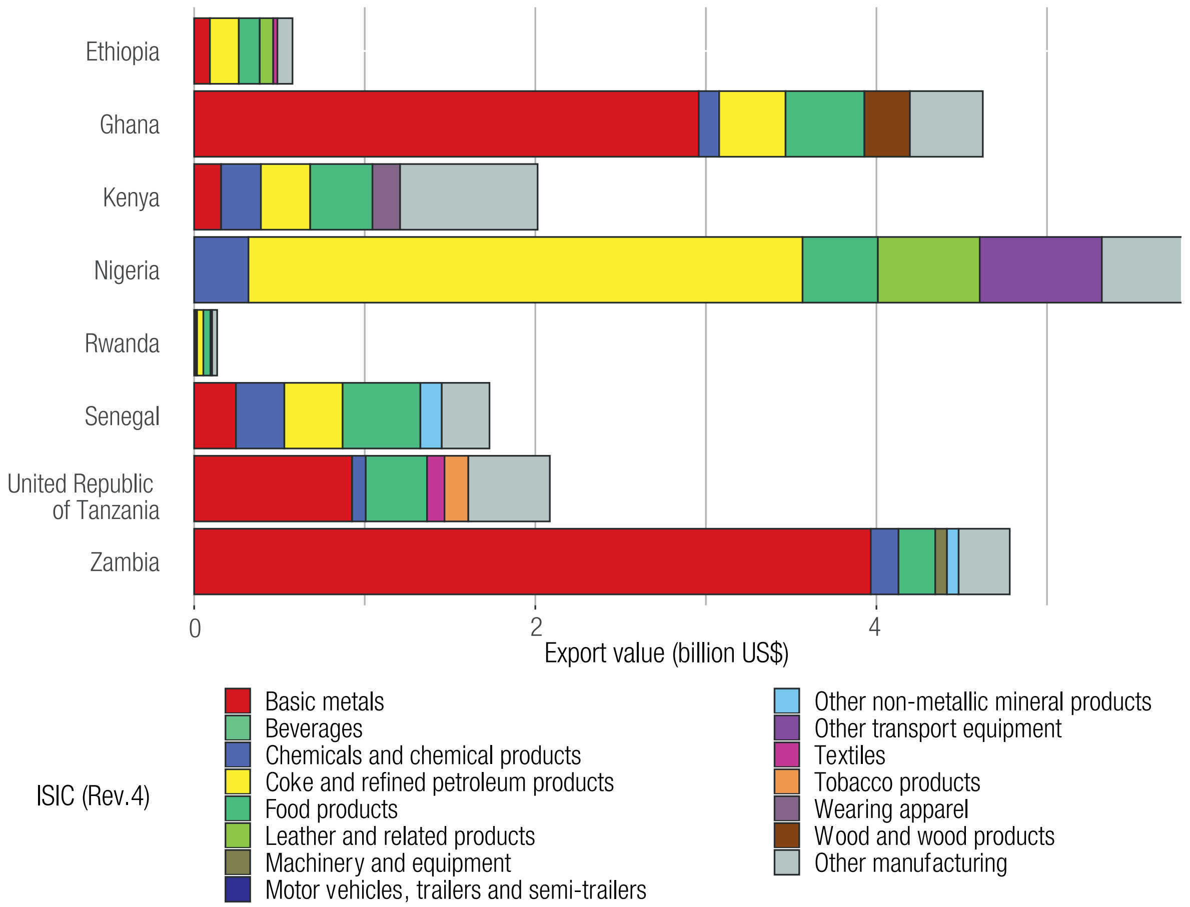
Figure 9. The top five manufacturing industries according to the number of establishments, number of employees and value added



Source: UNIDO (2020). Data are averaged over years for which they are available.

Notes: Data are averaged over years for which they are available. Value added is measured in current prices.

Figure 10. The average total export value of each manufacturing type



Source: OECD (2018).

Notes: Data are averaged over years for which they are available. All values are in current prices.

implications that unregulated, informal manufacturing activities may play in contributing to total pollution loads from all manufacturing activities.

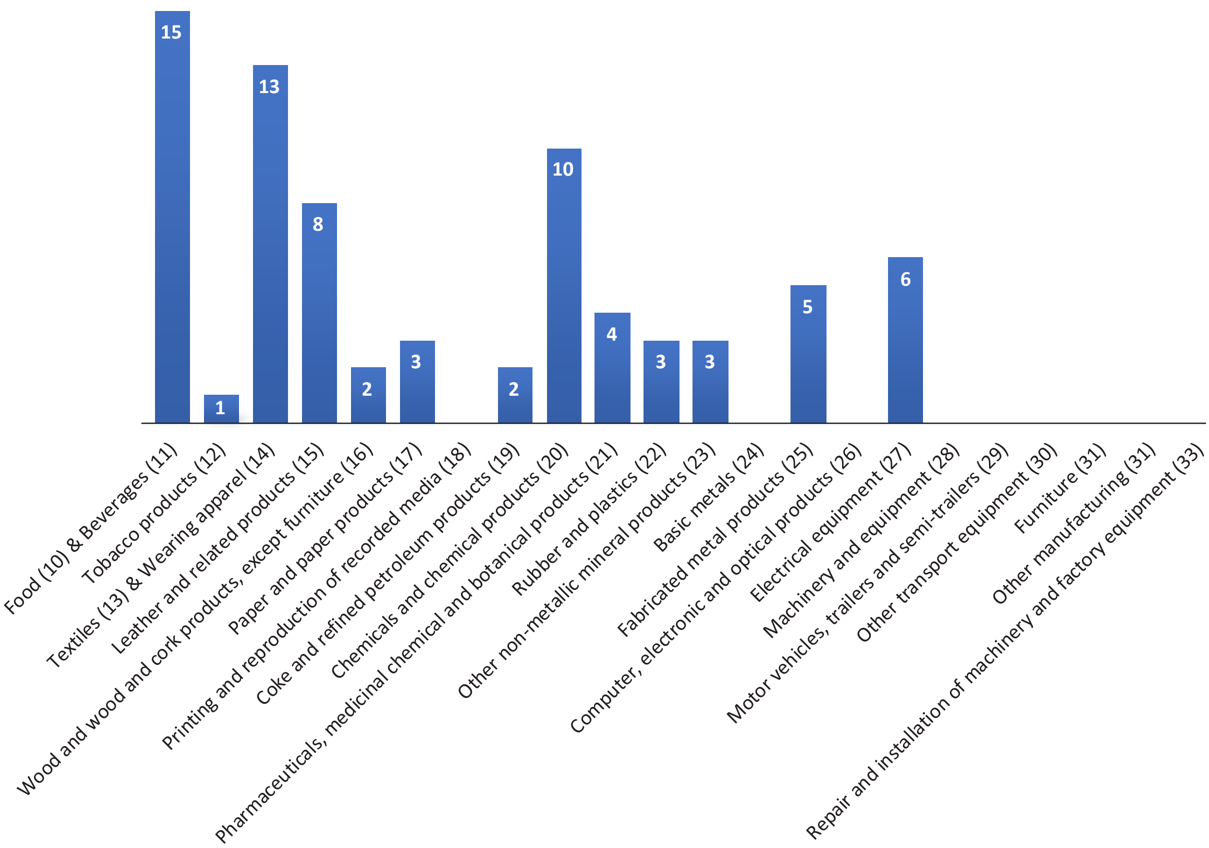
To compare this analysis of international datasets with results from the systematic literature review figure 11 shows the number of articles for SSA grouped into ISIC Rev. 4 divisions. Food and beverages and textiles and wearing apparel were the most studied (with 15 and 13 articles respectively) followed by chemicals and chemical products (10 articles) and leather and related products (eight articles). Of these industries, all but leather and related products feature in the top five rankings of at least one of the metrics of the international datasets (see table 6) which includes a ranking of the international datasets that define manufacturing subsectors in SSA).

3.2.3 Analysing international environment data for SSA SMEP target countries

The manufacturing relevant metrics described in section 3.2 have been used to rank industries based on physical size and economic importance, however, as discussed they are unable to indicate which are likely to be the most polluting industries that will cause harm to human health and ecosystems. This section describes the international environmental data that exist for SMEP target countries and describes what support these data can provide to the identification of the most polluting industries.

Several international datasets provide environmental emissions data (see table 2). These databases tend to follow IPCC guidelines on emissions reporting and, at most, provide manufacturing emissions from two

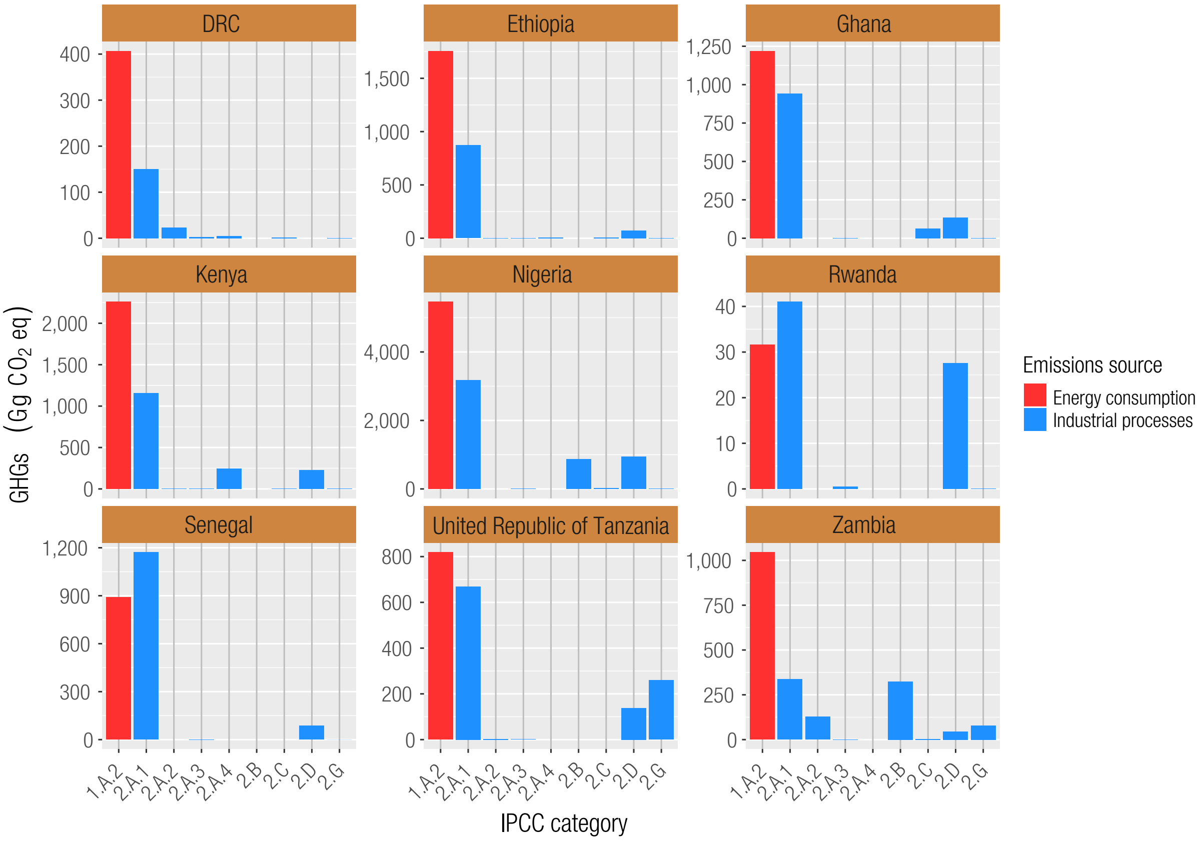
Figure 11. Number of articles dealing with different manufacturing sectors for SSA out of a total number of 38 articles identified that included details of 'manufacturing' + 'pollution' + 'impact' in SSA



sources: emission produced in fuel combustion for manufacturing (IPCC category 1.A.2) and emissions from industrial processes (IPCC category 2). Figure 12 presents total GHG emissions (in gigagrams (Gg) of CO_2 equivalent) from the Emissions Database for Global Atmospheric Research (EDGAR). Emissions from fuel combustion make up the majority of GHG emissions in SMEP target countries, with the exception of Senegal and Rwanda where cement production is the largest emitter. Though these data are modelled and therefore would be expected to be a more complete dataset, figure 12 demonstrates the gaps in international environmental datasets. Process emissions data for several SMEP target countries are incomplete, for example for Senegal, data are only provided for two types of industrial processes: cement production and other production. IPCC category 2, mineral production, is broken down into four subcategories, whereas categories 2B, C, D and G are not disaggregated. Food and beverages were identified as an important industry in section 3.1, however, in international environmental datasets it is reported under 'other production' (2.D) alongside paper and pulp production. Therefore, it is not possible to ascertain its individual contribution to industrial emissions.

The same difficulties in disaggregating data to manufacturing subsectors are found when investigating the emissions generated from fuel consumption during manufacturing. In all the aforementioned databases, manufacturing emissions are presented alongside emissions from construction and cannot be accurately disaggregated. These aggregated estimates are based on data from the IEA. The IEA does provide highly disaggregated energy data, however it is not freely available and only focusses on CO_2 emission data. Therefore, it was not deemed useful for this scoping study which aimed to use datasets that could be readily accessed by countries within the target regions. Such data access limitations highlight a lack of transparency in

Figure 12. Total GHG emissions (in Gg) of CO_2 equivalent for each of the SMEP target countries



Source: EU (2018).

Notes: DRC denotes the Democratic Republic of the Congo. IPCC categories are defined as follows: 1.A.2 – Manufacturing industries and construction, 2.A.1 – Cement production, 2.A.2 Lime production, 2.A.3 – Limestone and dolomite use, 2.A.4 – Soda ash production and use, 2.B – Chemical industry, 2.C – Metal production, 2.D – Other production, 2.G – Other. GHG emissions are averaged from 2000 to 2015.

the methods used and hence the results of emission estimates from sources including manufacturing in international environmental data sets.

The analyses of these environmental datasets have concentrated on the availability of GHG emissions data which deals with only one emission impact (climate change) via one pollutant pathway (air) of emissions from manufacturing. As discussed in section 2.2 there are extremely limited international data available on water and soil quality, where parameters are reported they are not attributed to an emission source and hence cannot be used to determine the levels of emissions from manufacturing. Therefore due to the current lack of consistent and sector level disaggregated data, environmental datasets were not included in the ranking analysis conducted in table 6.

3.2.4 Analysing national environment data for SSA SMEP target countries

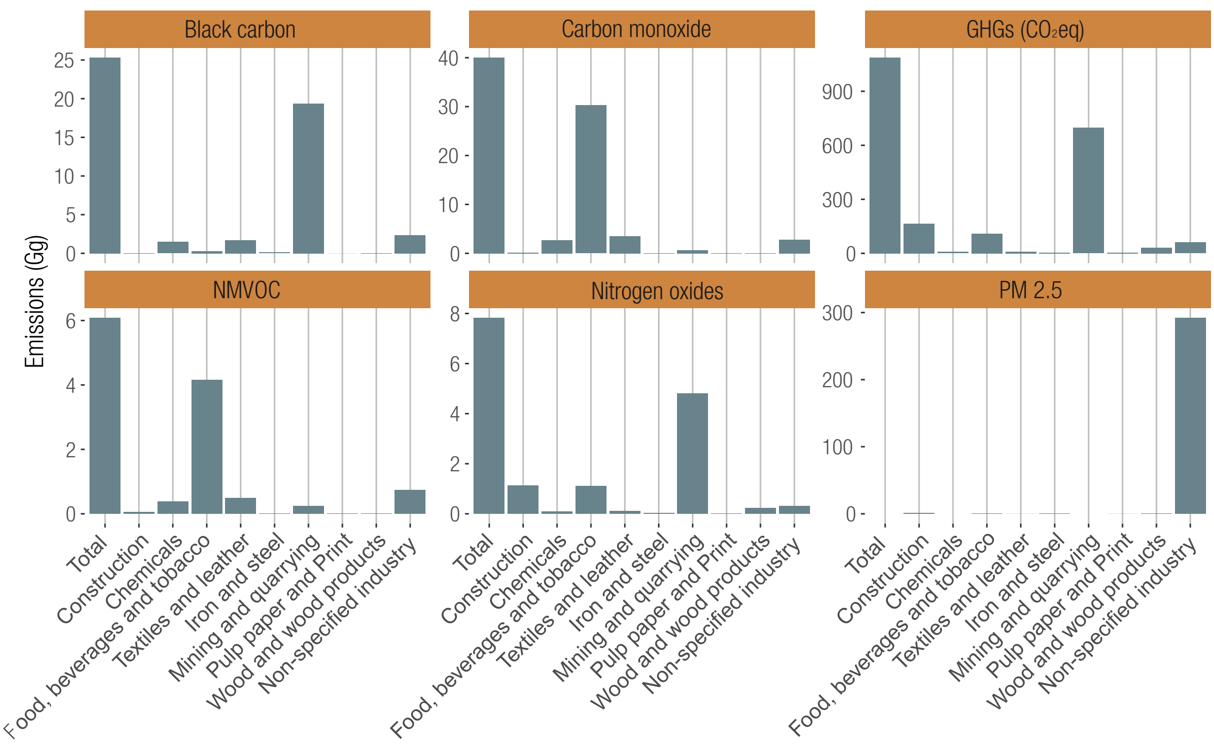
National datasets describing important aspects of environmental pollution are becoming more widely available as countries meet their reporting requirements under the UNFCCC as part of the MRV systems. Countries submit ‘National Communications’ to the UNFCCC as part of these reporting requirements and provide standardised data across countries due to the requirement to report according to the methodology of the IPCC guidebook (IPCC, 2019). This section explores the quality and quantity of national environmental data that are currently available, as well as those that might be available in the future as reporting requirements are refined, and considers how these data might be useful in supporting identification of key polluting manufacturing industries.

The type of national environmental data available within SMEP target countries in SSA from UNFCCC reporting are:

- GHG emissions data: Data are provided for GHG emissions from fuel combustion in the manufacturing and construction industries as well as from industrial processes. In some cases, these data are disaggregated further manufacturing subsectors.
- Air pollutant emissions: National Communications submitted to the UNFCCC sometimes also provide data on key air pollutants that include black carbon, carbon monoxide (CO), non-methane volatile organic compounds (NMVOCs), nitrogen oxides (NOx) and $PM_{2.5}$.
- Energy consumption: some countries provide energy consumption by subsector. Such data could provide an indication of the level of activity of different manufacturing activities between countries.
- Industrial wastewater: These data often have more limited availability than GHG and air pollution emission data. In addition, these data are not disaggregated by industry and only provide emissions of methane and therefore are of little use in describing pollution from the manufacturing sector.
- Solid waste: Limited data are available describing total industrial solid waste. Countries sometimes provide information detailing the composition of solid waste (e.g. from food, textiles, plastics, etc.) but this most commonly refers to municipal solid waste and is therefore not directly related to manufacturing.

A good example of the level of disaggregation of manufacturing subsectors to which GHG and air pollution emissions data are defined is provided by the national reporting for Ghana (see figure 13). These data identify food, beverages and tobacco as substantial sources of black carbon, CO and NMVOC. They

Figure 13. GHG and air pollution emissions from construction and manufacturing industries by subsector for Ghana in 2016



Source: Ghana's fourth National Communication (UNFCCC, 2020b).

also identify 'non-specified industry' as a substantial source of $PM_{2.5}$ warranting further future investigation of these datasets in future research.

A number of key factors currently limit the usefulness of these national environment data to inform on the state of pollution from the manufacturing sector: i. there is large variation in data availability between countries as countries differ in their fulfilment of reporting requirements; ii. the level of disaggregation of emissions to manufacturing subsectors varies, many countries currently only provide data on fuel use for manufacturing and construction as a whole; iii. currently, only a limited number of countries provide data on air pollutants, industrial wastewater and soil waste (in addition to GHG emissions reporting). The recent publication of a refined IPCC emission inventory methodology guidebook (IPCC, 2019) should support improved national dataset collection in the coming years across SSA. In the future, this should help to gain a better understanding on the scale and distribution of manufacturing pollution, and ownership, endorsement and acceptance of national data may help to support policy development.

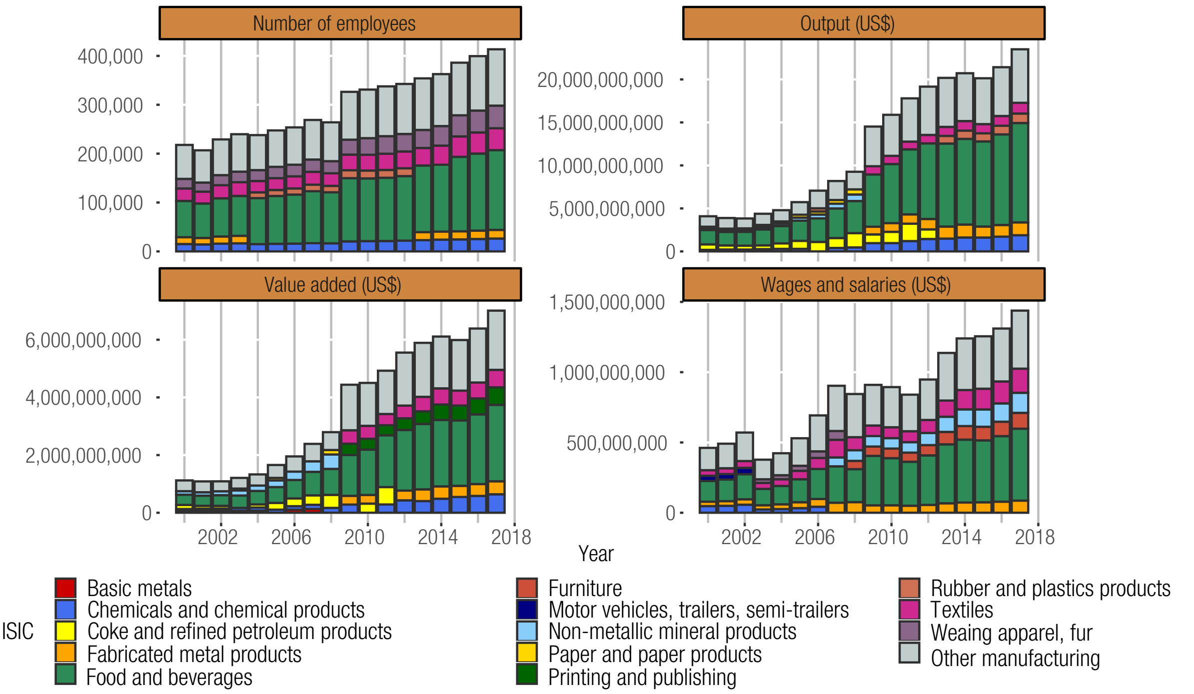
3.2.5 Analysis of the manufacturing sector in Kenya

Kenya is selected as a case study country to gain a more in-depth understanding of the industrial landscape in an important manufacturing country of SSA. Stakeholder interviews were conducted to provide further insight into the manufacturing industries explored in more detail in section 3.4. Stakeholders emphasised that industrialization has remained a priority for successive governments in Kenya since independence in 1963. Several initiatives to support the development and growth of the industrial sector have been implemented. These include policy reforms, establishment of industry-serving institutions, financing of priority industries, and development of infrastructure such as industrial parks and special economic zones linked by an expanding road and railway network (Kenya Association of Manufacturers, 2018). Since 2010, the manufacturing sector's contribution to the economy in Kenya has stagnated at around 10 per cent of GDP (ranging from a maximum of 11.8 per cent in 2011 to a minimum of 8.4 per cent in 2017 (KAM and KBG, 2018). This is largely due to the service sector increasing its contribution to GDP. However, this is considered likely to change due to deliberate government policy in which manufacturing has been identified as one of the key sector contributors to the 'Big 4 Agenda' (ibid.). This policy initiative, one of the four main priorities for government, aims to increase the contribution of the manufacturing sector to GDP from its current levels at around 10 per cent to a value of around 15 per cent by 2022 (KAM and KBG, 2018). Most recent economic reporting show that in 2019, the manufacturing sector's real value added grew by 3.2 per cent and value of output by 6.6 per cent from 2018. The sector's volume of output expanded by 2.0 per cent in 2019 on account of an increase in production of motor vehicles, trailers and semi-trailers; plastics; animal and vegetables fats and oils; and pharmaceuticals subsectors. There was decline in production of wood and products of wood, sugar, electrical equipment and other non-metallic mineral products among others. The sector's formal employment increased by 1.6 per cent to approximately 353,000 in 2019 (KNBS, 2020). The number of persons engaged in the informal sector in manufacturing is estimated to have grown over the last five years by 19.9 per cent, from around 2,438 in 2015 to 3,044 in 2019 (ibid.). Kenyan stakeholders interviewed in 2019 described the industrial sector as being comprised of small and medium enterprises with a few large industries including multinationals (although the larger industries have been declining rather than expanding in the recent past). The sector has not, however, been dynamic enough to transform into an engine of economic growth and most manufacturing production is for domestic consumption rather than export.

Figure 14 shows the trends for manufacturing in Kenya that can be derived from the INDSTAT2 international data. These data reflect the trends in manufacturing described by both the stakeholders and that detailed in reports on Kenyan manufacturing described above. The INDSTAT2 data show that food and beverages are a key manufacturing industry that has grown substantially since the early 2000s. The proportion of 'other manufacturing' is large and growing, suggesting that manufacturing is diversifying and expanding.

Comparing INDSTAT2 data with OECD export value data (OECD, 2018), similar trends are seen (figure 15). Manufacturing export appears to be increasing with food products as a key industry. Again, there has been growth in the 'other manufacturing' category, supporting the evidence that the sector is diversifying.

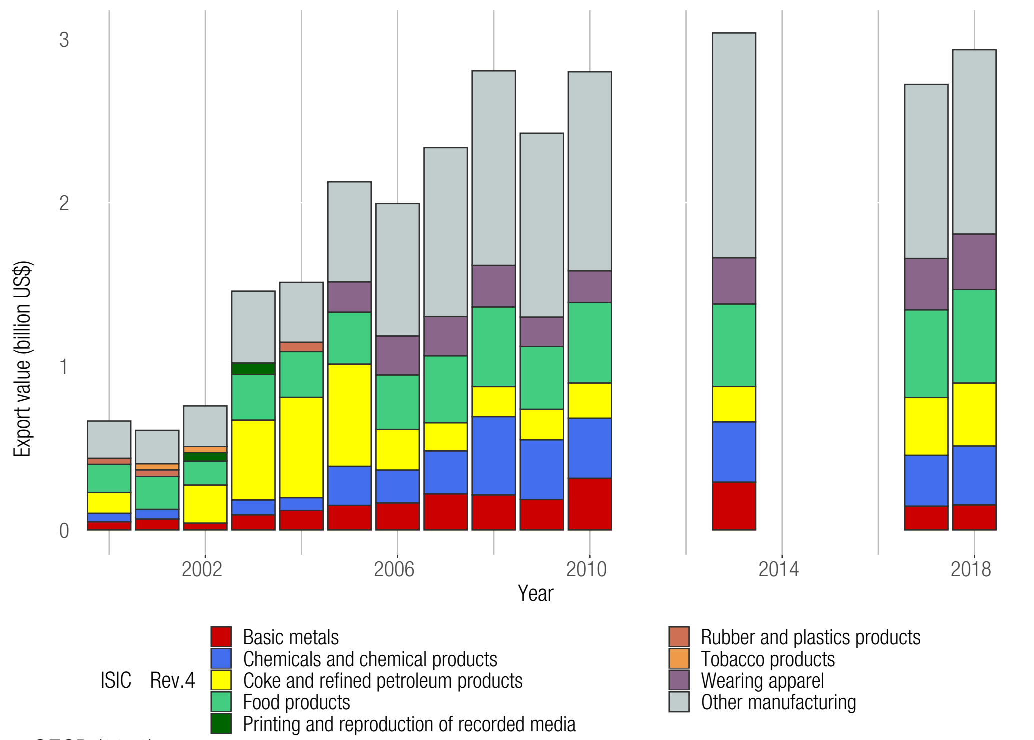
Figure 14. Top five manufacturing industries in Kenya, as ranked by INDSTAT2 data metrics (2000-2017)



Source: UNIDO (2020).

Note: All values are in current prices.

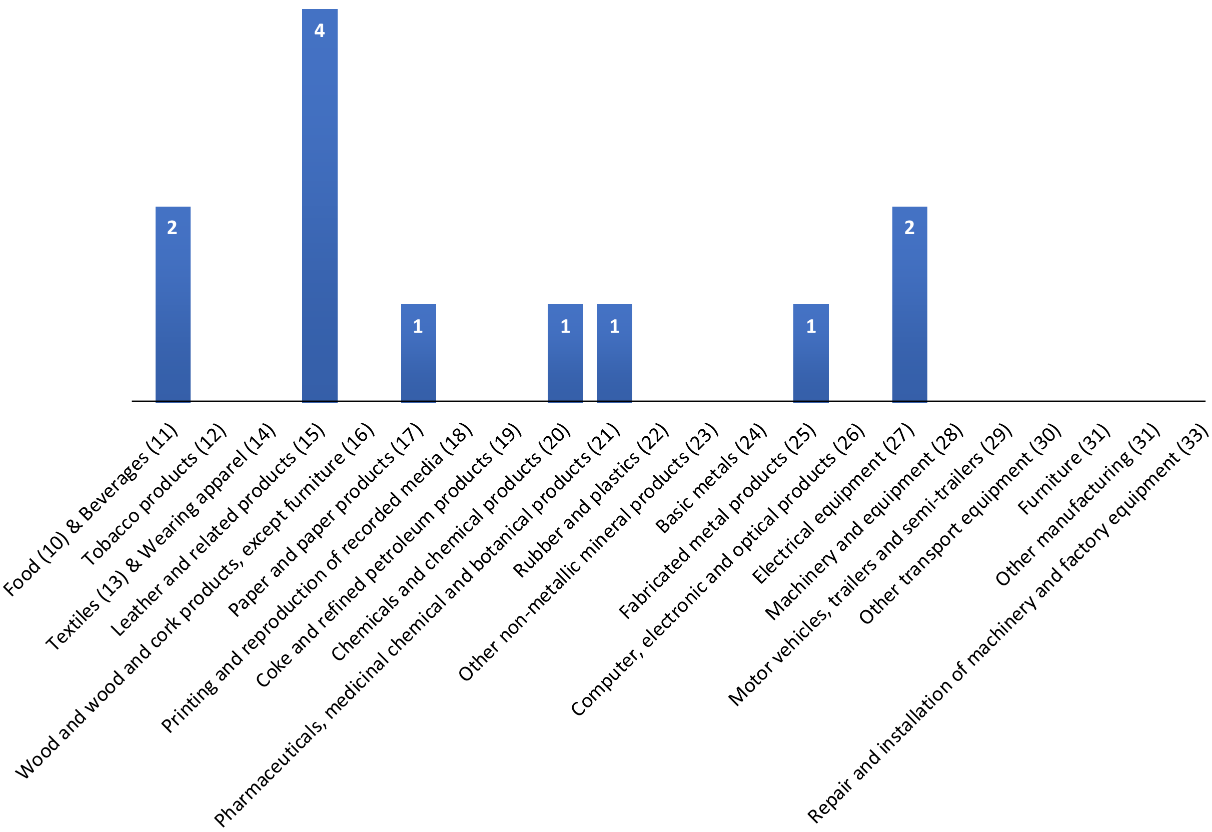
Figure 15. Top five manufacturing industries in Kenya, as ranked by OECD data on export value (2000-2018)



Source: OECD (2018).

Note: All values are in current prices.

Figure 16. Number of articles retrieved from the literature review for each manufacturing industry sector for Kenya



Note: The absence of bars indicates that no data are available.

Wearing apparel also appears to be increasing but on a smaller scale. The proportions of the remaining top five industries have fluctuated over the years.

Data from the systematic literature review (figure 16) show that of the 12 articles retrieved, leather and related products was the industry most frequently studied (four articles) in Kenya. This is the case despite the leather industry not featuring in the top five industries in either the INDSTAT2 or OECD international datasets. However, national data from Kenya do identify leather as an important and widely traded commodity estimated to be worth US$ 100 billion per year (KAM and KBG, 2018) and Kenya has named the leather sector as the second priority sector under the manufacturing sector of the Government of Kenya's 'Big 4 agenda' (ibid.). Under the 'Big 4 Agenda', by 2022 the value of leather exports are targeted to increase from US$ 140 million to US$ 500 million, the sector is further targeted to manufacture 20 million shoes and create 50,000 new jobs. This is expected to be achieved through the setting up and training of 5,000 cottage industries (KAM and KBG, 2018). Together, these national data and peer reviewed literature suggest that the leather sector is a polluting industry as well as an industry that has been identified as important for the continued economic development of the country.

3.3 Determining key polluting industries in SSA SMEP target countries

It is important to establish the key manufacturing industries most likely to be causing pollution that pose the greatest risk to the environment and human health in SMEP target countries in SSA. The first important step in this process is to try to identify those industries that are likely to cause emissions of harmful pollutants (see table 3). To achieve this the codebook (see section 2.4) developed from the systematic literature review of SSA data was used to identify articles that

Table 5. List of industries, associated pollutants and health risks defined in the literature review for SSA

Industry (ISIC Rev. 4 code)	Number of articles	Pollutant types							Human health impacts						
		Toxic metals	Dyes	Bleaching agents	Air pollutants	Noise	Pharmaceuticals	Other	Cardiovascular & respiratory	Carcinogens	Neurotoxins	Endocrine Disruptors effects	Reproductive toxicity	Irritants & inflammation	Other
Food products & Beverages (10 & 11)	15 (4)	x			x			e.g. pulp, husks, plastics, oil and grease	x	x	x		x		Genotoxicity
Tobacco products (12)	1 (0)	x			x			Suspended solids	x						
Textiles & Wearing apparel (13 & 14)	13 (3)	x	x	x	x				x	x	x		x	x	
Leather and related products (15)	8 (2)	x	x						x	x				x	Hypertension
Wood and products of wood and cork, except furniture; articles of straw and plaiting materials (16)	2 (0)	x			x	x									Hearing loss
Paper and paper products (17)	3 (1)	x	x	x	x			Plastic	x						
Coke and refined petroleum products (19)	2 (0)	x	x						x						
Chemicals and chemical products (20)	10 (2)	x	x		x	x		Sulfates and nitrates, hydrocarbons	x			x			Hearing loss
Pharmaceuticals, medicinal chemical and botanical products (21)	4 (0)						x		x						
Rubber and plastics products (22)	3 (2)	x			x			Nitrates & phosphates	x						
Other non-metallic mineral products (23)	3 (1)	x			x			Chlorides, sulfates, phosphate, nitrates	x						
Fabricated metal products, except machinery and equipment (25)	5 (1)	x	x	x	x	x		Oil, nitrates, phosphates	x						Hearing loss
Electrical equipment (27)	6 (4)	x	x						x						Death

Notes: Results from 38 articles. Only those that include "manufacturing + pollution + impacts" (where the latter can be ecological impacts) are counted in number of articles; information sourced from the literature is used to assess likely health impacts related to pollutant types, likely exposures and consequent impacts. Number of articles (in brackets) denotes articles that only dealt with that specific manufacturing industry.

associate industries with particular pollutant types and consequently to impacts on human health and natural ecosystems. The results for SSA are provided in table 5, which describes human health impacts. It is important to note that this analysis is largely reliant on the information provided in the articles and may miss industries and pollutants that do cause damage but for which such damage is not reported in the literature. Further research would be advisable to ensure that important pollutants and impacts are not missed.

This information is combined with the data from the international datasets and stakeholder online survey to identify which of these polluting industries are most important in terms of scale and extent for the SSA region. For SSA, the online stakeholder survey (see figure 17) found that the most commonly identified industry was chemicals and chemical products both in terms of concern about the level of pollution stemming from this industry but also in terms of the industry's economic importance. Basic metals, leather and related products and textiles and wearing apparel were also identified as being important. The survey data also show concern over water pollution consequences from leather and related products, textiles, wearing apparel and chemicals and chemical products.

Table 6 places the polluting industries identified in the literature review and online stakeholder survey in the context of manufacturing data collected from international datasets (i.e. INDSTAT2 and OECD data). This provides a sense of the importance of these polluting industries in the broader manufacturing industry sector for the region. For each polluting industry, table 6 provides the number of articles referencing the industry, the ranked number of respondents who identified the industry as polluting and economically important, and industry rankings from the INDSTAT2 and OECD data (achieved by averaging data across available years and summing across the region). Food and beverages are considered together because they are not distinguishable in the INDSTAT2 data. Table 6 highlights in red the industries with the greatest (top five) number of articles, ranking by stakeholders and ranking by manufacturing metric. Only SMEP target countries for SSA are described in these international data.

Figure 17. Number of online survey respondents stating a manufacturing industry contributes to air, water and soil pollution and the economy for SSA

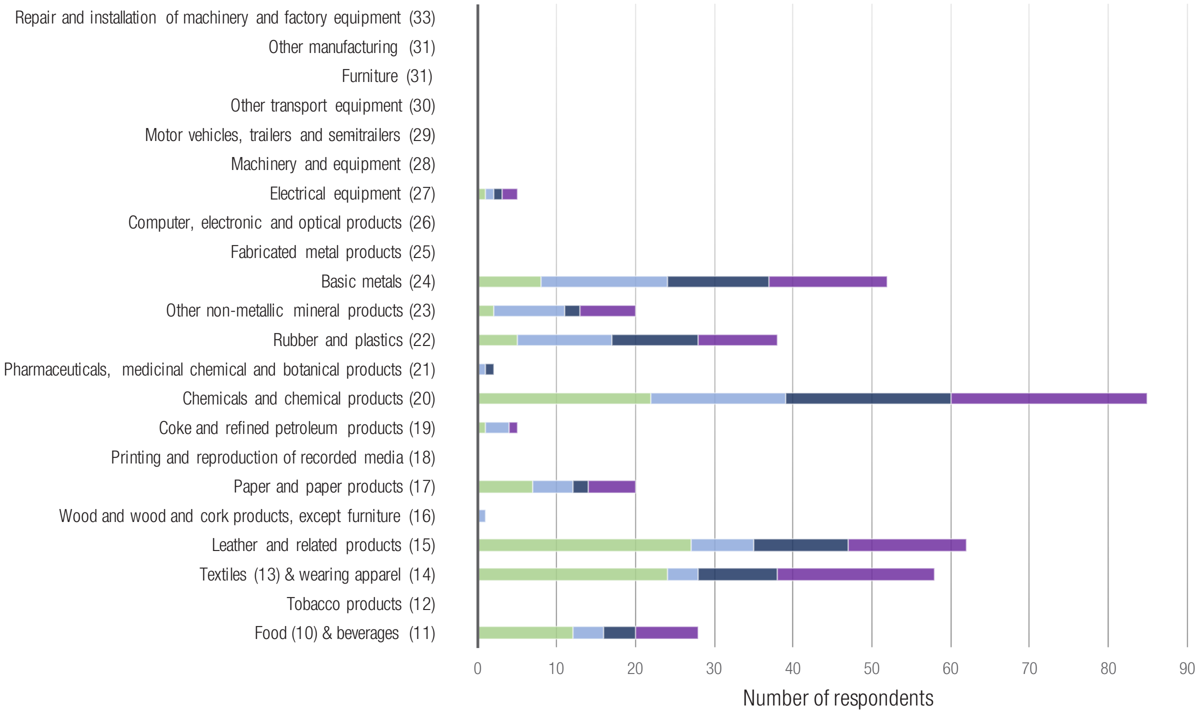


Table 6. Identification of key polluting manufacturing industries according to rankings of data from the literature review, stakeholder online survey and international data for SSA

Industries		Number of articles	Rank by no. of respondents	Ranking (INDSTAT2 and OECD data)			
ISIC description	ISIC (Rev. 3) code			Number of establishments	Number of employees	Value added	Exports
Food & beverages	15	15	6	1	1	1	3/20
Tobacco products	16	1	13	19	16	12	7
Textiles	17	13	3	9	2	7	12
Wearing apparel, fur	18	13	(3)	2	5	15	15
Leather, leather products and footwear	19	8	2	11	11	16	6
Wood & wood and cork products (except furniture)	20	2	12	6	3	11	9
Paper & paper products	21	3	7	14	13	13	18
Printing & publishing	22	-	13	7	10	8	22
Coke, refined petroleum products, nuclear fuel	23	2	9	20	14	6	2
Chemicals & chemical products	24	10	1 / 11	8	6	2	4/21
Rubber and plastics products	25	3	5	10	4	9	13
Non-metallic mineral products	26	3	8	5	7	5	8
Basic metals	27	-	4	12	12	4	1
Fabricated metal products	28	5	-	4	9	3	14
Machinery & equipment	29	-	-	13	17	17	10
Office accounting & computing machinery	30	-	-	21	22	19	19
Electrical machinery & apparatus	31	(6)	(10)	16	18	18	16
Radio, television & communications equipment	32	-	-	22	21	22	-
Medial, precision & optical instruments	33	-	-	18	20	21	-
Motor vehicles, trailers, semi-trailers	34	-	-	15	15	14	17
Other transport equipment	35	-	-	17	19	20	5
Furniture	36	-	-	3	8	10	11
Recycling	37	(6)	(10)	23	23	23	12

Notes: International data are provided and ranked for the SMEP target countries only. The top five metrics are highlighted for all data. Values in brackets indicate duplication of entries due to uncertainty in allocation of data from the literature and stakeholders to specific ISIC Rev. 4 categories. Entries with 2 values (e.g. x/y) provide the ISIC Rev. 3 and Rev. 4 categories where categories differ between ISIC revisions. '-' represents no data for this particular industry.

The analysis presented in table 6 was used to identify the key industries (classified according to ISIC Rev. 4) for SSA that were considered most likely to be a threat to the environment and human health; these industries are explored in further detail in section 3.4. Four industries were selected: (i) food and beverages, which were identified as likely to be hazardous to human health by the literature review (see table 5), as an extremely important and growing industry in the SSA region by the international datasets (see table 6), and as a source of water pollution by the stakeholders; (ii) textiles and wearing apparel, which was identified as likely to be hazardous to human health by the literature review (see table 5), as an important industry in terms of number of employees in the SSA region by the international datasets (see table 6), and as a source of water pollution while being important to the economy by the stakeholders; (iii) chemicals and chemical products, which was not identified as particularly hazardous to human health (at least in terms of the everyday running of these industries[19]) but was identified as a problem industry by the stakeholders with the potential for growth given its economic value; and (iv) electrical equipment, which was also not identified as particularly hazardous overall, though the pollutants associated with particular subsectors (i.e. battery manufacturing and recycling) can cause substantial human health effects, with the industry showing strong signs of growth, especially in the informal sector.

3.4 Polluting mechanisms of key manufacturing industries in SSA

This section provides a general summary of the pollutant impacts associated with the key manufacturing industries identified for SSA SMEP target countries in section 3.3. For each industry, emissions, pollutant pathways (via air, water and soil), environmental degradation and human health impacts are described along with interventions that have been identified to reduce emissions or clean up existing pollution. This provides information that can be used to support prioritization and implementation of interventions.

19 This assessment precludes the accidents associated with chemical plants that can cause severe human health impacts (e.g. the Bhopal disaster at a pesticide plant in India in 1984; the Visakhapatman gas leak at the L G Polymers chemical in India in 2020).

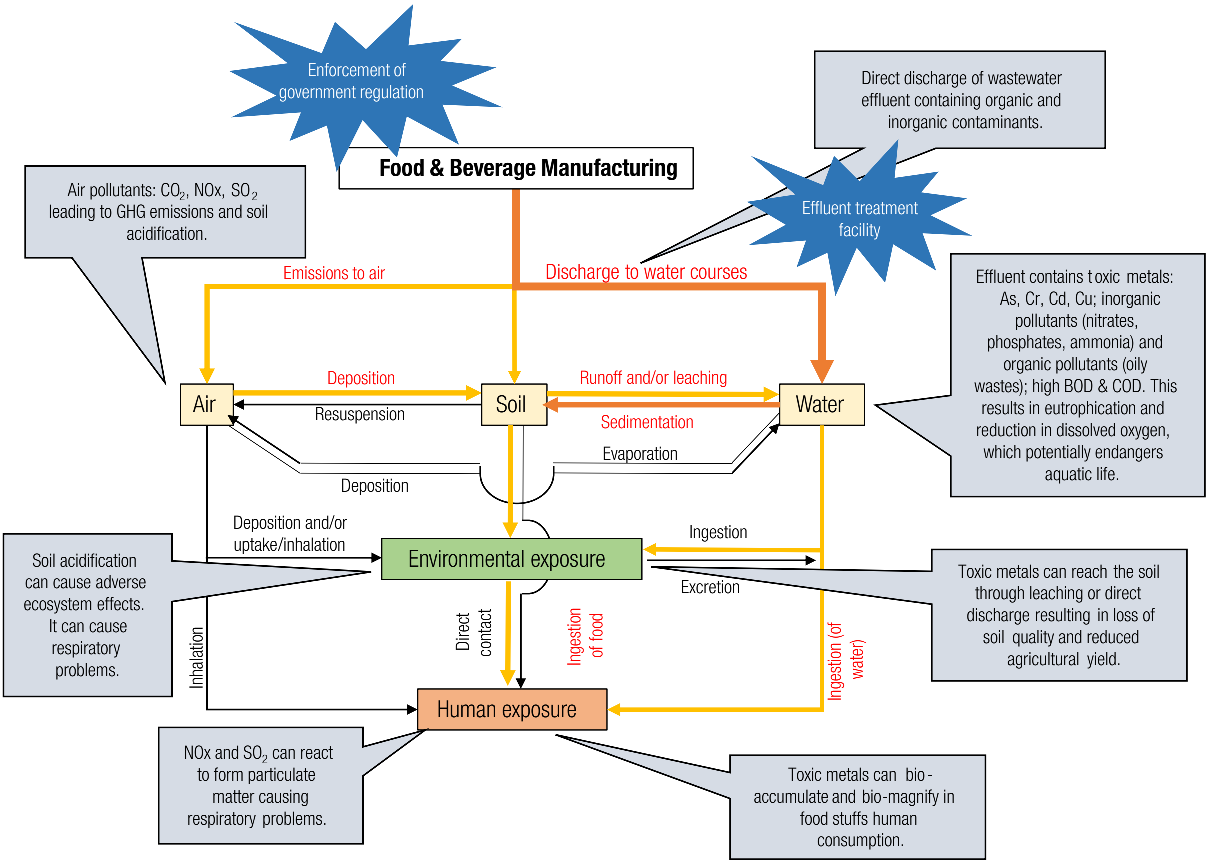
3.4.1 Food and beverages (ISIC Rev. 4 codes 10 and 11)

INDSTAT2 data indicate that the food and beverage industry is the most important industry in SSA SMEP target countries. When data are averaged across available years and summed over the region, food and beverages ranks highest in terms of number of establishments, number of employees and value added. The INDSTAT2 data also show a clear increasing trend in this industry over time (UNIDO, 2020). Export data (OECD, 2020) show the industry to be the third-most important sector in SSA though there is variation in trends in the value of exports over time. Food exports appear to be increasing in Ethiopia, Kenya, and Uganda. Food and beverages was the largest manufacturing subsector in Kenya, contributing 3.5 per cent of the country's GDP in 2017 (KAM and KBG, 2018). Kenya has been successful at growing the food and beverage industry, promoting agro-processing within its Industrial Sector Master Plan, which also looks to improve its regulations and policies to support the sector (ibid.). The systematic literature review found 15 articles that described pollution impacts associated with the industry in SSA. These articles dealt with a wide variety of industry subsectors including fishing, filleting, beverages, baking, sugar blending and packaging, wine making (Walsdorff et al., 2005; Kanu et al., 2006; Oguttu et al., 2008; Sahu, 2018; Zinabu et al., 2018) and coffee processing (Gathuo et al., 1991; Endris et al., 2008; Woldesenbet et al., 2016).

Figure 18 summarizes the pollutant pathways identified for the food and beverage industry. There are three principal sources of pollution: air pollutants associated with the fuelling of boilers and furnaces to provide energy for processing activities; wastewater effluent associated with those processes requiring water treatment (such as washing); and solid waste as a by-product of processing (e.g. pulp and husks).

Air pollutants emitted included sulphur dioxide (SO_2), nitrous dioxide (NO_2) and PM. Stakeholders also highlighted the problems of air pollution coming from the use of boilers or furnaces in the food and beverage industry, describing how they are powered by a variety of fuels including biomass (such as wood, briquettes and macadamia shells), diesel, heavy fuel oil and liquid petroleum gas. This resulted in stakeholders identifying the sugar and

Figure 18. Schematic showing the pollution pathways of the food and beverage industry in SSA



Notes: Red, amber and yellow lines (where present) indicate the more important contaminant pathways (red being the most important). Grey boxes provide annotations of the key pathways and their impact and blue stars suggest potential interventions.

brewing industries as substantial sources of pollution due to their large boilers. It is also worth noting here that heavy fuel oil and liquid petroleum gas are generally utilized by the larger scale industries while biomass is more common with the small- and medium-scale industries.

As a whole across SSA, the food and beverage industry accounts for about 55 per cent of industrial wastewater pollution (Adeoti, 2001) and results in the production of organic wastes (e.g. soil wastes including food bits, pulp and husks) that are mostly discharged to nearby watercourses and, or on land. Water pollution is exacerbated, as these industries tend to consume large quantities of water, which also means that they will be located close to watercourses. For example, a study of a sugar processing industry in Ethiopia found that 1,500–2,000 litres of water were required to crush a ton of sugar cane, generating 1,000 litres of wastewater (Sahu, 2018). Gathuo et al., (1991) also note that coffee industries in Kenya are located near watercourses, which are consequently polluted by solid wastes resulting from coffee processing. This corroborates the information from stakeholders surveyed online, who also identified the sugar industry as a key water pollutant (see figure 17).

Waste effluents from the food and beverage industry are often high in solid wastes such as pulp, husks and other organic pollutants, resulting in biochemical oxygen demand (BOD[20]) and total suspended

20 BOD represents the amount of oxygen consumed by bacteria and other microorganisms as they decompose organic matter under aerobic conditions in a body of water.

solids (TSS) (ibid.). For example, a study of the Jinja catchment area, in Uganda, provides evidence of the substantial amount of organic solid wastes that are produced from food processing industries with substances such as blood, fat, skins, bones, or other residues resulting from grain and bread processing (Oguttu et al., 2008). The release of these solid organic wastes result in high nutrient loading and enrichment of water bodies with nitrates, phosphates and ammonia. For example, food and beverage processing has been found to contribute significantly to aquatic organic pollution in Nigeria (Adeoti, 2001). Although several such studies demonstrate high nutrient levels associated with the industry, there is a paucity of controlled studies to show individual factory contributions to pollution loads that are likely to arise from a variety of pollution sources and run-off. Of the 15 articles found in the systematic literature review, only five dealt solely with the food and beverage industry, focusing on wastes from the wine, coffee and brewery industries. The others explored pollution close to industrial areas where food and beverage industries were located and therefore likely to be contributing to contamination, thus making it difficult to trace each contaminant to a particular industry. Careful fieldwork using information on the timing of effluent discharges from different industries can overcome these problems. For example, a study in Ethiopia demonstrated that most of the nutrient discharges from factory effluents came from a meat processing factory and a brewery (Zinabu et al., 2018). The study also demonstrated spatiotemporal differences in the amounts of total nutrient loads observed in the receiving water body, with less contributions during the wetter season.

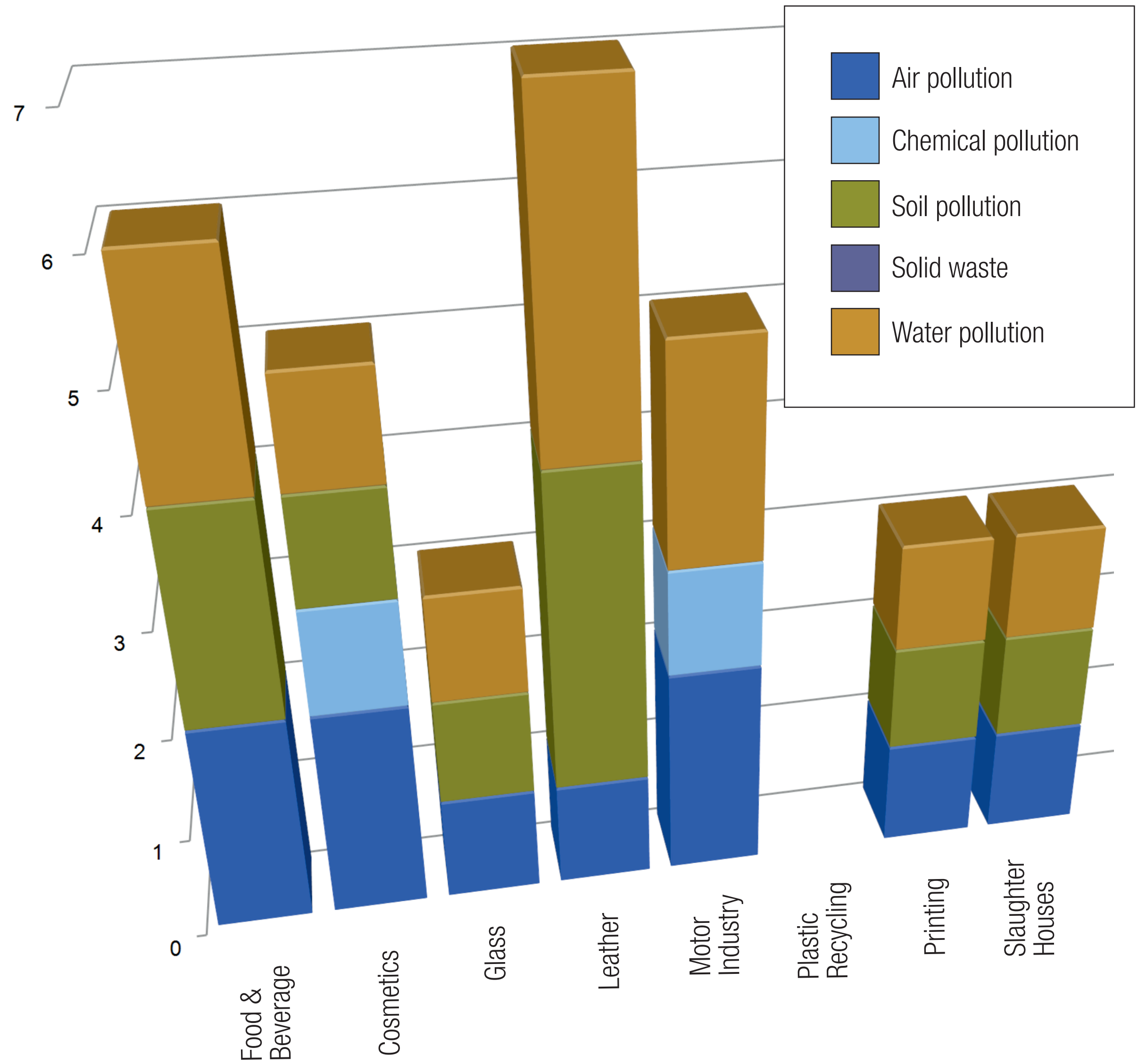
Finally, there is some evidence that waste effluents also contain potentially toxic metals. For example, Cr, Pb, Cu, nickel (Ni) and manganese (Mn) were found in effluent associated with beverage, fish filleting and food processing industries in Jinja town, in Uganda (Oguttu et al., 2008). High concentrations of iron (Fe) and zinc (Zn) were associated with breweries located in Abia state in Nigeria (Kanu et al., 2006) and Ni, Zn, Cr and Pb were found in industry effluent in the Alaro River, in Nigeria (Ipeaiyeda and Onianwa, 2011).

In summary, the literature suggests that the key emissions from the food and beverage industry are air pollutants from the running of furnaces and boilers to provide energy to power food processing activities; organic solid wastes polluting soil and water courses as food is processed; and waste effluent discharged into water courses. These pathways are described in figure 18 with their relative strength and importance depicted by amber and yellow arrows. The Kenyan stakeholders interviewed also described the food and beverage industry as contributing in almost equal measures to air, soil and water pollution and ranked the industry second only to leather in terms of its generation of pollution (figure 19). Analysis of the online stakeholder survey ranked the industry as the sixth most important, identifying water pollution as a key issue (see figure 17).

Most of the impacts identified in the systematic literature review focus on environmental effects. The release of organic wastes as solids and effluent result in the formation of nitrates, nitrites and phosphates. This can increase the BOD and COD[21] (chemical oxygen demand) in the aquatic environment. These are measures of the capacity of water to consume oxygen during the decomposition of organic matter and the oxidation of inorganic chemicals, and high levels of BOD and COD have potential consequences for aquatic organisms (Oguttu et al., 2008; Ntuli, 2012). For example, the Alaro River in Ibadan, in Nigeria, saw an increase in the BOD range from 2.12 mg/L to 6.3 mg/L downstream of a discharge point of effluent flowing from food and beverage industries (Ipeaiyeda and Onianwa, 2011). There is also some evidence to suggest that the heavy metals released by the industry may be at levels high enough to cause toxicity (ibid.; Oguttu et al., 2008; Kanu et al., 2006). Deposition of gaseous emissions such as SO_2 and NO_2 (Oketola and Osibanjo, 2007) can cause acidification of soils and watercourses, which can adversely affect fish and vegetation. Finally, the industry requires a substantial amount of plastic packaging to protect and preserve food, maintain its quality and safety, and reduce food waste (Bradley et al., 2011). Plastics (both macro and micro) can have harmful effects on the environment; an improved understanding of these potential impacts, especially for SSA country contexts, will be crucial and can help inform the development of new technologies (such

21 COD represents the amount of oxygen that can be consumed by bacteria and other microorganisms due to chemical reactions in a body of water. The higher the BOD and COD the greater is the oxygen stripping capacity of e.g. discharged effluent and the greater potential for damage to biological life in those waters.

Figure 19. Relative frequency of comments on pollution types by manufacturing industry from stakeholders in Kenya



as nano- and biodegradable materials) for use as packaging in the industry (ibid.).

Human health impacts resulting from the industry are primarily associated with toxic metals found in waste effluents, which can enter the food chain and accumulate in the tissues of organisms causing cumulative effects and risks to human health (Oguttu et al., 2008; Ipeaiyeda and Onianwa, 2011). However, the potentially toxic metal concentrations in effluent associated with the food and beverage industry tend to be low (Oguttu et al., 2008). Gaseous pollutants, especially PM associated with running the boilers and furnaces, can also cause respiratory effects (Oketola and Osibanjo, 2007).

A number of interventions exist that can reduce pollution from this industry. Many of these focus on the treatment of effluent. For example, anaerobic digestion has been used to treat solid organic waste and found to be economically feasible for food waste disposal (Ren et al., 2018). However, scaling up this type of technology in SSA contexts might be problematic. Coagulation (removal of solids by sedimentation followed by filtration) and flocculation (removal of suspended solids through the addition

of a clarifying agent) are also methods that have been found to be effective in treating food waste (Hussain et al., 2014). These methods are highly cost-effective and can be scaled up relatively easily. More novel methods for waste treatment have also been explored. For example, in Kenya, the farming of insects (black soldier fly) using organic wastes from the brewery industry as a suitable, protein-rich feedstuff, could offer opportunities for small entrepreneurs and business-to-business (B2B) innovations (Chia et al., 2018). Emissions resulting from the fuelling of boilers and furnaces could be reduced by improving energy efficiency by insulating boilers with glass wool, sheet and paper. Although these can be cost-effective Kenyan stakeholders suggested that incentives to implement retro-fitting measures are often lacking.

Emissions from the industry as a whole could be managed through enforcement of government regulations that appropriately license industry operations. Such regulations could be cost-effective, though a lack of resources, expertise and training in pollution monitoring, and a paucity of funds to ensure continuous and robust public engagement has meant such regulations tend to be less effective (Siaminwe et al., 2005). Economic incentives could include preferential access to credit to support measures to mitigate or clean up pollution. However, the lack of market-based incentives and government regulations makes such options less attractive (ibid.). The Kenyan stakeholder response to mitigation as well as enforcement and compliance for various industries is described in figure 20 and shows that the food and beverage industry was the most commented on. This could well be due to its importance in Kenya, with the sector outperforming other manufacturing sectors and accounting for over 35 per cent of total manufacturing sector output (African Development Bank, 2014). The food and beverage manufacturing sector is the most regulated in Kenya (ibid.), however there are challenges in adoption, implementation and enforcement of regulations, like in many SSA countries. Kolawole et al. (2018) point out that the lack of effluent treatment facilities across developing countries results in the discharge of effluent water to surrounding water bodies. Ntuli (2012) demonstrates that the pollutant levels in effluent from sugar and food manufacturing industries discharged to public sewers are characteristically high but could be reduced to low levels with physico-chemical treatment of the effluent water before discharge into surrounding natural waters, including underground aquifers. The Kenyan stakeholders explained that larger manufacturers have installed effluent treatment plants (ETPs) to limit pollution. However, smaller manufacturers do not always have access to these facilities or the resources to operate them. The implementation of such interventions can be constrained by the lack of robust policies and legislation, funds for investment, and lack of buy-in from the business and manufacturing community.

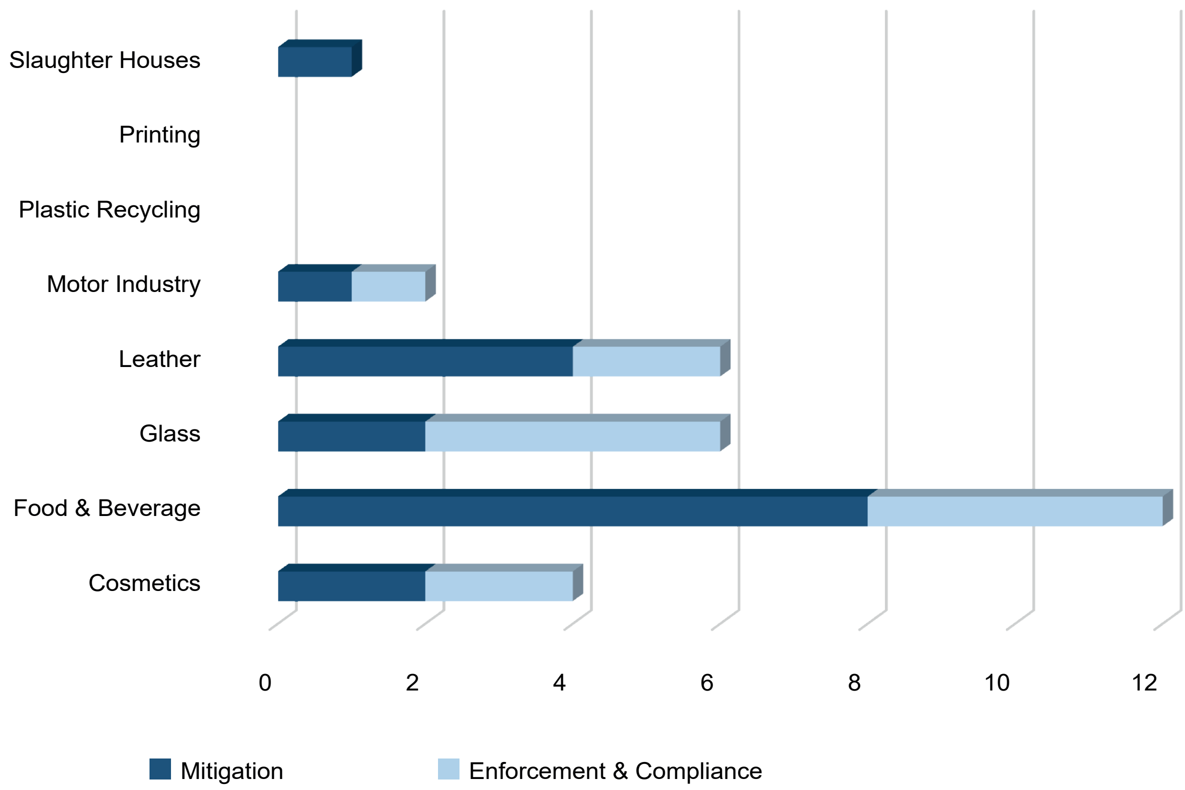
Stakeholder and activities mapping

Figure 21 depicts the value chain of sugar production. This is used as an example chain to understand where stakeholders and activities are relevant throughout sugar production and food production more generally. Key parts of the value chain where environmental impacts can be reduced are at the milling and refining stages, which both require large amounts of energy consumption. This can be achieved by increasing the efficiency of energy production. For example, Nigeria has established a Combined Heat and Power (CHP) programme for manufacturing industries and construction. The programme aims to replace 60 per cent of existing fuel oil-fired stand-alone boilers with natural gas-fired CHPs (UNFCCC, 2020c). Some food processing industries can not only mitigate their own emissions, but also increase renewable energy nationally. For example, Mumias Sugar Company Limited in Kenya, generates energy from bagasse (sugarcane waste) and sells it back to the grid[22]. This enables the plant to be self-sufficient and has helped to replace fossil-fuel based energy sources. Another example is the Komenda sugar factory in Ghana. Regional and national news articles report the government owned factory generating three megawatts of power from bagasse, and feeding a third of this back into the national grid[23]. However, after a failed opening in 2016 the government sought private investment. Following the establishment of the national sugar policy aiming to enhance sugar production and export, the Komenda sugar factory secured funding from Park Agrotech Ghana Limited, a company already operating in Ghana, and STM

22 See http://www.mumias-sugar.com/

23 See https://www.esi-africa.com/top-stories/ghana-sugar-factory-to-generate-3mw/

Figure 20. Frequency of comments related to mitigation or regulation enforcement by manufacturing industry type in Kenya



Project Limited, an Indian based project management company working in the sugar industry. This is a good example of the private sector as a key stakeholder supporting cleaner manufacturing, and how the contribution of private sector companies can be influenced by national policies.

Key stakeholders involved in the transition to 'greener' energy consumption include national offices such as the National Office for Technology Acquisition and Promotion in Nigeria, which is responsible for the evaluation and registration of new technology transfer agreements as well as technology and advisory support services. Similarly, the Gratis Foundation[24] in Ghana is an agency under the Ministry of Trade and Industry that researches, designs, develops, manufactures and markets technology-based products and training services. They work primarily with micro, small and medium enterprises to facilitate socio-economic and industrial development in the region. The Gratis Foundation manufacture agro-processing equipment such as driers, ovens and stoves as well as milling equipment. Trade fairs such as AFMAS Food Expos[25] can be platforms for B2B technology transfer. AFMAS Food Expos are regional trade events where food and beverage products and new technologies are showcased. The events are targeted at company directors and investors, technical and operational managers, academics, and general managers.

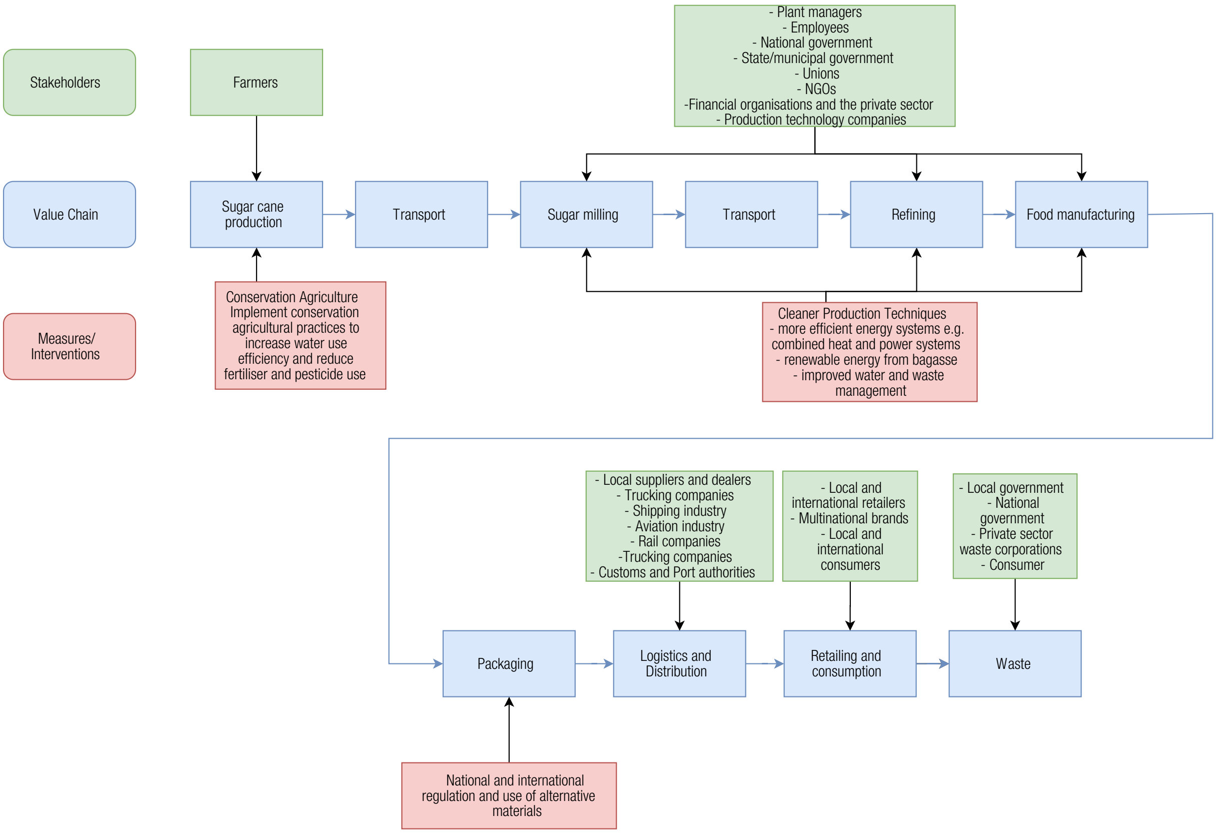
3.4.2 Textiles and wearing apparel (ISIC Rev. 4 codes 13 and 14)

The textile industry is hugely important for the global economy and has an estimated production volume of more than 88.5 million tons per year (Yacout and Hassouna, 2016). The developing country share of this production reached approximately 59 per cent

24 See http://gratis.gov.gh/

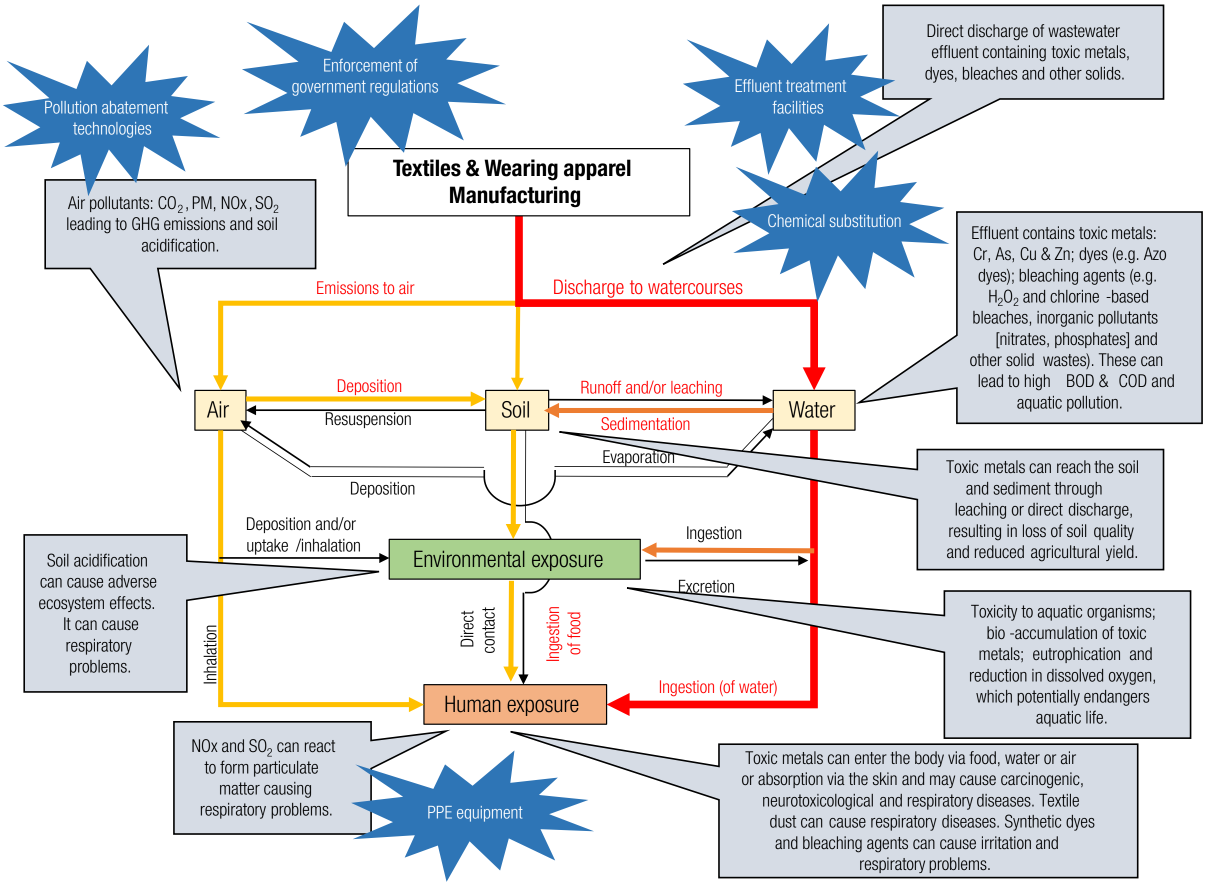
25 See https://www.afmass.com/

Figure 21. Sugar production value chain and associated stakeholders



and is expected to increase in the future in response to increasing demand (ibid.). The importance of the textiles and wearing apparel industries in SSA varies depending on which manufacturing metric is considered. Table 6 shows that on average, according to INDSTAT2 data (UNIDO, 2020), textiles is the industry with the second-largest number of employees. However, it ranks ninth in the number of establishments. Conversely, wearing apparel has the second-largest number of establishments but ranks fifteenth in terms of value added according to INDSTAT2 data (UNIDO, 2020). Over time, the textiles and wearing apparel industries have generally grown across the region. This rise is most obvious in East Africa (in the United Republic of Tanzania, Ethiopia and Kenya), with values in Kenya distinctly higher than those of the rest of the region. These trends have seen textile manufacturing become the second-most important sector in the East African countries of Ethiopia, Kenya, Rwanda, the United Republic of Tanzania and Uganda (African Development Bank, 2014). OECD export data (2018) rank textiles and wearing apparel eleventh and fourteenth respectively. There is no clear uniform trend in the textiles export data over time; most countries saw textile exports peak sometime between 2008 and 2015 and then sharply decline. Wearing apparel exports have increased in Ethiopia, Ghana, Kenya, Rwanda and Uganda but declined in Malawi. Other countries report less obvious trends in export data over time. The systematic literature review identified 13 articles that described the pollution impacts of textiles in SSA. However, only three of these focused solely on textiles and specifically explored effluent composition (Yusuff and Sonibare, 2004), coagulation and flocculation as effluent remediation methods (Akpomie et al., 2018), and occupational health impacts (Noon, 2018). Again, the large number of papers dealing with multiple industries makes it hard to gather very specific data. Therefore, the information describing the key polluting aspects of the textile and wearing apparel industries comes from literature sources both within and outside of SSA.

Figure 22. Pollution pathways of the textile and wearing apparel industries in SSA



Notes: Red, amber and yellow lines (where present) indicate the more important contaminant pathways (red being the most important). Grey boxes provide annotations of the key pathways and their impact and blue stars suggest potential interventions.

The textile manufacturing process includes spinning, weaving, dyeing, bleaching and finishing (Ghaly et al., 2014). Each of these phases in textile manufacturing uses different chemicals that produce assorted waste materials that may have detrimental effects on the physical, chemical, and biological properties of both the terrestrial and aquatic environments; and could be harmful to public health, aquatic life and other biodiversity (Islam, 2017; Sultana et al., 2009). In addition, the industry has a high consumption of water and fossil fuel use, which together with the chemicals used, results in the industry generating air pollution as well as aqueous and solid wastes (Parisi et al., 2015). The main contaminant pathways for these pollutants are shown in figure 22 along with their impacts and potential interventions.

Wet processing is a critical phase in the textile manufacturing process and means that the industry uses a large amount of water and produces a large volume of wastewater effluent. For example, approximately 2,500–3,000 litres of water are used to manufacture a single cotton shirt (Choudhury, 2014). It is estimated that 17–20 per cent of industrial water pollution comes from textile dyeing and finishing treatments given to fabrics (Kant, 2012). It has also been estimated that over 10,000 chemicals are used in various textile manufacturing processes (ibid.), with more than 3,000 individual textile dyes being available and commonly used within the industry (ibid.; Choudhury, 2014). Bleaching chemicals are also used and include wetting agents, caustic soda, peroxide, lubricants, stabilizers, acetic acid,

mordant, sulfides, hypochlorite, chlorine, hydrogen peroxide, detergents and sodium dichromate.

Dyes used in the textile manufacturing process can be classified into different types depending on their chemical compositions and properties. The type of dye used depends on the fabrics that are manufactured and include dyes for cellulose fibres, protein fibres and synthetic fibres (Ghaly et al., 2014). They include reactive and azo dyes, the latter making up 70 per cent of all dyes used in the textile industry (Hassaan and Nemr, 2017). Derivatives from azo dyes are toxic aromatic[26] amines that are considered harmful to human health (Ghaly et al., 2014). The dyeing process is a crucial step in textile manufacturing and involves the simultaneous application of other chemicals that include surfactants, acids, levelling agents, promoting agents, emulsifying oils and softening agents (ibid.; Choudhury, 2014). About 10–15 per cent of synthetic dyes are lost during different processes of the textile industry (Hassaan and Nemr, 2017). As such, wastewater from the textile industry typically contains high levels of organic substances such as dyes, bleaches, surfactants and potentially toxic metals (Arsenic (As), Copper (Cu), Cr, and Zn) since these are used in the dyeing and stabilization process (Ghaly et al., 2014). The use of dyes also releases a huge amount of coloured wastewater to ecosystems, a significant source of aesthetic pollution (Aravind et al., 2016).

Synthetic fibres account for a sizeable percentage of textiles manufactured. Concern over this group of textiles has increased in recent years since it has been demonstrated that synthetic textiles can shed a significant amount of microfibers during conventional washing that ultimately end up in the natural environment (Hartline et al., 2016). Textile wastewater also gives off unpleasant odours and produces turbid effluent with high TSS and total dissolved solid (TDS) constituents (Aneyo et al., 2016).

In addition to wastewater emissions of pollutants, the industry also contributes to airborne pollution arising from various aspects related to textile processing. Textile dusts are produced from working with textile raw materials that comprise natural and artificial fibres in materials such as wool, cotton, silk, jute, linen and synthetic fibres. Some of the chemicals used in the industry can also lead to emissions of volatile organic compounds (VOCs), solvents and formaldehyde vapours (Ghaly et al., 2014). Finally, the provision of energy to power the textile processing can lead to emissions of CO_2 as well as NOx, SO_2, CO and PM (Muthukumarana et al., 2018).

The most extensive environmental impacts associated with the textile and wearing apparel industry are those related to wastewater effluent, which are a major source of aquatic pollution (Choudhury, 2014). Toxic metals, dyes and bleaching agents are arguably those that create the greatest environmental problems, such as soil and sediment toxicity with implications for aquatic vegetation and organisms including fish. Toxic metals can also bioaccumulate in organisms with implications for the food chain. Effluent wastes such as nitrates, phosphates and other solid wastes will cause elevated levels of BOD and COD, which provide an important indicator of water pollution from organic contaminants (Ntuli, 2012; Choudhury, 2014). These wastes can result in environmental toxicity, acidification and eutrophication (Yacout and Hassouna, 2016; Muthukumarana et al., 2018). The emission of CO_2 from fossil fuel burning contributes to GHG emissions and climate change (Choudhury, 2014) and NOx and SO_2 emissions contribute to soil and water acidification. These different aspects of environmental contamination arising from textile manufacturing are associated with socioeconomic concerns for individuals and communities that subsist on ecosystem services that might be affected by industrial activity in their vicinity.

The release of textile effluent also represents a serious concern for human health. The most important health effects are likely to be due to the release of potentially toxic metals (including Cr, As, Cu and Zn) that can enter the body through food, water, air or absorption through the skin (Choudhury, 2014; Rochman et al., 2015). These metals can cause neurological and carcinogenic effects when exposures exceed safe levels (Ghaly et al., 2014; Choudhury, 2014). For example, Pb can negatively affect the nervous system, Cr the respiratory system and As is a known carcinogen that affects the skin. Airborne pollutants such as PM and formaldehydes can lead to cardiovascular and respiratory diseases;

26 Aromatic compounds are any large class of unsaturated chemical compounds that have a unique stability due to the covalent bonds that join the atoms.

textile dusts may cause particular respiratory related problems in terms of occupational health (Mwinyihija et al., 2005). Synthetic dyes have also been found to cause cardiovascular and respiratory problems (e.g. itching, watery eyes, sneezing and symptoms of asthma such as coughing and wheezing), immune system effects, irritation (e.g. skin irritation, dermatitis, itchy or blocked noses, sneezing and sore eyes) and to act as carcinogens if present at high-enough levels over long-enough exposure periods (Hassaan and Nemr, 2017). Many of the chemicals used in the textile industry (e.g. cadmium (Cd), Pb, Hg, Cr and As) have the potential to cause adverse effects on human health and some have hormone-disrupting properties (e.g. chlorobenzenes), can impair reproduction, or cause carcinogenic and mutagenic effects (Choudhury, 2014; Sarayu and Sandhya, 2012).

A broad spectrum of interventions are available for the textile industry (indicated by the blue stars in figure 22). These include (i) chemical substitution approaches to replace especially toxic chemicals with others that are eco-friendly, have less environmental impact and are more amenable to treatment (Choudhury, 2014; Sarayu and Sandhya, 2012); (ii) innovative processes that increase operational efficiency, which can reduce water use and limit or eliminate the discharge of toxic waste; (iii) effluent treatments such as flocculation, coagulation and ozonation coupled with biological treatments that allow for the removal of nitrogen, organics, phosphorous and toxic metals (Akpomie et al., 2018; Islam et al., 2017); (iv) the use of personal protective equipment (PPE) to protect workers in the industry; and (v) the use of pollution abatement technologies that can reduce emissions of, for example, airborne pollutants (Adeoti, 2001; Ntuli, 2012; Oketola and Osibanjo, 2007). The introduction of suitable legal frameworks, economic instruments (such as subsidies to support and improve prospects for cleaner production and environmental monitoring) and B2B relationships (such as the promotion of industrial symbiosis through an industrial waste exchange) will also play an important role in reducing waste from the industry.

The textile industry is also discussed in the part of this study covering SA, in section 4.4.1, where the focus is on interventions since the textile and wearing apparel industry is more mature in the region, providing more examples to draw upon to describe potential interventions and their advantages and disadvantages. Recently, attention has also been given to a full life cycle analysis of the textile industry (Moore and Ausley, 2004; Muthukumarana et al., 2018; Yacout and Hassouna, 2016) and ways in which this type of approach can identify broader supply chain options to encourage sustainable production, such options are discussed in the conclusions in section 5.2.5.

Stakeholder and activities mapping

Figure 23 depicts the value chain for the textiles industry. Interventions to mitigate the environmental impact and health risk of the industry are possible throughout the value chain, from the production of the raw fibre through to the products of consumption and waste. For each stage of the chain, there are stakeholders, which must be engaged in order to successfully mitigate these impacts.

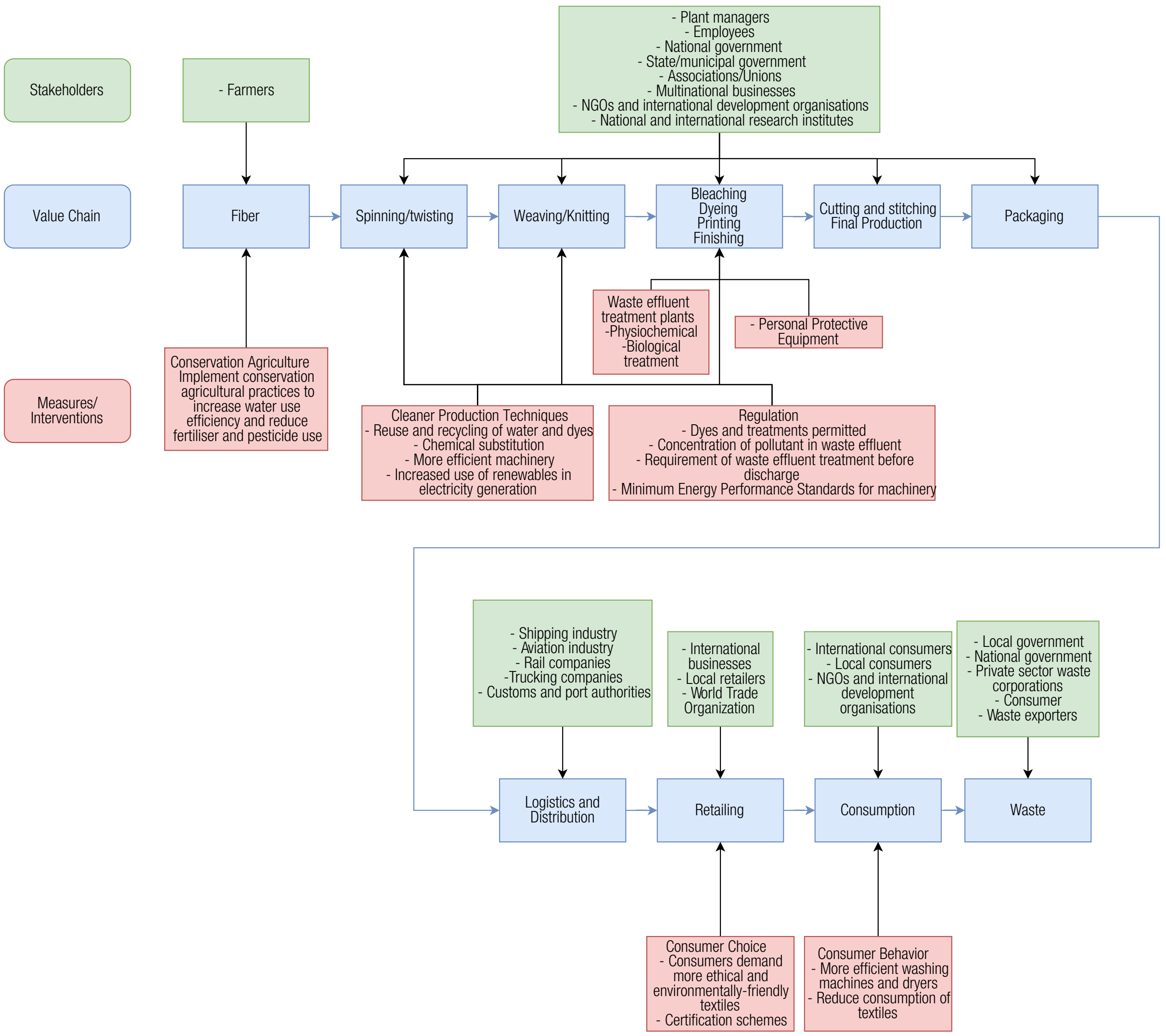
There have been several projects orchestrated by international development organisations which identified the projected growth in the African textiles industry as an opportunity for sustainable development. For example, the eTex project run by the German development agency Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). This project partners with the Ethiopian Ministry of Trade and Industry to provide institutional support to textiles manufacturers and engender environmentally and socially sustainable growth in the sector[27]. It tackles problems associated with multiple points along the value chain, from improving environmental standards during the manufacturing stages (e.g. improved sludge management) to forging market ties at the consumer end of the chain. A project run by the United States Agency for International Development, working alongside Ethical Apparel Africa[28], also targets the consumer aspect of the value chain and is developing trade relationships between Ghanaian manufacturers and American textiles brands[29]. In addition to these, FCDO's 'Supporting Indian Trade and Investment for Africa' programme supports the growth

27 See https://www.giz.de/en/worldwide/71852.html

28 See https://www.ethicalapparelafrica.com/

29 See https://www.usaid.gov/west-africa-regional/press-releases/may-8-2019-empowering-women-through-west-africa%E2%80%99s-growing

Figure 23. Textile production value chain and associated stakeholders



of African exports to India. The programme is implemented by the International Trade Centre and African and Indian businesses in four SMEP target countries: Ethiopia, Kenya, Rwanda and the United Republic of Tanzania. The programme focuses on the cotton textiles value chain, as well as leather and some food products, and will enhance South-South transfer of knowledge, skills, technology and investment partnerships[30].

The Kenyan Industrial Research and Development Institute[31] is an example of a national institute which conducts textile technology research and development and disseminates its findings throughout the industry. It also provides services including technology needs assessments, product design and development training, as well as design and implementation of environment management systems.

3.4.3 Electrical equipment (ISIC Rev. 4 code 27)

The electrical equipment manufacturing industry in SSA ranks in the bottom half of all industries (see table 6). However, the industry has grown at an average of 10 per cent annually by value of exports from 2005 to 2014 (Balchin et al., 2016), reflecting the proliferation of technology globally. Specific subsectors

30 See https://www.intracen.org/sita/

31 See https://www.kirdi.go.ke/

of this manufacturing industry (e.g. batteries and accumulators, wiring and wiring devices and other electronic and electric wires and cable) are emerging in SSA and have the potential to be highly polluting. These industries 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 (Perkins et al., 2014). Therefore, a focus here is placed on lead battery manufacturing and recycling and e-waste recycling since these have been identified as causing pollution affecting both occupational health as well as ecosystems and human populations located close to these manufacturing activities (UNEA-3, 2017). For example, lead acid battery recycling has been estimated to contribute to the toxicity of more than 150 sites in the TSIP Pure Earth database, potentially putting almost one million people at risk globally, with countries in Africa contributing a substantial number of sites to the total (Pure Earth and Green Cross, 2016). The Lancet Commission on pollution and health also estimated that between 6 million and 16 million people are exposed to dangerous concentrations of Pb each year at used lead acid battery recycling sites. These exposures result in the loss of an estimated 870,000 million disability-adjusted life years annually (Landrigan et al., 2018).

Lead acid battery manufacture and recycling

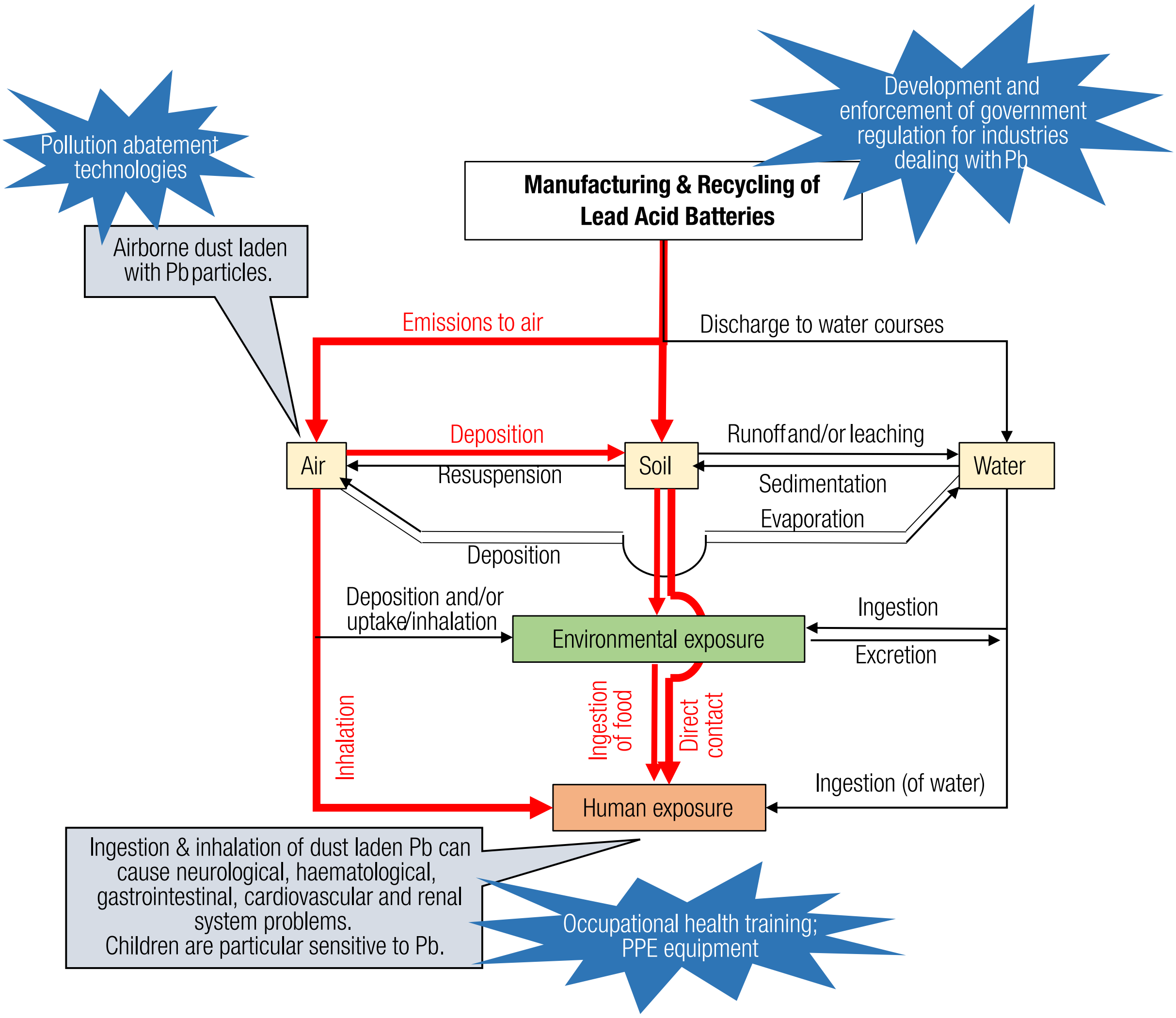
The lead battery recycling industry is expanding globally, particularly in SSA, as demand for replacement batteries increases due to growth in cell phone towers, uninterrupted power supplies, solar power and vehicle sales (Gottesfeld and Pokhrel, 2011). For example, in Kenya the industry is projected to grow at an annual rate of more than 24 per cent (Were et al., 2014), and the Kenyan case study survey also found that stakeholders identified the manufacture of lead batteries as a substantial contributor to chemical pollution. Manufacture and recycling of lead batteries is an extremely hazardous industry due to the associated emissions of airborne Pb, which have been related to Pb contamination of soil and dust and consequent elevated blood Pb levels in both industry workers as well as adults and children from nearby residential communities and schools (Were et al., 2014).

The processes that are particularly hazardous in the workplace include those related to manual battery breaking, the pasting process (involving manipulation of lead oxide) and the polishing of plates. In addition, dry sweeping of floors to recoup raw materials likely contributes to exposure as does poor hygiene leading to ingestion from eating and smoking behaviour and ‘take-home’ Pb contamination on work clothing (Were et al., 2012). The main contaminant pathways for this industry’s subsectors are shown in figure 24. A study at a Kenyan battery recycling plant found that employees were exposed to mean airborne Pb levels of approximately 180 $\mu g/m^3$, exceeding United States of America health standards (of 50 $\mu g/m^3$ as an eight-hour time weighted average) that also led to enhanced blood Pb concentrations. High blood Pb has been linked to increases in blood pressure and cardiovascular disease (Were et al., 2014).

A combination of poor work practices, limited training and education on safety procedures, and a lack of engineering controls contributes to elevated airborne Pb levels. Currently, there is very little emphasis on mitigation of occupational health hazards, control of Pb emissions or remediation of contaminated sites for these industries in SSA, and there is a severe lack of legislation specifically targeting Pb-using industries (ibid.; Were et al., 2012; Ebere et al., 1999). Soil contamination resulting from dispersion of airborne dust laden with Pb from these industries has also been found to affect local communities. This is due to the proximity of residential areas, schools and livestock (often within a few hundred metres) to industrial activities, with particular threats posed to children due to enhanced exposure pathways (through outside play) and sensitivity to heightened blood Pb levels (Gottesfeld and Pokhrel, 2011). This heightened sensitivity in children is due to a greater proportion of systemically circulating Pb entering the brain, and the fact that the developing nervous system is more susceptible to the toxic effects of Pb than the mature brain; this means children are particularly vulnerable to the neurotoxic effects of Pb (Haefliger et al., 2009).

Interventions to reduce adverse health effects of battery manufacturing activities should include 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 would also help by ensuring industries have sufficient resources

Figure 24. Schematic showing the pollution pathways of the lead battery recycling and manufacturing industry in SSA



Notes: Red, amber and yellow lines (where present) indicate the more important contaminant pathways (red being the most important). Grey boxes provide annotations of the key pathways and their impact and blue stars suggest potential interventions.

to install clean production. In SSA, activities tend to be small in scale, with capacities generally below 10,000 tons of Pb per year, compared to plants in the United States, China and the European Union, which can manage 50,000–100,000 tons of Pb per year. Minimum production capacities would ensure financial resources are in place to cover the cost of on-site and off-site remediation following plant closure and ongoing assessment of off-site contamination during operation (Gottesfeld et al., 2018). New efforts to reduce the cost of Pb soil remediation in communities local to battery recycling industries should also be explored (Laidlaw et al., 2017).

E-waste has only recently been identified as a hazardous waste product and refers to discarded electrical and electronic equipment (i.e. operating via a battery or power cord) containing costly components that have economic value if recycled. The global e-waste industry is projected to grow by 33 per cent from 49.7 million tons to 65.4 million tons per annum between 2012 and 2017 (Perkins et al., 2014). Short innovation cycles and low recycling rates are contributing to rapidly rising quantities of e-waste. Of the 20–50 million tons of e-waste generated yearly, it is estimated that 75–80 per cent is shipped to countries in Asia and Africa for 'recycling' and

disposal. It has been estimated that 23 per cent of the amount of e-waste generated domestically in OECD countries is exported to China, India and five West African countries (Breivik et al., 2014). Equipment components including batteries, circuit boards, plastic casings, cathode-ray tubes, activated glass and lead capacitors also are considered to be e-waste.

A key effort to tackle the e-waste problem is the Partnership for Action on Computing Equipment launched by the parties to the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal to facilitate environmentally sound management of used and end-of-life computing equipment.

However, the recycling process itself can release or generate hazardous substances that are often referred to as e-waste (Perkins et al., 2014). This recycling is frequently performed by the informal sector, which has limited or no access to modern industrial processes and worker protection. Examples of the processes used in e-waste recycling include: (i) physical dismantling of products using tools such as hammers, chisels and screwdrivers; (ii) heating of printed circuit boards and components for removal; (iii) recovery of gold and other metals by stripping metals in open-pit acid baths; (iv) chipping and melting of plastics without necessary and protective ventilation; and (v) burning electrical cables, often in open pits and at relatively low temperatures, to retrieve Cu (ibid.). These processes lead to direct exposure via skin absorption, inhalation and ingestion of contaminated dust containing hazardous materials such as potentially toxic metals (in particular Pb, Cd and Hg) and other toxic fumes (released as product components are incinerated, dissolved, leached or de-soldered to extract valuable parts). Indirect exposures can also occur via contamination of air, soil and water proximal to the e-waste recycling sites; for some chemicals this can result in bioaccumulation, food contamination and ecological exposure causing long-term exposures. Children may suffer exposure in schools, playgrounds and homes close to recycling sites and via 'take-home' exposure from parents and household members working at such sites. Many workers are not aware of the potential health risks and tend to be poor and less well educated than the population as a whole, and many are also women and children carrying out the work in scrapyards or homes (ibid.).

The health effects associated with exposure to hazardous e-waste substances are not fully understood, in part due to the mixtures of pollutants to which workers are exposed, but potentially include: changes in lung function, thyroid function, hormone expression, birth weight, birth outcomes, childhood growth rates, mental health, cognitive development, cytoxicity, genotoxicity, carcinogenic effects and endocrine-disrupting impacts. It is possible that lifelong effects could result from neurodevelopment anomalies, abnormal reproductive development, intellectual impairment and attention issues (ibid.). More research is needed on e-waste exposure and potential adverse health effects.

E-waste is identified as an emerging challenge for SSA countries but there are success stories. For example, in Ghana the e-waste problem received national attention when Agbogbloshie, a suburb of Accra, was reported to be among the top 10 most polluted places in the world (Pure Earth and Green Cross, 2016). This site processed an estimated 109,650 tons of waste electrical and electronic equipment in 2014 (URT, 2019). Since then, a number of development organizations have been undertaking various projects and interventions to address the problem. In 2014, Pure Earth supplied cable-stripping equipment and trained the operators to avoid burning of electronic components under a TSIP project supported by UNIDO and the EU. The German Corporation for International Cooperation GIZ and other NGOs are also undertaking various activities (PAGE, 2015). Given the variety of interventions available to achieve sustainable e-waste recycling it has been argued that a more systematic evaluation of the entire e-waste value chain needs to be conducted to establish an integrated management of this resource (Ilankoon et al., 2018).

3.4.4 Chemicals and chemical products (ISIC Rev. 4 code 20)

The chemicals and chemical products sector is an important industry for SSA; it ranks in the top 10 for each of the INDSTAT2 variables (when data are averaged across available years and summed over SMEP target countries), and is the second-highest ranked industry in terms of 'value added' and fourth-highest industry according to OECD export value data. It is also the third-fastest growing industry, with an annual average growth in value of exports of about 14 per cent (Balchin et al., 2016). The industry is diverse, with subsectors that include basic chemicals, agro-

chemical products, plastics, paints, soaps and man-made fibres. The systematic literature review identified 11 articles that explored the impacts of pollutants sourced from the industry. These included generic 'chemical industries' (four articles); the paint industry (three articles); the soap industry (one article); and the agrochemical industry (one article). However, only two of these 11 articles dealt specifically with a particular chemical industry. The diversity of the industry (and pollutants and associated impacts) and the paucity of data on each individual industry for SSA make it difficult to draw clear conclusions as to the role of the industry in pollutant-induced human health impacts. It has also been noted by others that new chemicals are being constantly introduced and old chemicals frequently withdrawn, changing the chemical manufacturing market and making it difficult to monitor and evaluate (Pure Earth and Green Cross, 2016). The sheer size of the industry also complicates its monitoring.

The chemicals manufacturing industry is commonly identified as a polluting industry either generally or alongside other industries (Oketola and Osibanjo, 2007; Oguttu et al., 2008; PAGE, 2015). Emissions from the industry tend to take the form of gases, PM and liquids, and Kenyan stakeholders identified the chemical industry as an important source of water pollution. Fertilizer factories can release water that is acidic and is contaminated with nitrates, sulfates, aluminium, fluorides and manganese, which can contaminate groundwater (Skinner and Schutte, 2006).

The manufacture of emulsion paints involves complex mixtures composed of both organic and inorganic substances and the wastewater that is generated can contain high levels of total solids, TSS, BOD, COD and oil and grease as well as potentially toxic metals (Aniyikaiye et al., 2019). These pollutants can have detrimental impacts on local ecosystems as well as human health. Lead compounds are commonly used in paint due to their durability, colour and affordability, and the release of lead-rich dust results in high airborne Pb levels (Were et al., 2014). Workers are then exposed through inhalation and contaminated clothing, resulting in elevated concentrations of Pb in their blood, which is thought to contribute to hypertension (abnormally high blood pressure) and cardiovascular disease (ibid.).

More generally, chemical manufacturing tends to see the release of SO_2 and NO_x air pollutants generated through fuel combustion (PAGE, 2015). Similarly, industrial equipment such as compressors, pumps, motors, fans, turbines, vents, steam leaks and control valves generate noise pollution that can cause stress as well as damage to hearing (Rikhotso et al., 2019).

Interventions to mitigate pollution from the chemicals industry were also identified in the literature. These include effluent treatments, for example with permeable reactive barriers, though these vary in their effectiveness and often require site specific design (Skinner and Schutte, 2006; Aniyikaiye et al., 2019). PPE can be used to minimize exposure to contaminated dust in industrial settings but greater training on occupational exposure as well as how to maintain and properly use PPE is required (Were et al., 2014). Technology exists for noise control in industry but upgrading plants may be expensive (Rikhotso et al., 2019). An alternative and more cost-effective option may be the introduction of appropriate PPE. Some government regulations exist but education, inspection regimes and enforcement can be an issue (Were et al., 2014; UNIDO, 2015; Aniyikaiye et al., 2019; PAGE, 2015). Difficulties in enforcing regulations were also identified by the Kenyan stakeholders with particular reference to the cosmetics industry, a subsector of the chemicals and chemical products industry.

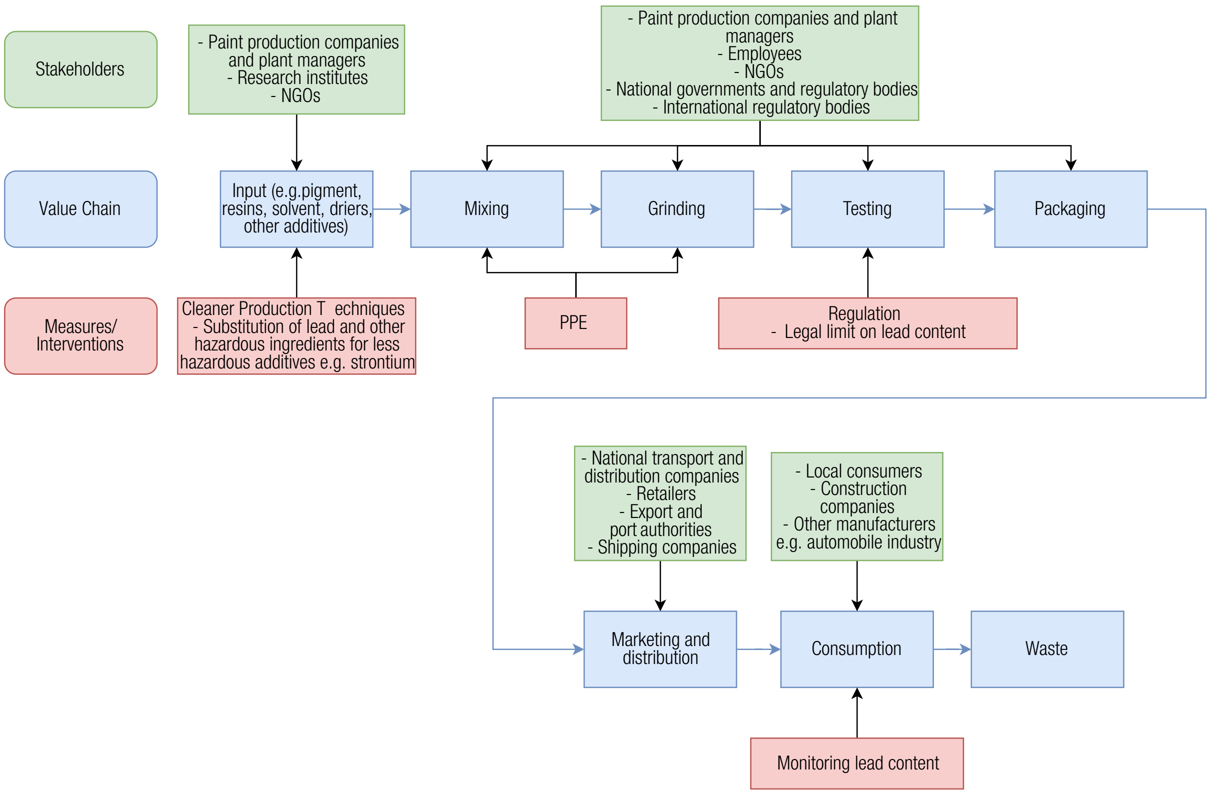
Stakeholder and activities mapping

A key activity in the chemicals industry is the Strategic Approach to International Chemicals Management (SAICM)[32]. Hosted by UNEP, this is a multi-sectoral and multi-stakeholder policy framework working to minimize the adverse impacts of chemicals and achieve sound chemical management globally. As part of the framework, Quick Start Programmes were established to support initial capacity building and implementation of activities in developing countries to facilitate chemical management projects. National chemical profiles were created in order to address priorities in chemicals management.

Figure 25 demonstrates the value chain for paint production as an example for the chemical sector. A common input for paint production, primarily as pigments or drying agents, is Pb, which can be detrimental to the health of workers and consumers.

32 See http://www.saicm.org

Figure 25. Paint production value chain and associated stakeholders



The SAICM Global Environment Facility conducts a project to promote the phase-out of Pb additives in paint. Project partners for this include the UN Environment Chemicals and Health Branch and the International Pollutants Elimination Network (IPEN). Two outputs of these projects are to address technical barriers faced by small and medium sized enterprises and policy support. In Nigeria, working alongside the Sustainable Research Action for Environmental Development demonstrations have been carried out to support enterprises in replacing Pb additives in paint with less hazardous alternatives. Regional and sub-regional workshops have also been conducted to provide advice and support the establishment of legislation on using Pb in paint. In Ethiopia, with the support of the SAICM, legislation has been passed to limit the Pb content in any paint items to 90 ppm. Regular paint testing, media involvement, support from the Global Environment Facility and UNEP, good awareness in government, and support from the industry were all identified as factors that contributed to the success of establishing the legally binding national legislation.

IPEN were also instrumental in developing the Global Alliance to Eliminate Lead Paint, which is now led by UNEP and the WHO. The initiative is voluntary and aims to bring together a diverse range of stakeholders to minimize exposure to Pb paint. Another partner of the Global Environment Facility lead project is the World Coatings Council, which is a network of trade associations representing paint companies.

3.5 Summary of manufacturing pollution in SSA in the context of stakeholder responses from Kenya

A key aspect of this scoping study were the stakeholder interviews which provided an understanding of how different stakeholders perceived pollution associated with manufacturing within particular country contexts (for SSA the interviews were conducted in Kenya). This section summarises the information gathered for SSA from the international data and literature review within the context of the findings from the Kenyan stakeholder interviews. This allows an assessment

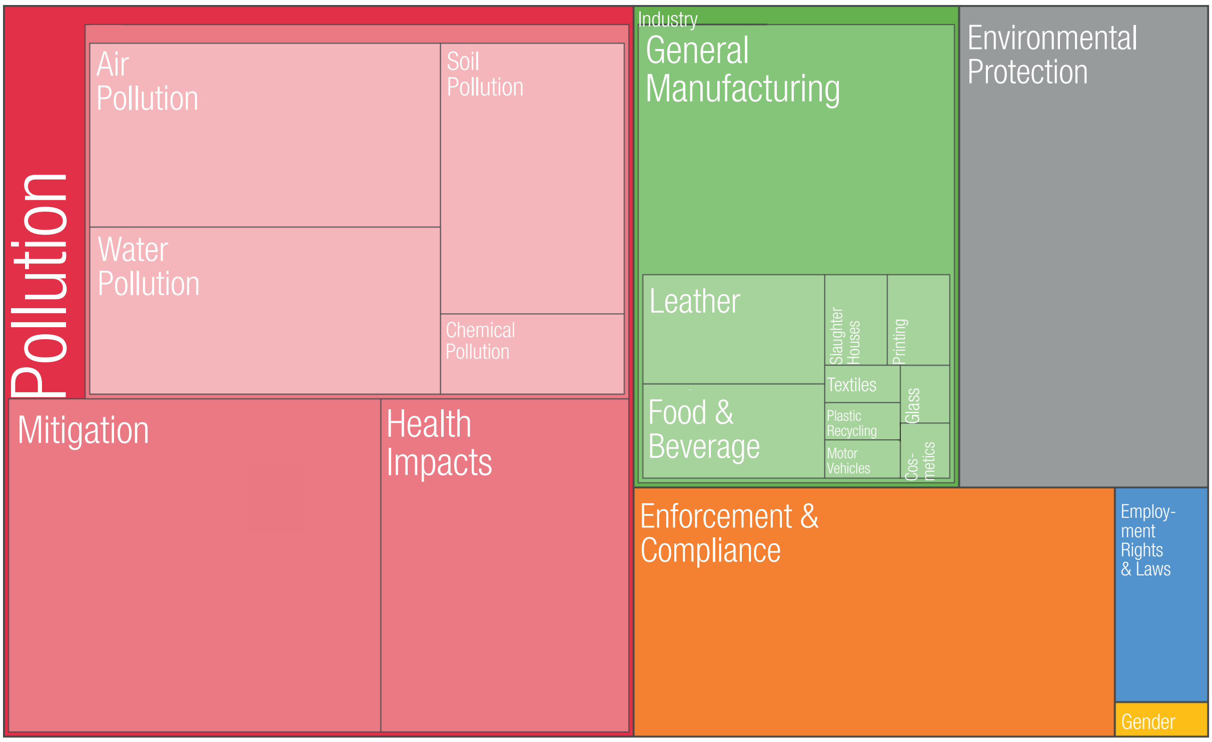
of the level of agreement on key issues related to manufacturing and pollution that can be gained from accessible data sources vs stakeholders working with manufacturing in their particular country contexts.

SSA has generally seen a growth in its manufacturing industry over the past decade in line with the ambitions set out in Agenda 2063. The key manufacturing sectors in SSA that are most likely to cause hazardous pollution, both now and in the future, are food, beverages, textiles, wearing apparel, electrical equipment, chemicals and chemical products, and leather and related products. The stakeholder interview themes shown in figure 26 reflect the information found in the literature where air and water pollution are identified as the most concerning. The stakeholders mentioned environmental protection more than human health (though this may reflect the fact that often the pollutant pathway to human health impacts is via ecosystems and the environment). The stakeholders also 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. They also reported the death of fish and livestock due to water pollution of rivers and ponds.

The stakeholders also highlighted other activities that are not often discussed in the academic literature, such as slaughterhouses (which fall under the food industry or the leather industry), plastic recycling, motor vehicles, printing, glass and cosmetics. Motor vehicle manufacture was identified as particularly polluting as a result of the waste engine oils and chemicals used in the spray painting of bus bodies. Kenyan stakeholders also described cement and steel manufacturing as industries contributing to air pollution these subtleties are missed in the international literature. Enforcement and compliance as well as employment rights and laws are important considerations for the stakeholders in relation to interventions.

Environmental agencies in Kenya have developed pollution regulations and standards for air and water quality, solid wastes and specific chemical pollutants that are enforced through an array of measures including impact assessments, audits,

Figure 26. Hierarchy chart of stakeholder interview themes for Kenya



Note: Area indicates number of coded statements.

notices of improvement and banning of products, legal measures and industry closures. To comply with regulations and enforcement measures, industries employ a broad range of pollution mitigation and control measures in their production systems, which can be classified into social, institutional and technical measures. The government also supports industrial compliance using fiscal incentives such as subsidies and tax rebates. The stakeholders noted that pollution control and mitigation faces diverse challenges such as limited collaboration between the industries and enforcement agencies during policymaking and standard setting, lack of internal industry capacity to install monitoring equipment, and the high cost of pollution control and mitigation. There was some divergence among the Kenyan stakeholders as to how they perceived the success of enforcement of these government regulations. Industry and industry association stakeholders maintained that levels of pollution are well managed and within standards. However, respondents from state corporations and NGOs alleged the existence of high levels of industrial pollution. Interestingly, gender issues receive very little attention from the Kenyan stakeholders. This lack of concern was reflected in the SSA literature, with no specific mentions of gender-related issues identified in the systematic literature review (i.e. that dealt with “manufacturing” + “pollution” + “impact”).

Key knowledge gaps for SSA are associated with the lack of data. The international datasets miss many SMEP target SSA countries, lack a good time series of data, and reveal inconsistencies between metrics that are hard to explain. The academic and grey literature is also very limited, with only 38 articles identified for the entire SSA region. This SSA literature is also heavily skewed towards particular industries, with more than ten articles describing pollution and associated impacts found for only three industries. The specificity by which industries are described is also limited; of those industries covered by over ten articles, only nine out of 38 articles deal with a single industry. This makes it extremely challenging to identify impacts and solutions for particular manufacturing activities. Finally, data are limited on the concentrations of, and exposures to, pollutants associated with the manufacturing activities frequently reported in SSA, and thus their impacts on ecosystems and human health are poorly understood; they would tend to be classified as Zone 2 or 3 pollutants according to the Lancet Commission on pollution and health (see section 1.3.4). Future research is urgently needed to fill these knowledge gaps and extend the existing analysis to a far wider range of manufacturing industries, associated pollutants, and occupational and public health risks. The incidence of high levels of noise pollution associated with certain manufacturing activities were noted both in the literature and by the Kenyan stakeholders and warrants further study. This research should go further to include an understanding of the difference in pollution impact and outcomes influenced by gender, and the role that manufacturing pollution plays in poverty and social equity; these research areas have barely been explored in SSA.

Further work is also required to understand the range and effectiveness of interventions that could support cleaner production. This should review technological solutions along with the socioeconomic and regulatory frameworks that could support and maintain their use, with a particular focus on the informal manufacturing sector. The Kenyan stakeholders provided a number of recommendations on improving industrial pollution control and mitigation including: streamlining the coordination of enforcement agencies and regulatory mechanisms; allocation of adequate resources for the enforcement of existing legal and regulatory instruments; public sensitization on pollution control mechanisms; incentives for manufacturers to adopt cleaner production; and zoning and re-planning of industries in relation to human settlements.

The location of industrial zones also requires further investigation. The stakeholder interviews suggested that industries and human settlements are often co-located due to the expansion or inappropriate zoning of industrial sites or expansion of residential areas (often informal settlements) next to industrial sites. Human settlements located in the vicinity of industries will have a higher exposure to pollution and are often inhabited by poor and more vulnerable communities, which are less likely to be aware of the types of pollution emanating from these industries and their potential impacts on their health. Finally, the Kenyan stakeholder interviews indicated that some of the manufacturing in Kenya is for export and therefore may benefit from market-based incentives for cleaner production.

4. MANUFACTURING IN SA: KEY SECTORS, POLLUTION PATHWAYS, INTERVENTIONS AND STAKEHOLDERS

The aim of this section is to identify the key polluting manufacturing industries in SA[33]. This is achieved by assessing and ranking information contained in international datasets (with supporting information from national datasets) that describe the scale and activity of manufacturing across the SA region (section 4.1). To provide context for this ranking, key features of the data are described for the SMEP target countries (section 4.2) and for the Bangladesh and Nepal case-studies where stakeholder interviews were also conducted (section 4.2.5). Other sources of information (i.e. peer-reviewed literature and stakeholder survey information) are ranked and combined, on consideration of the toxicity of pollutants from key SA manufacturing activities, to identify the most harmful polluting manufacturing industries across SA (section 4.3). Section 4.4 then takes these key identified industries (i.e. textiles and wearing apparel; leather and related products; pharmaceuticals and non-metallic mineral products) and investigates their respective pollutant pathways and consequent human health and ecosystem impacts using information retrieved from the peer reviewed literature. Section 4.4 also describes interventions that have been used to reduce pollution and its impacts and provide a mapping, by stakeholders along the value chain of each manufacturing industry, of existing activities and initiatives that have been implemented to date.

4.1 Identification of key manufacturing industries across SA

This section uses international data (described previously in section 2.2 and summarised in table 1) to identify the most important manufacturing industries across the region by ranking relevant manufacturing metrics available in these datasets. First, it is useful to understand the type of manufacturing relevant metrics in these datasets and the variability they show in the physical scale and economic importance of manufacturing across the region as a whole.

The datasets and their associated metrics are: i. INDSTAT2 data (UNIDO, 2020) which describe a. the number of establishments, b. the number of employees and c. the value added, each broken down into manufacturing subsectors (defined according to ISIC division Rev. 3) and ii. OECD data (OECD, 2018) which describe value (in US$) of exports, again broken down into manufacturing subsectors (but here defined according to ISIC division Rev. 4). The rankings were calculated by averaging each of these metrics across the years for which data were available for each manufacturing subsector and for each country and then summing the results for each country of the SA region; each manufacturing subsector is then ranked separately for each metric. For example, table 7 shows the top five manufacturing subsectors ranked according to each of the four metrics. The full rankings (i.e. for all manufacturing subsectors) are provided in table 10 along with similar rankings of data obtained from the peer reviewed literature and stakeholder surveys (see section 4.3 for a description of how these other rankings are performed). Together these rankings allow the key polluting industries across the SA region to be identified for further investigation of their pollutant pathways and impacts in section 3.4).

This ranking exercise shows that wearing apparel and textiles are important industries across SA. The other industries that frequently occur in the top ranking are food and beverages, chemicals and chemical products and non-metallic mineral products. This full ranking analysis is considered in relation to the pollutant types that are emitted by these industries and their potential to cause harm, and combined with the other ranked sources of information (from articles and stakeholder surveys) to identify the key polluting industries in SA (see table 8).

As discussed in section 3.2 for the case of SSA, it is also crucial to conduct further analysis of these international datasets to better understand the physical scale, economic importance and temporal

33 This section provides similar information for SA to that provided in section 3 for SSA. So that readers can access either section without having to have read the other, this section is written in the same style as the SSA section. This means there is some repetition of text.

Table 7. The top five ranked industries according to each of four manufacturing relevant metrics for the SA region

Ranking	INDSTAT2 data (UNIDO, 2020)			OECD data (OECD, 2018)
	Number of establishments	Number of employees	Value added	Exports
1	Textiles	Wearing apparel	Wearing apparel	Wearing apparel
2	Food and Beverages	Textiles	Textiles	Textiles
3	Wearing apparel	Non-metallic mineral products	Food and Beverages	Food
4	Non-metallic mineral products	Food and Beverages	Chemicals and chemical products (including pharmaceuticals)	Leather and, leather products and footwear
5	Furniture	Chemicals and chemical products (including pharmaceuticals)	Basic metals	Furniture

trends in manufacturing across the SA region. It is important to understand the limitations in using these international datasets to assess various aspects of manufacturing across the region, which largely result from the datasets being incomplete (i.e. there are many gaps in the data with incomplete records of different metrics for different countries and across different years). Other problems with the data relate to the fact that the metrics collected are not targeted towards assessing the polluting nature of manufacturing activities. To discuss this further, the same environmental data discussed in section 2.2 and 2.3 are used for SA and the limitations in using these datasets to identify key manufacturing activities causing pollution are summarised. A key issue with these international datasets is that they do not define the required level of manufacturing subcategories that could support identification of activities that are particularly polluting.

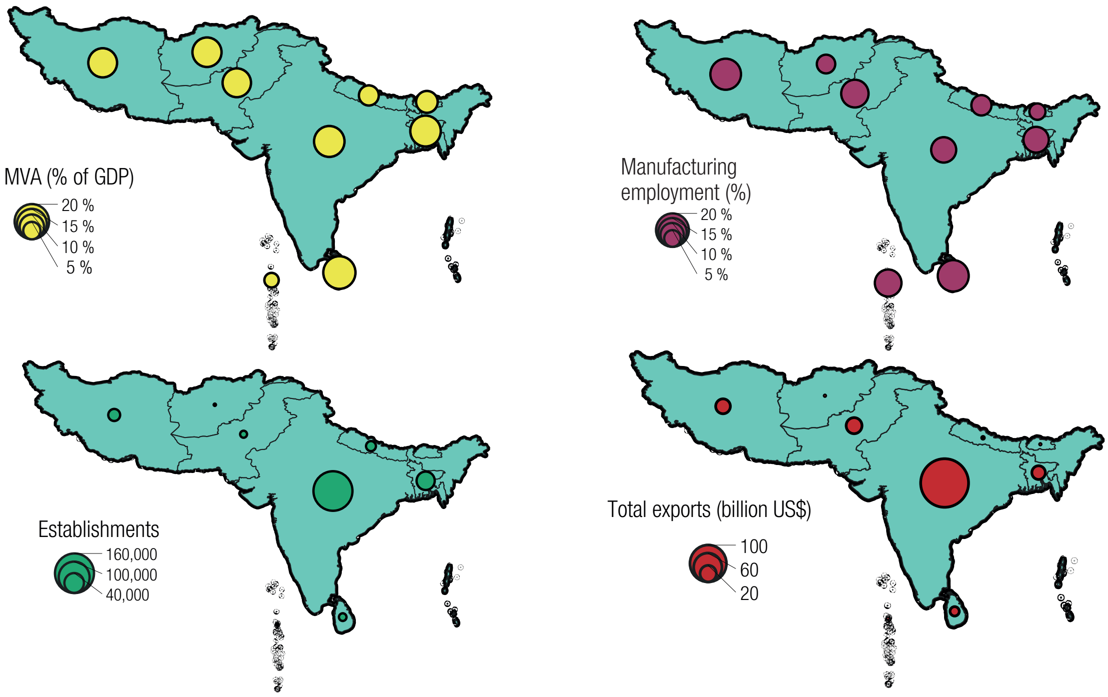
In the following sections, the additional information that can be derived from these, and other international and national datasets, is reviewed to support and critique the assessment of the scale and economic importance of manufacturing in the SA region. This analysis is predominantly used to identify some of the key concerns in using these data to define and identify key polluting industries in the SA SMEP target countries that should be considered in future research.

4.2 Manufacturing across SA and in SMEP target countries

4.2.1 Analysing international manufacturing data for SA

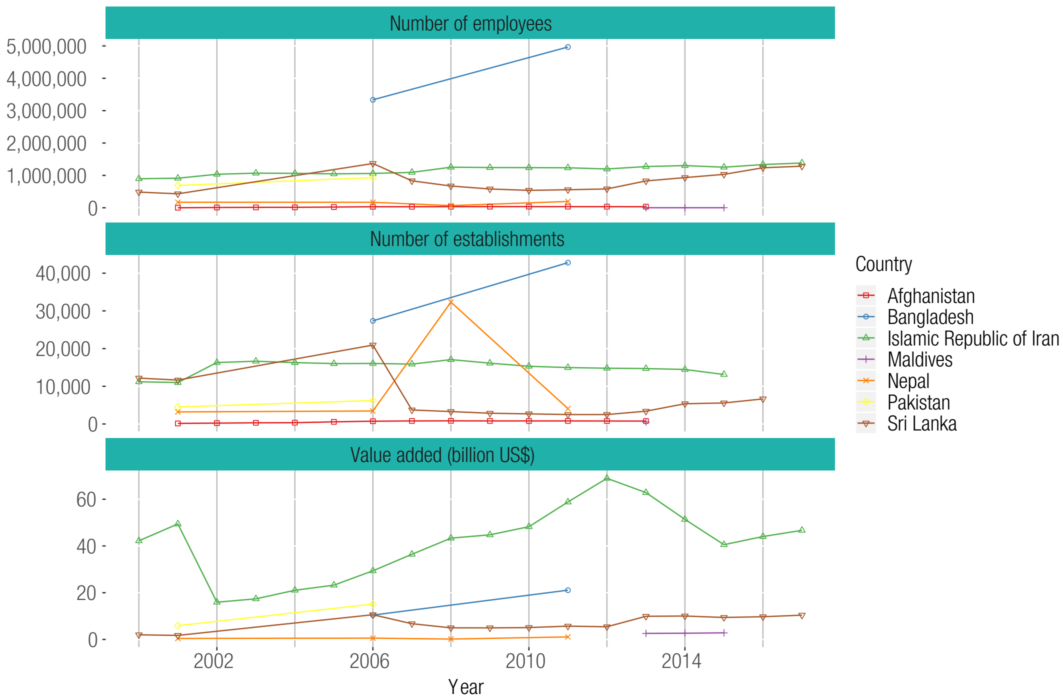
Figure 27 illustrates the geographical variability in five different manufacturing relevant metrics that are available from established international datasets that include the INDSTAT2 and OECD data used in the ranking analysis described in section 4.1, but which also include ILO and World Bank datasets. The metrics from each dataset are: MVA as a percentage of GDP (World Bank, 2018); percentage employment in manufacturing (ILO, 2020); the number of manufacturing establishments (UNIDO, 2020); and total export value in US$ (OECD, 2020). The temporal coverage of these data are more comprehensive for SA than for SSA (see section 3.1). However, the same caveats apply when comparing across datasets. Broadly, the different metrics agree with each other, with MVA and percentage of workforce employed showing similar trends while the number of establishments from INDSTAT2 data and total export value emphasize the particular strength of manufacturing in India compared to the rest of the region. The average number of establishments reported in SA as a whole was over 233,000 but almost 70 per cent of these were in India (UNIDO, 2020). Similarly, between 2000 and 2018,

Figure 27. Geographical distribution of manufacturing activities across SA



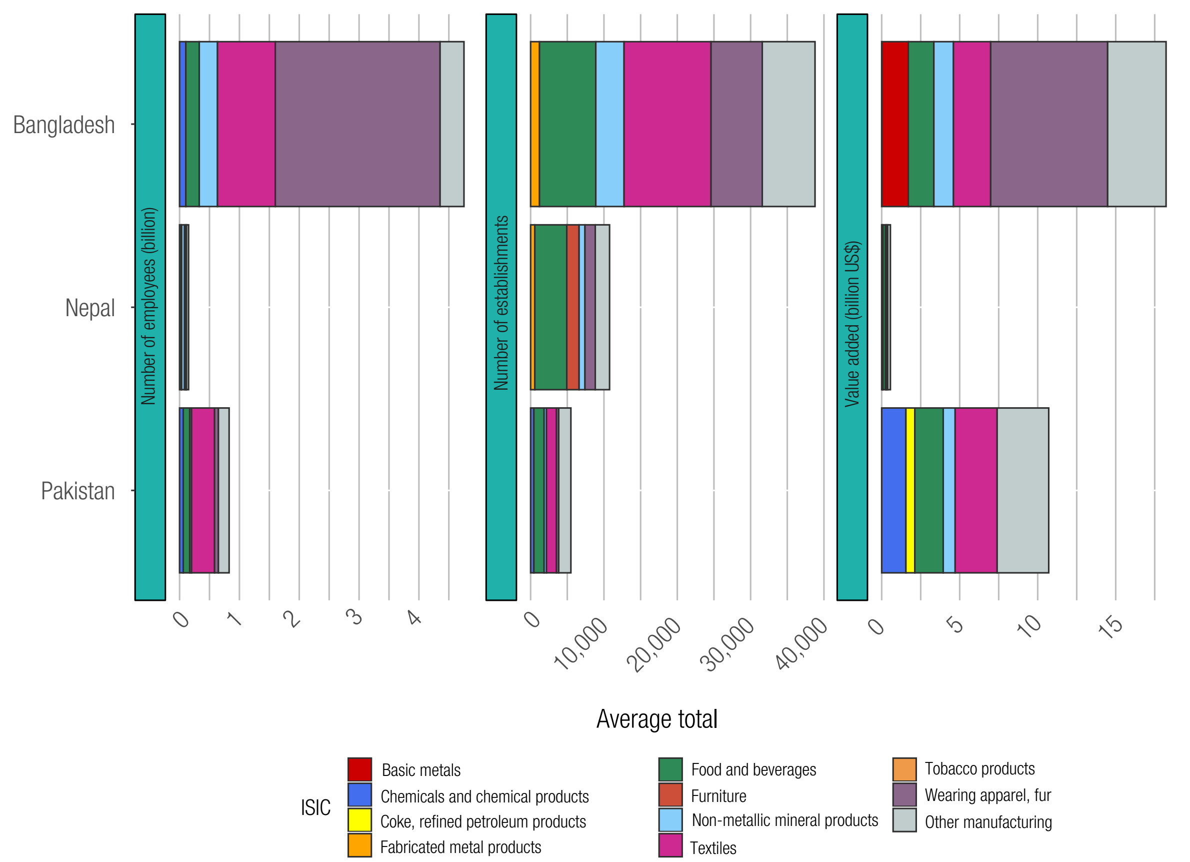
Source: MVA data (World Bank, 2020); Manufacturing employment (ILO, 2020); Establishments (UNIDO, 2020); Total exports (OECD, 2018).
Note: Country data for each metric are averaged across available years.

Figure 28. Trends in total manufacturing metrics from INDSTAT2 data, by SA country (2000-2017)



Source: UNIDO (2020).
Notes: India has been excluded. Value added is measured in current prices.

Figure 29. Top five manufacturing industries according to the number of establishments, number of employees and value added



Source: UNIDO (2020).

Notes: Data are averaged over years for which they are available. Value added is measured in current prices.

SA exported on average over US$ 231 billion of manufactured products annually (OECD, 2018).

Further analysis of INDSTAT2 data (UNIDO, 2020) for SA reveals the variability (and inconsistencies) both between countries and manufacturing metrics. Figure 28 presents data over time and provides an indication of the temporal availability in data and trends. India is excluded from this analysis as it masks the trends in other countries. Figure 28 suggests that manufacturing activities in Bangladesh are increasing but data only exist for two years, with the most recent year being 2011. It is difficult to draw conclusions about the trends in other countries due to the differences between metrics and the large gaps in the dataset as a whole.

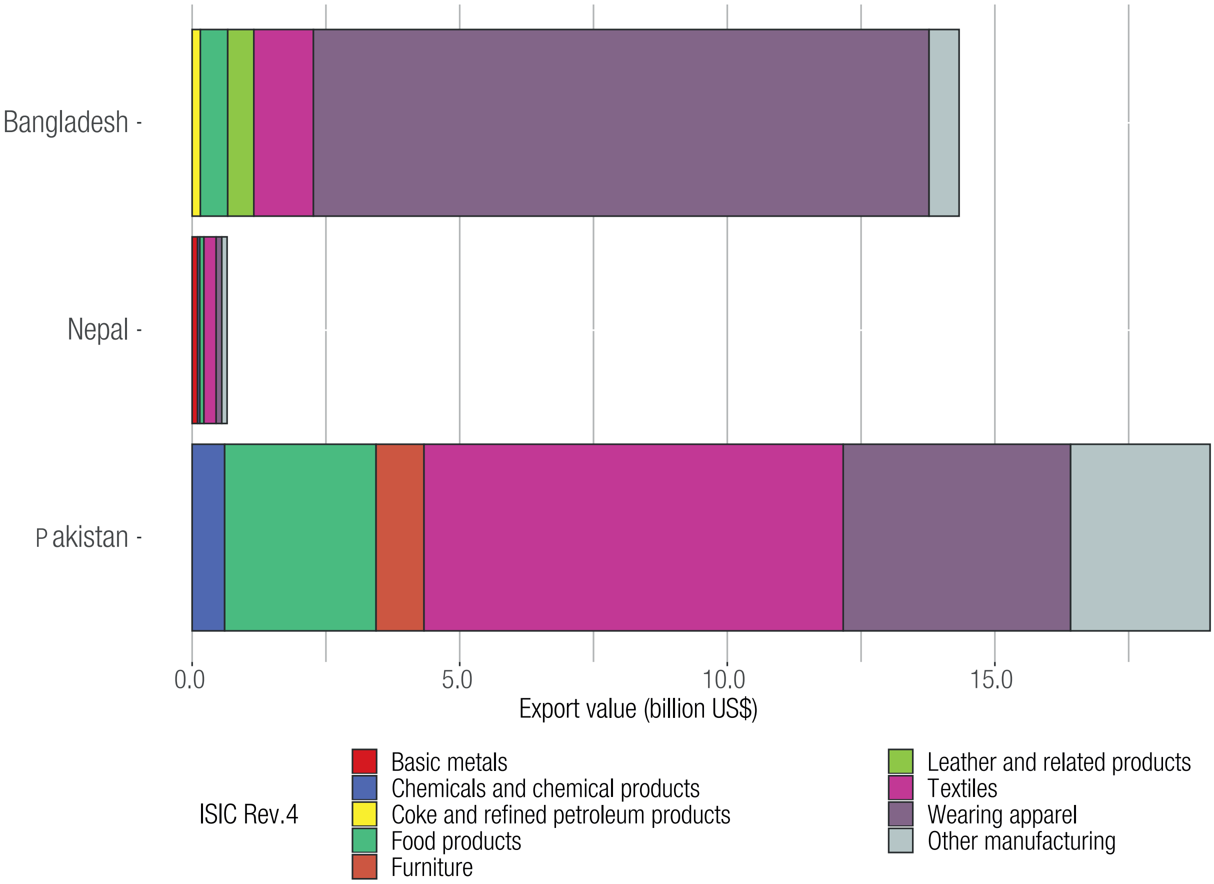
Analysis of data at this coarse scale provides limited insight into the physical and economic scale of the manufacturing sector within countries. Therefore, international data at the subsector level for SMEP target countries are analysed in section 4.2.2.

4.2.2 Analysing international manufacturing data for SA SMEP target countries

This section analyses the INDSAT2 (UNIDO, 2020) and OECD (OECD, 2018) international datasets that describe manufacturing subsectors activities for the SA SMEP target countries. This analysis is intended to identify the most important industries in terms of the number of establishments, the number of employees and economic importance.

Figure 29 summarizes the top five manufacturing industries according to the number of establishments, number of employees and value added (using the method described previously in section 4.1). Available

Figure 30. Average total export value of each manufacturing type



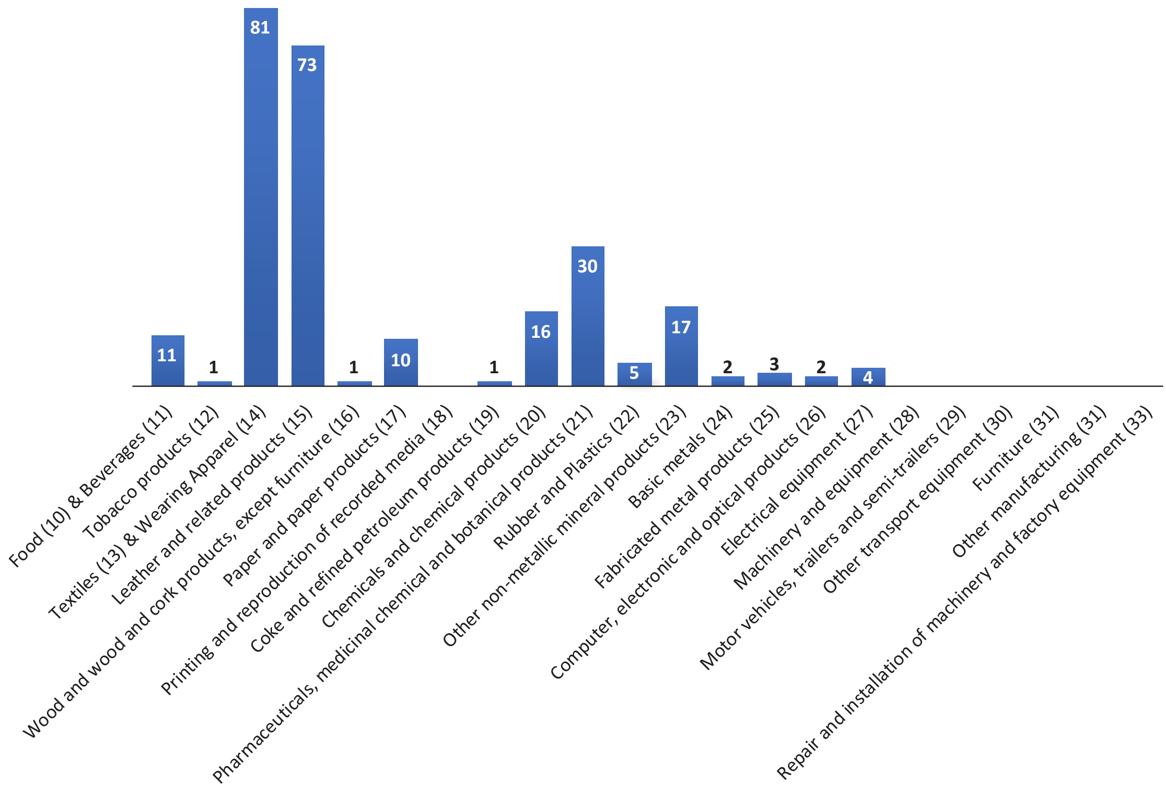
Source: OECD (2018).

Notes: Data are averaged over years for which they are available. Value added is measured in current prices.

data were averaged from the year 2000 up to 2017 as provided by INDSTAT2 (UNIDO, 2020); the remaining industries are grouped as 'other manufacturing' to show the proportion of these top five industries to all industries. Figure 29 also demonstrates that different industries are important in different countries and that the importance changes depending on which metric is considered. For example, in Bangladesh, considering purely the economic variable of value-added shows basic metals to be an important industry but it does not feature in the top five industries for the number of establishments or employees. Overall, for the SA SMEP target countries, key industries include textiles, wearing apparel and food and beverages.

Figure 29 shows the variation in scale of manufacturing across the SA SMEP target countries with Bangladesh consistently highest in the three metrics presented. This is most obvious when considering the number of establishments where textiles contributes about 30 per cent of all manufacturing establishments in the country. This large number of establishments is an important factor in establishing the nature, scale and scope of the pollution that may be generated by the sector (i.e. low-level and diffuse pollution across many core production units) which can compromise the effective introduction of certain types of interventions). The textile and wearing apparel sector in Bangladesh has also the greatest number of employees (3.72 million workers) and has generated the greatest MVA (US$ 9.8 billion) of all SMEP target countries in SA. Figure 30 shows OECD export data that indicate similar trends. Textiles and wearing apparel were responsible for the greatest proportion of manufacturing exports across the region due to the high export values of Pakistan

Figure 31. Number of articles dealing with different manufacturing sectors for SA that included details of "manufacturing" + "pollution" + "impact"



Notes: Out of a total number of 175 articles identified. The absence of bars indicates no data.

(US$ 12.1 billion) and Bangladesh (US$ 12.6 billion), which are substantially greater than that of Nepal (US$ 0.3 billion). However, INDSTAT2 data show that Bangladesh has a substantially larger industry than Pakistan (see figure 29). This may be because INDSTAT2 data for Bangladesh is available up to the year 2011 whereas the most recent year for Pakistan data is 2006, or simply that Pakistan produces and exports higher value goods. OECD data, on the other hand, go up to the year 2018, so may capture an increase in manufacturing since 2006.

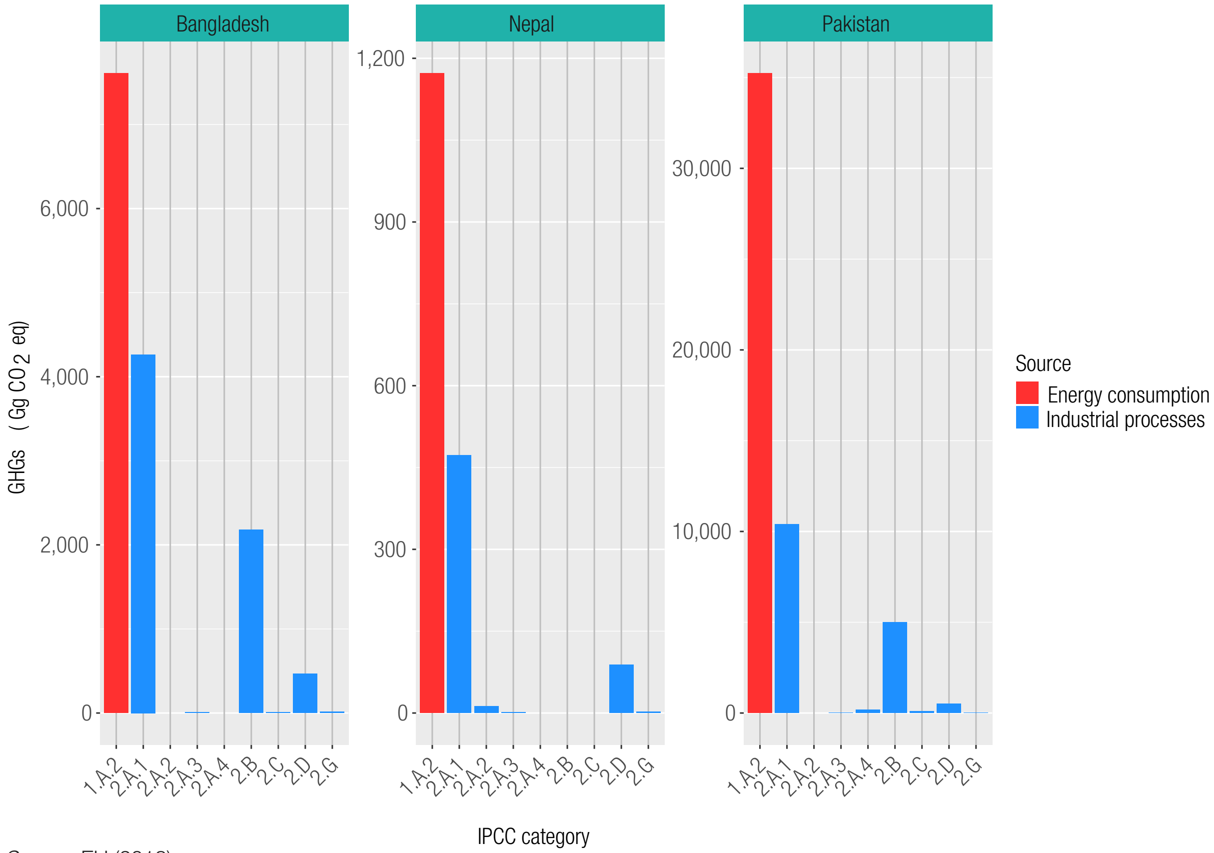
To compare this analysis of international datasets with results from the systematic literature review figure 31 shows the number of articles for SA grouped into ISIC Rev. 4 divisions. There were a significantly greater number of articles on textiles (81 articles) and leather products (73 articles), with the third-highest number on pharmaceuticals (30 articles). All these industries feature in the top five rankings of at least one of the metrics of the international data sets (see table 9) which includes a ranking of the international datasets that define manufacturing subsectors in SA.

4.2.3 Analysing international environment data for SA SMEP target countries

The metrics relevant to manufacturing described in section 4.2.1 have been used to rank industries based on physical size and economic importance, however, as discussed they are unable to indicate which are likely to be the most polluting industries that will cause harm to human health and ecosystems. This subsection describes the international environmental data that exist for SA SMEP target countries and describes what support these data can provide to the identification of the most polluting industries.

Figure 32 presents available data in the EDGAR database (EU, 2018) on emissions from energy

Figure 32. Total GHG emissions (in Gg of CO_2 equivalent) for each SMEP target country in SA



Source: EU (2018).

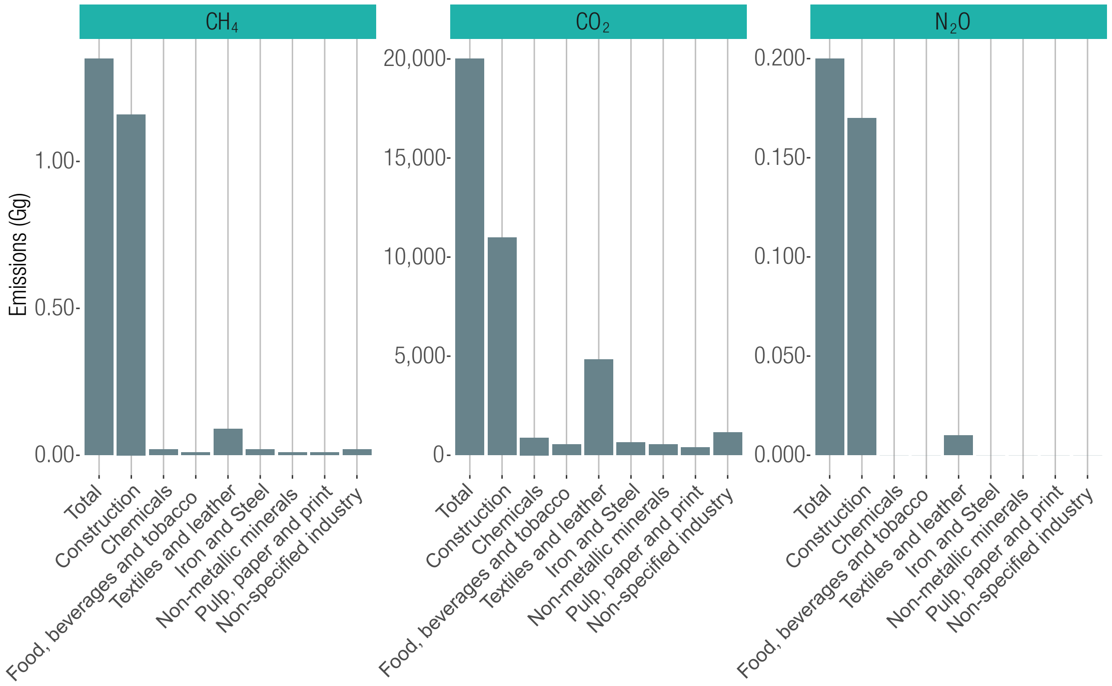
consumption and industrial processes. This shows the GHG emissions from energy consumption to be much greater than those from industrial processes. However, data for industrial processes are not comprehensive and it is not possible to ascertain how much the construction industry contributes to fuel consumption emissions. The same inadequacies of international environment data that were found for SSA (section 3.2.3) also apply to SA, summarised as follows:

- There is a lack of data on emissions from manufacturing that are disaggregated to particular IPCC source categories, especially for SA SMEP target countries.
- There are a limited number of environmental pollutants covered in these datasets i.e. they mainly provide data on GHG emissions. Where data are available, e.g. water quality data, pollutants are not attributed to source.

4.2.4 Analysing national environment data for SA SMEP target countries

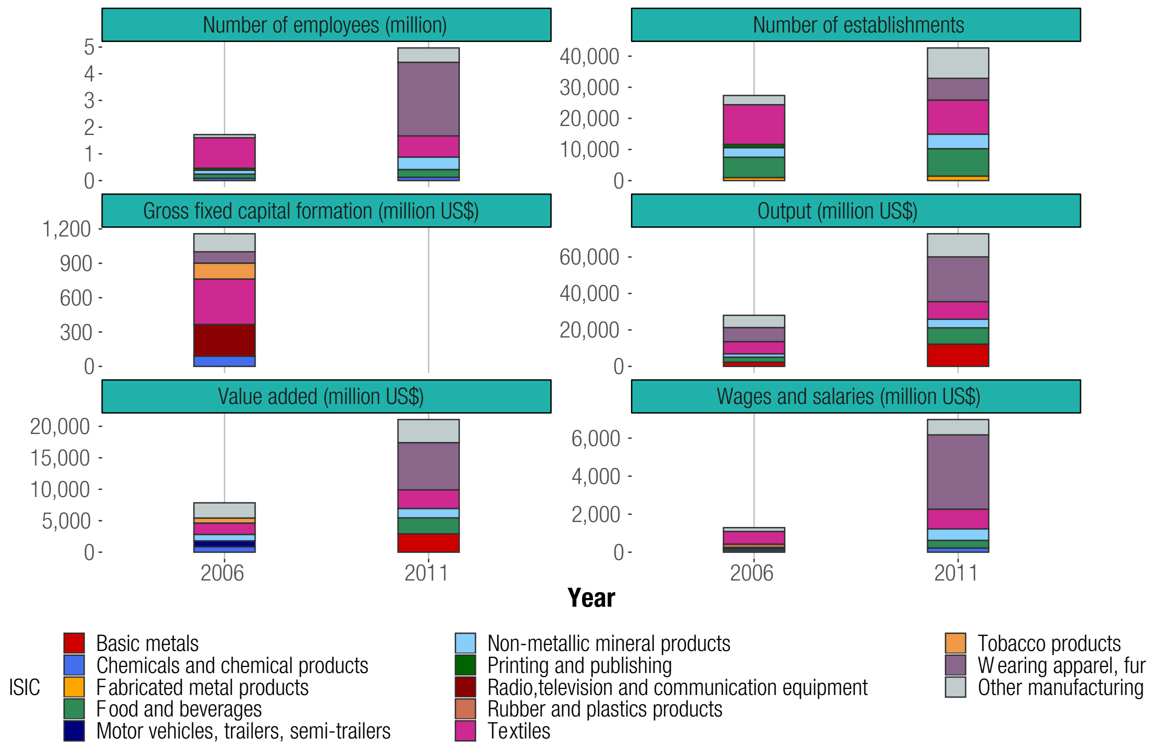
National datasets describing important aspects of environmental pollution are becoming more widely available as countries meet their reporting requirements under the UNFCC as part of the MRV systems. The National Communications that countries have to submit as part of these reporting requirements lead to datasets that may be particularly valuable as they provide standardised data across countries due to the requirement to report according to the methodology of the IPCC guidebook (IPCC, 2019). The types of national data available from UNFCCC reporting are described in section 3.2.3. The data availability is again variable between countries, of the three SA SMEP target countries, only Bangladesh provides disaggregated data on emissions from ‘manufacturing and construction’ fuel consumption. These data are presented in figure 33 and show that construction

Figure 33. GHG emissions (Gg) from Bangladesh 2012 fuel combustion for manufacturing and construction broken down by subsector



Source: Bangladesh's third National Communication 2018 (UNFCCC, 2020d).

Figure 34. Top five manufacturing industries in Bangladesh as ranked by INDSTAT2 data available between 2000 and 2017



Source: UNIDO (2020).

Note: All values are in current prices.

is responsible for a large proportion of these emissions (roughly 85 per cent of both CH_4 and N_2O emissions). Of all the manufacturing industries, textiles and leather are the biggest emitters.

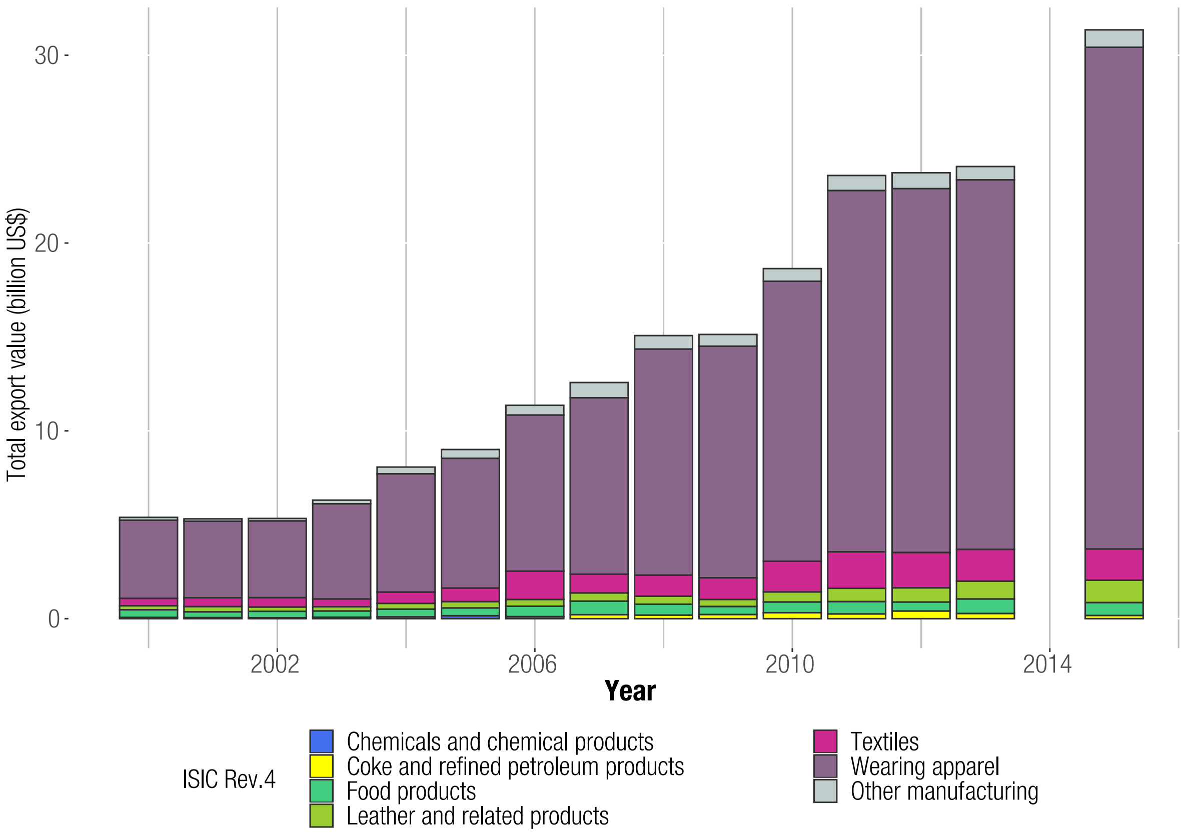
The same limitations of national data seen in SSA apply to SA SMEP target countries with a limited amount of data being reported on pollutants other than GHGs. However, it is important to reiterate that these are the data endorsed by national governments and hence are most likely to be the data that would be used to make policy decisions.

4.2.5 Analysis of the manufacturing sector in Bangladesh and Nepal

Bangladesh and Nepal were selected as case study countries to gain a more in-depth understanding of the manufacturing landscape in SA. Stakeholder interviews were also conducted in both countries to provide further insight into the manufacturing industry. INDSTAT2 data are lacking for Bangladesh (figure 34). Data are only available for two years but show a significant increase from 2006 to 2011 for all metrics where data were available for both years. This increase appears to be predominantly related to increases in the wearing apparel industry though this may be due to the fact that data for this industry are often unavailable in 2006. However, this may be due to the fact that output (in US$ million) is the only metric for which data are provided for this particular industry in 2006. Manufacturing activities within the food and beverages industry have also increased but by a smaller margin compared to the wearing apparel industry. Data on manufacturing activity after 2011 are not available leaving a substantial six year gap (i.e. between 2011 and 2017) of data on trends in manufacturing activity in Bangladesh in the INDSTAT2 database.

Figure 35 demonstrates the substantial export value of wearing apparel in Bangladesh (OECD,

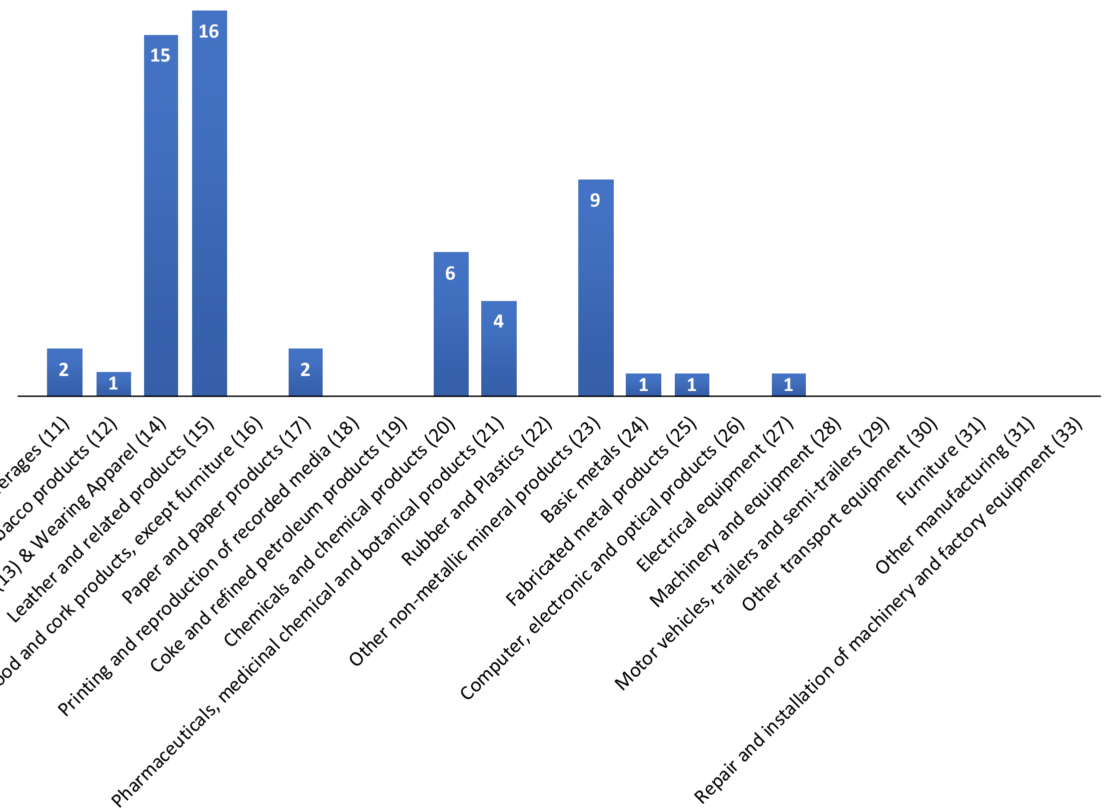
Figure 35. Top five manufacturing industries in Bangladesh, as ranked by OECD data on export value, 2000-2015



Source: OECD (2018).

Notes: All values are in current prices. Data are not available for 2014.

Figure 36. Number of articles retrieved from the literature review for each manufacturing industry sector for Bangladesh



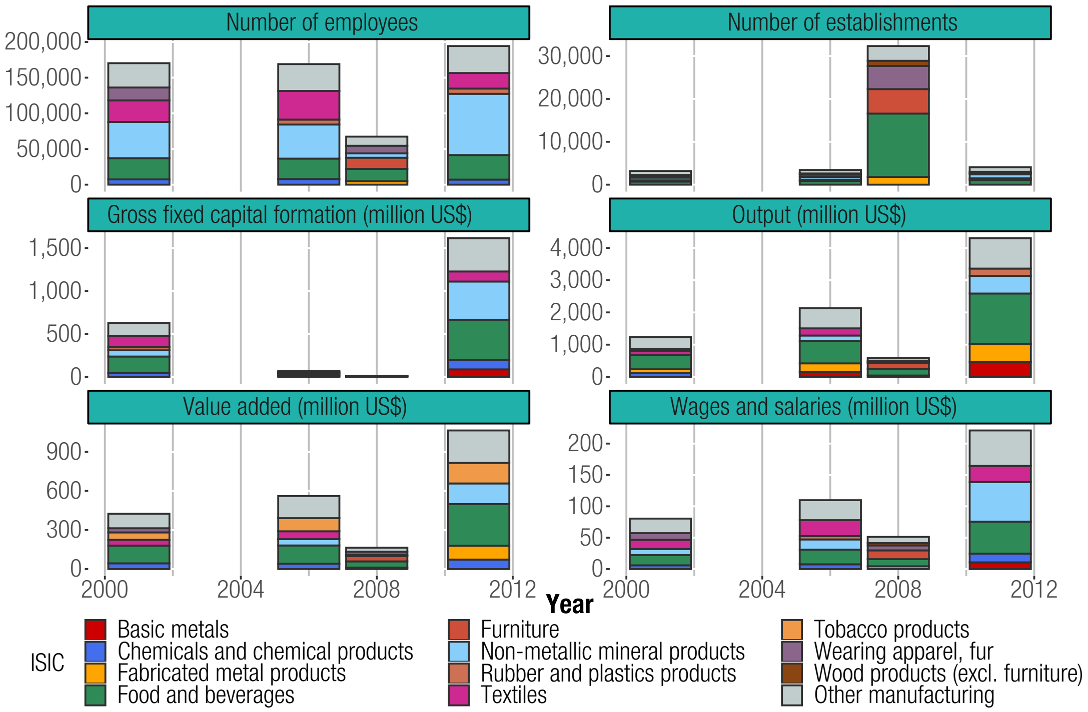
Note: The absence of bars indicates that no data were available.

2018). Not only is it the most valuable export, but its export value has also been growing rather rapidly since 2002. Exports in the other subsectors, primarily textiles and leather and related products show a far more moderate increase.

The stakeholder interviews revealed that Bangladesh is experiencing high rates of economic growth in the manufacturing sector, with stakeholders identifying leather, textiles, brick kilns, ceramics and cement as key polluting industries. Brick kilns, ceramics and cement are all classed as non-metallic mineral products according to the ISIC classifications, while textiles were generally considered by stakeholders to include mills that turn cotton into fabrics as well as the ready-made garment industry (which would fall under wearing apparel in the ISIC Rev. 3 classification). The industry is predominantly made up of the latter and according to stakeholders, Bangladesh is the second-largest exporter globally of ready-made garments. They also identified leather as a leading export product. This is in agreement with OECD data shown in figure 35. However, interviews also revealed that the growth in the textile and leather industries is currently slowing due to international competition and pressure on profit margins. This decline is discussed in more detail in the conclusions chapter.

Data from the systematic literature review (figure 36) show that of the 175 articles that mention manufacturing pollution and impacts, leather and related products was the industry most frequently studied (16 articles) closely followed by textiles and wearing apparel (15 articles) in Bangladesh. This is despite the leather industry only featuring in the top five industries in terms of export value and not in any of the other metrics (ibid.). As in SSA, this may indicate that the leather industry is an important polluting industry even if it is not such an important employer or contributor to the national economy.

Figure 37. Top five manufacturing industries in Bangladesh as ranked by OECD data on export values available between 2000 and 2017



Source: UNIDO (2020).

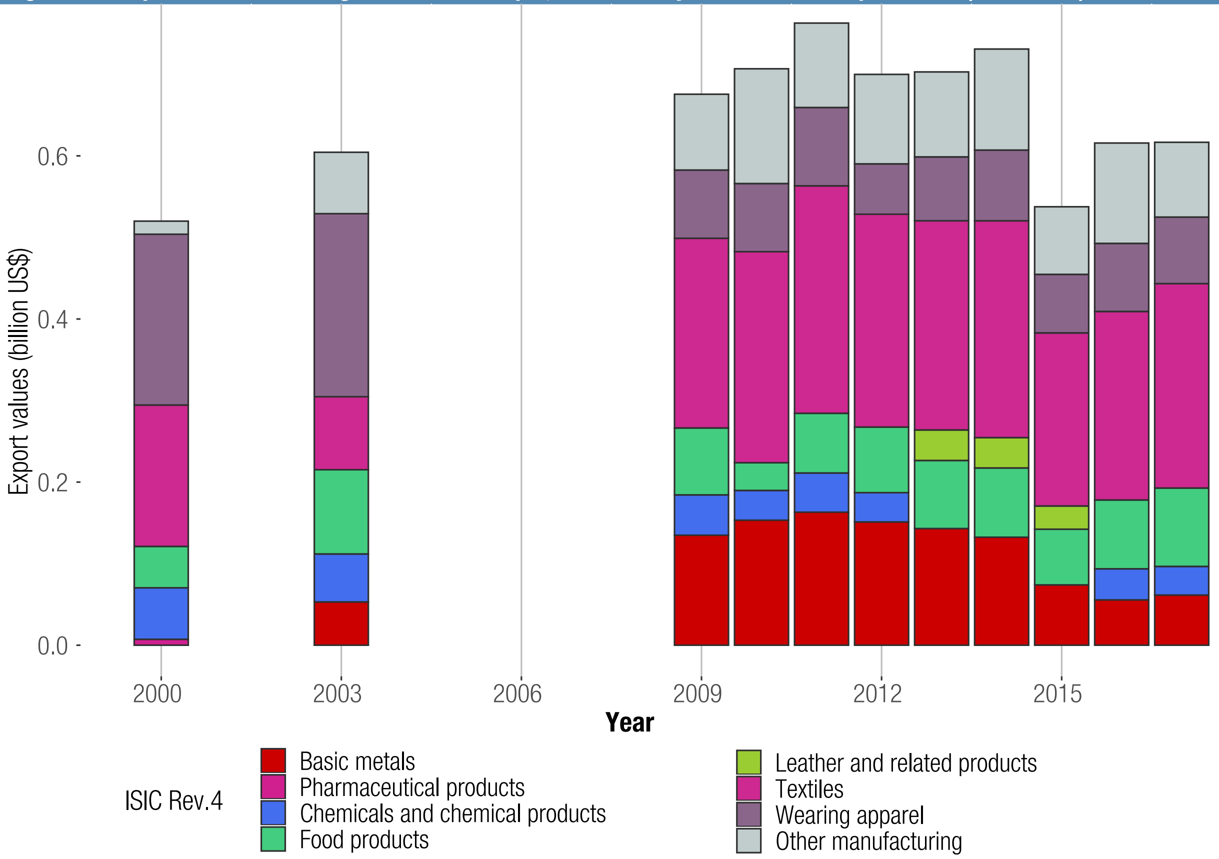
Note: All values are in current prices.

International data set coverage for Nepal is slightly better but again the most recent year for which data are available is 2011. Figure 37 shows that according to the INDSTAT2 data, manufacturing activities on the whole appear to be increasing (UNIDO, 2020). However, the trend in the number of establishments is unclear, primarily due to the large spike in this metric recorded in 2008, which coincides with reductions in value of other metrics. For example, the number of food and beverage manufacturing establishments increased by over 10,000 in 2008 and then dropped by a similar amount in 2011. This seeming anomaly suggests there may be some discrepancies in national reporting. Across all metrics, the most obvious increases in manufacturing are within food and beverages and non-metallic mineral products. Meanwhile, a reduction in the value of the manufacturing metrics associated with the textiles industry had occurred by 2011. As with Bangladesh, since the data only go up to 2011 they may miss more recent changes in the development, or indeed the decline, of the manufacturing sector.

The most valuable manufacturing exports from Nepal are textiles (OECD, 2018) and this has been the case since at least 2009 (figure 38). Overall, exports dropped in 2015 with reductions in all subsectors, though most subsectoral exports increased again the following year.

Stakeholder interviews in Nepal indicated that the manufacturing sector is currently in rapid decline due to political reasons. Stakeholders observed that the total contribution of the manufacturing sector to GDP had declined over the past five years. The sector is facing considerable competition from India and China, which is especially challenging due in part to the small-scale nature of most factory operations in Nepal. The stakeholders identified the following manufacturing industries as causing pollution problems in Nepal: steel and metal manufacturing, cement manufacturing and brick kilns, carpet manufacturing and agro-products. There were only four articles that focused on the impacts of polluting industries in Nepal; these dealt with cement and brick manufacturing, paints and electrical equipment.

Figure 38. Top five manufacturing industries in Nepal, as ranked by OECD data on export value (2000-2017)



Source: OECD (2018).
Note: All values are in current prices.

4.3 Determining key polluting industries in SA

All collected data have been used to establish the key manufacturing industries most likely to cause harmful pollution in SMEP target countries in SA. To achieve this, the codebook developed from the systematic literature review data (see section 2.4) was used to identify which articles associated industries with particular pollutant types and consequently to impacts on human health and ecosystems. The results for SA are provided in table 8, which describes human health impacts. Again, this analysis is largely reliant on the information provided in the articles and may miss industries and pollutants that do cause damage but for which such damage is not reported in the literature. Conversely, given the large number of articles that often dealt with multiple industries, it is difficult to be certain that particular health impacts are associated with particular industries. This may explain why the industries appear more hazardous than for the equivalent SSA industries (see table 5).

This information is combined with international datasets and a stakeholder online survey to identify which of these polluting industries are most important in terms of scale and extent for the SA region. There were 35 responses to the online stakeholder survey. When asked which industries were a source of air, water or soil pollution, the most commonly identified sector was textiles and wearing apparel, which was also the most economically important by some distance, with rubber and plastics, leather and related products, and food and beverages about equal in second place (figure 39).

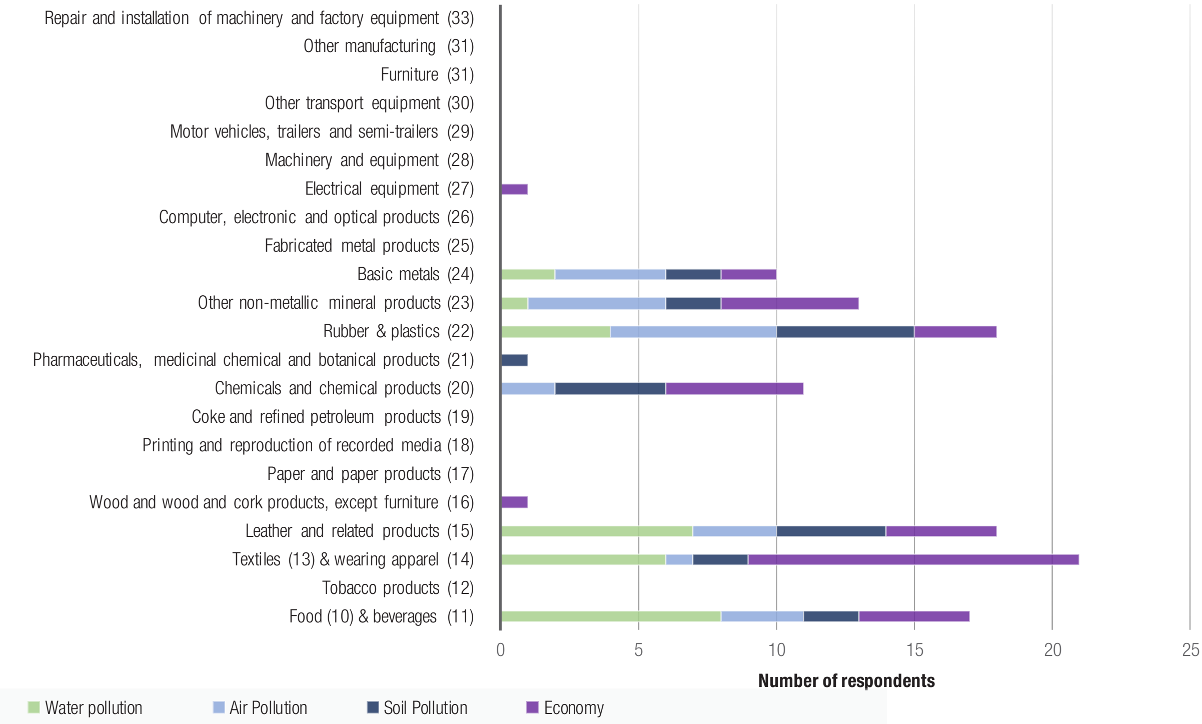
Table 9 shows the number of articles referencing the industry, the ranked number of respondents who identified the industry as polluting and economically important, and industry rankings from the INDSTAT2 and OECD data (achieved by averaging data across available years and summing across the region). Food and beverages are considered together because they are not distinguishable in the INDSTAT2

Table 8. Polluting manufacturing industries, associated pollutants and health risks defined using the literature review for SA

Industry (ISIC Rev. 4 code)	Number of articles	Pollutant types							Human health impacts						
		Toxic metals	Dyes	Bleaching agents	Air pollutants	Noise	Pharmaceuticals	Other	Cardiovascular & respiratory	Carcinogens	Neurotoxins	Endocrine Disruptors	Reproductive toxicity	Irritants & inflammation	Other
Food & Beverages (10 & 11)	11 (4)	x	x	x	x	x		e.g. bagasse, organic solids	x	x	x		x		Anaemia
Textiles & Wearing apparel (13 & 14)	81 (52)	x	x	x	x	x		e.g. oil & grease, organic solids	x	x	x		x	x	Hypertension
Leather & related products (15)	73 (54)	x	x	x	x	x		e.g. sulfates, phosphates, nitrates	x	x	x	x	x	x	Hypertension
Paper & paper products (17)	10 (1)	x	x	x	x	x		e.g. organic matter, bagasse, sulfates	x	x					
Chemicals & chemical products (20)	16 (1)	x	x	x	x	x		e.g. oil & grease, benzene	x	x	x			x	Gastrointestinal problems
Pharmaceuticals, medicinal chemical and botanical products (21)	30 (21)	x	x		x	x	x		x	x	x				AMR
Rubber & Plastics products (22)	5 (0)	x			x			Dissolved solids	x	x			x		Gastrointestinal problems
Other non-metallic mineral products (23)	17 (7)	x	x	x	x	x		Oil & grease	x	x	x			x	
Fabricated metal products (25)	3 (1)	x	x						x	x	x				Gastrointestinal problems
Electrical equipment (27)	4 (0)	x	x							x					Gastrointestinal problems
Wood & wood and cork products, except furniture; articles of straw and plaiting materials (16)	1 (0)	x													
Coke & refined petroleum products (19)	1 (1)	x						e.g. oil, ammonia	x	x					Gastrointestinal problems
Tobacco products (12)	1 (0)	x			x	x									

Notes: Results from 175 articles. Only articles that include "pollutants" + "manufacturing" + "impacts" (where the latter can be ecological impacts) are counted in number of articles; information sourced from the literature is used to assess likely health impacts related to pollutant types, likely exposures and consequent impacts. Number of articles (in brackets) denotes articles that only dealt with that specific manufacturing industry.

Figure 39. Number of online survey respondents stating a manufacturing industry contributes to air, water and soil pollution and the economy for SA



data. Table 9 highlights in red the industries with the greatest (top 5) number of articles, ranking by stakeholders and ranking by manufacturing metric. Only international data for the SMEP target countries are used in the ranking of these industries.

The analysis presented in table 9 was used to identify the key industries (classified according to ISIC Rev. 4) for SA that were considered most likely to be a threat to the environment and human health; these industries are explored in further detail in section 4.4. The industries selected were: (i) textiles and wearing apparel: this looks to be a substantial manufacturing sector for the SA region, and was identified as hazardous to human health by the systematic literature review (emitting most of the pollutant types known to cause harm to human health), and as a key polluting industry in Bangladesh and Nepal by stakeholders; (ii) leather and related products: this industry is an important manufacturing sector for the SA region, and was identified as hazardous to human health in articles in terms of pollutant types emitted, and as a key polluting industry in Bangladesh by stakeholders; (iii) pharmaceuticals: this industry is substantial, has important multinational connections with implications for regulation enforcement (in addition to government regulations) as a means of pollution control, and was identified as hazardous to human health; and (iv) non-metallic mineral products (in particular brick and cement manufacture): this industry was identified as an important emerging industry in the region by international datasets and stakeholders.

4.4 Polluting mechanisms of key manufacturing industries in SA

This section provides a general summary of the pollutant impacts associated with the key manufacturing industries identified for SMEP target countries in SA. For each industry, emissions, pollutant pathways (via air, water and soil), environmental degradation and human health impacts are described along with interventions that have been identified to reduce emissions or clean up existing pollution. This provides information that can be used to support prioritization and implementation of interventions.

Table 9. Identification of key polluting manufacturing industries according to rankings of data from the literature review, stakeholder online survey and international data for SA

Industries		Number of articles	Rank by no. of respondents	Ranking (INDSTAT2 & OECD data)			
ISIC Description	ISIC (Rev. 3) code			Number of establishments	Number of employees	Value added	Exports
Food & Beverages	15	11	2	2	4	3	3/21
Tobacco products	16	1	-	15	9	7	19
Textiles	17	81	1	1	2	2	2
Wearing apparel, fur	18			3	1	1	1
Leather, leather products and footwear	19	73	4	11	7	11	4
Wood products (excl. Furniture)	20	1	-	10	19	21	20
Paper & paper products	21	10	-	12	11	12	17
Printing & publishing	22	-	-	8	8	18	22
Coke, petroleum products, nuclear fuel	23	1	-	22	22	9	7
Chemicals & chemical products /pharmaceuticals	24	16	7/8	7	5	4	6/13
Rubber and plastics products	25	5	3	9	10	13	14
Non-metallic mineral products	26	17	5	4	3	6	8
Basic metals	27	2	5	13	6	5	9
Fabricated metal products	28	3	-	6	13	14	11
Machinery & Equipment	29	-	-	16	15	17	10
Office accounting & computing machinery	30	-	-	20	20	20	-
Electrical machinery & apparatus	31	4	-	14	14	10	15
Radio, television & comms equipment	32	-	-	21	18	19	-
Medical, precision & optical instruments	33	-	-	19	21	22	-
Motor vehicles, trailers, semi-trailers	34	-	-	18	17	8	18
Other transport equipment	35	-	-	17	16	15	12
Furniture	36	-	-	5	12	16	5
Recycling	37	-	-	23	23	23	-

Notes: International data are provided and ranked for the SMEP target countries only. The top five metrics are highlighted for all data. Values in brackets indicate duplication of entries due to uncertainty in allocation of data from the literature and stakeholders to specific ISIC Rev. 4 categories. Entries with two values (e.g. x/y) provide the ISIC Rev. 3 and Rev. 4 categories where categories differ between ISIC revisions. '-' represents no data for this particular industry.

4.4.1 Textiles and wearing apparel (ISIC Rev. 4 codes 13 and 14)

In SA, the textiles and wearing apparel industries are commonly referred to as the ready-made garment industry. Textiles generally refer to factories involved in spinning, weaving, knitting, dyeing and finishing while the garment-manufacturing factories tend to incorporate the sewing, knitting, printing and packaging; some factories span the entire range of these processes (Selim, 2018). Textiles was the industry most commonly associated with pollution by stakeholders in Bangladesh (figure 40) and generated the greatest number of articles in the literature review overall (81 articles). International datasets indicate that the textiles and wearing apparel industries are two of the most significant manufacturing industries in SMEP target countries in SA (see sections 4.2 and 4.3). Stakeholders indicated that wearing apparel manufacturing is performed at a larger scale than textiles. Taken together, the textiles and wearing apparel sectors are well established in Bangladesh, where export value in 2015 stood at approximately US$ 28.4 billion; the industry is smaller in Nepal (with export value comprising US$332 million in 2017). By contrast, Kenya exported US$ 393 million worth of wearing apparel and textiles in 2018 (OECD, 2018). Bangladesh has seen a steady growth in this sector's export value since the early 2000s, while growth has been more variable in Kenya and Nepal, with the latter recovering from a decline since 2015 (see figure 41).

It is tempting to assume that both the textiles and wearing apparel industries are expanding in Bangladesh, but stakeholders noted that textiles manufacturing has slowed in Bangladesh. This was attributed 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. In Nepal, stakeholders described a rapid decline in the textiles industry due to a multitude of factors including the country's geographical limitations, recently formed trade unions, political relations and high competition from neighbouring countries. Some of these factors are discussed further in section 5.2.5.

The causes of pollution and consequent impacts are similar to those of the textiles and wearing apparel industries in SSA (see section 3.5.2). The textiles industry is likely to be more polluting than the wearing apparel industry since the wet processing and use of chemicals are more prevalent in the former, while the dry processing (e.g. cutting and sewing) of the wearing

Figure 40. Relative frequency of comments on pollution types by manufacturing industry stakeholders in Bangladesh

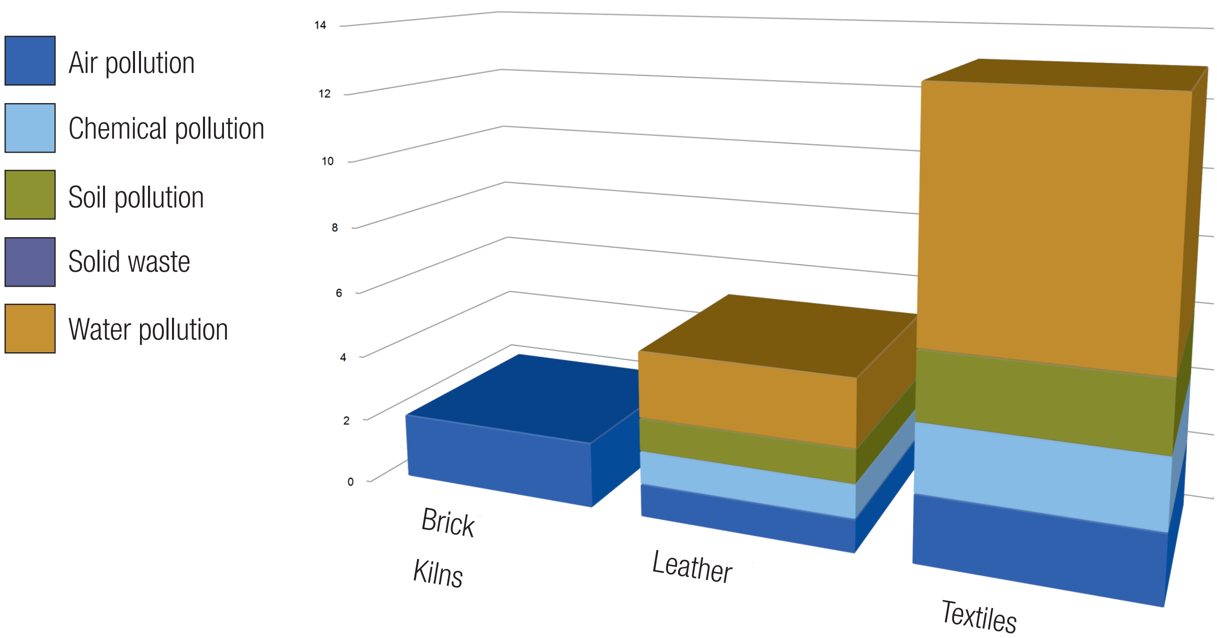
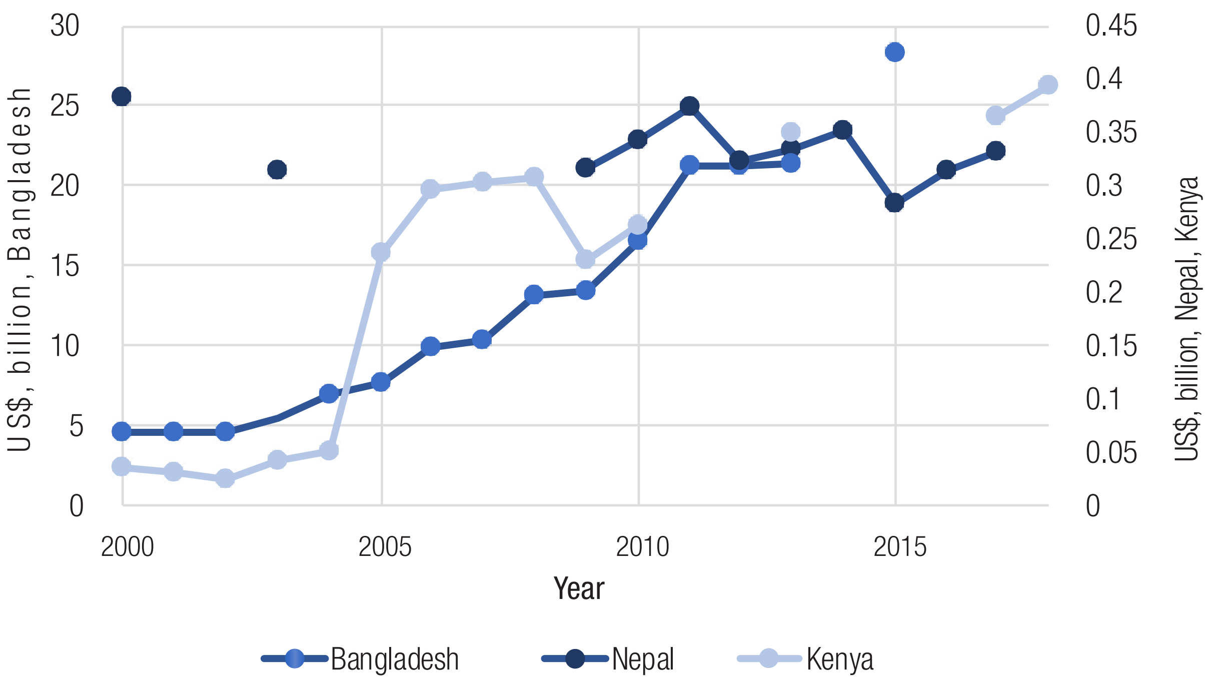


Figure 41. Trend in export value (US$ billions) of textiles and wearing apparel manufacturing in Bangladesh, Nepal and Kenya



Source: OECD (2018).

Note: All values are in current prices.

apparel industry causes less pollution. Therefore understanding the which of these industries is most prevalant in a country can provide some insight into the level of pollution likely to be associated with the textile and garment industry as a whole.

According to interviewed stakeholders, air pollution emissions from textiles and wearing apparel are caused by the use of industrial boilers to generate energy rather than directly by the manufacturing processes. These are typically gas powered and the low cost of gas in Bangladesh means there is little interest in energy efficiency or reduction. Consequently, CO_2 emissions are relatively high. Most industrial textile processes produce air pollution. Boilers, ovens and storage tanks are the three most important sources of air pollution in the textile industry. The boilers generate sulphur oxides and nitrogen. The high temperature textile drying process emits hydrocarbons and gaseous pollutants are also emitted from residues of fibre preparation during the heat settling process, as well as chemicals during the dyeing process (Ghaly et al., 2014).

Stakeholders in Bangladesh explained that the wastewater from many textile processes flows directly into rivers and then the sea through the Sundarbans forest. This has resulted in severe pollution of the estuarine mangroves and forests due to the accumulation of solid waste and chemicals from manufacturing activities. Stakeholders in Nepal noted a similar occurrence leading to major problems with river water quality due to direct disposal of untreated effluent from carpet factories located along rivers. Dyes and toxic metals have detrimental, even lethal, impacts on aquatic ecosystems and fish (Sharma et al., 2007; Kibria et al., 2016; Madhav et al., 2018) and this can ultimately affect people's livelihoods and human health.

Potentially toxic metals are generally present in high concentrations in soil and water environments to textile industry effluent is discharged and are responsible for human health effects such as cancer, asthma central nervous system damage and eczema. Some metals, including Cd, As and Pb, have the ability to bioaccumulate and bio-magnify in the environment, leading to aggregated impacts on humans consuming aquatic food like fish (Kibria et al., 2016). Many non-

metals and dyes like malachite green and methylene blue are mutagenic and lead to dermatitis, lesions and alterations of gene expression (Rajaguru et al., 2002; Ghaly et al., 2014). Textile mills often have high noise levels, causing hearing impairment and stress in workers (Bedi, 2006).

A summary of the interventions commonly used in the textiles and wearing apparel industries in SA is provided in table 10. ETPs are the most widely adopted intervention for wastewater, and employ physio-chemical, biological and combination treatments to remove contaminants. Physio-chemical mitigation technologies include, for example, adsorption (Reddy et al., 2008), electrical coagulation and flocculation (Bhaskar Raju et al., 2009) and membrane filtration (reverse osmosis and nanofiltration) (Chakraborty et al., 2003; Dasgupta et al., 2015). These methods have been shown to be effective treatments in removing salts, and dyes and lowering COD. However, drawbacks include the production of waste sludge, which requires further treatment, high operational and capital costs, and a large operational footprint (Parvathi et al., 2011; Ghaly et al., 2014). Cheaper technologies, such as sand filters instead of reverse osmosis, are less effective (Nishadh et al., 2010).

Biological treatments include bioremediation and biosorption. Bioremediation is the use of microorganisms or plants to remove or neutralize contaminants and can be achieved in the presence or absence of oxygen (aerobic or anaerobic). It is often proposed as a more cost-effective method of effluent treatment (Anjaneya et al., 2011; Babu et al., 2013; Mahmood et al., 2015) and water can subsequently be reused, reducing the cost of purchasing dyes and the manufacturing process as a whole (Babu et al., 2013). However, the presence of toxic metals can affect the growth of microbes and the treatment process requires a long time (Ghaly et al., 2014). This approach could be implemented through constructed wetlands and the use of plants and endophytic bacteria that can reduce the toxic effect of effluent and enhance its degradation. However, wetlands would require a large land area, the process takes time to establish, and it is dependent on local climatic conditions (Shehzadi et al., 2014; Tara et al., 2019).

Biosorption is an alternative method to neutralize contaminants. Activated carbon is typically used as an adsorbent to take up dyes from effluent. However, due to its high price, a range of cheaper alternatives have been proposed, including agricultural wastes and other cellulose biomass, fungal or bacterial biomass, and other materials such as lemongrass ash, available as waste from the oil distillation industry (Parvathi et al., 2011; Nahar et al., 2014; Singh and Tshering, 2014; Holkar et al., 2016). The effectiveness of these adsorbents depends on the types of dye present in the effluent and treatment conditions such as temperature and pH (Parvathi et al., 2011).

Textiles effluent is a complex mix of chemicals and contaminants. Not only are there multiple types of dyes present, there are also a variety of multi-element chemical compounds and trace metals that need to be removed, so no single method is appropriate to all situations (ibid.; Holkar et al., 2016). The suitability of a treatment depends on factors such as dye type and concentration, wastewater composition, cost of required chemicals or biological agent, and operational costs (Parvathi et al., 2011). Ghaly et al. 2014 describe an effective three-stage treatment process that utilizes a variety of physio-chemical and biological methods (screening, flocculation, sedimentation, biodegradation, reverse osmosis). However, this seems to be less applicable to small-scale industries with limited capital. A combination of physio-chemical treatments and biological methods is likely to be the most effective and economically feasible method but thorough cost analysis of different treatment combinations is essential to identify the most suitable option (Holkar et al., 2016).

In some instances, when an ETP is installed it may not be effective or properly maintained. This can be attributed to high operating costs and the low likelihood of being penalized (Nandy et al., 2005; Nishadh et al., 2010; Selim, 2018; Mani et al., 2019). Plant managers are likely to install treatment plants primarily to satisfy regulations, adopting the most affordable option regardless of its ability to reduce pollution (Nishadh et al., 2010). There is a lack of awareness and technological know-how among plant managers, inhibiting uptake which means that treatment processes are not optimized (ibid.; Hossain et al., 2018). Increasing the skills and knowledge of plant managers is a key aspect of pollution mitigation. Stakeholders in Bangladesh identified the Partnership for Cleaner Textiles (PaCT), which was established by the IFC[34] , as a successful intervention strategy

34 See https://www.textilepact.net/

to assist managers in pollution mitigation. The programme provides guidance for industries willing to modify their production to more sustainable practices, and knowledge transfer and technical support is key to its success (Selim, 2018).

Even when ETPs are a legal requirement, barriers to uptake include a lack of monitoring and enforcement by governments, lack of know-how among plant managers, limits on the space required and an inability to afford the cost (ibid.; Sakamoto et al., 2019). The financial barrier is higher when technologies are unavailable on local markets, meaning additional import costs are incurred (Sakamoto et al., 2019). In Nepal, stakeholders noted that although ETPs may exist for carpet manufacturing plants, this does not necessarily mean they will be functioning. Stakeholders in Bangladesh identified private initiatives, such as ETPs installed by individual companies, as more successful.

An alternative approach to pollution reduction is to minimize the waste produced in the first place by adopting cleaner production methods throughout the manufacturing process. This approach is embraced in the previously mentioned PaCT programme. Companies involved in the scheme first undergo a detailed assessment of their current practices and are then supported in the introduction of cleaner production methods such as more efficient use of water, electricity and chemicals, which in turn generates financial savings (Selim, 2018). Bangladeshi stakeholders also identified limited water use, conservation of rainwater and solar energy as successful mitigation measures, but made it clear that these interventions are performed at relatively few premises. This was also true of government-led policies such as free banking, green financing and loan limitations for any initiatives that cause pollution. Stakeholders also described a carbon tax but acknowledged that this suffered implementation problems. Lack of monitoring by regulatory agencies to ensure the efficacy of ETP interventions is also an issue and Bangladesh lacks baseline pollution data and information on vulnerable coastal and marine ecosystems (Kibria et al., 2016). Monitoring could be conducted through surprise inspections, power consumption records, real-time sensing or the use of bioassays to monitor the genotoxicity of treated effluent waste (Nishadh et al., 2010; Hemachandra and Pathiratne, 2016), although governments may still lack the capacity to collect and then act on this information (Haque, 2017; Selim, 2018).

Selim (2018) assessed wearing apparel companies in Bangladesh that performed well from an environmental perspective, determining key enablers and barriers to the adoption of ‘greener’ manufacturing. Internal factors such as management commitment, corporate vision, fiscal health, employee involvement and training, and existing compliance with established standards were identified. Top performers were professionally managed corporate organizations that acknowledged the business benefits of adopting more sustainable practices. External factors such as government policies and incentives, technology availability and pressure from competitors, buyers, investors and environmental groups could support greater sustainability. This highlights the importance of ‘buyer-driven’ interventions for the textiles and wearing apparel industry. Consumer pressure is particularly important in these industries in SA as the majority of the industry is export orientated, meaning it can play an important role in voluntary acceptance of environmental standards. One example is the Sri Lankan textile and apparel sector, which operates under high voluntary environmental standards because of the pressure from international buyers from Europe and the United States of America (Hemachandra, 2015). Stakeholders also identified international client pressure as an effective intervention in Bangladesh. Buyer preference for more sustainable industries has led to more than 10 green textile industries achieving platinum status (the highest level) in the globally recognized Leadership in Energy and Environmental Design (LEED) certification scheme[35]. Market demand for more sustainable production is not always coupled with a willingness to pay a higher price (ibid.). This highlights the importance of establishing manufacturing systems that not only reduce pollution but maximize water and energy efficiency, making them economically favourable as well as sustainable (Holkar et al., 2016). These issues are discussed further in section 5.2.

Stakeholder and activities mapping

Due to the high profile of textile manufacture in Bangladesh and to a lesser extent Pakistan, there are multiple national and international activities

35 See https://www.usgbc.org/leed

Table 10. Summary of key interventions for the textiles and wearing apparel industries

Hard options	Method	Advantages	Disadvantages	References
Equipment	Installation of ETPs. The plants utilize either physio-chemical, biological or combination treatments on polluting effluent. See below text for a description of these methods.	In theory, ETPs decontaminate effluent so that it can be safely deposited into watercourses or reused in processes. ETPs can be installed at individual plants or as common ETPs for multiple manufacturing activities.	The cost is a barrier to installation, in particular where technologies are not available on local markets. Even if installed, they may not be effective or properly maintained.	(Nishadh et al., 2010; Selim, 2018; Mani and Hameed, 2019; Sakamoto et al., 2019)
Physio-chemical treatment	**Adsorption**, where material is added to the effluent and adheres to the pollutant molecules.	Activated carbon can be used to remove suspended solids and organic substances. It is capable of adsorbing many different dyes.	Expensive, and regeneration is costly because the desorption of dyes is difficult.	(Reddy et al., 2008; Parvathi et al., 2011)
	Coagulation/flocculation involves the addition of coagulants that chemically associate with pollutants and can then be extracted.	This method can eliminate insoluble dyes and is relatively quick and easy to manage.	Produces a waste sludge that requires further treatment.	(Parvathi et al., 2011; Babu et al., 2013; Madhav et al., 2018)
	Membrane filtration prevents larger molecules from passing through so can filter out dyes, salts and chemical auxiliaries. **Reverse osmosis** is the most effective method, followed by **nanofiltration**.	The permeate produced can be reused. It is a quick method that does not have a large footprint.	Filters require a lot of maintenance and the concentrate produced requires further treatment. Other filtration methods such as ultrafiltration only partially remove dyes.	(Parvathi et al., 2011; Babu et al., 2013; Holkar et al., 2016; Madhav et al., 2018)
Biological	**Bioremediation** involves the degradation of dyes and detoxification using bacteria and fungi or plants.	Complete degradation of dyes can be achieved with a mix of cultures.	Anaerobic treatment can produce toxic amines requiring sequential treatment. Single treatments can be less effective. The process can be time-consuming.	(Parvathi et al., 2011; Holkar et al., 2016; Madhav et al., 2018)
	Biosorption uses alternative organic materials as adsorbents.	Cheaper alternative to activated carbon, can utilize waste from other industries, e.g. agricultural wastes.	Substance used is dependent on specific conditions and most adsorbents do not remove all different dye types.	(Parvathi et al., 2011; Holkar et al., 2016; Madhav et al., 2018; Nahar et al., 2018)
Soft options	**Method**	**Advantages**	**Disadvantages**	**References**
Government regulations	Regulations can make effluent treatment a legal requirement, and can penalize polluting industries by introducing pollution fines, etc.	Can provide a framework to manage pollution, incentivize plant managers and punish non-compliance.	Requires effective monitoring and there is often a lack of enforcement with limited risk of penalties.	(Nishadh et al., 2010; Haque, 2017)
Economic incentives	Tax breaks or green financing to encourage more sustainable practices and inhibit polluting industries.	Profit margins are likely to be a barrier to intervention, particularly for small factories.	It is not always simple to access green financing, and investing in cleaner production may not be a priority, especially for smaller firms.	(Selim, 2018)
Knowledge and skills transfer	Plant managers are up-skilled and staff can be made aware of cleaner production techniques. One successful example is PaCT.	Leads to financial and competitive benefits for plants while simultaneously reducing pollution. Increases optimization of ETPs.	Needs to be upscaled to the industry level.	(Nishadh et al., 2010; Selim, 2018)
Consumer demand	Pressure from consumers wanting sustainable products can increase the uptake of pollution mitigation strategies	Can increase uptake of interventions such as the LEED certification scheme, particularly where government enforcement is weak.	Consumer pressure is not as strong on smaller, less formal firms that are not associated with a brand. Pressure can demand more sustainable products without an increase in price.	(Hemachandra, 2015; Selim, 2018)

working to reduce the impact of the industry. PaCT is a leading example which aims are to implement sound practices in the textile sector focussing on the wet processing stages of the value chain reducing water consumption and wastewater pollution. The project is implemented by the International Finance Corporation of the World Bank Group partnered with Bangladesh Garment Manufacturers and Exporters Association. PaCT intervenes at the manufacturing stages of the value chain as well as at consumption and is based on four pillars: helping brands to adopt sustainable consumption, supporting factories to adopt cleaner production techniques, addressing sector transformation and regulatory policy gaps and facilitating investment in more efficient technologies. Stakeholders engaged include international and national governments, technology suppliers, textile factories and international brand partners. PaCT has developed a resource savings calculator and established the Textile Technology Business Center, a knowledge hub with information on specialised technology and services including knowledge transfer and business to business linkages. To date they estimate they have supported avoidance of 18.8 billion litres of wastewater per year, saved 2.5 MWh per year in energy and saved factories US$ 16.3 million per year.

Other consumer-orientated activities are eco-labelling and certification schemes. One example mentioned above is the LEED certification scheme, which sets environmental standards for buildings and credits initiatives that reward water and energy efficiency, recycling systems, indoor environmental quality and sustainable buildings. However, its main challenges are strategic planning from the outset and monitoring subsequent to certification.

Other projects and activities work to improve socio-economic dimensions of the textiles and wearing apparel industries, for example Shimmy Technologies and the Awaj Foundation both funded by the Laudes Foundation. Shimmy Technologies[36] is an Industry 4.0[37] company working to upskill women in the garment industry and the Awaj Foundation[38] is a grassroots labour rights organization founded and led by garment workers. Through projects, services and advocacy they train workers on their legal rights, life skills such as financial management and nutrition and forming and running of trade unions.

The German development agency GIZ have carried out many projects working in the textiles sector in Bangladesh[39]. Recent projects have included the promotion of social and environmental standards, developing an employment injury protection scheme for textiles and leather workers, closing the skills gap of mid-level managers and 'The Green Button' project currently underway to provide guidance for companies and consumers on purchasing sustainable textiles[40].

There are multiple designated associations in SA SMEP target countries including, in Bangladesh: the Bangladesh Garment Manufacturers and Exporters Association, Bangladesh Textile Mills Association, the Bangladesh Knitwear Manufacturers Association; in Pakistan: Pakistan Textiles Exporters Association, All Pakistan Textile Mills Association; as well as government departments, such as Bangladesh's Department of Textiles and the Textiles Industry Division of the Government of Pakistan.

4.4.2 Leather and related products (ISIC Rev. 4 code 15)

Leather and related products ranks in the top five for export value according to OECD data (see table 7) and the online survey ranked the industry fourth from the point of view of causing harmful pollution. In addition, the systematic literature review retrieved the second-highest number of articles (73) for this industry. This is therefore an important industry although the international data suggest variability in growth in recent years for key SA countries. For example, INDSTAT2 data suggest the industry is growing in Bangladesh although 2011 was the most recent year for which data were available. In Nepal, the different metrics were contradictory: the number

36 See https://www.shimmy.io/

37 Industry 4.0 relates to the fourth revolution (or transformation) of the way in which products are manufactured (Lasi et al., 2014). Previous revolutions were: the first, industrial revolution (mechanization through water and steam power); the second revolution (electrically powered mass production and assembly lines); and the third revolution (adoption of computers and automation). The fourth revolution will enhance advances made in the third revolution with autonomous systems fuelled by data and machine learning.

38 See http://awajfoundation.org/

39 See https://www.giz.de/en/html/index.html

40 See https://www.giz.de/en/worldwide/85043.html

of leather establishments peaked in 2008 and then fell, but the values for number of employees and value added showed the inverse pattern.

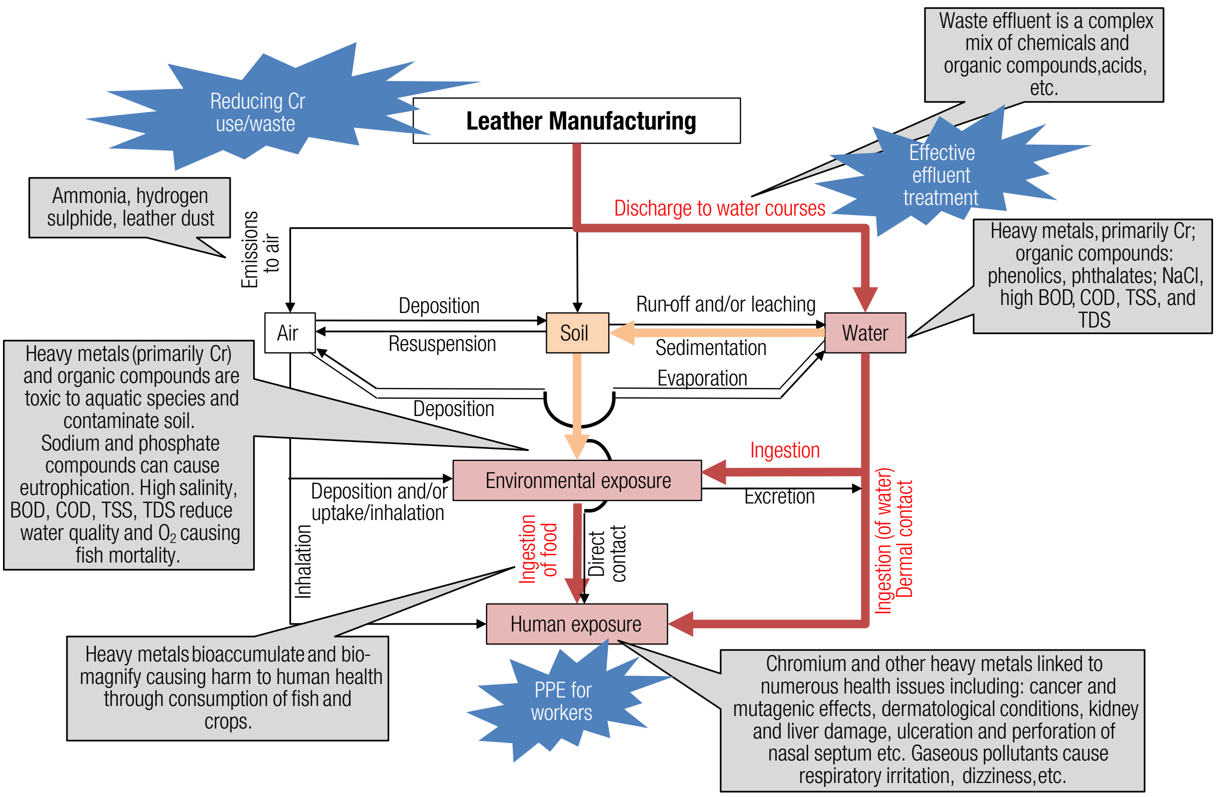
According to the online survey, the two major concerns with tanneries are water and soil pollution with consequences for environmental and human health. Leather manufacturing involves several sequential processes and a concoction of chemicals. First, the raw hides are treated to prevent decomposition. They are then soaked and the hair is removed. Following this, the hides 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 (Shakir et al., 2012). The resulting effluent consists of multiple potentially polluting substances, such as potentially toxic metals, acids, sulfates and various organic pollutants (e.g. proteins, tannins, phthalates and many more). Most notably, effluent contains high levels of chromium, which comes from chromium sulfate in the tanning process. Chromium has a high oxidizing potential and can permeate biological membranes, making it a risk to humans and the environment. The tanning process involves extensive use of salt, meaning effluent has a high salinity. Leather effluent is characterized by high BOD, COD, TSS, TDS and electrical conductivity (Verma et al., 2008; Chowdhury et al., 2015; Ahsan et al., 2019; Yadav et al., 2019). The high oxygen demand is due to a high amount of proteins, fatty matter, hair and other inorganic pollutants (Chowdhury et al., 2015), while high TDS relates to the high salt use and indicates the presence of metal ions (Mondal et al., 2013; Yadav et al., 2019).

This effluent is commonly deposited directly into waterways, which not only causes environmental impact but is ultimately a risk to human health as these watercourses often provide water for agriculture, aquaculture, washing clothes, bathing and drinking (Kibria et al., 2016). Contaminated water is used to irrigate crops where toxic metals can bioaccumulate and reach the food chain (Shafiq et al., 2017). Similarly, metals can bioaccumulate in fish and aquatic species and may ultimately be consumed by humans (Kibria et al., 2016). Soils are also polluted through the leaching of tannery effluent and the direct deposition of solid wastes (Tariq et al., 2005, 2010). Solid waste that is regularly dumped includes hides, hairs, shavings, etc. and can be a source of Cr pollution and noxious odours (Sunny et al., 2012; Fatemi and Rahman, 2015; Shafiq et al., 2017). Leather manufacturing also emits dust, hydrogen sulfide and ammonia, which are all a source of air pollution (Khan et al., 1999). These pollution pathways and their possible interventions are summarized in figure 42.

A key environmental impact of the leather industry is that associated with effluent discharged into water bodies, which can have a detrimental effect on aquatic ecosystems. Potentially toxic metals (primarily Cr in this instance) can change the morphology of aquatic plants, interfere with their metabolic processes and be genotoxic to fish (Chandra and Kulshreshtha, 2004; Mishra et al., 2009; Gupta et al., 2011; Nagpure et al., 2015). Effluent is a complex mixture and it is not just metals that have detrimental effects. Sodium and phosphate compounds (used in the leather treatment process) can cause eutrophication of receiving water bodies (Yadav et al., 2019). In addition, sulfate can stimulate sulfate-reducing bacteria, which in turn produces sulfuric acid, which is toxic to fish and can lead to eutrophication (Verma et al., 2008). Phenolics (used in the preservation of raw hides), phthalates (used to increase the flexibility of leather) and other organic residues can be toxic and genotoxic to plants and animals, including fish (Yadav et al., 2019). The concoction of tannery effluent as a whole affects the immune response of fish (Prabakaran et al., 2007).

The high BOD and COD typical of tannery effluent reduces oxygen availability for aquatic species. The pH of effluent can be highly variable and hence detrimental to some aquatic species (Chowdhury et al., 2015). Similarly, high salinity caused by high concentrations of TDS, chloride, ammonia nitrate and sulfates can exceed safe levels for fish and aquatic species while higher electrical conductivity alters metal availability for flora and fauna (Verma et al., 2008). When effluent infiltrates soil or is used in irrigation, the receiving soil becomes contaminated. High metal concentration in soil can be toxic to plants and consequently, species composition changes and diversity is reduced (Khan, 2001). Excess Fe in contaminated soil can

Figure 42. Pollution pathways of the leather industry in SA



Notes: Red, amber and yellow lines (where present) indicate the more important contaminant pathways (red being the most important). Grey boxes provide annotations of the key pathways and their impact and blue stars suggest potential interventions.

cause acidification and accelerate the depletion of essential plant nutrients while salinity can inhibit seed germination and deplete vegetation grown on contaminated soils (Ali et al., 2013). Ammonia emissions also cause loss of land productivity and inhibition of seed germination (Khan et al., 1999). There is also evidence that Cr from tannery effluent can impact larger animals. For instance, wild mongoose exposed to tannery effluent suffer from ovarian dysfunction and potentially impaired reproductive function (Andleeb et al., 2019).

Many pollutants associated with leather manufacturing pose health risks. Of these, the greatest risks most likely arise from metals, primarily Cr, as this is seen in the highest concentrations. Humans can be exposed to Cr through inhalation, ingestion and dermal contact. Consequently, workers and neighbouring residents are exposed to excessive Cr, with tissue samples of workers, in particular, showing high Cr concentrations (Hasan et al., 2019). Workers are exposed mainly through inhalation of leather dust, which contains Cr, and through dermal contact with chemicals (Junaid et al., 2017). Residents are exposed to high levels of Cr in water sources that exceed permissible limits (Brindha and Elango, 2012; Yoshinaga et al., 2018; Kanagaraj and Elango, 2019). They can also be exposed through ingestion of contaminated food, for example crops (Shafiq et al., 2017), or chicken fed on feed prepared using solid wastes acquired from tanneries (Esa Abrar Khan, 2017; Hasan et al., 2019). However, some evidence shows that even in highly polluted sites the concentration of metals in fish is within safe consumption limits (Asaduzzaman et al., 2016).

The health impacts of Cr exposure described in the literature include: cancer and mutagenic effects, skin rashes and dermatological conditions, heart disruptions, brain damage, kidney and liver damage, oxidative stress, ulceration and perforation of the nasal septum, decreased spermatogenesis,

respiratory illnesses, gastrointestinal diseases, damage to immunological systems, reproductive and developmental problems, genotoxic effects and nervous system damage. Other metals identified in waste effluent also pose a risk to human health. For example, Mn can affect the central nervous system, cardiac function and fertility, while Ni exposure can cause nausea, vomiting and diarrhoea (Abbas et al., 2012).

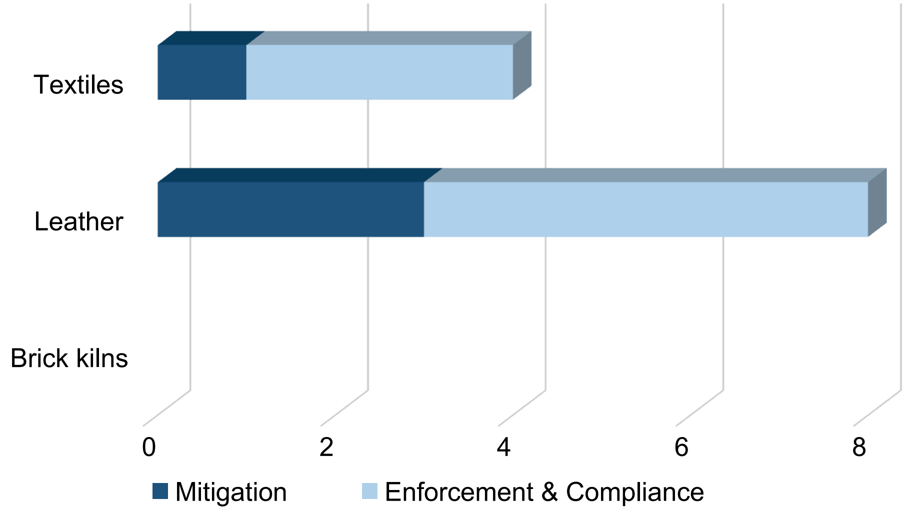
Other pollutants identified in waste effluent are also a risk to human health. An increase in chlorine may lead to disparity in immune responses, impair neuro-behaviour and have the ability to form other toxic compounds and cause illnesses such as kidney failure (Shakir et al., 2012). Phthalates and phenolic compounds may cause genotoxic and carcinogenic effects and along with benzoic acid are potential endocrine disrupters (Alam et al., 2009; Yadav et al., 2019). Workers are also exposed to hydrogen sulfide and ammonia, which causes respiratory irritation, headaches, dizziness and skin disorders (Khan et al., 1999). Stakeholders in Bangladesh also indicated that the majority of workers have eye-related health issues. Furthermore, tannery treatment plants have been shown to foster the growth of microbial populations, which has been linked to associated infections in workers (Verma et al., 2008). Health risks are not always attributed to a specific pollutant. For example, haematological and neurological disorders and jaundice are also identified as health risks for workers while waterborne diseases such as retinal toxicity and hepatic fibrosis are thought to be linked to tannery effluent water even if the causal link is not proven (Syed et al., 2010; Azom et al., 2012; Shakir et al., 2012). Due to the complex nature of effluent it is difficult to attribute the health risks to one component and the characteristics of some pollutants are still not fully understood (Alam et al., 2009; Yadav et al., 2019).

Stakeholders in Bangladesh strongly identified the leather industry as requiring mitigation or regulation enforcement (figure 43). ETPs are the most commonly recommended strategy to reduce pollution, if they have not already been established. Biotechnology that uses enzymes to remove toxic metals can be an economical way to treat effluent (Verghese and Garg, 2015). However, common ETPs tend to remove Cr but do not reduce TDS, so the effluent that is released is still high in ions, BOD and COD, supports microbial growth, and is capable of causing genotoxic damage in plants (Verma et al., 2008; Brindha and Elango, 2013; Yadav et al., 2019). Techniques have been developed to reduce the salinity of effluent. For example, membrane technologies have been developed that filter out contaminants. Reverse osmosis can remove TDS and produce water that can then be reused in the manufacturing process (Kavitha and Ganapathy, 2015). This is an attractive option in water-scarce areas but is expensive to install and operate and the remaining salt still has to be disposed of. An alternative way to reduce salt levels is by adopting alternative methods of preservation, such as chilling or drying. However, slaughterhouses lack formalized, systematic processes, so this is difficult to implement (ibid.).

Effluent composition varies between plants so it is challenging to establish a standard treatment method (Khan et al., 1999) and to effectively remove all effluent pollutants is a multi-stage process (ibid.; Paul et al., 2013). Stakeholders identified the difficulty in collection and treatment of effluent as barriers to the uptake of sustainable systems. In addition, the size of the plant and volume of wastewater affects the feasibility of new technologies (Khan et al., 1999). Smaller factories cannot afford to build treatment plants due to a shortage of land. Both the literature and stakeholder interviews stated that even when treatment plants are installed, they are often not properly maintained and do not operate continuously, if at all, due to the high expense (Sunny et al., 2012; Paul et al., 2013; Yadav et al., 2019). It is not just liquid effluent that needs be properly dealt with; several studies call for an effective system for disposing of solid waste (Syed et al., 2010; Azom et al., 2012; Brindha and Elango, 2012).

It is also possible to use cleaner production techniques such as desalting of hides and skins (Kavitha and Ganapathy, 2015), undertake better chrome management including chrome recycling or recovery, and use high-exhaust tanning methods, which can be cost-effective methods of reducing pollution and have been implemented in some Indian tanneries (Raghava Rao et al., 2002). Other pre-treatment methods such as sulfide oxidation are available but can be expensive (Dotaniya et al., 2017). Yoshinaga et al. (2018) advocate environmentally engineering effluent by adding a purifying agent, which adsorbs Cr. They propose the use of a Mg- and Fe-based hydrotalcite-like compound as a low-cost and high-efficacy depurative able to remove both Cr(VI) and

Figure 43. Relative frequency of stakeholder comments related to mitigation or regulation enforcement by manufacturing industry type in Bangladesh



Note: Stakeholders identified brick kilns as a polluting industry but it was not mentioned in relation to mitigation or regulation enforcement.

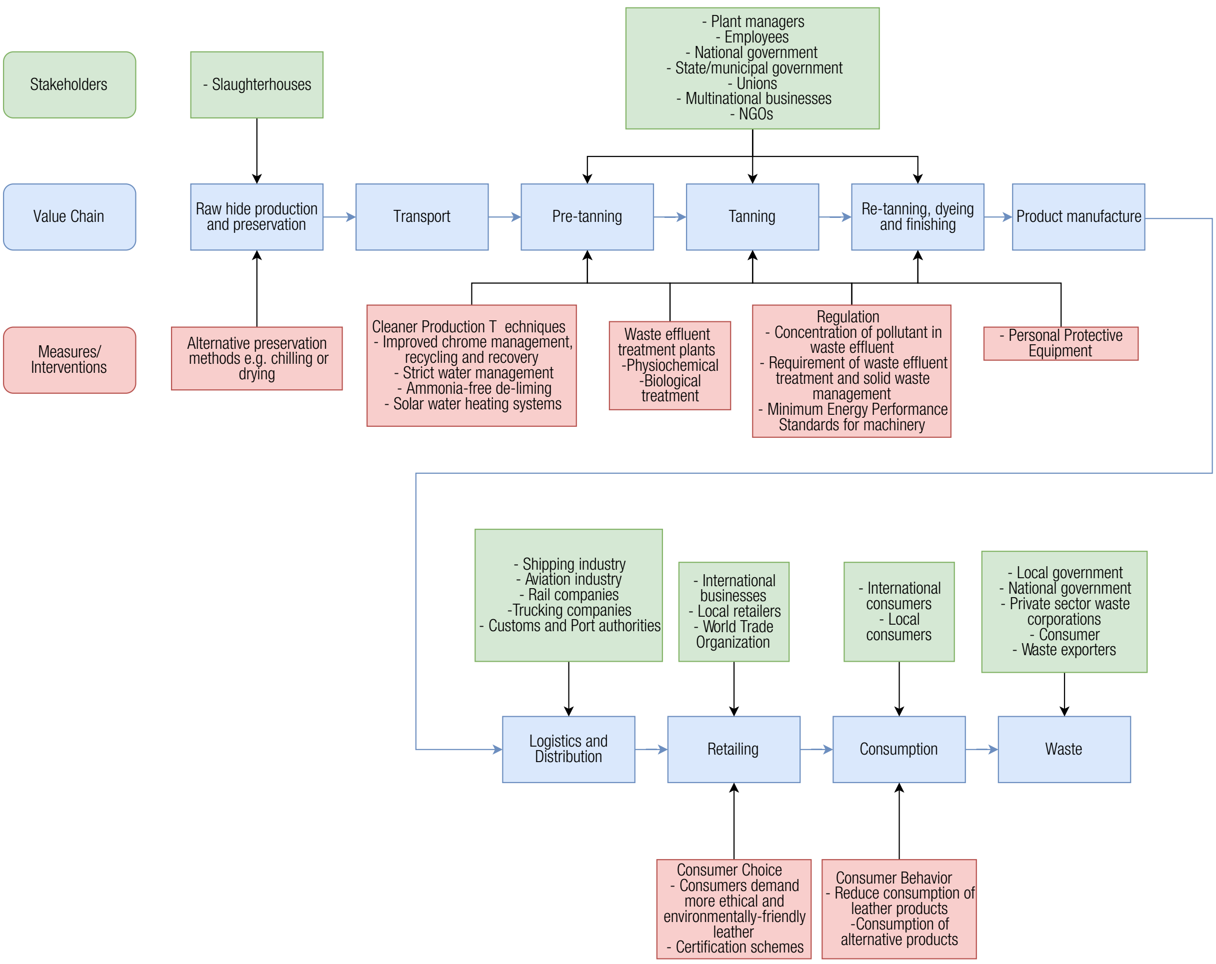
Cr(III). Bioremediation of contaminated land and water can be achieved through phytoextraction (the use of plants to remove contaminants from soil and water), and chelating agents can be used to increase the capacity of plants to take up metals (Bareen and Tahira, 2011; Shukla et al., 2011).

Occupational health and safety can be improved through worker training and safety measures on, for example, the use of PPE (Dawn and Basu, 2016; Hasan et al., 2019). However, this incurs costs and there is a lack of pressure from workers for better working conditions. Even when safety procedures are in place they are not always adhered to due to a lack of awareness in workers (Hasan et al., 2019). Any educational campaigns aiming to change this must take into consideration the low literacy levels of workers and local communities (Syed et al., 2010).

Improved regulations concerning legal limits to tannery discharges and increased enforcement of existing policies is also commonly recommended (Rasal et al., 200; Sunny et al., 2012). This could be coupled with environmental impact assessments and effective monitoring (Dawn and Basu, 2016). Rasul et al. (2006) observe that in Bangladesh, environmental issues are a low priority in terms of law enforcement. Regulations should be accompanied by increasing education and awareness of local people (Chowdhury et al., 2015) and it is important to acknowledge the poverty-inducing aspect of pollution, which can reduce access to clean water and cause a loss in health and productivity (Khan et al., 1999). In Bangladesh, stakeholders described how the leather tanneries were initially set up in the Hazaribaug area inside Dhaka. In 2003, the government moved the industry out of Dhaka. In 2017, the tanneries were shifted again to the Savar area (also a wearing apparel industry hub). Currently, there are 155 established factories with pollution reduction infrastructure. The challenge is now in the implementation of changes in practice to make use of the new infrastructure. However, the new Savar site is isolated, with no residential area or community facilities such as hospitals, schools or canteens, leading to increased commuting costs for workers and overall, poorer conditions for workers.

Stakeholders in Bangladesh noted that tanneries have many incentives from government to clean up leather production, but no reporting on the effects of these incentives has been carried out. This omission was true of the literature in general, as it lacked critical appraisals of interventions and their implementation. Even though mitigation methods are available, there is limited uptake, maybe in part because plant managers do not recognize the potential of such methods (Hoque and Clarke, 2013). Future work should strive to better understand the effectiveness of current interventions, how extensively they have been implemented, and what the barriers are to their uptake. It should also

Figure 44. Leather and leather products value chain and associated stakeholders



evaluate the success of interventions that have been established. Finally, consumer-orientated interventions should also be explored further, compelling consumers to take more responsibility for the way their products are produced (Esa Abrar Khan, 2017).

Stakeholder and activities mapping

There are multiple stakeholders and intervention activities present throughout the value chain of leather production, illustrated in figure 44. Interventions to mitigate the environmental and health impacts of the sector are available right from the generation of the raw material (hides and skins) to the consumption and waste at the end of the value chain. The UNIDO Leather and Leather Products Industry Panel is a global forum which provides technical programmes, information on good practices and professional training for stages throughout the value chain[41]. The forum provides case study examples of where interventions have been carried out, for example relocation to leather industry parks including Savar in Bangladesh[42]. UNIDO has also developed the Framework for Sustainable Leather Manufacture[43] which provides a comprehensive summary of cleaner production technologies developed from practical experience. The framework discusses each stage of the manufacturing process (e.g. raw material preservation, soaking, unhairing,

41 See https://leatherpanel.org/

42 See https://leatherpanel.org/sites/default/files/publications-attachments/case_study_leather_industrial_parks_p.pdf

43 See https://leatherpanel.org/sites/default/files/publications-attachments/the_framework_for_sustainable_leather_manufacturing_2nd_edition_2019_f.pdf)

Table 11. Examples of organizations and institutions associated with leather manufacturing in SMEP target countries in SA

SMEP target country	Organization	Website
Bangladesh	Leathergoods and Footwear Manufacturers and Exporters Association	http://www.lfmeab.org
	Leather Engineers and Technologists Society Bangladesh	http://letsb.org/
	Bangladesh Tanners Associations	http://www.tannersbd.com/
	The Institute of Leather Engineering Technology	http://iletdu.blogspot.com/
Nepal	Leather Footwear and Goods Manufacturer's Association	Not available
	Nepal Leather Industries Association	Not available
Pakistan	Pakistan Institute of Fashion and Design	http://www.pifd.edu.pk/
	Pakistan Footwear Manufacturing Association	https://pakfootwear.org/
	Pakistan Tanners Association	http://www.pakistantanners.org/
	National Institute of Leather Technology	Not available

liming, tanning, etc.) as well as water and waste management, energy consumption, occupational safety and emerging technologies.

The Leather Panel is also a useful resource for identifying stakeholders and provides links to roughly 400 organizations and institutions associated with leather manufacturing. The list includes international organisations, education institutions, research and development institutions as well as trade associations involved in the leather industry. Example organizations specific to SA SMEP target countries are presented in table 11. The Leather Working Group (LWG) is an example of a multinational organization whose objective is to develop and maintain a protocol that assesses environmental compliance of leather manufacturers[44]. They have developed an environmental auditing system and manage the Manufacturing Restricted Substance List as part of their Chemical Management Module. They report that LWG-rated manufacturers have saved 12.1 billion litres or water per year and saved 775 megawatts of energy annually.

Additional to the organizations presented in table 11, the centre of excellence for Leather Skill Bangladesh Ltd[45] is a national institute which aims to increase the overall skill level of the leather sector's workforce through training programmes. The centre has been developed with the National Ministry of Finance as well as international partners including GIZ, the EU, the Swiss Agency for Development and Cooperation and the ILO.

4.4.3 Pharmaceuticals (ISIC Rev. 4 Code 21)

Pharmaceuticals are a subcategory within the chemicals and chemical products manufacturing sector in the INDSTAT2 data, so their importance cannot be considered separately within this dataset. Table 9 shows that pharmaceuticals in SA rank 13 out of all 23 manufacturing divisions in terms of export value. Overall, this industry seems to be growing across the region with the trend being most clear in Bangladesh and Pakistan. The industry also receives attention in the literature; the systematic literature review in this study identified 30 articles (the third-highest number of any industry in SA) that dealt with pollution impacts arising from the pharmaceutical industry.

Pollutants are produced throughout the production process but emissions primarily take the form

44 See https://www.leatherworkinggroup.com/

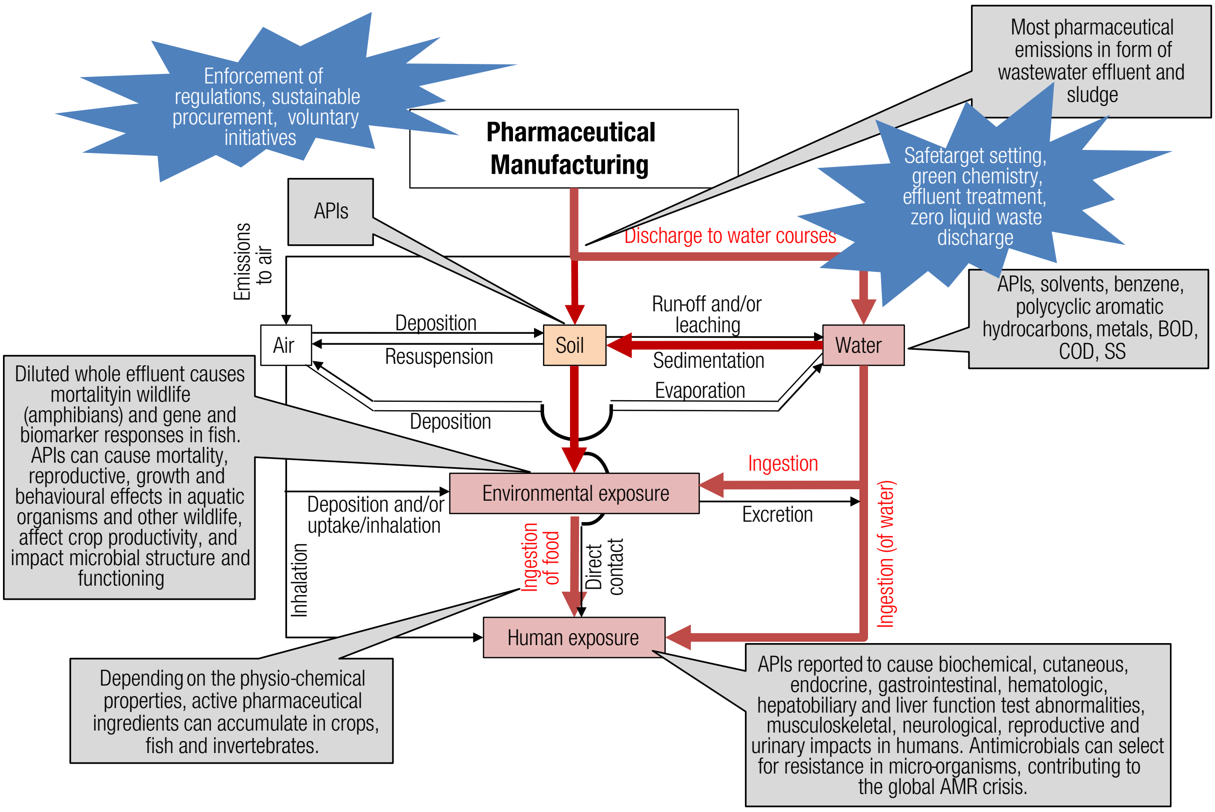
45 See http://coelbd.com/

of wastewater effluent and sludge (Brems et al., 2013; Gadipelly et al., 2014). A key pollutant group comprises active pharmaceutical ingredients (APIs). Over 1,900 APIs are used in human medicine around the globe (Burns et al., 2018) and around 750 are used in veterinary medicine (Kools et al., 2008). These APIs are present in pharmaceutical wastewater, for example, Larsson et al. (2007) monitored the occurrence of 59 APIs in effluent samples from a wastewater management facility receiving wastewater from 90 bulk drug manufacturers in the Hyderabad region of India.

Since this initial work, further studies have revealed the occurrence of APIs in manufacturing effluent, surface water, sediment, groundwater, sludge, soil and soil waste impacted by pharmaceutical manufacturing sites in Asia, including in Pakistan (Ashfaq et al., 2017; Khan et al., 2013) and India (Fick et al., 2009; Lübbert et al., 2017; Rutgersson et al., 2014; Gothwal and Thatikonda, 2017) (see figure 45 for the pharmaceutical contaminant pathway). A wide range of APIs have been detected, including antimicrobials (fluoroquinolones, tetracyclines, macrolides, sulfonamides, chloramphenicols), analgesics, non-steroidal anti-inflammatory compounds, antidepressants, antacids, bronchodilators, anti-hypertensives and blood lipid regulators. The bulk of data are available for effluent, with fewer data available on surface water, sediment, sludge and soil.

In addition to the APIs themselves, effluents from pharmaceutical manufacturing plants have been shown to be contaminated with other organics, such as benzene, polycyclic aromatic hydrocarbons and heterocyclic compounds (Sun et al., 2011), and with halides, nitrates, sulfates, cyanides and metals (Gadipelly et al., 2014). Untreated pharmaceutical wastewater can also contain high concentrations of TSS, have high COD and BOD, and also be

Figure 45. Pollution pathways of the pharmaceutical industry in SA



Notes: Red, amber and yellow lines (where present) indicate the more important contaminant pathways (red being the most important). Grey boxes provide annotations of the key pathways and their impact and blue stars suggest potential interventions.

contaminated with ammoniacal nitrogen (Yu et al., 2014). Reported pH values range from 3.04 to12.7 (Gadipelly et al., 2014; Yu et al., 2014). Some gaseous pollutants are also released in the manufacture of pharmaceuticals, for instance VOCs released from storage tanks and reactors and through handling, and NOx and SO_2 from combustion of boilers (Brems et al., 2013).

APIs are biologically active molecules that target biochemical pathways and receptors in humans or pathogens. As many of these receptors and pathways are conserved in organisms in the environment, the occurrence of APIs in waterbodies and soils can result in adverse effects on organisms in the environment (Gunnarsson et al., 2008). A range of effects of APIs have been reported either in the field or in laboratory studies, including effects on bird mortality (Oaks et al., 2004), fish reproduction (Kidd et al., 2007), wildlife behaviour (Brodin et al., 2013; Bean et al., 2014) and crop growth (Carter et al., 2019). Effects on microbial structure and function are also possible, including impacts on microbial biomass, community structure and effects on functional endpoints such as substrate-induced respiration, iron reduction, ammonification, N-mineralization, nitrification and potential to degrade other anthropogenic substances (Brandt et al., 2015). While these studies have not focused specifically on pollutants from manufacturing activities, they do demonstrate the potential adverse impacts of APIs that could occur due to emissions from manufacturing sites.

Selected studies have also explored the ecotoxicity of diluted effluent from pharmaceutical manufacturing plants. Carlsson et al., (2009) showed that a 1 in 50 dilution of an effluent from a manufacturing area in India reduced the growth of tadpoles by 40 per cent. Work in the same region (Gunnarsson et al., 2009; Beijer et al., 2013) showed effects of the diluted effluent on gene expression and biomarker levels in fish. Work in France (Sanchez et al., 2011) demonstrated effects on biotransformation enzymes, neurotoxicity and endocrine disruption biomarkers in fish downstream of a manufacturing effluent discharge. Fish also exhibited strong signs of endocrine disruption including vitellogenin induction, intersex and male-biased sex ratios. These individual effects were associated with a decrease of density and a lack of sensitive fish species.

Impacts on human health can occur either directly or indirectly. Depending on the properties of an API, these molecules can be taken up by plants (Carter et al., 2019) and fish and invertebrates (Huerta et al., 2018; Miller et al., 2018), which are then consumed as food, resulting in human exposure. Studies using cropping systems involving irrigation with treated wastewater demonstrated that one API, carbamazepine, is released into soils, taken up by plants and can then be detected in the urine of individuals consuming these crops (Paltiel et al., 2016). Even where drinking water treatment is in place, APIs can enter drinking water supplies (Huerta-Fontela et al., 2011).

A wide range of toxic effects of APIs on human health is possible, including: biochemical, cutaneous, endocrine, gastrointestinal, haematologic, hepatobiliary and liver function test abnormalities, and musculoskeletal, neurological, reproductive and urinary impacts (Olson et al., 2000). Attempts have been made to assess the potential risks of exposure via food and drinking water to human health (Huerta-Fontela et al., 2011), with these assessments typically demonstrating that exposure levels are orders of magnitude lower than acceptable daily intake values for APIs. However, limited work has been done for areas impacted by APIs from manufacturing.

There is growing evidence of the presence of antimicrobial compounds in natural environments that is indirectly impacting human health by promoting antimicrobial resistance (AMR) in bacteria (Williams-Nguyen et al., 2016) or by deselecting non-resistant strains, increasing relative AMR abundances across nature (Knapp et al., 2008). Elevated levels of antimicrobial-resistant organisms have been detected in manufacturing treatment systems (Marathe et al., 2013) and in surface water and sediment in areas receiving API manufacturing inputs in India (Gothwal and Thatikonda, 2017) and Pakistan (Khan et al., 2013). The concern is that the transfer of these resistant determinants back to the human population is contributing to the global AMR crisis (UNEP, 2017).

A wide range of technological solutions exist for reducing the use of hazardous substances in pharmaceutical manufacturing and the generation of waste and wastewater, such as substitution for

less toxic materials, process modification, recovery and recycling (Brems et al., 2013). A large number of treatment systems are also available for treating waste and wastewater, including: biological treatment processes (aerobic treatments, anaerobic treatments); advanced treatments (membrane technology, activated carbon, membrane distillation); advanced oxidation processes (ozone and hydrogen peroxide treatment, Fenton oxidation, photocatalysis, electrochemical oxidation and, or degradation, ultrasound irradiation, wet air oxidation); and hybrid technologies involving a combination of approaches (Gadipelly et al., 2014). The effectiveness of an individual approach will vary according to an API's chemical functionality and physico-chemical properties. While these solutions exist, they are not always adopted or operated effectively by manufacturing sites, hence some of the high concentrations that have been observed in some manufacturing areas around the globe. Implementation of these approaches could be achieved through tighter regulation or encouraged through sustainable procurement programmes, for example the Sustainable Procurement in the Health Sector initiative[46] or voluntary industry programmes such as that of the AMR Industry Alliance.

Due to concerns over the increase in levels of AMR around the globe, the pharmaceutical industry has been relatively proactive in ensuring that management and treatment systems are adopted, thus reducing emissions of antimicrobial compounds from manufacturing into the natural environment. This work has been co-ordinated by the AMR Industry Alliance, a network of over 100 biotech, diagnostics, generics and research-based pharmaceutical companies. The Alliance has developed a common manufacturing framework to tackle AMR. While focused on antimicrobials, this framework could be applied to the wider antimicrobial manufacturing community as well as pharmaceutical and chemical manufacturing more broadly.

The framework sets out minimum expectations for business policies, practices and behaviours to minimize the release of antibiotics into the environment from drug production and formulation. With a focus on effective waste management and control, the framework is designed to minimize conditions that may increase the development and spread of resistant bacteria. The framework requires the following of all manufacturing sites:

- Comply with all applicable laws and regulations;
- Have a robust environment, health and safety management system in place and periodically evaluate it for continued effectiveness;
- Provide appropriate training, in line with industry best practice;
- Exercise appropriate duty of care for all discharges and waste streams containing antibiotics;
- Allow and facilitate on-site audits of their operations.

In particular, systems for managing waste discharges must be able to: ensure the safe handling, movement, storage, recycling, reuse and disposal of waste; provide adequate control and treatment of any waste with the potential to adversely impact human or environmental health; and effectively prevent and mitigate any accidental spills or releases to the environment.

To support this work, the Alliance has developed a set of science-based target values for antimicrobial compounds in receiving waters (Tell et al., 2019). The Alliance is also encouraging innovative solutions to reduce manufacturing emissions, including: the use of enzymatic production processes, which have no need for chemical solvents and so are more environmentally sustainable as well as more energy-efficient; and installing zero-liquid-discharge equipment in antibiotic factories to recycle and reuse wastewater and keep antibiotic residues (and other APIs and resistance contributing compounds) out of the environment. Recent, unpublished work by the University of York and IIT-Hyderabad in the Musi catchment, where the Larsson et al. (2007) study was located, suggests that levels of antimicrobials are orders of magnitude lower than that seen 13 years ago, indicating these initiatives are having an effect on the ground.

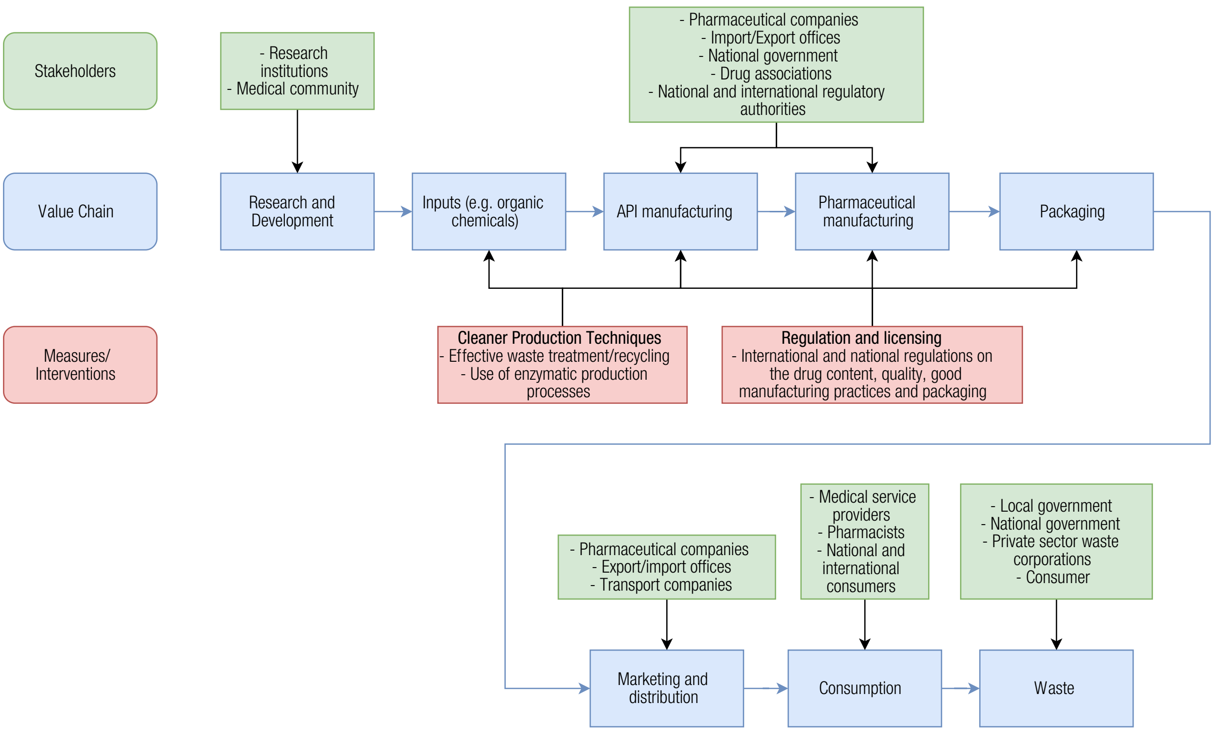
However, at present India is the only country in SA with members in the Alliance, even though the literature review generated 30 articles that assess the

46 See https://savinglivesustainably.org

Table 12. Associations and organizations relevant to pharmaceuticals in SMEP target countries in SA

SMEP target country	Organization	Website
Bangladesh	Bangladesh Association of Pharmaceutical Industries	http://www.bapi-bd.com/
	Bangladesh Small and Cottage Industries Corporation	http://www.bscic.gov.bd/
Pakistan	Pakistan Pharmaceutical Manufacturer's Association	https://www.ppma.org.pk/
	Drug Regulatory Authority of Pakistan	https://www.dra.gov.pk
Nepal	Association of Pharmaceutical Producers of Nepal	https://appon.org.np/

Figure 46. Pharmaceutical industry value chain and associated stakeholders



pollution of pharmaceutical manufacturing in Pakistan and Bangladesh, where the industry appears to be expanding. In India, cost savings, regulations and reputation have been identified as drivers for the uptake of 'greener' manufacturing methods (Veleva et al., 2018). Conversely, barriers to uptake include time pressures to deliver drugs and the perceived risk of losing United States Food and Drug Administration approval status (ibid.). This latter barrier highlights the influence of international buyers and the need for increased transparency throughout the pharmaceutical supply chain (Larsson and Fick, 2009).

Stakeholder and activities mapping

Initiatives such as the AMR alliance encourage the uptake of cleaner production techniques across the manufacturing stages of the pharmaceuticals value chain (figure 46). However, the alliance does not currently have members in SMEP target countries. Similarly, 'Bad Medicine' campaign run by the Changing Markets Foundation aims to raise awareness of, and address the pollution issues, associated with the pharmaceuticals sector but is focused on India and China[47]. The Pharmaceutical Supply Chain Initiative[48] has multiple international partners and aims to promote responsible practices throughout the supply chain. There are 44 members worldwide but the location of these members is not readily available. Some associations and organizations which are relevant to pharmaceuticals in SA SMEP target countries are listed in table 12. The Bangladesh Association is involved in the establishment of the new API Industrial Park. The park is 200 acres with 42 industrial units and Indian environmental engineering firm Ramky[49] are installing a common ETP and waste dumping yard[50]. At present, Bangladesh is highly dependent on imports of API's to use in pharmaceutical manufacturing. This new park will reduce the reliance on API imports into Bangladesh and will likely facilitate a large expansion of the pharmaceuticals industry in Bangladesh.

4.4.4 Non-metallic mineral products (ISIC Rev. 4 code 23)

Non-metallic mineral products include ceramics, bricks, glass, concrete and cement. On average, the industry ranks in the top five for SA for a number of the key manufacturing metrics (see table 9). Exports of non-metallic mineral products appear to be increasing in Nepal, but are beginning to decline in Bangladesh, Pakistan and Afghanistan (OECD, 2018). Within the broader division of non-metallic mineral products, stakeholders from Nepal identified cement and bricks and stakeholders from Bangladesh identified brick, cement and ceramic manufacturing as key polluting industries. In Bangladesh, brick is the main construction material, due to the lack of stone and concrete, and rapid urbanization has increased its usage (Luby et al., 2015).

Stakeholders in Nepal identified the manufacture of construction materials, including brick and cement, as key sources of air pollution. The Bangladesh Department of Environment (2018) identifies brick kilns as the most dominant source of industrial air pollution and this corresponds to the pollution sources identified by stakeholders (see figure 40), who also identified it as the single largest source of air pollution. Of the industries classed as non-metallic mineral products, brick kilns also featured most heavily in the literature review and it is therefore used as a focal industry within this manufacturing sector.

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, such as low-grade coal, production is energy intensive and highly polluting (Croitoru and Sarraf, 2012; Saju et al., 2020). Emissions include PM (i.e. coal, dust, PM_{10}, $PM_{2.5}$) and potentially hazardous gases such as SO_2, NOx, hydrogen sulfide, and CO and black carbon (Raza et al., 2014; Saju et al., 2020). Pollution is highest during the dry season as kilns generally do not operate in the rainy season (Luby et al., 2015, as well as stakeholders).

Farmers sell soil for use in brick manufacturing. This contributes to soil degradation and reduces crop production (Biswas et al., 2018; Hossain et al., 2019), while air pollutants contribute to climate change and can also have serious health impacts. High ambient concentrations of PM can cause inflammation in lung tissue and lead to oxidative stress (Raza et al., 2014). Persistent exposure to PM can lead to short-term (coughing, wheezing, chest tightness) and long-term (reduced lung function, chronic bronchitis, lung cancer risk and even mortality) health impacts (ibid.; Saju et al., 2020). The health risk is particularly high for workers who endure occupational exposure (Raza et al., 2014; Shaikh et al., 2012). Children are particularly vulnerable due to the high levels of child labour in brick manufacturing (Anti-Slavery International, 2017; ILO, 2014).

Interventions for the brick kiln industry are predominantly related to increasing production

47 See https://changingmarkets.org/portfolio/bad-medicine/

48 See https://pscinitiative.org/home

49 See https://ramkyenviroengineers.com/

50 See http://www.bapi-bd.com/api-park/brief-outline

efficiency in order to reduce fuel consumption. Traditional kilns, for instance bull trench or fixed chimney kilns, are the most polluting. More advanced zigzag kilns increase fuel efficiency by increasing air circulation and can reduce PM emissions by roughly 40 per cent per unit of brick compared to traditional kilns (Guttikunda et al., 2013; Nepal et al., 2019). Hoffman kilns are the most efficient and can reduce PM emissions by up to 90 per cent if gas fuelled or 60 per cent if run on coal (Guttikunda et al., 2013). However, these require the largest upfront investment, which is a strong barrier to uptake for manufacturers (ibid.; Luby et al., 2015). In Bangladesh, brick kilns are usually built on cheaper land that floods in the rainy season and contentions over land ownership make managers reluctant to invest in kilns with high fixed capital costs (Luby et al., 2015). Furthermore, the informality and seasonality of the industry makes it difficult to obtain loans (ibid.; Croitoru and Sarraf, 2012). Few workers know how to build the more advanced kilns and those that do require higher salaries, further increasing the cost for employers (Luby et al., 2015).

Despite the availability of more efficient systems, traditional brick kilns are still prevalent across Bangladesh and Nepal (ibid.; Nepal et al., 2019). In Bangladesh, there has been a lack of government enforcement with inspectors lacking authority and issues over corruption, with many brick kilns operating without approval (Luby et al., 2015; Hossain et al., 2019). Stakeholders in Bangladesh discussed how various regulations regarding brick kilns have been implemented but only two have been implemented successfully: requirement of higher height specifications and conversion to zigzag-shaped towers (with only a 75 per cent successful conversion rate). However, they indicated that the government is currently working on better regulation, as evidenced in the National Action Plan for reducing short-lived climate pollutants, which aims to address several of the issues described above, including financing and technical support (Bangladesh Department of Environment, 2018). In Nepal, stakeholders explained that pollution issues and levels largely depend on the success rate of regional government interventions. For example, the Chandragiri Municipality took successful measures to either eliminate polluting production or install sustainable production of brick kilns through grants. Other recommended interventions for the brick kiln industry are providing access to carbon markets and creating technology centres that can disseminate information (Croitoru and Sarraf, 2012). Training brick kiln managers may be a more effective use of resources than government regulation as it is less susceptible to corruption (Luby et al., 2015).

Stakeholder and activities mapping

Figure 47 presents a value chain for brick production as an example of non-metallic mineral products manufacturing in SA. There are two stages of the process where interventions are key, at brick firing and at consumption where alternative materials could be used. Brick firing is the process which generates the highest level of pollution throughout the value chain. This can be mitigated through the introduction of regulatory control and the adoption of cleaner production techniques. One example of regulatory activity in Bangladesh was the 2010 Government circular that banned fixed chimney kilns by 2012[51]. This evolved into the Brick Manufacturing and Kiln Establishment (Control) Act 2013 which also included restrictions on the fuel type and source. In 2019, the Climate and Clean Air Coalition (CCAC) reported that 71 per cent of fixed chimney kilns have been converted but that the uptake of modern technology such as hybrid Hoffman kilns was limited[52] they identified the lack of awareness of available technology and financing as barriers to uptake.

An important stakeholder in brick production in Nepal and SA more broadly is the International Centre for Integrated Mountain Development (ICIMOD[53]). ICIMOD is an intergovernmental research centre, which have been the lead partner in the CCAC's Brick Production Initiative[54] as well as implementing Nepal's Clean Brick Initiative. Following the 2015 earthquake in Nepal where many brick kilns were damaged, ICIMOD and the CCAC worked to rebuild cleaner technology kilns. The CCAC report

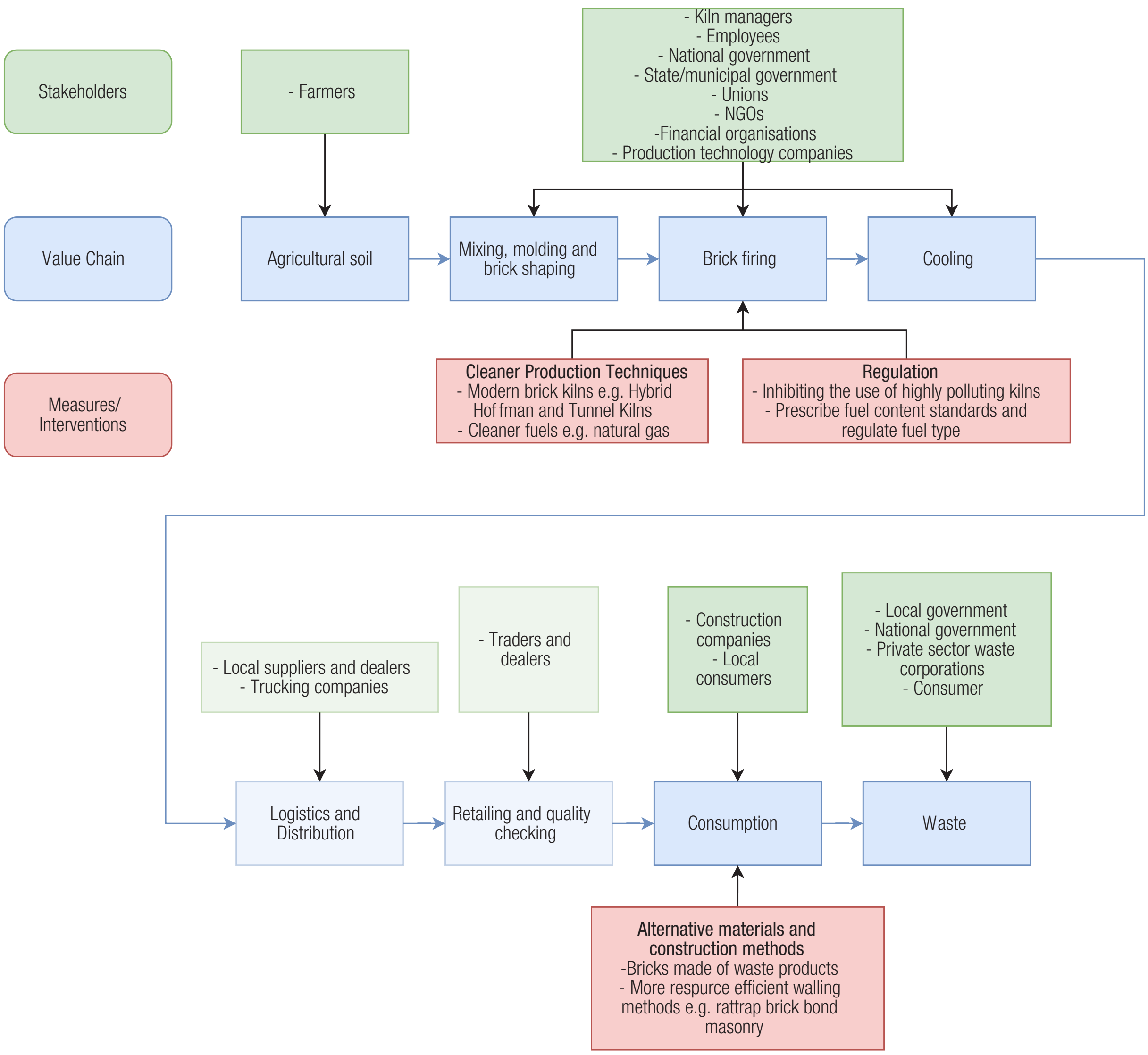
51 https://www.ccacoalition.org/en/resources/national-strategy-sustainable-brick-production-bangladesh

52 See https://ccacoalition.org/sites/default/files/resources/2019_Report_Bangladesh%20Brick%20Sector%20Roadmap.pdf

53 See https://www.icimod.org/

54 See https://www.ccacoalition.org/en/initiatives/bricks

Figure 47. Brick value chain and associated stakeholders



a resulting 60 per cent decrease in PM and a 40-50 per cent reduction in coal consumption. This was partly achieved through the development of a design manual for improved fixed chimney zig-zag brick kilns[55] and provision of engineers to assist with reconstruction, though entrepreneurs were responsible for their own investment. The manual was developed with the input of brick associations, MinErgy[56] (an NGO working on efficient technologies, GreenTech[57] (an advisory firm) and the Climate and Health Research Network[58].

Brick Associations (e.g. Brick Kiln Owners' Association of Pakistan) are also important stakeholders in the industry. As part of these initiatives, ICIMOD have facilitated the Federation of South Asian Brick Kilns Association which unites brick entrepreneurs and associations across the region to establish a regional approach to meet the demand for clean bricks in a sustainable way. The Federation aims to optimize South-South knowledge exchange, once well-established it will function independently

55 See https://lib.icimod.org/record/31703

56 See http://www.minergynepal.com/

57 See https://www.greentechnology.com.np/

58 See https://climateandhealthresearch.org/

from ICIMOD. To improve energy and resource energy efficiency and support from ICIMOD, the Federation of Nepal Brick Industries has invested in the establishment of an incubation centre, which allows brick manufacturers to test soil properties and calorific value of coal. ICIMOD are also working to address the socio-economic issues with the brick industry including the poor working conditions and gender inequalities.

An example focused on the consumption stage in the value chain is SUSBUILD Bangladesh[59]. Completed in 2019 the project aimed to promote sustainable building in Bangladesh through alternative construction materials and technologies. SUSBUILD was a SWITCH ASIA project, which is funded by the EU and provides grants for sustainable consumption and production projects. Oxfam were the lead partners alongside the Bangladesh Housing and Building research Institute and other national partners. Key lessons learnt from the project were that there is no single solution to the traditional use of bricks and that fluctuating market demand and supply are barriers to investment. There is also a hesitancy to invest in greener technologies without direct financial support[60].

4.5 Summary of manufacturing pollution in SA in the context of stakeholder responses from Bangladesh and Nepal

This section summarises the information gathered for SA from the international data and literature review within the context of the findings from the interviews with stakeholders from Bangladesh and Nepal. This allows an assessment of the level of agreement on key issues related to manufacturing and pollution that can be gained from accessible data sources vs stakeholders working with manufacturing in their particular country contexts.

The manufacturing industry is important for SA, and provides approximately 15 per cent of the region's GDP (WDI, 2018) and 12 per cent of the region's employment (ILO, 2020). India is by far the dominant manufacturing country in the region (especially when measured in terms of total exports), followed by Bangladesh and Pakistan (OECD, 2018). The key manufacturing industries in SA are textiles, wearing apparel, food, beverages, chemicals and chemical products, and non-metallic mineral products. Stakeholders in Bangladesh and Nepal identified the textile and leather industries as the key manufacturing industries likely to cause pollution in their countries (see figure 48 and figure 49). Stakeholders also identified brick kilns (a subsector of non-metallic mineral products) in Bangladesh as well as informal recycling and the construction industry as particularly polluting activities (though construction falls outside of the manufacturing industry, according to the ISIC classification). Stakeholders observed that the rapid growth rate of industry in Bangladesh is occurring with limited implementation of regulations. Due to the relatively low level of manufacturing in Nepal, pollution levels were generally reported to be low though illegal waste dumping was identified as a key area for concern along with extremely limited implementation of pollution control regulations.

The systematic literature review identified a large number of industries as potentially harmful in terms of human health effects. However, this assessment needs to be treated with some caution due to the fact that the majority of studies investigate pollutants and impacts associated with multiple industries (of 238 articles identified for the seven most polluting industries less than half focused on a single industry). The hazardous pollutants most commonly associated with manufacturing activities were potentially toxic metals, dyes (e.g. malachite green, methylene blue), bleaching agents, air pollutants, organic wastes, oil and grease, sulfates, phosphates and nitrates. As with SSA, noise pollution was also identified as a substantial hazard. These pollutants had the potential to cause a variety of adverse health effects including cardiovascular and respiratory problems, cancers, neurological diseases, reproductive effects, gastrointestinal, irritation and inflammation.

Industrial zoning was identified as particularly relevant to the manufacturing industries in SA. Stakeholders in Nepal described how the government is trying to find ways to better manage pollution from micro-

59 See https://www.switch-asia.eu/project/bangladesh-susbuild/

60 See https://www.switch-asia.eu/site/assets/files/1513/susbuild_bangladesh_impact_sheet.pdf

Figure 48. Hierarchy chart of the interview themes in 20 semi-structured interviews with stakeholders in Bangladesh

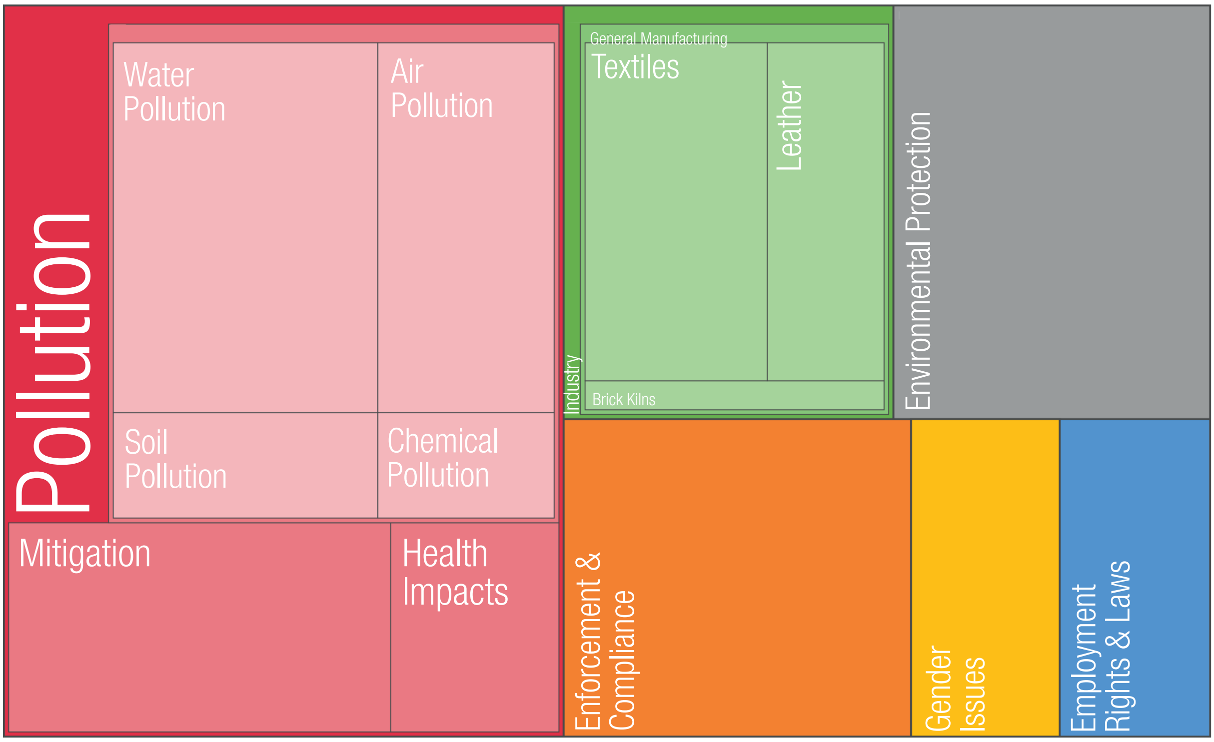
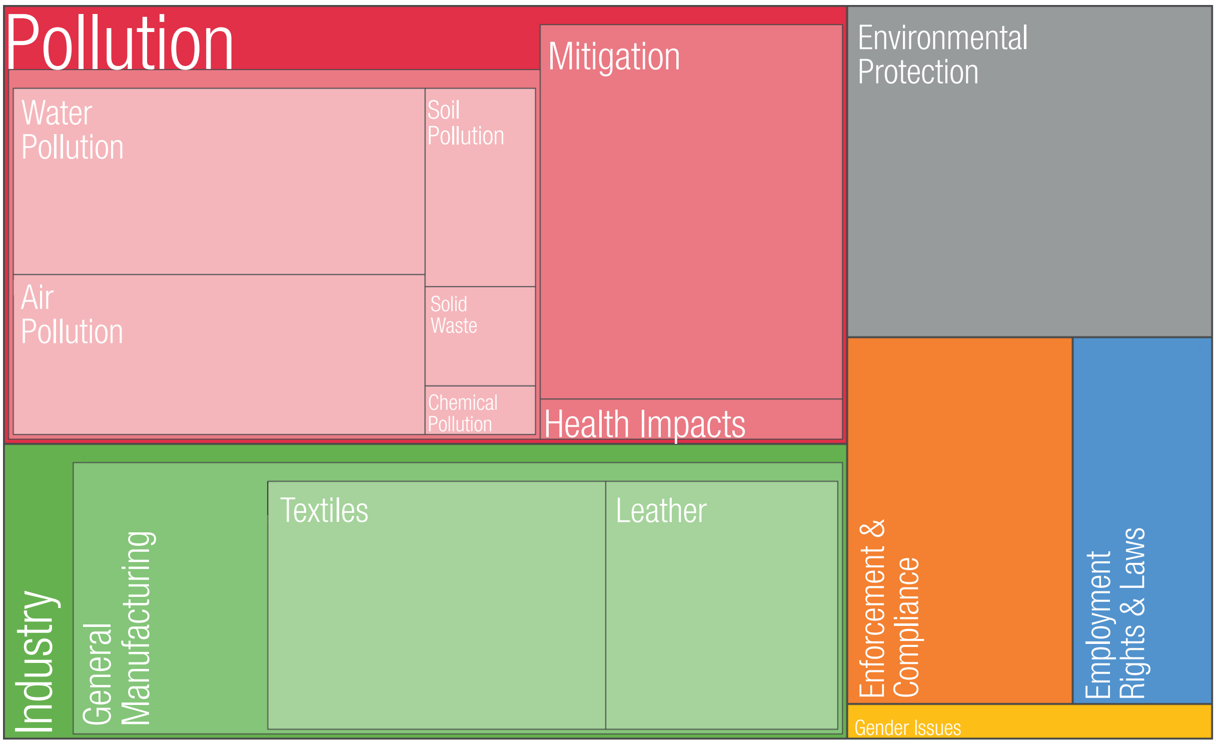


Figure 49. Hierarchy chart of the interview themes in 17 semi-structured interviews with stakeholders in Nepal



and small-scale industries by moving them to 'industrial villages' at a particular location. These 'industrial villages' will be funded by a three-tier government system, with the aim being to create shared responsibilities leading to low-cost, more efficient, and cleaner production systems. Industrial zones will provide employee accommodation and other facilities, employee training and equipment procurement. Stakeholders also described how the government has launched efforts such as funding for wastewater purification in the leather sector. Currently, the government is working to increase the scale of the industry, by requiring factories to have at least 30 per cent local sales before their remaining goods can be exported.

External drivers were also identified as being important in determining the sustainability of the manufacturing sector. The economy of Bangladesh is driven largely by the manufacturing sector, especially by exports that have more than doubled in the last decade. The resulting scaling up of the manufacturing sector, often without improvements in regulation and, perhaps more importantly, regulation enforcement, has resulted in increased occupational health and safety issues and worsened environmental degradation. For example, the government has enforced a minimum wage standard that has not yet been implemented by employers in the manufacturing sector. Consequently, over the last seven to eight years, worker pay has risen three times but has not kept pace with the increase in other expenses such as housing or consumer goods, meaning workers are typically worse off overall.

Occupational health has been highlighted in many of the industries. Improvement could help limit human health impacts caused by pollution from manufacturing. Stakeholders in Nepal stated that most employees were migrant workers, whose main priority is to earn a wage irrespective of the working conditions. Hence, there is little incentive for employers to provide PPE; there is also a cultural issue in the use of PPE, with workers wanting to portray themselves as "bahadur" (strong).

Stakeholders also suggested that the level of awareness regarding environmental pollution is increasing, especially among younger people. However, there is a knowledge gap when it comes to understanding the relationship between pollutant toxicity and disease, even among health care workers. NGOs and citizen groups are working towards increasing awareness of the threat from pollution among the general population. Stakeholders in Nepal also identified the lack of collective government action as a major issue limiting the implementation of interventions to reduce pollution. This is in part due to certain major political changes and the fact that the current government is still relatively new in post and working its way towards forming substantial effective policy interventions to tackle environmental pollution issues. There are some emerging success stories, for example in addressing pollution in the Bagmati River, which flows through the heart of Kathmandu. Collective efforts between citizen groups and the government are having some success in keeping the upstream areas of the river clean and reducing the levels of untreated industrial effluent entering the river.

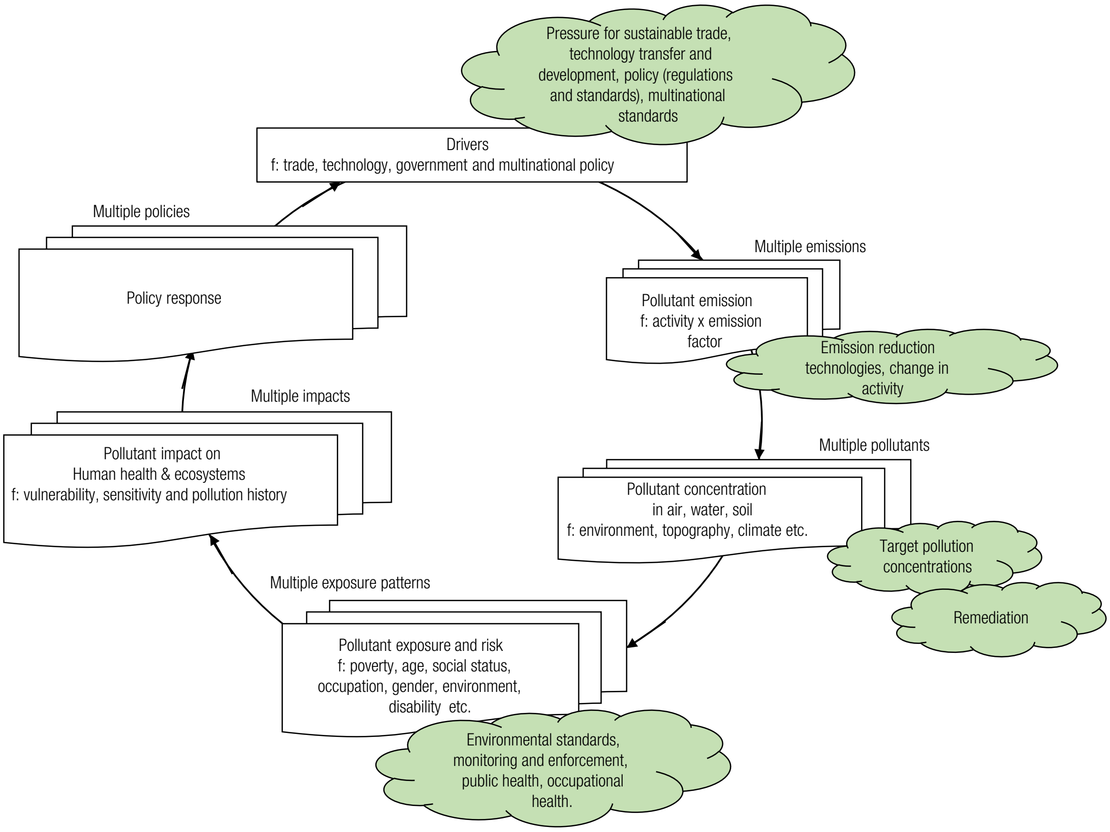
5. CONCLUSIONS

This study has enabled the identification of factors common to manufacturing industries that are important in determining the scale and extent of pollution and its impacts. These key factors are summarized in figure 50, which uses a DPSIR (drivers, pressure, state, impact and response)[61] framework 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 e.g. environmental factors) which will lead to pollutant 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 are developed to reduce pollution impacts, the green clouds in figure 50 indicate that different policy responses can be implemented at different parts of the pollution chain. An important aspect of the DPSIR framework for manufacturing pollution is the multi-pollutant nature of emissions and their subsequent concentrations, which 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 lead to complex pollutant concentrations that vary with proximity to the emitting source and that also vary 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. Similar factors are at play that determine impacts on ecosystems. This level of complexity highlights the difficulty in prioritising action to reduce manufacturing pollution and decide which industries (or groups of industries) are most polluting. This requires identification of the key pollutants affecting human health that arise from particular industries. This may depend on the length of time that the polluting industries have been in operation since this will determine how the pollutant concentrations have built up over time in soil and watercourses. Even with identification of the key pollutants it is necessary to define safe target pollution concentrations which will vary with the vulnerability and sensitivity to pollution of the population that faces exposure. The key approaches to tackling pollution along the DPSIR chain, start with changes in the initial drivers of pollution (e.g. developing sustainable trading systems, improving and transferring technology, developing national and international regulations and standards) and continue with interventions that include emission reductions, remediation of toxic pollutant concentrations and monitoring and enforcement of pollution standards. Identifying target pollutant concentrations is a crucial step in the effective implementation of interventions since they allow optimization of emission reductions and remediation measures. The identification of targets 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 such 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 use of the DPSIR framework allows issues along the pollution chain to be explored in more detail and with reference to particular manufacturing industries, in particular countries and regions and for particular socioeconomic and political contexts. Section 5.1 explores each of the links of the chain in turn, following the structure of figure 50. It is useful to start with pollutant emissions and concentrations and discuss approaches that could be introduced to improve the identification of the key industries causing the most serious levels of pollution causing damage to human health and the environment and to assess and monitor changing pollution levels over time. Interventions are then considered that might reduce

61 The DPSIR framework assumes a chain of causal links starting with 'driving forces' (economic sectors and human activities) through 'pressures' (emissions and waste) to 'states' (physical, chemical and biological) and 'impacts' on ecosystems, human health and functions, eventually leading to political 'responses' (prioritisation, target setting and indicators).

Figure 50. Key issues that influence the scale and extent of human health and ecosystem impacts from manufacturing industry pollution



Note: 'f' denotes factors that are important in determining the different aspects of the DPSIR framework.

emissions or remediate sites that are already polluted. A discussion of some of the key variables that will affect human exposure, risk and vulnerability, focusing here on gender and social equity, age and environment follows, with consideration of how these issues relate to public and occupational health programmes. Finally, drivers of the manufacturing industry are discussed in relation to how these might support change to more sustainable practices.

5.1 Pollution pathways and responses

5.1.1 Pollutant emissions and interventions

This study has identified emissions of a variety of pollutants from the manufacturing industry including metals, dyes, metals, bleaching agents, air pollutants and pharmaceuticals. These pollutants are emitted directly to air, water and land, with the level of emissions being a key factor determining the consequent concentration of the pollutant in the environment and hence the hazard it may pose. Quantifying emissions of pollutants is theoretically straightforward, being a function of the level of manufacturing activity (that creates the emission) and the emission factor of each pollutant (i.e. the rate of emission per unit of manufacturing activity). The effect of emission reduction technologies can also be estimated if the effectiveness of abatement or recovery technologies is known. As such, pollutant emissions can be calculated as described in the equation below (Vallack et al., 2020):

$$\boldsymbol{E} = \boldsymbol{A}\ x\ \boldsymbol{EF}x(\mathbf{100} - \boldsymbol{R})/\mathbf{100} \qquad \text{eq. (1)}$$

Where E = emission (kg/year), A = activity rate (i.e. annual rate of production of the relevant commodity) (metric ton/year), EF = emission factor of the manufacturing process for a pollutant (kg/metric ton) and R = abatement/recovery efficiency (per cent). The

emission abatement efficiency (R in eq. (1)) depends on the proportion of total capacity in the manufacturing sector subject to controls (see Vallack et al. 2020 for further details).

However, this equation requires data for each manufacturing plant and for each pollutant. In the developing countries of SSA and SA, plant level monitoring of emissions to air, water and soil is virtually non-existent. This is due to the extremely limited availability of reliable monitoring equipment, limited data storage, and the lack of trained personnel with the knowledge and skills to deploy and use such equipment to collect data. This means that estimating pollution loads associated with the wide variety of manufacturing processes that exist is virtually impossible (Odesanya et al., 2012). Similar methods have been developed to provide coarse assessments of pollutant emissions. For example, the IPPS approach (see section 1.3.2 and Odesanya et al. (2012)) estimate a pollution load according to the following equation:

$$\boldsymbol{PL} = \frac{\boldsymbol{PI \times TEM}}{\boldsymbol{1000 \times 2204.6}} \quad \text{eq. (2)}$$

Where PL = pollution load (metric ton/year), TEM = total number of employees, PI = pollution intensity in pounds per thousand employees per year, and 2204.6 is the conversion factor from pounds to tons.

The application of these broad-brush methods is complicated by data availability. Data are lacking on the variety, number, size and scale of manufacturing industries that are sources of pollution across SSA and SA. The IPPS estimate also provides no indication of which media the emissions are released into: to the atmosphere (as gases or suspended particles, i.e. dust); to watercourses (e.g. as waste effluent that can also contaminate land via irrigation); or to the surrounding land surface and soil (e.g. as solids). This information is crucial to understanding the contaminant pathways that will lead to human health effects such as inhalation from the air; drinking from contaminated watercourses; or via uptake of contaminants by agricultural produce and ingestion. Some pollutants such as toxic metals also bioaccumulate in food commodities such as crops and fish, meaning concentrations can increase up the food chain. The pollutant pathways that are specific to each of the industries explored in this study are provided in sections 3.4 and 4.4. The Lancet report (Landrigan et al., 2018) stresses the importance of data collection and monitoring and suggests the use of new technologies such as satellite imaging and data mining as part of the solution.

Accurate estimation of emissions allows an assessment of the need for and effectiveness of interventions for emission reductions. These are often technological interventions that can either make the manufacturing process more efficient, alter the process so that emissions are reduced, or extract contaminants before they are released into the environment. Often GHGs are co-emitted with those pollutants from manufacturing industries that have direct toxic effects, so introducing emission reduction options may also help counter climate change, for example by introducing cleaner technologies in brick kilns (ibid.).

Unfortunately, there are many barriers to implementing technological solutions. Even when interventions are available, uptake can be low. For example, stakeholders in Bangladesh felt that the larger manufacturing industries had sufficient resources and so were generally good at implementing environmental pollution control measures, but small-scale industries, which made up most of the sector, had fewer control measures and tended to release polluting substances unabated. In addition, the 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. Alongside financial barriers, the education level of workers is thought to influence uptake of interventions, with better-educated individuals more likely to adopt them (World Bank, 1999). Hoque and Clarke (2013) indicated that a key factor in industrial pollution is the lack of awareness of plant managers about the serious consequences of pollution and called for more research to better understand drivers of adoption of pollution prevention initiatives.

A further barrier to uptake in developing countries is the lack of enforcement of pollution initiatives. The World Bank (1999) report recommended flexible and targeted pollution charges, social pressure and informal community regulation as successful mechanisms in countries where enforcement capacity is low. The report also emphasized that a pollution agency needs to be credible to be successful and

advocated obtaining political support and using information technology. These recommendations were criticized by Rooij (2009) on the grounds that they are undermined by the prevalence of weak law enforcement in developing countries; positive changes can be attributed to increased monitoring and regulatory pressure. Rooij (2009) also emphasized the need for law enforcement to reprimand non-compliant polluters and accurate monitoring data for these interventions to be successful. This theory was also supported by the stakeholder interviews: Bangladeshi stakeholders identified lax implementation of rules as an issue. This suggests that additional resources and improved regulations are needed to successfully implement pollution regulations. Stakeholders in Nepal noted a similar lack of enforcement of governmental policies. This was attributed to industry lobbying as well as a lack of human resources,technical capacity and knowledge in implementing factory inspections. Consequently, illegal waste dumping has become a key concern in Nepal.

In Kenya, stakeholders were aware of the broad range of pollution mitigation and control measures employed by industries (social, institutional and technical measures) as well as governmental support of industrial compliance using fiscal incentives such as subsidies and tax rebates. They listed several means by which they were enforced (e.g. impact assessments, audits, notices of improvement and banning of products, legal measures and closures of industries) but effectiveness of pollution control and mitigation measures were not known. Moreover, while the respondents from industries and industry associations maintained that levels of pollution are well managed and within standards, respondents from state corporations and NGOs alleged the existence of high levels of industrial pollution. Kenyan stakeholders also identified a number of recommendations on improving industrial pollution control and mitigation including: streamlining the coordination of enforcement agencies and regulatory mechanisms; allocation of adequate resources for the enforcement of existing legal and regulatory instruments; public sensitization on pollution control mechanisms; and incentives for manufacturers to adopt cleaner production and zoning and re-planning of industries in relation to human settlements. Stakeholders identified as challenges the lack of internal industry capacity to install intervention measures and the high costs of pollution control and mitigation.

5.1.2 Pollutant concentrations and target setting

Manufacturing activities emit a variety of pollutants to air, water and soil. Manufacturing activities proximally located in industrial zones very likely lead to a pollution cocktail arising from multiple sources. These pollutants mix and may undergo transformation within these media with pollutants from other sectoral activities (e.g. transport, industry and power generation).

The impact that pollutants have on human health and ecosystems will depend on the levels of pollutant concentrations in these media to which the receptor (human or ecosystem) is exposed, how these change over time, the vulnerability of the receptor and the exposure pathway (see section 5.1.4). The variety in levels of toxicity of different pollutants, in different media and for different receptors (with varying sensitivity) have resulted in the development of a large range of target levels for pollutants, commonly referred to as pollutant standards.

Standards for particular pollutants and media often vary depending upon who sets the standard, both in terms of the pollutant concentrations for a given response but also in terms of the response parameter. For example, standards from the United States Environmental Protection Agency (USEPA) and the EU may be more stringent than other national government standards, which may result in lower levels of risk. It may also be that conditions in a country or region may influence the acceptable level of a pollutant, which may be due to scientific reasons or socioeconomic and political considerations. Stakeholders in Kenya identified limited collaboration between industries and enforcement agencies during policymaking and standard setting as a barrier to the adoption of interventions to reduce emissions.

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. More sophisticated 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. There is a lack of clear and harmonized standards against which to assess what level of pollution might provide a safe level of exposure, and there is also limited information on how exposures above this level might translate into impacts. Impacts will also vary with factors that affect exposure and toxicity (see section 5.1.3). Identifying key pollutants and appropriate standards that are particularly relevant to the manufacturing industry from the international literature could support the development of a more robust risk assessment framework.

5.1.3 Pollutant exposure and risk

Occupational exposure

Those who work directly in industrial and manufacturing processes (e.g. factory floor-level employees) are at the greatest risk of direct exposure to any potentially harmful pollutants that are either considered inputs, outputs or by-products of the production process. Workers may be exposed through a number of different routes including dermal contact via direct handling of toxic effluents, solids or wastes and the inhalation of toxic fumes or dust.

The degree of exposure and risk is greatly influenced by working practices and conditions as well as the vulnerability of different worker groups such as migrants, women and children. In the case of migrant labour in Nepal, many of whom work in manufacturing, some stakeholders suggested that due to their immediate need to earn money they were more willing to work in poorer conditions. 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. Indeed, even exposure to low doses of pollutants during key developmental stages can be more harmful to children than higher doses of the same pollutants in adults (Suk et al., 2016; Landrigan and Fuller, 2014). With respect to potential risk and exposure differences between men and women, it should be noted that the lack of gender-disaggregated data for different manufacturing sectors and production processes makes it difficult to identify where men or women may be more likely to be exposed to key pollutant risks.

Nevertheless, the evidence suggests that improved working practices through the provision of suitable and adequate PPE could reduce the overall level of occupational risk and exposure. Unfortunately, PPE provision across industries in SA and SSA is generally quite low. In Nepal, some informant stakeholders suggested that the low prevalence of PPE use stems mainly from a lack of awareness, as well as a cultural belief that using PPE displays weakness. In addition, the costs associated with supplying PPE alongside the lack of pressure exerted by employees for improved working conditions were identified as further reasons for lack of PPE use. In contrast, in Bangladesh, since the 2013 Rana Plaza incident where a garment factory collapsed killing over 1,000 people, the general awareness of occupational health and safety has increased substantially, and there is evidence that the use of PPE is observed in many major industries (ILO, 2018b). Despite this some employers, especially in small industries, are less inclined to provide PPE to avoid higher production costs. Furthermore, in hotter climates where wearing PPE may cause discomfort, there is a tendency to be less observant in its use.

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; because unemployment is often high, and thus they are dispensable. Those who are less educated and more dependent on industries for employment are less able to act as informal regulators and pressure plants to reduce pollution (World Bank, 1999). Furthermore, in the case of women employees in SA, gender norms and social structures function to restrict their mobility, free time and other employment opportunities, preventing them from uniting around common issues and forming trade unions (Nazneen et al., 2019). Moreover, existing trade unions are set up and run by men to tackle issues experienced predominantly by male workers.

Importantly, only once the specifics of how certain factors, such as age, sex, body weight, working hours and type of PPE, influence exposures are understood can target pollution concentrations be established.

Household exposure

Beyond those that work in manufacturing, local residents living in relative proximity to manufacturing industry sites are also open to being exposed and at risk from industry-associated pollutants through contaminated water sources, crops and livestock. Residents who are malnourished are also more likely to be more affected by pollution (Sekhar et al., 2003). In Kenya, stakeholders noted that 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. If pollution is reduced land and house prices go up, forcing low-income households to move elsewhere (World Bank, 1999). In Kenya, one of the reasons for co-location was the expansion of informal settlements near industrial areas.

Industrial zoning

Industrial zoning has been widely adopted in SA. Stakeholders in Nepal explained that the government is working towards developing certain clusters and industrial areas called ‘industrial villages’ focused on moving all the micro- and small-scale industries to a specific location. Similarly, in Bangladesh, according to key stakeholders, most of the textile and tannery industries have been moved from Dhaka in order to improve industry networks and occupational health and safety and tackle the industrial pollution problem. 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.

Climate change

There is some evidence that climate change may exacerbate pollutant exposure. Elevated temperatures can enhance the toxicity of some pollutants, decreased precipitation in some regions can enhance volatilization of persistent organic pollutants and pesticides, areas with increased precipitation will likely have elevated surface deposition, and storm events could increase severe events of water contamination (Noyes et al., 2009).

5.1.4 Pollutant impact

A large variety of ecosystem and human health impacts can be caused by pollution from the manufacturing sector. This study has focused on human health impacts, identifying key pollutant types that are known to cause impacts when concentrations exceed safe limits. In an attempt to identify the most polluting manufacturing industries key health impacts were identified: cardiovascular and respiratory diseases, carcinogenic effects, neurological conditions, reproductive toxicity, and irritants and inflammation. However, it is clear from the literature that manufacturing sector pollutants can cause a far wider range of health impacts. It is also clear (and emphasized in the recent Lancet Commission on pollution and health) that knowledge of the causal links between pollutants, exposure and disease is limited (Landrigan et al., 2018; see also section 2.5).

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. There is also evidence that men and women have different toxic thresholds to certain pollutants. Most work on these gender differences has explored the impact of pollutants (e.g. organic Hg, Pb) on reproductive health (Rim, 2017) and reproductive cancers. This has important repercussions, particularly in relation to pollutants produced from industries with high female employment, such as the textile industry. Further research is urgently needed to better understand differential toxicity to pollutants by gender; such research could be prioritized by focusing initially on pollutants with strong gender disparity for environmental risk factors (Butter, 2006). The exposure route (e.g. uptake via inhalation

or ingestion) will also influence the magnitude of response; additional metrics can be used that are more directly relevant to impacts (e.g. level of pollutant concentration in blood).

Far more research is required to fully understand the range of diseases and disability that exposure to pollutants from the manufacturing industry can cause. This research would ideally be conducted in collaboration with occupational and public health bodies. There is also a body of literature that recommends that physicians and health care providers be trained to recognize and manage pollution-induced diseases. This effort should take place in parallel to the formation of an international clearinghouse to track the global movement of toxic pollutants and defining health effects, similar to the International Agency for Research on Cancer (Suk et al., 2016).

Gender and social equity

It is also important to be aware that diseases caused by pollution generate economic costs, including medical and opportunity costs from reduced productivity (Suk et al., 2016). It has been estimated that in rapidly developing countries seven per cent of health spending is on people made ill by pollution (Landrigan et al., 2018). At the same time, pollution that causes cognitive impairment can lower national intelligence levels and subsequently impact productivity (Suk et al., 2016). Despite these negative impacts, manufacturing represents an important development activity. 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 (UNIDO, 2019b). Female employment in manufacturing tends to concentrate in particular industries, often due to the perceived higher productivity of women. For example, the wearing apparel industry can be an important source of employment for women, and in several developing countries it has shown the potential to improve their economic and social status while narrowing the gender gap and reducing income poverty (ibid.). In Bangladesh, women working in the garment industry act as a cultural flagship, providing a visual example of changing gender norms; this can increase girls' enrolment in schools and delay marriage and childbirth (Nanzeen et al., 2019; Heath and Mushfiq Mobarak, 2015).

However, employment in itself is not necessarily empowering, and work is often too poorly paid to overcome poverty or vulnerability (Nanzeen et al., 2019). From a gender equity perspective, women are generally employed in low-skilled labour such as beverages, textiles and wearing apparel (particularly in sweatshops in Bangladesh) (Ahmed et al., 2015). In India, women are vulnerable to economic downturns because they are mostly engaged as temporary or casual low-skilled workers in labour-intensive roles (Mehrotra and Parida, 2017). Further, employment can intensify the burden of unpaid care work (Nanzeen et al., 2019) 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 (Mehrotra and Parida, 2017).

Moreover, at higher levels of industrial employment, there is a lack of female representation. A study in Ghana found that women were underrepresented on corporate boards (Amidu and Abor, 2006). Strong arguments have been made that policy needs to promote equitable access to education and skill development to close the gender gap (Ahmed et al., 2015). It is important to note, however, that gender-disaggregated employment data are largely lacking from international datasets for SSA and SA, even though this is a metric targeted for collection (UNIDO, 2020).

Finally, the technological advancements that often occur with increasing capital investments in manufacturing can improve gender equality at the national level. However, they can also reduce the demand for unskilled workers. Given that women are predominantly employed in low-skilled labour, this can result in the 'defeminization' of industry (Seneviratne, 2020; Tejani and Milberg, 2016). This has occurred in the textile and garment industry in Sri Lanka, where the proportion of women in the workforce fell from 78 per cent in 1992 to 63 per cent by 2014. This was attributed to rising global competition that led to an upgrading of manufacturing processes, resulting in an overall reduction in employment, particularly of low-skilled women (Seneviratne, 2020). Similarly, India has witnessed rising inequality (not necessarily just for women) with the adoption of technology and more advanced processes (Kapoor, 2016).

5.1.5 Drivers

Industrialization is often seen as a pathway to greater economic growth. As such, 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 the Sustainable Development Goal (SDG) 9. This 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 (UNIDO, 2019), 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. This section discusses drivers that might influence more sustainable production.

Consumer demand

The globalization of manufacturing consumer demand is significant and can cause fluctuations in demand for various products. For example, a contributor to the falling demand for textile and leather products in Bangladesh is an increase in consumer demand for cheaper, synthetic leather products from Viet Nam and China. This suggests the need for a transparent supply chain so consumers can make informed choices on which products to buy and encourage more sustainable production through their purchasing power.

This study has found that the textiles industry is one of the most polluting manufacturing industries in SA and SSA. A variety of interventions to reduce pollution are available but often not implemented. The textiles industry is unsustainable for reasons other than just the pollution associated with manufacturing processes. It relies mostly on non-renewable resources – 98 million tons in total per year – including oil to produce synthetic fibres, fertilisers to grow cotton, and chemicals to produce, dye, and finish fibres and textiles. Textiles production (including cotton farming) also uses around 93 billion cubic metres of water annually, contributing to problems in some water-scarce regions (Ellen MacArthur Foundation, 2017). A further 85 per cent of textiles, 21 billion tons, are sent to landfills (UNECE, 2018) with between 10–20 per cent of textiles wasted during garment manufacture (Lau, 2015). The development of different methods and ideologies to better understand which parts of a product's life cycle are most likely to reduce sustainability (e.g. life cycle analysis and circular economy ideologies) have the potential to identify and thereby promote cleaner production. A variety of technological innovations are being used by fashion brands and manufacturers to make clothing production and consumption more sustainable. These vary from the use of plant-based textiles and bacteria-based dyes to using waterless systems, recycling textiles and blockchain-based supply chains to increase transparency. To support these innovations the following changes in business policies, practices and behaviours could be considered to reduce pollution associated with the manufacturing of textiles as well as other negative externalities associated with the industry:

- Comply with all applicable international and national policies and regulations;
- Review a chosen international certification standard linked to sustainability and follow the guidelines of the certification to ensure the product manufactured is of a certain quality;
- Review production processes, and initiate circularity and efficient use of resources;
- Source responsibly, ensuring all inputs are sustainably approved;
- Engage in environmental audits, provided by agencies like SMETA (ethical trade auditors) and EcoVadis (business sustainability ratings);
- Engage with other digital and technological solutions to achieve improvements in environmental practice and waste management across the supply chain;
- Upskill the workforce in sustainability, ensuring commercial leads on the incorporation of environmental best practice.

Governments have an important role to play to introduce and enforce policies and legislation using

mechanisms such as tax incentives and stimulating integration of environmental technologies across the supply chain. Together with the practices outlined above, this could result in a more efficient allocation of resources, better working conditions and the use of sustainable materials that could boost profit margins by 1–2 per cent by 2030 (Global Fashion Agenda, 2019). In addition, practices would generate goodwill and improve the accountability of the industry to the public. 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 (Fadnis and Arnold, 2018) and struggle to afford cleaner production processes due to their low economies of scale. The impact that the COVID-19 global pandemic may have on these smaller enterprises will play out over time but substantial reductions in turnover in the textile industry of 30 per cent in SA and 25 per cent in Africa for the period of May 20 to June 8 (relative to the same period in 2019) could have serious ramifications (ITMF, 2020).

Trade

Improved infrastructure, geopolitical relationships and a reduction of trade barriers have all contributed to the expansion and global spread of product manufacturing (Pure Earth and Green Cross, 2016). Clearly, international and national trade systems play an important role in the material flow of manufactured commodities across the globe and can also influence 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. For example, 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 (World Bank, 1999). Indeed, the Lancet Commission proposed that governments terminate subsidies and tax breaks for polluting industries as a means to bear down hard on the worst-polluting manufacturers (Landrigan et al., 2018).

Global trade arrangements can also be a double-edged sword, and more often favour those nations with greater political and economic sway. In Bangladesh, according to stakeholders, a major problem with the ready-made garment industry is that fabrics and cotton are imported from elsewhere in the continent, meaning a limited amount of the revenue earned stays in Bangladesh. Furthermore, the rising influence of China is changing global manufacturing dynamics (Muradian et al., 2012). China is an important hub of cheap manufacturing and stakeholders in Nepal and Bangladesh identified both China, India and Viet Nam as competitors. China is also a rising supplier of manufacturing technology. Botchie et al. (2017) find that garment sewing machines imported from China are cheaper, less reliant on advanced infrastructure and have a greater spread effect, leading to a reduction in technology gaps, compared to those imported from northern economies.

5.2 Future work

This scoping study has highlighted a number of key issues that need addressing to support the move towards more sustainable manufacturing in SSA and SA. These are discussed below within the context of what could most usefully be achieved over the next five years.

5.2.1 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. This will allow an integrated and cross-cutting assessment of the sector's ability to support sustainable growth within such frameworks as the circular economy, regional agendas (i.e. African Union's Agenda 2063) and the SDGs. This could include consideration of the governance, power dynamics and politics at play in each country context, and how these may be barriers to change in manufacturing practices.

Understanding the role of supply chains, consumer demand and multinational companies in encouraging more sustainable and cleaner production. 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) would be helpful to assess what works and what could be improved or adapted for the manufacturing industry in SSA and SA contexts. For example, there could be substantial benefits in the further development of sustainable procurement initiatives and the expansion of the AMR Industry Alliance safe manufacturing framework, to non-members manufacturing antimicrobials, and to the pharmaceutical manufacturing sector more generally. Connections via supply chains and multinational companies may also help support the development of SSA and SA industries benefiting from Industry 4.0 activities. This could explore the relationship between the more traditional SSA and SA manufacturing sectors and next-generation technologies, for example, looking into how industry 4.0 activities might be applied to these sectors to scale up ‘greener’ forms of operationalization and development.

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. Developing methods (e.g. through social science research) to collect data for the informal sector would be important for those manufacturing activities that usually take place under unlicensed conditions. This work could provide a rapid assessment of those manufacturing activities, and locations, that are most likely to pose a threat to workers and residents living close to industrial sites. 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 potential scale of the problem, in line with ambitions for sector growth in national action plans, as well as the role that interventions (such as chemical substitution and biodegradable plastics) can play will help identify future problems and potential solutions.

Understanding the role of poverty and gender in influencing vulnerabilities to pollution arising from the manufacturing sector. 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. The main exception to this is work that has explored occupational health and considers the socioeconomic status of workers.

5.2.2 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 government 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.

5.2.3 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 likely to result from the continued growth and increase in scale of manufacturing activities will be crucial to identify 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. These interventions need to be implemented after consideration of the local context to ensure appropriateness and take-up of new technologies. Working with existing occupational health groups, plant managers and workers themselves to develop suitable occupational health programmes for the manufacturing industry would likely have substantial benefits and could help roll-out of best practice to other similar manufacturing industries in the countries and regions as well as different types of manufacturing activity.

5.2.4 Data improvement and assessment of interventions

Developing and implementing rapid assessment methods building on methods such as those developed by the IPPS 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, e.g. in industrial zones, industrial regions, urban areas, scattered units of activity). Where these data are incomplete, approaches to improve the collection of data (both spatially, temporally and with enhanced accuracy) could be developed, ideally with relevant government departments and potentially using new technologies (e.g. GIS remote sensing applications, and digital technologies that could be used to connect factories to improve supply chains and best practice learning). In this respect, connection to industry 4.0 activities (i.e. the trend towards automation and data exchange in manufacturing technologies and processes) could support identification, trialling and take-up of new technologies. Efforts to identify barriers to industry 4.0 technologies in developing countries are now emerging (Raj et al., 2020).

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) building on recent research efforts that have focused on personal exposure rather than ambient pollution (e.g. Steinle et al. 2013). Together, this information would also help design pollution monitoring campaigns to assess where, when and over what time periods, and using what type of calibrated measuring instruments, pollutant monitoring would ideally be conducted. Standard methods to collect time activity data from which risk of personal exposure can be estimated could also be developed. Along with population data in the affected areas, this would provide estimates of populations at risk of exposure and again help to identify hotspots of hazardous manufacturing activity at sub-national and national levels. Building capacity in the implementation of such methods would be important to ensure standardisation and widespread uptake of these approaches.

Improving exposure assessments that are crucial to determining the potential impact of manufacturing activities causing pollution. There are two key aspects here. First, threshold pollutant concentrations should be established for those pollutants considered most responsible for human health impacts. This requires the key pollutants to be identified, and modelled estimates or physical on-site monitoring of pollutant concentrations to take place along with an assessment of personal exposure for those groups considered to be at risk from pollution. Key pollutants by manufacturing industry could be identified from the information provided in this study. Threshold pollutant concentrations for these key pollutants could be established from information available from different organizations (e.g. WHO, USEPA and EU). For example, for wastewater manufacturing effluent, new science-based threshold concentrations could be established. In developing these thresholds, there should be a move from single compound targets to consider the mixtures of molecules to which real systems will be exposed. Thresholds should also consider 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 prioritise 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, 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. As presented in this study, the level of maturity of these interventions varies (i.e. in development, scaled-up, trialled, implemented, being assessed for effectiveness). The effectiveness of these interventions primarily depends on their cost, how well they are implemented, and their necessity, the latter primarily depending upon enforcement of government regulations or pressure from buyers and consumers along the supply chain. This work could focus on the development of a 'toolbox' of solutions to reduce emissions of hazardous substances from manufacturing sites. This toolbox should incorporate an understanding of the relationships between chemical functionality, physico-chemical properties and the treatability of pollutants, along with an assessment of the feasibility of introducing a system. Toolbox approaches have been in development and application for some years now and could provide a powerful method of tackling pollution from the manufacturing sector (e.g. e.g. Reibstein, 2009).

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, repurposed for smaller scale industries, 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. Is technology transfer likely to benefit cleaner production: what are the costs and benefits and resource requirements in terms of skills, capacity, human capital and so on? How best to leverage coordination across different sectors and actors to work towards improvements in cleaner production technology roll-out within the contexts of SSA and SA? Consideration also needs to be given to whether interventions are culturally acceptable (e.g. would workers be prepared to wear PPE?) and the package of fiscal measures (e.g. fines, subsidies and other incentives that would encourage consumer product purchase) that would be necessary to make them cost-effective and hence attractive to plant managers.

It will be important to understand whether economies of scale are possible, especially where multiple manufacturing industries could be co-located that have similar needs, for example, in terms of wastewater effluent clean-up. Further considerations include whether multi-industry measures benefit from coordinated government subsidies for the establishment, operation and maintenance of large-scale, multi-industry EFTs. It will be important to gain an understanding of these issues from in-depth consultation with employees, manufacturing managers, government representatives and trade union representatives to support the co-design of interventions. This will help identify the opportunities and barriers to the uptake of interventions within manufacturing industries and allow interventions to be better tailored to particular industries, locations, regulatory contexts and socioeconomic situations.

5.2.5 Collaboration among stakeholders

Establishing collaborations 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 NGOs and civil groups. An initial, non-exhaustive, mapping of existing initiatives has been conducted in this scoping study and identifies some of the more important initiatives that exist for the key polluting manufacturing sectors identified. It will be crucial to conduct a comprehensive mapping of initiatives, activities and stakeholders for targeted manufacturing to ensure collaboration and avoid duplication of future efforts to reduce pollution from the manufacturing sector. This will also have the benefit of identifying opportunities for capacity building the knowledge, skills, and expertise required to reduce pollution from manufacturing. This capacity building should be conducted across a range of stakeholders (e.g. technicians, researchers, policy makers, NGOs, etc.) through international, regional and national cooperation to help achieve timely, effective and

mutually supportive implementation of interventions to reduce pollution from manufacturing.

The activities described above could create a framework within which individual activities could drive forward particular aspects of work (i.e. related to particular manufacturing industries, particular stakeholders, and targeted to supporting development within particular sustainability frameworks). To provide solid grounding for this range of activities the following could be prioritized in the shorter term:

- Establishment of target concentrations for key manufacturing pollutants and pollutant mixtures, building on guidelines available from international and national bodies such as WHO, the USEPA and the EU;

- Detailed investigation of a range of interventions and technology transfers for key manufacturing industries, including an assessment of the physical capabilities and socioeconomic benefits, feasibility and cost-effectiveness of interventions for SSA and SA settings;

- Identification of key partnerships and collaborations of regional, national and global stakeholders for particular industries to raise awareness of the overarching ambitions of the five-year SMEP programme.

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