Shifting to Circular Manufacturing in the South: Challenges and Pathways

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Abstract

As the global South shifts towards increased manufacturing, the negative effects on climate change and environmental pollution raise serious concerns. Not only are such effects increasingly felt locally, as reflected in health surveys in the South, but they have global implications in air, land, and marine ecosystems. The world cannot afford to wait for a natural development process to take place where rising incomes would start to curb pollution. The effects are more acute given the limitations of resources and technical capacity in the South. This article examines the challenges for reforming manufacturing in the South towards more sustainable practices, and features lessons from the Sustainable Manufacturing and Environmental Pollution Programme, a series of environmental improvement projects across sub-Saharan Africa and South Asia focused on reducing pollution in the manufacturing process itself. The lessons include the need to improve knowledge and better track the negative effects of environmental damage; the need to break down supply chain processes to better identify potential points of intervention; and the acute need for external support for financial and technical resources to begin to transform the waste infrastructure in the South.

Introduction

Manufacturing is one of the key sources of global pollution. While it is not the largest source of greenhouse gas emissions, lagging energy, transport, and agriculture, emissions from the industry have grown the fastest among different sectors (cumulatively) since 1990 at 187%, according to the World Resources Institute (2021).[1] More promisingly, manufacturing offers multiple pathways towards sustainability. The often-centralized manufacturing location (Rosenthal and Strange 2001) means that businesses and policymakers can focus on key supply-side interventions to transform supply chains, rather than relying upon unpredictable market shifts or technological breakthroughs (Cedillo-Campos, 2014; Leopoulos, Kirytopoulos and Voulgaridou 2007).

Manufacturing is growing fast in the global South. Manufacturing value-added[2] in Sub Sahara Africa and South Asia has seen an approximately 3-fold and 7-fold increase, respectively, between 1990 and 2020 (The World Bank 2021) . In previous years, there was an expectation that economic growth from industrialization would precede a shift to environmental values in the South as part of a "postmaterialist" or environmental Kuznets curve logic. However, there is increasing evidence that populations in the South are paying too high a price to wait for such a transition. In fact, with industrialization comes an increasing burden of environmental pollution and disease. Beyond contributing to climate change, for example, manufacturing contributes to ambient

[1] https://www.wri.org/insights/4-charts-explain-greenhouse-gas-emissions-countries-and-sectors, Accessed Nov. 1, 2021.

[2] Manufacturing, value added (current US$)

particulate matter, now the sixth leading cause of deaths across the globe (HEI 2018). The most significant number of deaths from pollution is concentrated in sub-Saharan Africa, South Asia, and parts of Eastern Europe that were part of the Soviet Union. Contaminants spread through air and water, lead exposure, occupational and contamination sites, and pesticides are leading disease causes (Landrigan et al., 2018).

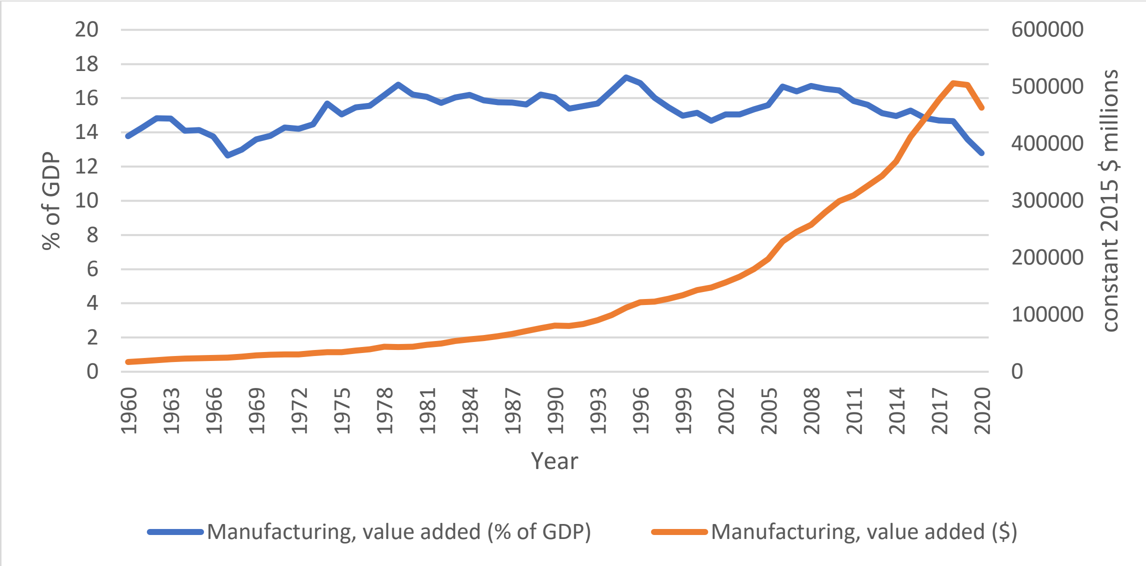
Very few studies of pathways towards green or sustainable manufacturing in the South exist. The literature is too nascent to arrive at any clear conclusions about moving forward. There is not even consistent monitoring of manufacturing pollution effects. However, commonly cited factors inhibit the transition to circularity, such as inefficient and dirty energy systems and lack of finance, knowledge, and market incentives.

This article focuses on a series of experiments to reduce manufacturing pollution at its source in the global South to provide some insights. It shares lessons from the Sustainable Manufacturing and Environmental Pollution Programme (SMEP), a series of projects in South Asia and Sub-Saharan Africa funded by the UK Government at $33.3 million) to reduce pollution and promote a more circular production process. Beyond the challenges cited in the literature, the SMEP projects point to additional obstacles for manufacturing transition, including informality, lack of centralized waste infrastructure, and the need for greater public-private collaboration and awareness-raising.

The Growing Challenges of Pollution in the South

The low wage levels and high population growth of South Asia and Sub-Saharan Africa make them two likely destinations for future global manufacturing growth. Manufacturing is slowing radiating outwards from China, where labor costs have increased. As seen in Figure 1 below, while manufacturing has stayed stable in South Asia as a percentage of GDP, the overall value of manufacturing has risen rapidly in the region, particularly from the 1990s. A slight dip due to the covid pandemic in 2020 is also noticeable.

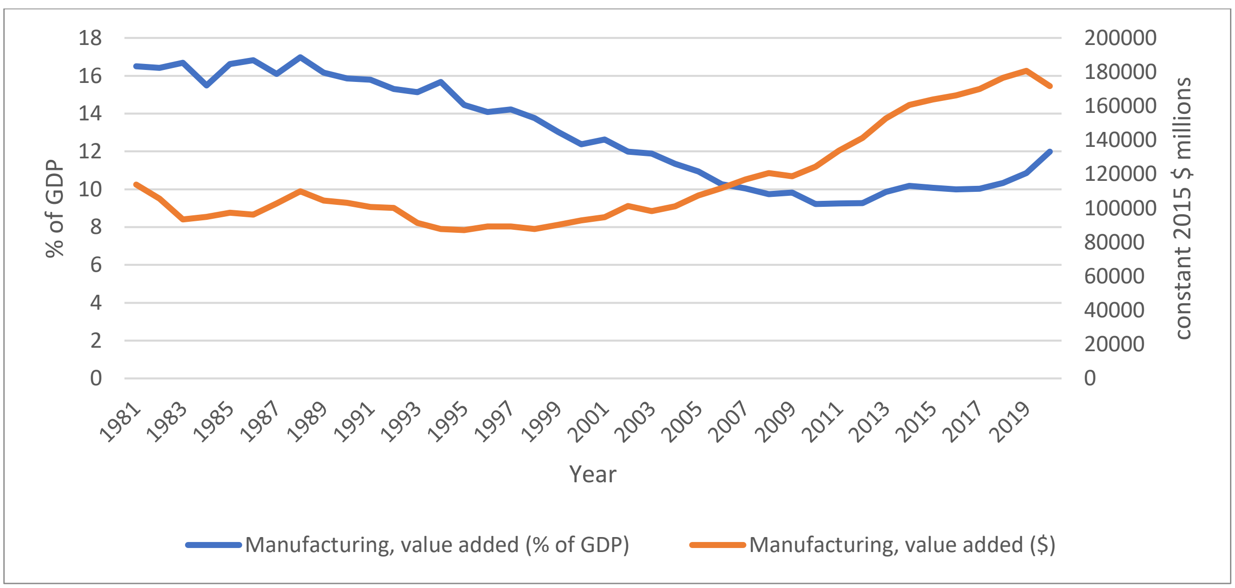
Figure 1: Growth of Manufacturing in South Asia, 1960-2020



Note: Author from World Bank World Development Indicators, accessed Nov. 8, 2021.

Much of Sub-Saharan African production remains centered in agriculture, and manufacturing's overall regional contribution to GDP has dipped in recent years. It is still at a level far below regions in Asia. Yet, we can also see the rapid increase in absolute volumes of manufacturing activity, principally from the 2000s. Manufacturing in the region tends to be concentrated in a few of the largest economies, such as Nigeria, Ethiopia, Kenya, and South Africa.

Figure 2: Manufacturing Increases in Sub-Saharan Africa, 1981-2020



Note: Author from World Bank World Development Indicators, accessed Nov. 8, 2021. 1981 is the first year of the data.

According to UNEP (2021), annual global health costs in 2016 concerning mortality and morbidity caused by exposure to PM2.5 were approximately equivalent to 7.3% and 3.0% of GDP for South Asia and sub-Saharan Africa, respectively. Table 1 below shows the relationship between the SMEP (2018) regions and global estimated deaths per year for leading manufacturing sources of pollution:

Table 1: Estimated deaths from leading manufacturing industries

Sources of pollution	Associated Industries	Estimated deaths per year (in millions)	Associated SMEP regions
Unsafe water	Leather, Food processing, Textiles, Rubber, Plastics	1.7	South Asia, Sub-Saharan Africa
Indoor smoke	Rubber, Food processing	1.6 - 2.9	South Asia, Sub-Saharan Africa
Lead exposure	Chemicals	0.23	South Asia
Urban air pollution ($PM_{2.5}$)	Timber, Plastics	0.8	South Asia
Unintentional poisonings	Apparel, Plastics, Rubber, Food processing	0.35	South Asia, Sub-Saharan Africa

Source: UNEP 2021

Rapid increases in manufacturing bring up the accompanying question of waste and pollution. While it's impossible to separate individual pollution causes, there is no doubt that manufacturing causes increased health burdens in the South (Soledayo Babatola 2018). In Africa, for example, air pollution was responsible for 1.1 million deaths in 2019, with ambient air pollution deaths rising from 361,000 in 2015 to 383,000 in 2019. In 2019, ambient air pollution was responsible for 9.3% of all deaths on the continent (Fisher et al., 2021). Sub-Saharan Africa has some of the highest concentrations of ambient air pollution globally, following only the Middle East (HEI 2018).

Asia more generally is the fastest-growing region for industrial emissions. China's rapid transformation into an industrial powerhouse leads the way. However, other parts of Asia are also industrializing rapidly. In India, for example, Jain (2017 113-8) points out that manufacturing output increased by 12% and pollution load by 24% from 2004-2010, this is up considerably from 1990 to 1998, when the figures were 67 and 8% respectively. The top polluting industries have remained relatively stable, with cement, metals, and vegetable and animal oils and fats topping the list.

More specifically, there are increasing concerns around environmental issues and natural resource depletion in South Asia. The region of 1.9 billion people, or 23% of the world's population, is rapidly urbanizing. While economic growth has reduced poverty in the region, from 50% in 1999 to 33% in 2010, there are increasing signs of environmental stress. Estimates of the costs of pollution are 10% of GDP in 2016. Air quality levels are far below WHO thresholds in all of the countries. Air pollution is responsible for an estimated 13-22% of deaths in the region. There are growing problems with municipal solid waste, of which there were an estimated 334 million tons in 2016. Yet, only 50% of waste is collected, and open dumping or informal collection remains the norm (SACEP 2019; TERI 2019).

More optimistic discussions in previous decades expected a gradual shift in environmental values, along with an "Environmental Kuznets Curve" (EKC) over time as countries industrialized, which would increase incomes, thus allowing for a gradual shift towards greater environmental values. In a sense, the expectation was of an inverted U curve, where pollution would increase for a few decades and decline as countries reached a certain income threshold and started developing post-industrial service-based industries. The EKC theory is highly contested (Churchill et al. 2018; Özokcu and Özdemir 2017; Arpegis and Ozturk 2015). Industrialization has not yet peaked in most of the South, so we can not yet see if pollution will eventually decline with any certainty. This uncertainty creates alarm in the context of growing global environmental crises, especially climate change. Nonetheless, it is not plausible to demand countries in the South to reduce growth or industrialization, given the continuation of endemic poverty. Moreover, the urgency of climate change and increasing awareness of the health costs of pollution felt locally in the South have pushed policymakers towards considering how to develop a more green or circular path to manufacturing.

The fact is that even if an EKC exists, it will take too long for rapidly developing economies to pass through it before significant damage to climate, biodiversity and other natural systems ensues. However, arresting such processes is also untenable given the need for economic growth to reduce poverty and provide solid incomes and employment to raise living standards. More importantly, whether there is a clear trade-off between environment and economic development. For example, Liu et al.'s 2018 modeling of Chinese manufacturing finds no apparent adverse effects on employment for firms adopting environmental pollution reduction or control measures. They suggest pollution control may add substitute jobs for those that are reduced. However, the effects are heterogenous by industry, region, and ownership.

Nonetheless, what is clear is that the movement to reduce pollution and waste as part of a general transition to sustainability requires capital, technology, and knowledge. Many suggest that the entire production supply chain needs to be transformed from a linear to a circular or closed-loop approach (Blanco and Cottrill, 2014). Circularity is still a contested concept. Geissdoerfer et al. (2017) define a circular economy as "CE is "a regenerative system in which resource input and waste emission and energy leakage are minimized by slowing, closing and narrowing material and energy loops." The question then becomes, what are the possibilities for transforming the rapidly growing industries of the South towards more sustainable pathways?

Multiple Pathways Towards Manufacturing Circularity

According to the UN IPCC (2014), industrial processes offer multiple pathways for reducing emissions that would apply to pollution more broadly, including energy efficiency; production process efficiency; product/process redesign; collaboration with other sectors such as shared resources, including heating and cooling; and developing new supply chains for reuse and recycling (Fischedick et al. 2014, 743-4). However, as we discuss, each pathway presents additional significant obstacles for manufacturers in the South.

Energy is one of the most significant inputs for manufacturing and thus offers the most immediate saving opportunities. IPCC (2014, 747 & 753) states that cement, iron ore, ammonia, aluminum, and paper are the most important industrial products, and their production requires copious amounts of energy. Electricity and heat are the most significant contributors to emissions from industry, followed by cement production. However, the shift to renewable energy requires large capital investment and technology transfer. Many of the largest fossil fuel producers are in the South. Beyond that, intermittency and lack of grid infrastructure are among the many obstacles to shifting to clean energy in the South.

Co-location offers other advantages for pollution reduction as well. Excess heat or wastewater can be used multiple times across co-located industries. Because of economies of scale, manufacturing tends to be concentrated; thus, changing the processes of one factory can be a lot easier than changing the habits of thousands of drivers or consumers. The centralized location of industrial processes thus opens the way for shared waste facilities, permitting greater reuse and avoiding redundancies, such as multiple wastewater treatment facilities. For this reason, co-locating industries in industrial parks could be one way to increase cooperation.

A World Bank report (2021) provides an overview of *eco-industrial parks (EIPs)*, which offer one ready mechanism for increasing energy efficiency. It notes the benefits of co-location, whereby waste products, energy, heat, and water can be shared among different industries. Similarly, renewable energy generation and waste treatment costs can be shared. Because of these benefits and growing knowledge about them, EIPs have grown from less than 100 in 1990 to 438 in 2020. EIPs implementation requires careful planning and coordination, as the concentration of industries can also strain local resources. East Asia and the Pacific boast the largest EIPs, with 220, followed by Europe and Central Asia with 147. South Asia has just 11 and Sub-Saharan Africa only 4. Public sector engagement appears central, with 67% of all EIPs being owned and managed by the public sector and 10% through public-private partnerships. The public sector operator helps plan and coordinate centralized services for the parks, including maintaining a data system to optimize resource uses and pollution systems. It can invest in shared resources using standard fees, such as solar energy farms, rainwater collection systems, waste heat recirculation, and anaerobic digesters for waste gasification. Thus a financial plan for investing in and operating the EIP is needed. EIPs can help promote the adoption of new technologies and enforce standards more effectively on-site.

UNIDO (2017) notes the growing awareness of EIPs in the South. It has helped to set up pilot project EIPs in India, Tunisia, South Africa, China, Viet Nam, Morocco, Peru, and Colombia. The lessons note the importance of having a local independent lead, such as a university, to improve the support for such projects. It documents the importance of a robust data system to show "quick wins" to consolidate support among key ministries. There are fewer EIPs in the South because of a lack of access to finance, regulatory/policy capacity, and infrastructure investment. Creating a solid governance model around park management is crucial for ensuring smooth operations and regulatory compliance. At the same time, there need to be adequate business incentives for park viability. Thus, the scoping process should deeply consider whether there is a business case for an EIP, including the availability of technology and transport distances. Finally, the park's location is crucial for all the factors noted above, to increase synergies with local waste production, and to ensure local support.

Repair, reuse, and by-product use are inspiring to improve environmental outcomes. Along with improving the effectiveness of waste disposal, they fall broadly under the umbrella term of "reverse logistics," or how to manage the waste supply chain. For example, scrap metal or plastic can develop the same or new products. "Upcycling" refers to using scrap materials to create new products of higher value-added. Remanufacturing is a term to restore used products into a new state. During World War II, the processes were common due to limited input availability (Rochester Institute of Technology 2020). Remanufacturing requires a separate set of processes, including disassembling, cleaning, inspection and sorting, refurbishing and reassembly (Lieder and Rashid 2016). In general, actual examples of such circular supply chains are now rare. Customers prefer new products, and virgin input materials are often cheaper than refurbishing old ones. Disassembly of materials can be a hazardous and labor-intensive process.

Collection of used materials for reassembly can be costly and challenging; by contrast, recycling is cheaper though it creates more waste (Gungor and Gupta 1999; Steeneck and Sarin 2017). Moreover, it is not easy to develop solid and reliable remanufacturing/reuse systems as not all used materials will be of the same condition. So, remanufacturing will likely contain a mix of new and used materials. In many consumer product lines, innovation continues, thus inhibiting remanufacturing or refurbishment. In general, there is a lack of understanding about constructing or managing remanufacturing supply chains.

Product and process redesign offers opportunities for improving both material and energy efficiency in manufacturing. Product design can help facilitate and significantly reduce the costs of recycling and remanufacturing. For example, Ford's European Mondeo model is supposedly 85% recyclable. BMW offers US customers a $500 credit if they turn in their old vehicle to a dismantling center (Gungor and Gupta 1999). Redesign in the future could use more biodegradable materials and less packaging. However, product design and innovation capacity is quite limited in the South.

Managerial processes can also significantly accelerate the shift towards circularity. There is a gradual shift among Northern firms to develop deeper relationships with input suppliers and customers to reduce emissions and waste. The term "pull production" refers to downstream customers signaling their needs leading to adaptation by upstream suppliers. Such efforts are more generally termed "environmental collaboration." Such requires regular and close contacts among key managers in each firm. The results can be significant. For example, Vachon and Klassen (2008) cite a commercial printer that reduced the number of chemicals in its printing stock from 80 to 24 through collaborative efforts with its suppliers. However, the authors also point out that such measures are not comprehensive regarding pollution, as they do not include effects on the natural environment and tend, understandably, to be limited to processes that improve profits. More fundamentally, this paradigm hides a critical tension between the resource-based view (Teece 1980) of competitive firm advantage, which posits that such lies in specific and nontransferrable assets at the firm level, and this more collaborative view of supply chains. The tension will always exist concerning the former because every firm/customer has an incentive to have potential suppliers compete for their business. As Simpson and Power point out (2005, 67), attempting to coordinate with suppliers in manufacturing presents challenges beyond the financial and supply chain risks of relying on one source. They state,

> "*Supplier development for performance improvement requires the firms involved to commit financial, capital, and personnel resources to the development task and to share timely and sensitive information…. The buyer must be convinced that investing company resources in a supplier is a risk worth taking. The supplier must be convinced that their best interest lies in accepting direction and assistance from their customer*."

A related pathway to redesign is *"lean" manufacturing*. Based on Japanese production techniques developed after World War II, the lean movement seeks to eliminate waste through excess use of materials, capacity, or inventory. This pathway is accomplished by assiduously and continually improving the manufacturing process to improve efficiency and quality, particularly the number of defective products. An essential part of the management process is to include discussion with shopfloor workers and take statistical samples of products based on process alterations, breaking the process down into small parts. However, lean processes also constrain the flexibility of the production process (Hines et al. 2004). For example, if inputs are unavailable or a sudden increase in demand arises, the manufacturing line will be slow to respond. A related proposal towards a new approach is "agile manufacturing," which suggests creating a more flexible and rapid-fire response to changes in the environment, customer needs, technology, etc. The tools for increasing flexibility in supply chains are related to customized production but require more profoundly re-orienting companies towards rapid response. These include organizing virtual design teams that continually update products and processes, integrating product/process/and business information systems to provide steady stream data, and team members working together across firms in the supply chains for coordinate response (Gunasekaran 1998). The movement towards lean manufacturing requires excellent infrastructure, a comprehensive data inventory and sales system, supply chain communication, and coordination, which present considerable obstacles to development in the South.

The term "Industry 4.0" (a.k.a. "*smart manufacturing*"), coined by the German government (Kagermann, Lukas, and Wahlster 2011), refers to the shifting of production systems towards sustainability. The term anticipates a production system that is responsive to real-time demand and customizes products to meet customer specifications in real-time (Lopes de Sousa Jabbour 2018). Deriving from this idea is the term "additive manufacturing," which seeks to use moldable materials such as plastic resin that can be created on-demand. This idea, in turn, allows for customization and easy continual redesign. Both reduce manufacturing waste.

Such processes have gained attention with the rise of internet communications and 3D printing. In this case, products can be made to order for customers at the time of the order, reducing or eliminating energy use the need for inventory, processing, or transport. In theory, the materials could be reused. However, materials currently in service tend not to be recyclable. So far, additive processes have mainly been used in sectors that require low scales of production and highly tailored/complex parts, such as aerospace (Ford and Despeisse 2016). The Internet of Things (IoT) is a related movement to create "smart" products, such as those that can turn off or turn down when not in use. IoT would relate to developing smart sensors on equipment to improve production efficiency and quality in the manufacturing process. The increasing use of robots in Western factories offers opportunities for developing rich datasets that can be shared across factories and enable more precise real-time management adjustments through the internet.

Furthermore, manufacturers can use radio frequency identification (RFID) to track the flow of materials across the factory floor (Zhong et al., 2017). This will eventually extend to virtual reality modeling of manufacturing processes that allow managers to test out the optimality of production process adjustments. In short, a continual gathering of data allows for more precise improvement of the production process. It seems far-fetched to think such movements will enter into the South any time soon, as they still require years, if not decades, of development in the West.

Any movement towards circularity implies a layer of *policy and regulatory reform* and stakeholder coordination. Indeed, Williamson et al.'s (2006)study of 31 small and medium manufacturing firms in the UK concluded that voluntary incentives alone were insufficient to move towards green supply chains. In addition, technology transfer and development, even in the absence of cost pressures, is vital to improving the efficiency of manufacturing processes. Moreover, changing businesses processes and regulations around manufacturing offers the possibility to internalize external costs, such as a carbon tax, in a way that levels the playing field for all firms involved in a particular industry. For example, offering more sustainable sources of inputs, such as the possibility to use scrap instead of forging new metal, can create circular economy synergies that lead to new supply chains, in this case, metal recyclers.

Figure 1 summarizes different manufacturing pathways to circularity (summary of the section above)-raw materials, inputs, processes/mgt., transport; product/input reuse/repair; end of life safe disposal, and obstacles in the South

Additional Challenges for Manufacturing Transitions in the South

The limited literature around manufacturing transitions in the South suggests a standard set of factors that inhibit the transition to circularity. Moreover, our understanding of causal pathways that might lead to pragmatic recommendations remains murky. The general categories can be summarized as weak market forces; weak regulations; lack of knowledge and access to technology at the state, managerial, and consumer levels; the need for financial and tax/subsidies given the lack of market incentives; the catalyzing role that export markets can play (UNCTAD 2021)[3]; and the need for stakeholder coordination to move along regulatory reform.

[3] The UNCTAD report - The role of exports in manufacturing pollution in sub-Saharan Africa and South Asia - how the group of the SMEP target countries located in Sub-Saharan African (SSA) and South Asia have participated in the global trade, specifically in relation to the role of trade in manufactured goods. They correspond to thirteen countries, of which ten are in SSA, namely the Democratic Republic of the Congo, Ethiopia, Ghana, Kenya, Nigeria, Rwanda, Senegal, Uganda, the United Republic of Tanzania, and Zambia, and three are in South Asia, namely Bangladesh, Nepal, and Pakistan.

One part of the literature focuses on *market forces*, such as lack of competition in supply chains and markets more generally in the South. For example, Barrows and Olivier's (2018) study of product mixes among Indian manufacturing firms finds that more competitive markets lead to lower pollution intensity. A larger amount of sales and a less mix of products also are correlated with lower pollution.

Related to market forces are *weak and poorly enforced regulations*. Esfahbodi et al. (2016) surveyed 128 manufacturing firms' supply chains in China and Iran. They trace sustainable initiatives primarily to regulatory and customer pressure. They find that adopting sustainable supply chain practices leads to better environmental performance but "does not necessarily lead to improved cost performance," clarifying that the relationship held for Chinese but not Iranian firms. They, therefore, conclude that "firms need to undertake SSCM (sustainable supply chain management) practices in a bearable and equitable sense that do not harm their financial bottom line. This finding promises to allow firms in developing countries to balance existing in a growing economy with environmental protection."

Sahu and Narayan's econometric study of Indian manufacturing firms highlights the importance of R&D activities in explaining the difference between firms who adopt green standards from those who do not. This jives with the general literature on environmental activities by companies that highlights the importance of internal capabilities for knowledge and technology acquisition. The literature also highlights challenges of lack of access to knowledge, technology, and managerial strategies. This lack extends to inadequate training systems for producing highly qualified manufacturing and knowledgeable consumer about the price of pollution.

Even where environmental awareness and motivations exist, a *lack of access to financial resources* inhibits action, especially important since the literature is *ambiguous* about whether there are *market incentives* for the green transition. For example, Kusi-Sarpong et al.'s 2018 study of 5 different Indian manufacturing firms emphasizes finance, followed by technical expertise and capabilities as the main factor inhibiting sustainable supply chain transition. Yuan and Xiang's 2018 study of Chinese manufacturing firms using data from 2003-14 similarly finds that environmental investment tends to "crowd out" investment in R&D, though it can improve energy efficiency. This information contradicts the famous Porter and Linde (1995) hypothesis that innovation and green investment go hand-in-hand and suggests the need for promotional industrial policies, such as regulation, taxes, and subsidies, to promote the green transition of supply chains. Ali and Hao (2021) find, exceptionally, in a study of 228 Chinese manufacturing firms, that sustainable manufacturing practices go hand-in-hand with the competitive capabilities of firms, including product quality and cost and production flexibility. Hong et al.'s 2018 study of 220 Yangtze River Delta Chinese manufacturers yields similarly contradictory results. They find that sustainable practices go hand in hand with economic success, but dynamic capabilities do not, defining the latter as the ability to adjust supply chains. Afum et al. (2020) find a positive relationship between green practices and profits in Ghana. Kamand and Lokina's 2013 study of Kenyan manufacturing firms also finds a correlation between profitability and environmental practices. However, Abdul-Rashid et al.'s 2017 study of 115 Malaysian manufacturers finds that sustainable product design and development have no significant impact on economic or social performance. Such negative findings are reinforced in Namagembe and Sridhararn's (2019) study of small and medium-sized manufacturing enterprises in Uganda, where higher environmental practices are correlated with higher costs, highlighting the importance of internal management practices. These authors cite the positive influence of Ugandan environmental regulations and the United Nations' sponsored National Cleaner Production Centres as positive forces that help reduce costs. Overall, we can see the potential for a virtuous circle, whereby better environmental practices lead to healthier workers and clients, and preserving the natural environment as a continuing source of inputs and natural waste processing.

Arguably, the most important transformation pressures come from overseas buyers' demands, linked to Southern exports. The principal impetus for these comes from the European Union, developing sustainability standards for imports. The EU has proposed a Carbon Border Adjustment Mechanism (CBAM) that would add tariffs to imports based on their production emissions. The proposed CBAM would exclude the "least developed" countries and allow duty-free imports from lower-middle-income countries up to a proposed threshold. The CBAM's focus is matched by standards for environmental sustainability in imports, such as food and minerals (Lowe 2021, Usman et al. 2021, UNCTAD 2021a). Similarly, the EU's Sustainable Products Initiative – which strives to address the presence of harmful chemicals in textiles, electronics, and chemical products (European Commission 2021) – and regulations on illegal, unreported, and unregulated (IUU Regulation) (European Commission 2021) will likely influence Southern exports to the EU market. Furthermore, according to the International Trade Center's Standards Map, a database for global sustainability standards, there are 17 chemicals-related standards enforced in Europe, such as the Carbon Trust Product Footprint Certification, the UN Global Compact, and the EU Ecolabel (ITC 2021).

There is, in addition, a growing panoply of voluntary standard-setting by industry associations and private firms. These emerging global standards include promises to abide by environmental and labor sustainability principles regardless of where production occurs (UNCTAD 2021b. Prominent examples include the Forest Stewardship Council and the Roundtable on Sustainable Palm Oil. Related to such efforts is a growing movement in global finance to follow ethical principles around investment decisions. Such actions push a variety of concentrated public and private investment funds to add non-financial sustainability standards to their decision-making (Hira, forthcoming). So far, the results of such voluntary efforts have been mixed, at best. Hira (2020) points out that voluntary systems lack transparency and enforcement mechanisms. Other authors question whether sustainability standards have really shifted global supply chains towards sustainable practices or merely incentivized different sources or intermediate inputs (Houghton and Naughton 2017). Even if well-meaning, both public and private standards for sustainability will cause significant strain on exporters, especially small and medium enterprises in the South (Plassmann 2018; Higgins and Richards 2019).

Zhu et al.'s (2013) study of 396 Chinese manufacturers finds that *external pressures*, particularly from new sustainability requirements for exports to the EU, such as extended manufacturer responsibility for electronic waste, were a primary driver for the transition to sustainable supply chains. The study of Yu et al. (2008), including 36 electrical and electronic manufacturers in China, concur that such external pressures are the primary drivers behind green supply chain movements. Similarly, Child and Tsai's study (2005) of chemical firms in China and Taiwan found that MNCs were more likely to adopt and spread sustainability practices and that local NGOs could also spur pressure for change. Gouyou et al. (2013) arrive at a similar conclusion after examining results from a 2000-5 survey of 1268 Chinese manufacturing firms; external pressures are the most important variable for explaining green practices.

A survey of 221 manufacturing companies in Jordan also found a high correlation between green supply chain practices and exporting (al-Ghwayeen and Abdallah 2018). Similarly, Mitra and Datta (2013) surveyed 232 manufacturing firms and found that India's green supply chain strategies are "still in their infancy." They suggest that lack of awareness among buyers and a weak regulatory framework are the principal obstacles. They emphasize the importance of supplier relationships for green transitions. They also single out MNCs as more likely to exhibit green practices. Barash-Harman (2018) studies five firms in textiles, petrol, and pharmaceuticals and finds that those oriented towards product differentiation and exports were significantly more likely to comply with environmental regulations. He finds that such regulations tend not to be enforced, and customers do not demand green performance locally, leaving the main pressure to purchasing MNCs. External pressures on exporters from the South are likely to increase over time. In late 2021, the U.S. Biden Administration announced that its new trade deal with the EU on steel and aluminum would include a tax on carbon emissions above a certain threshold for imports, a decision echoing an EU proposal along the same lines.[4]

Unlike China, most manufacturers in South Asia and sub-Saharan Africa are small to medium-sized enterprises (SMEs) with limited capacity to export, with some notable exceptions in India. In Ghana, for example, the estimate is that 85% of the manufacturing is SME. Beyond the lack of access to credit (similar to China), they also suffer from low capacity in R&D; and limited managerial and technical skills that prevent them from taking advantage of global markets (Asare 2014). As Mathiyazhagan et al. (2013) point out in their study of the Indian auto industry, the small to medium-sized enterprises that dominate most manufacturing in the South face additional hurdles to achieve green or circular supply chains. These include a lack of awareness by suppliers and customers; challenges in measuring environmental performance; lack of government support; inability to take risks because of tight margins; lack of human resources and technical or managerial expertise; failure to engage in the complex redesign and general lack of access to technology; disbelief that it is their responsibility; financial access constraints; high costs and lack of options for safer waste disposal. Of all of these, they signal supplier awareness and opportunities as one deserving particular attention.

Environmental regulators in the South generally lack the resources or ability to enforce provisions where they exist, reflecting more general challenges of *stakeholder coordination* that would enable regulatory reform. Regulations are needed to ignite circular markets, such as recycling and reuse; for example, mandatory eco-labeling could help to inform consumers. Public procurement could also be an important lever for the green transition. Adeoti's (2002) examination of Nigerian manufacturers offer some positive reflections on the ongoing evolution of Nigerian

[4] See https://www.nytimes.com/2021/11/03/business/economy/biden-trade-policy-steel.html, and https://ec.europa.eu/commission/presscorner/detail/en/qanda_21_3661, both accessed Nov. 4, 2021.

firms towards more environmentally-friendly technology, particularly in end-of-pipe wastewater treatment, and in the development of labs for regulators to conduct water testing. He posits that environmental policy is the main driver for change. However, there is a shortage of qualified personnel in regulatory agencies. While obstacles vary by sector and firm, he finds that lack of knowledge is generally not as significant as access to capital. Jakhar et al. (2020, 2649) are quite skeptical of the potential for environmental regulations to be effective in India, in contrast to China, stating, "*In the Indian context, the regulatory pressures can easily be overcome using symbolic gestures or superficial efforts without entailing many costs*." Likewise, according to the UNEP, most sub-Saharan African countries do not have legal instruments containing ambient air quality standards (UNEP 2021). These institutional challenges in Africa also extend to the limited availability of national ambient air quality monitoring networks (UNEP 2021).

Regarding Pakistan, a more general study of CSR through surveying companies finds that a shortage of resources is the most important barrier, with a lack of effective regulations or policy incentives coming in second (Bux et al., 2020). Silvestre's study of the Brazilian oil and gas sector highlights the importance of sectoral and local context, concluding that sustainability in developing economies is considerably more challenging as there is "a higher degree of complexity and uncertainty due to the existence of highly turbulent business environments and institutional voids. These factors, in turn, hinder supply chain learning and innovation, and reduce the slope of supply chains sustainability trajectories." One can even go even further in highlighting the importance of natural resource-based industries in the South, which bring vital revenues and create powerful lobbies of resistance to change. Such is reflected in the global struggles to phase out subsidies for fossil fuels.

Lessons for Improving Manufacturing Circularity from the SMEP (Sustainable Manufacturing and Environmental Pollution Programme).

The SMEP highlights the growing importance of interventions to reduce manufacturing pollution in the South and adds important new insights into the challenges. While the key factors presented in the literature around production and process redesign, access to finance, technology, managerial techniques, and weak regulation are echoed in the project documents (SMEP 2021),[5] new factors are also brought to light through the projects. These include a lack of awareness of pollution costs, the challenges presented by large informal and fragmented industrial sectors, and the daunting obstacles of creating stakeholder coordination around a new regulatory framework and sustainable business models. Moreover, the SMEP indicates that challenges tend to be sector- and even-product-specific, thus reinforcing the need for animating local actors to understand the local context to drive the transition process. The project reports also offer concrete suggestions. These include reducing upstream causes of industrial pollution, creating centralized waste infrastructure, and spurring stakeholder collaboration around regulatory reform.

SMEP (2020) commissioned a baseline study to examine the levels of manufacturing pollution in exports from South Asia (SA) and sub-Saharan Africa (SSA) as a first step to the SMEP Programme. The report conducts an environmentally extended input-output analysis

[5] See SMEP website for full resources: https://www.smepprogramme.org/s/files

(EEIOA) and a life cycle analysis (LCA) to measure the pollution results of key industries in the regions. The study notes that the countries of interest across the two regions[6] (which excludes India and South Africa) together account for just 0.9% of global trade. The levels of trade openness vary considerably, from 28-70%. Five of the countries in the sample dominate manufactured exports: Pakistan, Bangladesh, Kenya, Nigeria, and Nepal. The SSA countries rely heavily on commodity trade, while the SA countries produce more labor-intensive exports. The report notes that each country suffers from a series of factors that impede the development of higher value-added production, particularly capital formation. At the same time, manufacturing exports have been increasing over time, from $26 billion in 2001 to $108 b. in 2019 for SSA, and from $6.5 b. to $48 b. in SA over the same period (UNCTAD 2021, 10). With this massive increase comes a similar increase in pollution with global implications. Beyond carbon emissions are a host of other issues from toxicity for humans and ecosystems on lands and sea to acidification of lands to water contamination. SMEP estimates the costs of yearly pollution for the studied countries as $12.1 billion for the SA cases and $6.8 billion for the SSA countries (SMEP 2018, 25).

The UNCTAD (2021) report for the SMEP further observes that the challenges and effects of manufacturing pollution tend to be sector-specific. Many studied countries specialize in 1-2 industries, facilitating intervention. For example, Bangladesh and Pakistan are focused on textiles and apparel, while Kenya and Tanzania are both concentrated in food and beverage production. In the case of textiles and apparel, there is growing international pressure and accompanying initiatives to push production towards greater sustainability. The SMEP baseline report (2020) more explicitly identifies points of concern with manufacturing pollution pathways, namely toxic metals, dyes, bleaching agents, air pollutants, pharmaceuticals, and noise. Its recommendations are sector-specific, other than steps to improve energy efficiency, however the categories of recommendation overlap sectors. The report signals clear indicators of adverse health effects from manufacturing pollution in the two regions, particularly from toxic waste sites. Identified health effects include inflammation and cardiovascular effects; respiratory issues, carcinogenic disease; neurotoxic effects; and antimicrobial resistance. Because of the challenges and costs of remediation, the report suggests that efforts reduce *pollution at the source*.

In Bangladesh, SMEP partners Pure Earth conducted a study of lead-acid battery recycling that highlights the additional challenges of manufacturing transition in the South. This project highlights the importance of a *lack of knowledge of pollution costs* among supply chain actors and the general public. It also highlights the role of informality. A factor underestimated in the existing literature. Lead-acid batteries (LABs) are increasingly used in transport, energy, and manufacturing. The market for LABs is estimated at $129 million and is growing at 12% per year in Bangladesh. Around 50 battery factories, 30 Chinese-owned, produce 500,000-600,000 units per year. This finding undermines the claim in the literature that foreign investment leads to improvements in sustainability; perhaps the conditions of foreign investment matter. A LAB lifespan is estimated at only two years, creating a major hazardous waste issue. ESDO (2021) further notes no enforced regulations around child labor in the sector, which may affect children's

[6] Bangladesh, Nepal, Pakistan, Democratic Republic of the Congo, Ethiopia, Ghana, Kenya, Nigeria, Rwanda, Senegal, United Republic of Tanzania, Uganda, and Zambia.

average lead concentration levels, estimated at eight micrograms per deciliter, while 5 is the generally accepted level for triggering a health warning. Bangladesh thus loses an estimated $15.9 billion in GDP from lead exposure. Dependence on batteries also reflects the lack of access to reliable grid-based energy. While there are other batteries, such as Nickel-Metal Hydride, Nickel-Zinc, Sodium-Nickel, and Lithium-Ion, these are considerably more expensive than lead-acid batteries.

Lead can act as a neurotoxin in the body, creating serious issues for children's development, though knowledge of lead's dangers appears limited in the country. However, most battery recycling efforts remain in the informal sector; there are an estimated 1,100 recycling sites, of which only six are in the formal sector. Thus an estimated 80% of batteries are informally recycled. Yet, there are insufficient market incentives or enforced regulations to shift activity back to the formal sector; in fact, informal recyclers require little capital or equipment. The report recommends a deposit refund scheme and/or a green tax for batteries, a single environmental standard agreed upon by government and private sector stakeholders, the development of a battery swap system for e-rickshaws, and a new hydrometallurgical recycling process. The last would need to be developed first as a pilot project. Each of these solutions would require significant government and private sector consensus and foreign partner investment and technology transfer. The dominance of informality appears to make such tasks quite challenging, so the report also recommends a vigorous public health campaign (SMEP Pure Earth 2021). Moreover, the government lacks the personnel capacity to develop a sound environmental management plan for the sector; this is reflected in the lack of effort to enforce licensing among existing recyclers (ESDO 2021).

Most prominent among the findings is the need to rethink *production processes in supply chains*. SMEP's (2020) general suggestions for intervention include materials substitution for less toxic inputs where possible; air and water effluent treatment; personal protective equipment; waste recycling and reuse; and generally improving training and production processes. The report also calls for improved pollution standards and more rigorous enforcement of existing ones. Therefore, a multi-stakeholder approach is needed to enlist and engage the private and public sectors and local communities affected by pollution. Another commissioned report (PA Consulting 2019) for SMEP signals additional intervention points. The first is to reduce the number of product lines produced as changing processes is wasteful. Secondly, they suggest "identifying manufacturing pinch points" by referring to bottlenecks that slow down manufacturing lines. The third is to reduce waste during the processes through improved quality control; this helps to reduce the number of sub-par or unacceptable batches. The fourth is to improve the technology available. More generally, they suggest looking at how goods are transported, reducing inventory over-stock, and enhancing personnel's know-how. These intervention points should be overlaid with a robust data system and access to capital for upgrading.

The project reports note the importance of capital injections, technology, and managerial strategies to improve circularity and shift production processes. They also emphasize the need to bring together stakeholders to reform regulatory processes. For example, SMEP Open Capital examined pollution mitigation across Kenya and Uganda across 12 manufacturing sectors, focusing on the two most polluting food and beverage; textiles, clothing, and leather and footwear. The food and beverage sectors are the fastest growing in both countries, at an estimated annual rate of 10%. The project recommends a wide array of solutions falling into the general categories of waste collection and recycling, raw material substitution, energy efficiency, including switching to locally sourced biofuels, waste treatment, including anaerobic digesters, and pollution monitoring technologies.

A study of distilleries, tanneries, and textiles in Kenya, Ethiopia, and Tanzania (SMEP Teifa IQ) similarly highlights specific interventions to transform supply chains, particularly processing with environmental safeguards. The distilleries study focused on solid and water waste treatment, including installing anaerobic digestion to produce biogas. Currently, water from various manufacturers in Kenya is primarily discharged without treatment into the Nairobi River and Lake Victoria. The textile sector in Tanzania is also a source of concern, despite its rapid growth to become the largest in East Africa. It emits sulfur dioxide, heavy metals, various chemicals, and organic waste.

The industry also burns biomass. These can lead to various health issues, including respiratory and carcinogenic problems and contamination of nearby water bodies. In this case, the project recommends seeking substitute materials that would be less toxic, pollution abatement technologies, personal protection equipment, and introducing renewable materials. The study focused on the leather sector in Ethiopia because it is one of the fastest sources of exports, increasing from a value of $53 m. in 1996 to $135 m. in 2017. Meanwhile, employment grew from 11,365 in 2012 to 21,094 in 2017, mostly in leather footwear, where 50% are women. These are driven by foreign investment. Most of the environmental footprint is from upstream inputs of leather products, including the use of hexavalent chromium in the tanning process. Workers in surrounding areas often have more respiratory problems than others; however, solid waste is also a concern. There is also the possibility for by-product production, creating glue or biogas from wet fleshing residues. The report recommends developing a new environmental plan to manage tanneries, including improved effluent treatment and better disposal of solid wastes, including anaerobic digestion.

The SMEP Asia Report study of Bangladesh tanneries recommends operationalizing a central effluent treatment plant to manage tannery waste. The impetus here is a 2015 EU regulation limiting chromium in leather products sold there, which led to a 2019 Bangladesh Leather and Leather Good Development Policy requiring chromium effluent screening, sedimentation tanks, and distilling machines to desalinate effluents. This report also recommends some restrictions and substitutions in using chemicals for tanning. Public-private dialogue is needed to ensure that a new certification system is understood and followed in governance. A sizeable financial injection will also be required to catalyze a central treatment plant's construction and operation.

The SMEP GHAP-AQA study of tanneries in Pakistan combines supply chain transformation and central waste infrastructure solutions. The leather industry is important for the country, with 500,000 workers. The industry association claims that 95% of its members are export-oriented. Increasing concerns about export sustainability requirements are pushing the industry to make changes. The project report recommends consolidating currently disparate one-stage processors into integrated SMEs; improving the storage and treatment of hides and water use, providing workers personal protective equipment and safety training; and increasing the use of solar energy. As in Bangladesh, there are significant issues with the operation of central effluent treatment plants. Thus, the project recommends shifting the industry towards operations clusters near the plants.

Needs inputs from partners

UNCTAD's summary report (2021) emphasizes that the transformations in supply chains, managerial practices, and financial and technology transfer imply that business processes and regulatory reform must work hand-in-hand. It suggests that countries in both regions study how to strengthen their environmental disclosure, transparency, and public participation on the domestic level and consider policy coordination, including through multilateral environmental agreements, on the regional level. They also recommend considering green manufacturing guidelines, the development of eco-industrial parks, and a national industrial symbiosis program that would enhance capacity building, regulation, and sustainable management practices. In terms of the private sector, the report recommends developing local environmental management system (EMS) certification and adopting resource-efficient and cleaner production (RECP) measures. In general, they suggest creating more training opportunities for circular economy concepts and identifying transition opportunities. The significant size of the informal sector means any efforts have to be widely available. Last but not least, campaigns to raise awareness across society of the costs and solutions for environmental degradation are vital. In line with this, a more rigorous monitoring system is required.

Conclusion

The SMEP projects support the existing literature's key barriers to circularity, including finance, knowledge, technology, and management capacity in the public and private sectors, and adds additional challenges around: knowledge and metric deficits, informality, lack of infrastructure, regulatory and private sector capacity, and supply chain and stakeholder coordination in response to exporting requirements to be considered as summarized in Fig. 2 below.

Figure 2: Summary Lessons from SMEP for Manufacturing Transition

Needs more once inputs are received

One place where SMEP findings differ from expectations in the literature is that increases in exports have *not*, for the most part, led to a natural improvement in environmental technologies. However, growing sustainability requirements in import markets such as the EU and pressure on MNEs are and could increasingly catalyze the transformation of Southern manufacturing. Absent sustainability transition, they could otherwise find themselves shut out of important revenue and employment-generating activities. For example, the textile industry in South Asia is a focal point for Western activist pressures on large MNE clothing buyers that have changed supply chain consideration, such as the Better Cotton Initiative. The good news is that SMEP reports suggest very feasible ready alternatives, some relatively low-cost, and almost all involve already proven technologies that could be introduced to lead to significant improvements. Organic waste seems to be open to accessible solutions. To introduce such interventions would require a concerted effort by global and local stakeholders, including efforts at regulatory and policy capacity.

While the challenges noted above are daunting, some positive actions signal possible ways forward. Foremost is the push for compliance with external market requirements for exporters. Secondarily, there are regional-level efforts that promote circularity. For example, there have been recent discussions around shifting to a regional circular economy framework in Africa. Measures include financing by the African Development Bank for green projects, establishing national cleaner production centers to promote clean transitions, and general efforts to raise regulatory and consumer awareness of waste problems (African Ministerial Conference on the Environment 2019). Across Africa, regional economic communities have adopted environmental policies geared towards protecting biodiversity and preventing industrial pollution and environmental degradation (Africa Growth Initiative – Brookings 2021). The East African Community, Common Market for Eastern and Southern Africa, and the revised Treaty of the Economic Community of West African States are examples of such regional community agreements (WTO 2016). Additionally, the African Continental Free Trade Agreement also includes minor references to environmental protection within the Protocol on Trade in Services (Africa Growth Initiative – Brookings 2021).

There is also the fact that in many countries of the South, manufacturing tends to be primarily geographically concentrated, facilitating the possibilities for coordinated intervention. In Tanzania, for example, 80% of all industrial pollution is concentrated around the city of Dar es Salaam (World Bank 2019, 84). In this sense, industrial pollution and urban resident pollution can be tackled together, such as e-waste and solid waste. Similarly, energy and water systems can be redesigned with industry and residents in mind.

Since manufacturing is still at an early stage in many countries in Sub-Saharan Africa, there is a potential for intervention with less sunk costs. Governments need to inject financial, managerial, and technology transfer into their industries as they seek to shift from pure labor-intensive manufacturing towards greater value-added. For example, a World Bank (2021b) report on Bangladesh points to the need for upgrading its garments factories to keep up with technological innovation on competitors such as Viet Nam. Technology differences overcome labor cost differences over time, and the lack of technology know-how prevents upgrading towards higher value-added segments of the supply chain. The report points to the same factors of lack of access to finance and technology at the firm level and the lack of a technical training system for producing higher-skilled workers and managers as the primary challenges. The report interestingly notes through surveys of firms that they do not perceive these technology and knowledge gaps. The important point here is that the need for technology upgrading across the Southern industry allows doing so in a circular fashion.

There is a vast opportunity for learning across the globe as various policy and private sector experiments to shift towards circularity get under way. While being cognizant of important contextual differences, the needs for tanneries, as we see from SMEP, are similar in Bangladesh or Ethiopia. Therefore, solutions pursued on a regional or global level will accelerate the process. For example, integrating renewable energy systems can enhance demand-side management and improve energy sources' diversity and resiliency (Pineau et al., 2004). Regarding increasing Western trade requirements for sustainability production processes, the desire for transformation can only occur if the West pro-actively assists by sharing resources knowledge and promoting harmonized labeling. In sum, the sharing of knowledge and regulation and policy-building and the solutions sets such as financial and technology transfer should and need to occur on the global level.

Transforming industrial processes in the South towards greener alternatives allows us to reduce pollution without harming the possibility of reducing poverty. Moreover, such efforts can be seen as "win-win" in more direct terms as reductions in emissions in the South can be counted as "offsets" for Northern partners in some cases through the Clean Development Mechanism and other arrangements, particularly the significant commitments made by Western countries to the South as part of the Paris Agreement on climate change. In the end, pollution affects everyone, so its dissipation is a global public good.

Target Journals: Journal of Cleaner Production; Sustainability; Intl Journal of Production Economics;

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