5 Impact on the environment

Key findings

- **Global value chains (GVCs) are a mixed blessing for the environment.** Scale effects—which refer to the rapid growth of GVC economic activity—are bad for the environment, whereas composition effects—which refer to how tasks are distributed across the globe—have ambiguous effects. Technique effects—which refer to the environmental cost per unit of production—are positive for the environment.

- **GVCs are associated with more shipping and more waste in the aggregate than standard trade.** Both have environmental costs.

- **One important concern has been that industries might migrate to jurisdictions where environmental regulations are lax, but that concern is not borne out by the data.** Rather, by locating production where it is most efficient, GVCs can lower the net resource intensity of global agricultural production.

- **The relational aspect of GVCs can attenuate environmental concerns.** Knowledge flows between firms can enable the spread of more environmentally friendly production techniques throughout a GVC. The large scale of lead firms in GVCs can accelerate environmental innovation and push for higher standards.

- **GVCs also facilitate the production of new environmentally friendly goods.** Products such as solar panels, electric cars, and wind turbines are produced at lower costs in GVCs and help reduce the environmental costs of consumption.

The $4,995 Pedego Conveyor electric bike is produced in Vietnam with parts from all over the world (figure 5.1).[1] Gears, pedals, brakes, and other components are shipped from China, Europe, Indonesia, Japan, and other economies to Vietnam for assembly, and then the bike itself is shipped to the United States for final sale. Roughly 60 percent of the bike's value is from outside Vietnam.

Because parts are crisscrossing the globe, producing the Conveyor through a global value chain (GVC) has greater environmental costs than standard trade. Even more worrisome, some of the most environmentally damaging parts, such as the batteries and tires, may end up being produced in countries with the weakest regulations, leading to more environmental degradation.

But GVCs are also engines of innovation that help drive the creation and diffusion of less-damaging products and processes. GVCs make new environmentally friendly products like this electric bike possible. Big international brands can use GVCs to encourage the global adoption of clean and efficient technologies and processes aimed at enhancing both profitability and sustainability.

Environmental consequences arise from features of GVCs, including the hyperspecialization of tasks, geographic dispersion of production, economies of scale, and the market power of lead firms. The total environmental impact of GVCs is considered here along three dimensions:

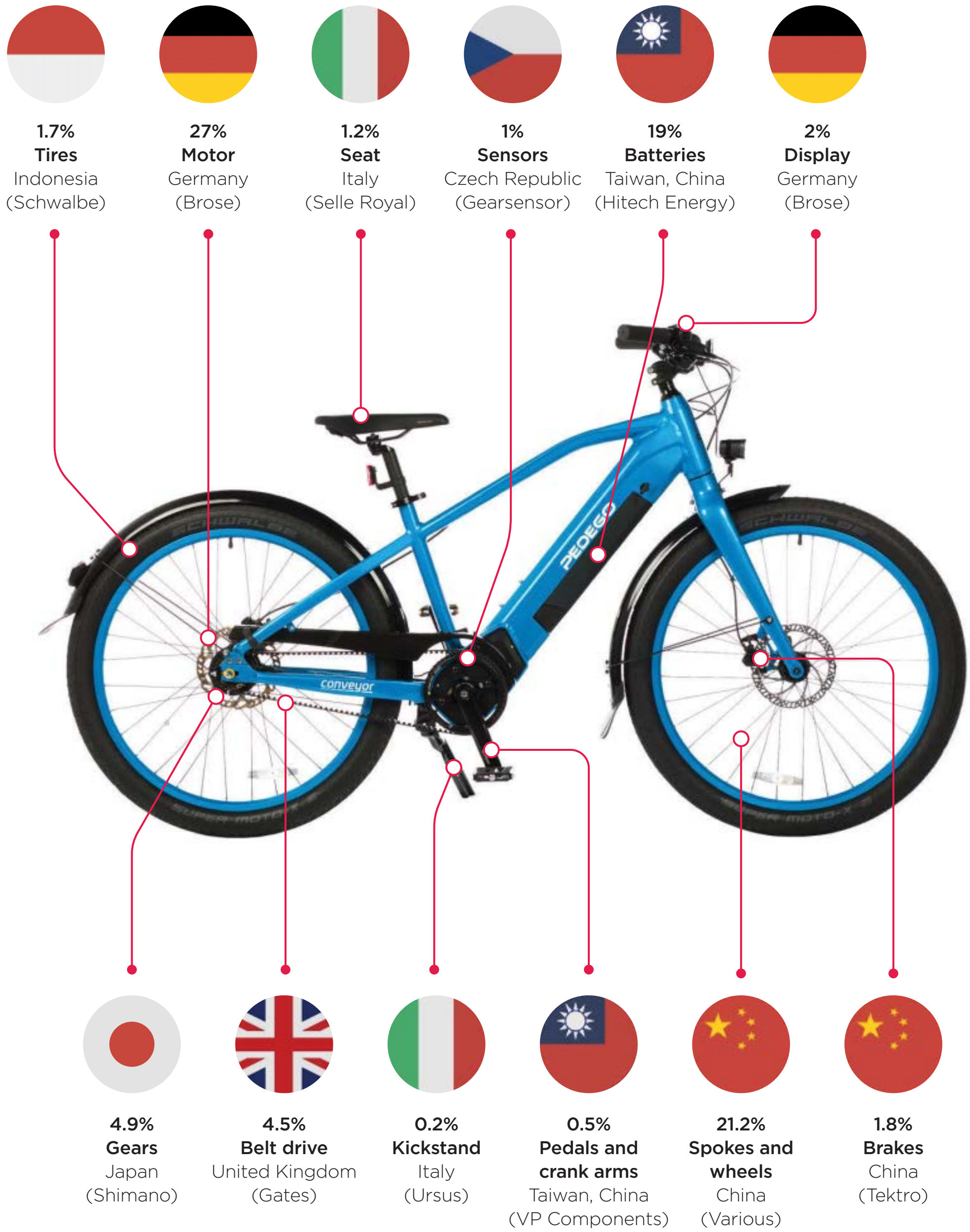
- *Scale effect.* If GVCs spur the growth of economic activity, and if composition, consumer preferences, and production techniques remain the same in the sense that pollution per unit of output is constant, then growth leads to environmental deterioration. GVCs also have some consequences that extend beyond those of standard trade. In particular, GVCs are associated with more waste and more shipping in the aggregate, both of which have environmental costs.
- *Composition effect.* GVCs, by promoting trading in tasks, prompt certain types of economic activity to relocate internationally, thereby transforming patterns of production and trade. Shifts in production toward countries with abundant natural resources allow the preservation of scarce resources, helping to sustain global resources such as land and water. However, the redistribution of "dirty" and "clean" tasks among countries may create environmental benefits for some countries and environmental costs for others.
- *Technique effect.* GVCs can also promote improvements in production techniques. The knowledge flows among networks of firms can enable the development or quicker application of more environmentally friendly techniques. With their large scale, the lead firms in GVCs are able to sustain high rates of innovation. Market concentration can lower the difficulty in managing common pool resources such as fisheries and forests. The relational aspect of GVCs is also important in this context because lead firms are increasingly transferring environmentally friendly technologies to their suppliers and pushing for higher standards.

Policies can influence the net impact of GVCs. Subsidies on fuel, for example, can exacerbate the overproduction of fuel-intensive exports. But subsidies for environmental goods can promote their production and further innovation. GVCs in new environmental goods, from solar panels to LED light bulbs, many subsidized over the years, expanded rapidly, thereby facilitating the diffusion of low-carbon technology. Variations in regulation can also lead to net global increases in environmental damage if polluting tasks migrate to countries with lax regulations—part of the composition effect called the pollution haven hypothesis (PHH). However, a large body of literature does not find evidence in support of this hypothesis. Comparative advantage for many of the most polluting industries rests primarily on factors such as capital and resource abundance, and so these industries tend not to migrate to the least regulated countries. However, low- and middle-income countries are often reluctant to raise environmental standards because in a world of liberalized trade and investment they fear losing the interest of foreign investors.[2] Policies for preserving the environment in a world of GVCs are discussed in chapter 8.

Scale effects of trade and growth

As GVCs grow and economic activity expands, emissions increase—a simple scale effect. The effect would be greater if production increased more in higher-polluting industries—a composition effect. Absent technological innovation, the scale effect of GVC trade tends to be negative for the environment because, although production-related pollution and carbon dioxide (CO_2) emissions fall with a country's income, consumption-related environmental emissions and degradation tend to increase.

Figure 5.1 **The complexity of producing the Pedego Conveyor electric commuter bike in Vietnam with parts from all over the world**



Source: Frothingham 2018.

Note: Diagram shows the percent of total value added from each component.

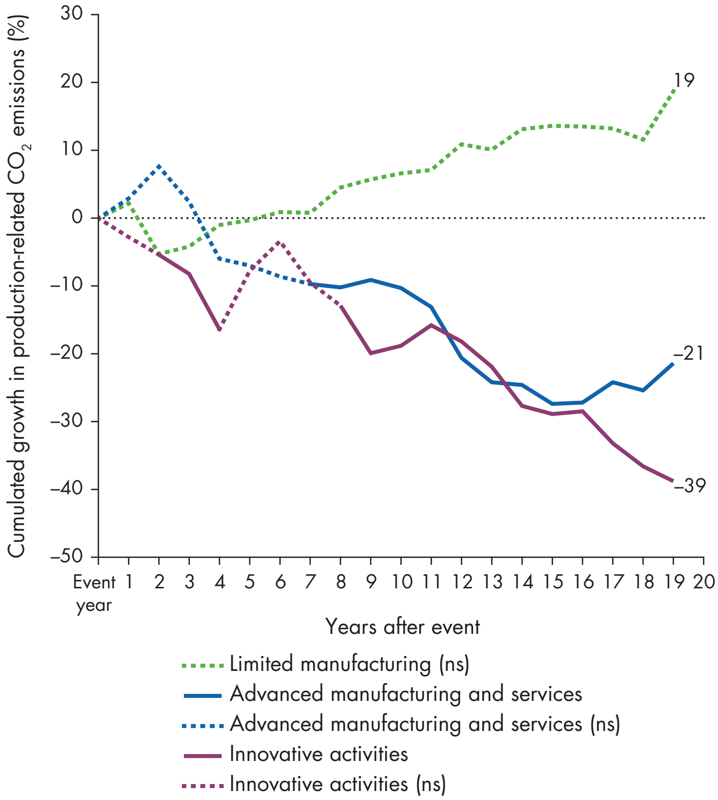
Countries that recently transitioned into limited manufacturing-linked GVCs tend to experience faster growth of production-related CO_2 emissions relative to the previous period, although some countries have also seen their emissions growth decline—which is why the effect of transitioning is not statistically significant (figure 5.2). Indeed, in some countries manufacturing has expanded without rising emissions. Meanwhile, countries that recently transitioned into advanced manufacturing and services GVCs, as well as into innovation hubs, typically experience a decline in average production-related CO_2 emissions.

In these countries, which tend to be at a higher stage of development, consumers may demand more regulations, and the technology of production becomes more environmentally friendly.

These contrasting results are consistent with the literature. On the one hand, the environmental Kuznets curve (EKC),[3] an inverted-U, reveals that economic growth increases the presence of local pollution and production-related CO_2 emissions when country incomes are low. Beyond a certain turning point, it is instead associated with improvements in environmental indicators, and rising country incomes appear to lead to an increase in demand for environmental quality.[4] On the other hand, there is a clearly positive correlation between higher GVC activity and a number of indicators of global environmental damage. Because of the urgency of the global environmental challenge, relying on countries growing first and cleaning up later may be misguided, and such an approach may fail to deliver the reductions in emissions needed to avoid a climactic catastrophe.

One way in which GVCs can encourage manufacturing while also protecting the environment is by inducing GVC firms to opt for industrial parks that have higher standards and encourage environmentally friendly production techniques. More than 300 industrial parks now consider themselves to be eco-industrial parks (EIPs)—a number that is expected to rise. In many countries, governments have become more conscious of green approaches to manufacturing, and lead firms, concerned about reputation, are eager to improve the sustainability of production (see box 8.5 in chapter 8).

Figure 5.2 Production-related CO_2 emissions drop in countries that recently transitioned into advanced GVCs and innovation hubs



Sources: WDR 2020 team, using data from the World Bank's WDI database and the GVC taxonomy for 1990–2015 based on Eora26 database. See appendix A for a description of the databases used in this Report.

Note: The event study quantifies cumulated CO_2 emissions in the 20 years following a switch from a lower to a higher stage of GVC engagement. Carbon emissions are normally expressed in kilograms per 2011 dollars, adjusted for purchasing power parity (PPP). Dotted lines indicate statistically nonsignificant (ns) coefficients. See box 3.3 for a discussion of the methodology.

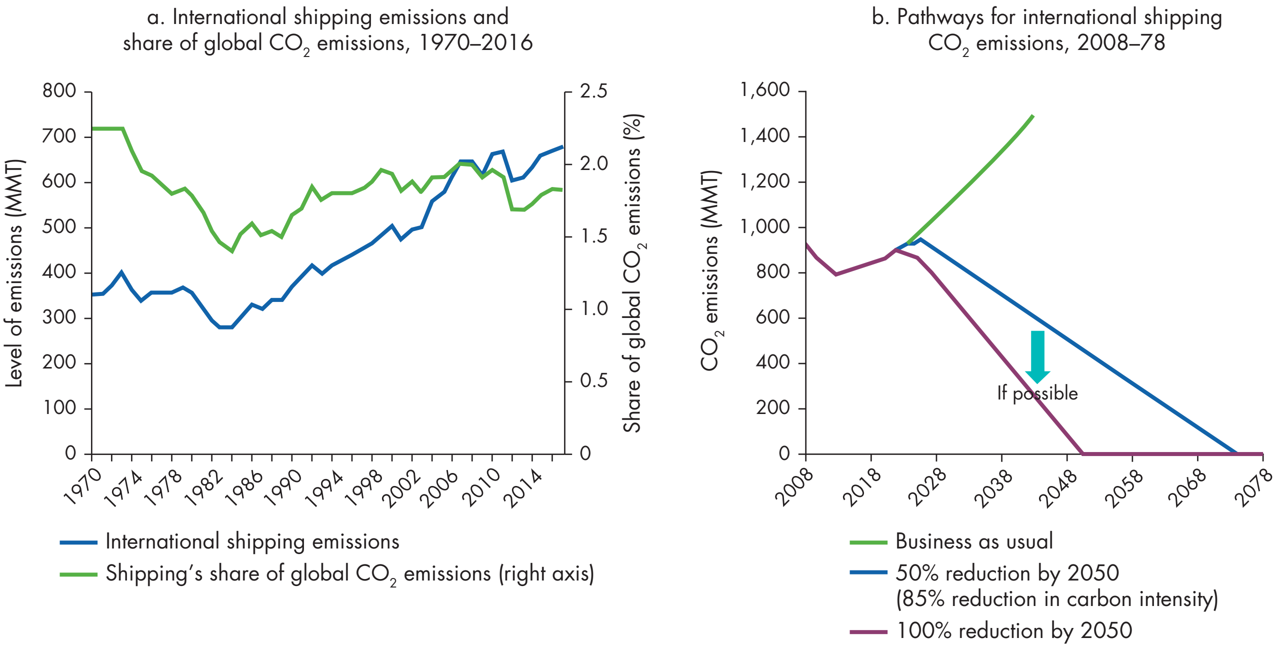
Transportation

One concern about GVCs is their more intensive use of transportation than other types of trade. Parts and components are shipped to a country only to be shipped out after assembly. This back-and-forth transport of goods across long distances generates CO_2 emissions through the combustion of fossil-based fuels, thereby directly contributing to climate change. CO_2 emissions from international freight transportation account for about 7 percent of total CO_2 emissions globally.[5] By 2050, CO_2 emissions related to international freight are estimated to quadruple, which threatens the temperature goals of the Paris Agreement.[6] In the past, industries more heavily into offshoring produced the greatest increases in carbon emissions related to international trade.

GVCs are most closely linked to maritime transport. More than 80 percent of world trade by volume and more than 70 percent by value is transported by sea.[7] The capacity of the merchant shipping industry has surged since 1990, and so have emissions from shipping. In 2016, CO_2 emissions from international shipping were about 2.0 percent of global CO_2 emissions (figure 5.3, panel a). This is not a small number: if a country had the same percentage of emissions, it would be the seventh-largest emitter, ranking between Germany and the Republic of Korea.

Under business-as-usual conditions, these emissions are projected to increase by 50–250 percent by 2050[8]—that is, if the maritime sector continues to expand at an annual rate of more than 3 percent, as it has over the past 40 years.[9] Although emissions from other sectors have begun to decline or are expected to peak soon, none of the business-as-usual scenarios for shipping foresee a decline in emissions before 2050.

Figure 5.3 International shipping emissions are increasing



Sources: Panel a: Muntean et al. 2018; panel b: UCL Energy Institute, London (https://www.ucl.ac.uk/bartlett/energy/research/themes/transport/shipping).

Note: MMT = million metric tons.

As a result, the United Nations Conference on Trade and Development predicts that the maritime sector's share of global CO_2 emissions could account for 10–17 percent by 2050.[10] Technological advances and ambitious climate policy will have to counter this trend. As transport technology has improved, growth in emissions since 1990 is already less (1.85 times) than the near tripling of capacity over the same period (figure 5.3, panel a).

Aware of these rapidly rising emissions challenging the world's remaining carbon budget, the International Maritime Organization (IMO) has committed to at least halving CO_2 emissions by 2050, aiming to eliminate CO_2 emissions from shipping as quickly as possible (figure 5.3, panel b).[11] Although technical and operational efficiency measures could reduce emissions by 30–55 percent by 2050, according to the Intergovernmental Panel on Climate Change,[12] technological innovations will be required to achieve full decarbonization of the sector as envisaged by the IMO.

This energy transition in shipping toward zero-emissions fuels could be facilitated by effective policy support in the form of carbon taxes, emissions trading, low-carbon fuel standards, and a gradual ban of fossil fuels, among other measures. From an environmental perspective, maritime activities are currently undercharged. For example, unlike in domestic transportation, fuels in international transportation are not subject to excise taxes. Charging for maritime fuels based on their true social cost could support fully exploiting the potential of existing energy efficiency and developing alternative fuels. The challenge is that ships are highly mobile: they travel mostly in international waters and can easily be registered anywhere. Thus pricing emissions appropriately would work best with a global solution such as taxing maritime fuels at a single international carbon rate.[13] And yet because a global solution is not in place yet, and notwithstanding potential market distortions, some governments are exploring unilateral measures. The European Parliament, for example, is considering regional carbon pricing on maritime fuels in the absence of a global agreement.[14] Other options include taxing ships based on the type of vessel or taxing based on bills of lading that show the distance the imported cargo traveled. These and other policy considerations are discussed in chapter 8.

Maritime shipping also poses major pollution challenges in other areas. However, some international solutions have begun to emerge and lead to improvements:

- *Air pollution.* Shipping accounts for roughly 15 percent of global emissions of sulfur dioxide (SO_2) and

nitrogen oxides (NO_x). Ship engines burn the dirtiest fuel possible (heavy fuel oil, a residual product of the refinery processes of gas, diesel, kerosene, among other fuels). A recent study by the International Council on Clean Transportation attributed 60,000 premature deaths a year to shipping emissions.[15] The IMO therefore recently decided to reduce the mandatory sulfur limit from 3.5 percent to 0.5 percent as of 2020 for maritime fuels.
- *Maritime litter.* Although most plastic waste that ends up in the ocean comes from land-based sources and is transported through rivers into the sea, about 20 percent originates directly from ships and other sea-based sources, including aquaculture, fishing, and dumping of waste and other matter from deep-sea platforms. Next to environmental misconduct, a big problem is that port reception facilities—waste disposal facilities provided for ships by authorities—are often nonexistent, or they are inadequately equipped, complicated to use, or too expensive. Shipbreaking (that is, scrapping vessels) is also a problem.[16]
- *Invasive species.* To float in a balanced way, ships often have to take on board ballast water. This water is then discharged at another location when the weight and volume requirements change. Invasive species are transported around the globe in this water and released at locations where they may not have any natural predators and can pose a threat to sensitive ecosystems.
- *Water pollution*. Other pollution-related problems are linked to oil spills, sewage disposal (from ship operations), and bilge water (a cocktail of oil and chemicals leaking from the engines and machinery and water that accumulates in the lowest part of vessels and must be pumped out from time to time).

Road and rail transport are two additional sources of the impacts of GVCs on the environment because of their predominance in domestic value chains. The efficiency and performance of the trucking industry can have a significant impact on the carbon footprint of GVCs. The adoption of more fuel-efficient vehicles reduces associated emissions, and the reduction of empty backhauls improves overall efficiency, results in less waste, and contributes to lower prices. For example, when the Lao People's Democratic Republic abolished restrictions on backhauling by foreign trucking companies, road transport prices declined by 20 percent. Substitution between road and rail modalities and the associated development of more seamless containerized logistics are another important area that will determine the overall impact of GVCs on the environment. Rail is the lowest emitter of CO_2 (3 percent of the total), whereas road freight is over 50 percent of the total.

GVCs and waste

GVCs can influence the amount and type of waste generated during the production and transport of goods from source to consumer. They have contributed to a large share of the waste in the electronics and other GVC-intensive sectors, but they are also well positioned to be part of the solution.

E-waste is the fastest-growing waste stream in the world, accounting for more than 70 percent of the toxic waste in U.S. landfills (figure 5.4).[17] GVCs have enabled rapid declines in the cost of electrical and electronic devices,[18] benefiting large numbers of people who otherwise could not afford even low-cost items. GVCs also drive the rate of technological innovation that leads to high replacement rates worldwide.

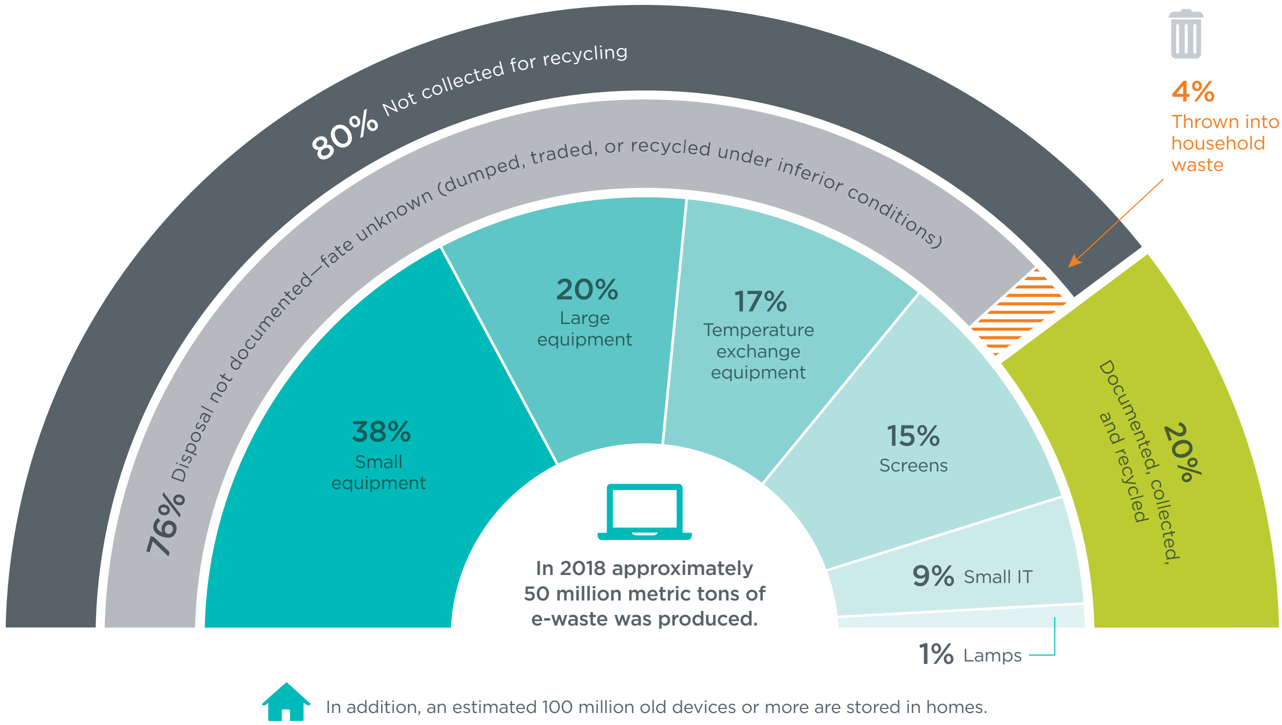
But GVCs have the potential to close the loop and turn e-waste into valuable resources. The United Nations University conservatively estimated the value of recoverable materials in last year's e-waste to be $55 billion, or more than the 2016 gross domestic product of most countries.[19] Some countries such as Japan have e-waste management laws that make manufacturers and retailers responsible for taking back used home appliances, recycling them, and publishing the costs of recycling.

E-waste flows should be viewed as sources of inputs for next-generation products.[20] The World Economic Forum's call for a circular electronics value chain represents a model of sustainability that is difficult to envisage without GVCs.[21] Inputs from retired electronics should be removed and recycled by the very companies that produce them.

The global trade in plastic waste grew in lockstep with the expansion of GVCs through the 1990s and 2000s. In 1990 worldwide imports of plastic waste were worth less than $1 billion, and by 2010 they had peaked at around $10 billion. In the last decade, they have begun to level off and even decline.[22] Meanwhile, plastic and microplastic waste have proven to be a major challenge for solid waste management and have become a global crisis for the environment, especially the oceans. In 2018 the Center for Biological Diversity estimated that swirling convergences of plastic make up about 40 percent of the world's ocean surfaces and that at current rates they could outweigh all the fish in the sea by 2050.[23]

Gross trade data from UN Comtrade are not well suited to portraying what is happening to plastic

Figure 5.4 **The world produced 50 million metric tons of e-waste in 2018**



Source: Adapted from Ryder and Zhao (2019).

Note: IT = information technology.

waste worldwide. Input–output data are in principle better able to track plastic waste, but in both statistical sources the information is too aggregated to track international flows. The two most common polymers, PET and PP, lack specific codes in UN Comtrade because trade codes for these waste materials are not yet harmonized across countries, and the available multiregion input–output data do not include a category for waste. Thus calculating plastic waste urgently requires better statistical measurement.

Today's recycling technologies cannot handle the rapidly growing quantities of global waste. For many years, China was accepting a large share of the world's plastic waste, but eventually the environmental costs of recycling "dirty" plastics became formidable, and China raised the import standards in 2017, all but cutting off acceptance of plastic waste (box 5.1). With most plastic waste now ending up in landfills or incinerators, reducing waste and developing better technology for packaging goods and recycling are environmental priorities in many countries. These countries are promoting a shift away from plastics in bags and water bottles, encouraging reuse, and using more economical and environmentally friendly packaging of parts, components, and goods traveling the world.

Changes in the composition of production

Falling trade costs, tighter environmental regulations, and pollution havens

Because trade costs are falling while environmental regulations are tightening in many countries, polluting manufacturers may respond to new environmental regulations by relocating to countries with less strict standards. Moreover, because GVCs foster hyperspecialization, with tasks moved to the most productive location, lead firms from countries with tight environmental regulations may locate "dirty" production in countries where environmental norms are lax—that is, in so-called pollution havens. Relocating conventional local pollutants thus improves the air and water quality in places with strict regulations at the expense of environmental quality in pollution havens.

In theory, concerns about pollution havens are well founded.[24] Pollution is a production input, just like labor and capital. One could think of pollution as the disposal services of the environment, where the unregulated price is zero. Countries export the goods in which they have a comparative production

Box 5.1 The ban on plastics by China disrupted the waste GVC

One way GVCs extended a product's life was through recycling of paper and plastic waste. In recent decades, goods shipped from China to the United States were consumed, and paper and plastic containers, along with domestic plastic and paper waste, were sent back to China for recycling.

At the end of 2017, China stopped accepting large amounts of imported waste for recycling because a large share was "dirty" and causing environmental damage. The prices of plastic scrap and low-grade paper then collapsed, disrupting the global recycling industry. In the first half of 2017, China and Hong Kong SAR, China, absorbed 60 percent of the plastic waste exported by G-7 countries. A year later, they imported less than 10 percent.[a]

In their place, Malaysia, Thailand, and Vietnam, among other East Asia and Pacific countries, experienced significant increases in contaminated and plastic waste imports. However, many containers were misrepresented as plastic scrap, and when their contents could not be recycled it was burned or dumped. As a result, Indonesia, Malaysia, the Philippines, Thailand, and Vietnam have announced they would ban and send contaminated waste back to the countries of origin, with the threat of abandoning the waste in countries' territorial waters if the waste is not accepted.

Reducing the paper and plastics in packaging and using cleaner technology for recycling has become a priority for environmentally concerned countries. In May 2019, 187 countries—not including the United States—agreed to amend the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal[b] to better regulate the global trade of plastic waste and make it more transparent. Among the commitments, private companies will have to secure the consent of receiving countries before they can trade contaminated and most mixes of plastic waste.

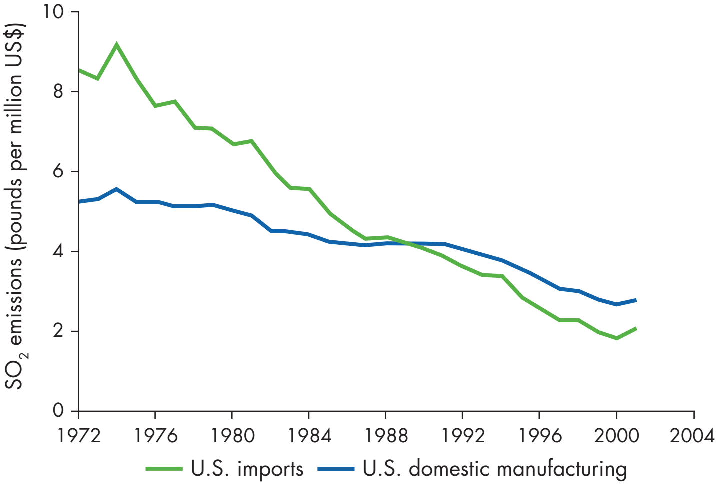
a. Hook and Reed 2018.
b. The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal was adopted on March 22, 1989, by the Conference of Plenipotentiaries in Basel, Switzerland, in response to a public outcry following the discovery in the 1980s in Africa and other parts of the developing world of deposits of toxic wastes imported from abroad.

advantage—that is, their costs of producing those goods are lower relative to their costs of producing other goods. Countries with lax pollution regulations have a comparative advantage in goods whose production is pollution-intensive, and they will export those goods—becoming pollution havens.

Evidence of the pollution haven effect (PHE) has, however, been very limited so far. Polluting industries—paper, metals, cement, and refineries—tend to be costly to relocate, and production is tied to local factor or product markets. Paper plants locate near the trees, and cement plants near their customers. It is therefore not obvious that countries with lax regulations will have a comparative—or even an absolute—advantage in polluting goods. Environmental regulations are a small part of costs. Consistent with this, empirical evidence shows that strict environmental regulation of polluting industries has not led to large relocations to countries with less-strict standards.[25] In some cases, polluting industries and strict regulations are in fact positively correlated.[26] Of all the recent papers finding a PHE, few attempt to untangle the causal negative effect of pollution regulations on polluting industries. Those that do untangle that effect find a statistically significant but quantitatively modest effect for the most polluting industries. One study showed that a 10 percent increase in pollution abatement costs in the United States leads to a 0.6 percent increase in net imports from Mexico and a 5 percent increase in net imports from Canada.[27]

The association of falling trade costs and tighter environmental regulations could drive polluters to flee to developing countries. But this has not happened. Take, for example, what happened to the types of goods produced in the United States compared with U.S. imports as trade costs declined and U.S. environmental standards became stricter (see chapter 1).[28] Emissions from U.S. domestic manufacturing fell by 60 percent from 1990 to 2008, stemming from changes in environmental policy.[29] Meanwhile, the structure of imports shifted toward cleaner goods. Contrary to the conventional wisdom about industrialized countries "offshoring" production of polluting goods, imports to the United States have been shifting away from pollution-intensive goods even faster than U.S. domestic production (figure 5.5). As trade costs fall, the U.S. increasingly imports goods in which it has a comparative disadvantage, which happen to be those that are relatively less pollution-intensive. Trends in Europe are similar, with imports becoming progressively less pollution-intensive, especially from low-income countries.

Figure 5.5 U.S. output has increasingly shifted away from polluting goods, but imports have done so even faster



Source: WDR 2020 team, using data from Levinson (2010).

Note: The figure shows the pounds of sulfur dioxide (SO_2) air pollution per million U.S. dollars of value produced by the U.S. manufacturing sector between 1972 and 2001 and those of imported value. Those totals are calculated using the World Bank's Industrial Pollution Projection System, which is simply a list of emission intensities for each of more than 400 manufacturing industries in 1987 (Hettige et al. 1995). Averaging across industries, weighted by their values shipped in each year, gives the average pollution intensity of the entire U.S. manufacturing sector each year. The blue line in the figure plots that average, holding pollution intensities fixed as of 1987. The green line in the figure reports the same calculation for imports. These averages drop over time because of changes in the composition of the manufacturing sector. U.S. output has increasingly shifted away from goods that generate the most pollution per dollar of output toward cleaner goods. Graphs for nitrogen oxides, volatile organic compounds, and carbon monoxide look similar, with the pollution intensity of U.S. domestic manufacturing falling less quickly than that for imports.

Although the PHE has been overplayed to date, it may become more relevant as some countries adopt more ambitious climate policies to reduce emissions rapidly.

Environmental effects of agriculture and commodity GVCs

Much of the literature on trade and the environment and the nascent literature on GVCs and the environment focus on carbon emissions and, to some extent, other forms of pollution. However, land use changes such as deforestation and overfishing are equally important from a purely environmental and human health perspective. These are conceptually distinct issues, with very different impacts from trade and GVCs.

In agriculture, GVCs can help save scarce resources by ensuring that raw materials are sourced closest to natural resources. But they can also lead to overuse because of specialization and a growing global demand. The pernicious effects are magnified when resource use is subsidized.

GVCs allow countries to preserve scarce resources by importing raw agricultural products from countries with more abundant resources. A good example is the water embodied in cereals and oils. Arid countries that do not have a comparative advantage in water-intensive culture no longer need to grow these products domestically. They can import them for consumption or further processing with considerable savings in water usage (box 5.2). Trade in "virtual water," the water embodied in agricultural production, is estimated to have saved 4 percent of the global water footprint.

National policies can make the environment worse by subsidizing activities that lead to environmental problems. Subsidizing fisheries can lead to overfishing, which has been recognized as a major global issue since at least the 1990s.[30] When agriculture is subsidized, deforestation, soil erosion, and chemical runoff into bodies of water are greater than they would be otherwise, and natural biodiversity will decline.[31]

Even in the absence of subsidies, GVCs and trade create some concerns about hyperspecialization and degradation of land for agricultural use, a major driver of forest loss. Four products—soy, cattle, palm oil, and wood products—alone are responsible for 40 percent of global deforestation, at an average rate of 3.8 million hectares a year.[32] But many more commodities—such as cocoa, coffee, spices, vanilla, bananas, cut flowers, orange juice, and natural rubber—are experiencing a growing global demand that threatens the environment in the hotspots where these goods grow. Some fear that this demand may translate into the depredation of resources from developing countries—especially because incomplete markets mean that the biodiversity contained in forests is not valued sufficiently. Through more efficient production and lower prices, trade and GVCs increase the global quantity demanded of certain agricultural resources and commodities. The result can be deforestation, biodiversity loss, and other environmental problems in countries where resources are concentrated.

However, GVCs also present an opportunity to use value chain connections with concerned consumers to address these issues through voluntary standards and regulated changes. Meanwhile, large-scale operations and upstream connections allow lead firms to efficiently provide information and services that give small-scale producers an opportunity to demonstrably meet standards that they otherwise could not. The appropriate regulations and policies will, however, have to be put in place for achieving large scale impact.

The challenges and the possible solutions in a GVC world are well illustrated by the cocoa and chocolate industry. Cocoa—the primary ingredient in the world's chocolate—has been identified as a major driver of deforestation in West Africa. For many years, the soaring global demand and expanding cocoa production

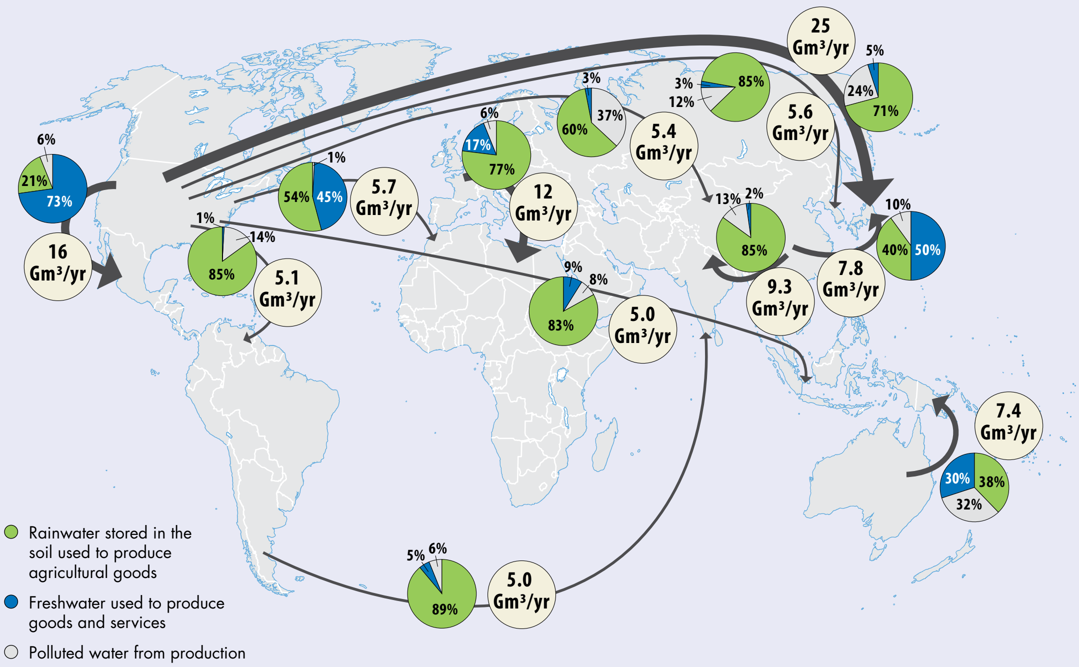
Box 5.2 Virtual water

Are countries that have scarcer water reserves importing water-intensive goods?

The global water footprint in 1996–2005 was estimated at 9,087 billion cubic meters per year: 74 percent green (the rainwater stored in the soil used to produce agricultural goods), 11 percent blue (the freshwater used to produce goods and services), and 15 percent gray (polluted water from production). Agricultural production contributes 92 percent to this total footprint, and about one-fifth of the global water footprint is attributed to production for export.

Because water-efficient countries can export water-intensive goods, especially agricultural products, to less efficient countries, trade has helped reduce the amount of water used in aggregate production. The global water savings related to trade in agricultural products in 1996–2005 was an estimated 369 billion cubic meters per year (58.7 percent green, 26.6 percent blue, and 14.7 percent gray), which is equivalent to 4 percent of the global water footprint related to agricultural production (map B5.2.1).

Map B5.2.1 Global water savings associated with international trade in agricultural products, 1996–2005



IBRD 44678 | SEPTEMBER 2019

Source: Mekonnen and Hoekstra 2011.

Note: Virtual water balance per country and direction of gross virtual water flows related to trade in agricultural and industrial products over the period 1996–2005. The thicker the arrow, the bigger the virtual water flow. Only the biggest water savings are shown—more than 5 billion cubic meters per year (Gm³/yr).

have degraded forests. Suitable land is shrinking because of climate change, and trees are aging and need to be replanted, particularly in Côte d'Ivoire and Ghana. However, the 5–6 million smallholder farms that produce almost the entire global supply of cocoa lack good agricultural practices to address these challenges. They also face difficulties in obtaining farming supplies and financing any improvements they may want to make. Ongoing deforestation to increase cocoa production is not sustainable.

Certification schemes are one possible means of addressing the environmental and socioeconomic issues in the industry. This opportunity for moving to more sustainable methods of cocoa production is supported by the downstream industry. Processing is dominated by a few large traders, grinders, and chocolate producers.[33] Six companies alone process and trade 89 percent of the annual global cocoa production, and five chocolate producers buy 39 percent of it. Because a few large companies dominate and compete at the downstream stages of production, they are well placed to cooperate in fighting environmental degradation, a huge threat to their productivity, particularly as climate change is making cocoa harvest yields extremely unpredictable. And yet despite the strong incentives to work together to improve the social and environmental footprint of the upstream operations, the private sector commitments are not translating into improved sustainability of the supply chain in the absence of regulatory change. To improve sustainability of the cocoa value chains, domestic regulators and international development partners need to work together with the private sector.

Relational GVCs and production techniques

Environmental concerns associated with globalization may be alleviated in the age of GVCs. Because lead firms have a brand name to protect, they pay attention to how their supply chains function in terms of social and environmental standards. Typically, the lead firms in GVCs are well known, and so their behavior can be easily monitored. Some firms actively promote standards along the value chain, including by assessing the monetary value of better social and environmental standards in their balance sheets. Consumers are demanding more sustainable products, and so producing such products can have positive economic returns from either cost savings, risk mitigation, or product recognition.[34]

Recent studies provide empirical evidence that stricter regulation can enhance business performance.[35] At the country-industry level, higher compliance with social and environmental standards is correlated with economic upgrading.[36] An example of how higher standards help save the water and energy of supplying firms is described in box 5.3. As in other successful cases, the example described in box 5.3 involves a joint effort of private and public stakeholders.

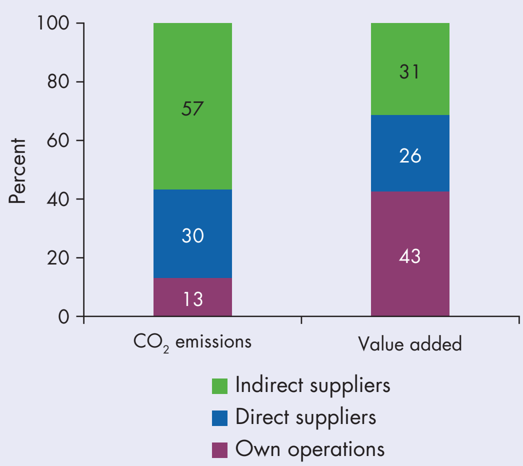
Box 5.3 Toward sustainable fashion

In 2018 the greenhouse gas emissions from textile production totaled 1.2 billion metric tons of CO_2 equivalent, or more than that from international flights and maritime shipping combined.[a] Textile production (including cotton farming) uses about 93 billion cubic meters of water a year, and 20 percent of industrial water pollution globally is attributable to dyeing and treating textiles. If the sector continues on its current trajectory, resource consumption will triple between 2015 and 2050, while the industry share of the carbon budget associated with a 2°C pathway could increase to 26 percent.

Most emissions associated with the Swedish textile and apparel sector are produced by its suppliers outside Sweden, suggesting that cross-country and cross-industry collaboration is needed to reduce emissions (figure B5.3.1). A partnership between Swedish textile producers and the Swedish International Development Cooperation Agency (Sida) reveals how higher standards can help save the water and energy of supplying firms, with environmental and economic gains.

The Sweden Textile Water Initiative (STWI), launched in 2014 and supported by Sida, was a public-private development partnership with 24 textile and leather companies. Its goal was to help establish a network of private companies committed to improving the efficiency of water use by the

Figure B5.3.1 Swedish lead firms in apparel and textiles produce a lot of value added with little CO_2, and their suppliers produce a lot of CO_2 with little value added



Sources: WDR 2020 team, using data from OECD's TiVA database; WIOD; Exiobase.

Note: Estimates were obtained through a multiregional input–output model extended with satellite accounts for carbon emissions. The direct and indirect suppliers of the Swedish textile and apparel sector include upstream industries from both Sweden and foreign countries.

(Box continues next page)

Box 5.3 Toward sustainable fashion *(continued)*

suppliers and subsuppliers associated with their brands in Bangladesh, China, Ethiopia, India, and Turkey. Sida provided the financing; clothing brands contributed by engaging their factories; and the Stockholm International Water Institute oversaw implementation. This collaboration generated significant cost savings and time savings in terms of rolling out the initiative.[b] Although Sida exited in 2018, the network continues to expand globally and to pursue its mandate of supporting sustainability champions with business intelligence, networking, and advice on resource efficiency.

In the first three years, STWI supported 276 factories in the five initial countries, training more than 1,300 managers and 37,000 staff. The savings amounted to almost 11 million cubic meters of water and almost 80 million kilowatt-hours of electricity (table B5.3.1). Despite some variation in savings among countries and across factories, the factory investments were generally sustainable because of the cost savings in water and chemicals over time, and companies' awareness and capacity increased. These numbers confirm that development interventions can play a catalytic role in improving the sustainability of GVCs by raising awareness and providing technical assistance. But cost sharing with companies is important to ensure ownership and engagement.

The initiative had a limited impact on national water governance practices in each country. The STWI's upcoming Mill Improvement Alliance hopes to extend the program to a larger number of factories to achieve broader sector- and economywide impacts. But governments also will have to join the effort, particularly in updating their water governance frameworks. Private actors in initiatives such as the STWI can submit recommendations for regulatory change—and possibly counter pushback that might otherwise come from affected companies.

Table B5.3.1 Total reported savings generated by the Sweden Textile Water Initiative in its five partner countries, 2015–17

Savings	Bangladesh	China	Ethiopia	India	Turkey	Total
Water (m^3)	2,680,005	6,316,597	99,323	339,659	1,085,973	10,521,557
Electricity (kWh)	18,364,890	45,526,706	21,780	6,074,612	9,599,713	79,587,701
Thermal use (metric tons)	1,708,103	4,695,729	115,881	0	0	6,519,714
Chemical use (kg)	1,187,505	18,611,056	5,185	281,635	2,497,178	22,582,559
Waste water (m^3)	16,319	2,435,680	0	0	229,860	2,681,859
Natural gas (m^3)	20,798,126	1,407,313	0	24,514	5,130,815	27,360,768
Fossil fuel (metric tons)	702,334	0	444	1,904	625	705,309
Coal (kg)	0	1,002	0	6,319,396	3,823,737	10,144,135
GHG emissions (metric tons)	45,365	353,277	0	41,274	24,850	464,766

Source: Swedish International Development Cooperation Agency (Sida).

Note: GHG = greenhouse gas; kg = kilograms; kWh = kilowatt-hours; m^3 = cubic meters.

a. Ellen MacArthur Foundation (2017).
b. Andersson et al. (2018).

The relational nature of GVCs can also promote the transfer of clean technology and know-how. Firms that have a brand to defend naturally tend to align practices within the corporation. The clothing firm Puma, in collaboration with the International Finance Corporation, the bank BNP Paribas, and the fintech firm GT Nexus launched a program in 2016 that offers better receivable financing terms to suppliers who score high on Puma's sustainability index. Levi's has a comparable arrangement with its suppliers through the International Finance Corporation's Global Trade Supplier Finance Program. Investment firms are also pushing for more sustainable practices among the major brands. They are paying more attention to environmental, social, and governance (ESG) performance and pushing the major brands to adopt higher standards.

Box 5.4 Demanding environmental standards in GVC upstream firms

Saitex International (Vietnam) and Zakład Pierzarski Konrad Ożgo (Poland) are GVC suppliers whose comparative advantage includes their ability to meet demanding voluntary environmental standards.

Saitex produces denim jeans in a LEED (Leadership in Energy and Environmental Design)-certified facility for the California company Everlane, whose "radical transparency" is the core of its marketing strategy. According to Everlane's website,[a] Saitex recycles 98 percent of its water, relies on alternative energy sources, and repurposes by-products to create premium jeans minimizing the waste. Standard denim manufacturers use "belly" washing machines, which consume as much as 1,500 liters of water to produce one pair of jeans. Saitex instead consumes only 0.4 liter of water per pair of jeans thanks to state-of-the-art recycling.

On-site rainwater collection pools allow Saitex to minimize the impact of the consumption it does have, and its sophisticated five-step filtration process separates water from toxic contaminants and then sends the clean water back into the system. Saitex is also committed to using renewable energy resources such as solar power and cutting energy usage by 5.3 million kilowatt-hours a year—and CO_2 emissions by nearly 80 percent. It also plants trees to offset its emissions. Furthermore, it minimizes the waste from production. All denim creates a toxic by-product called sludge, but at Saitex the sludge is extracted and shipped to a nearby brick factory. Mixed with concrete, the toxic material can no longer leech into the environment. The resulting bricks are used to build affordable homes.

Zakład Pierzarski Konrad Ożgo, which preprocesses white goose down for the outdoor clothing firm Patagonia, has a fully traceable supply chain to comply with its brand philosophy. Internal audits and third-party verification ensure that the birds are neither live plucked nor force-fed and that they are raised in humane conditions. The adoption of this costly technology allows this supplier to have a long-lasting relationship with the buyer, Patagonia, which in this way can trace its supply back to the more than 100 individual smallholder farms—including parent farms, hatcheries, and raising farms—whose output passes through the preprocessor.

a. https://www.everlane.com/factories/denim-saitex.

The long-term nature of firm-to-firm relationships and contracts in relational GVCs can be a force for convincing companies in their supply chain to adopt new costly technology (box 5.4). This point is important because many of the environmental impacts are borne upstream, by the suppliers, even if most of the value is created downstream, as in the Swedish example in box 5.3.

The positive role of relational GVCs does have its limits, however. First, the technology transfer tends to benefit direct suppliers the most, and to a much lesser extent second- and lower-tier suppliers, which in some cases are invisible to the GVC lead firm. Second, the positive local effects of relational GVCs may not translate into an overall gain for the environment globally. When a lead firm relocates production to a developing country, and it produces there with carbon intensity that is lower than the prevailing carbon intensity of the host country, that is not in itself a reduction in pollution and emissions. The carbon intensity can still increase overall relative to a counterfactual where the firm did not relocate.

Green goods

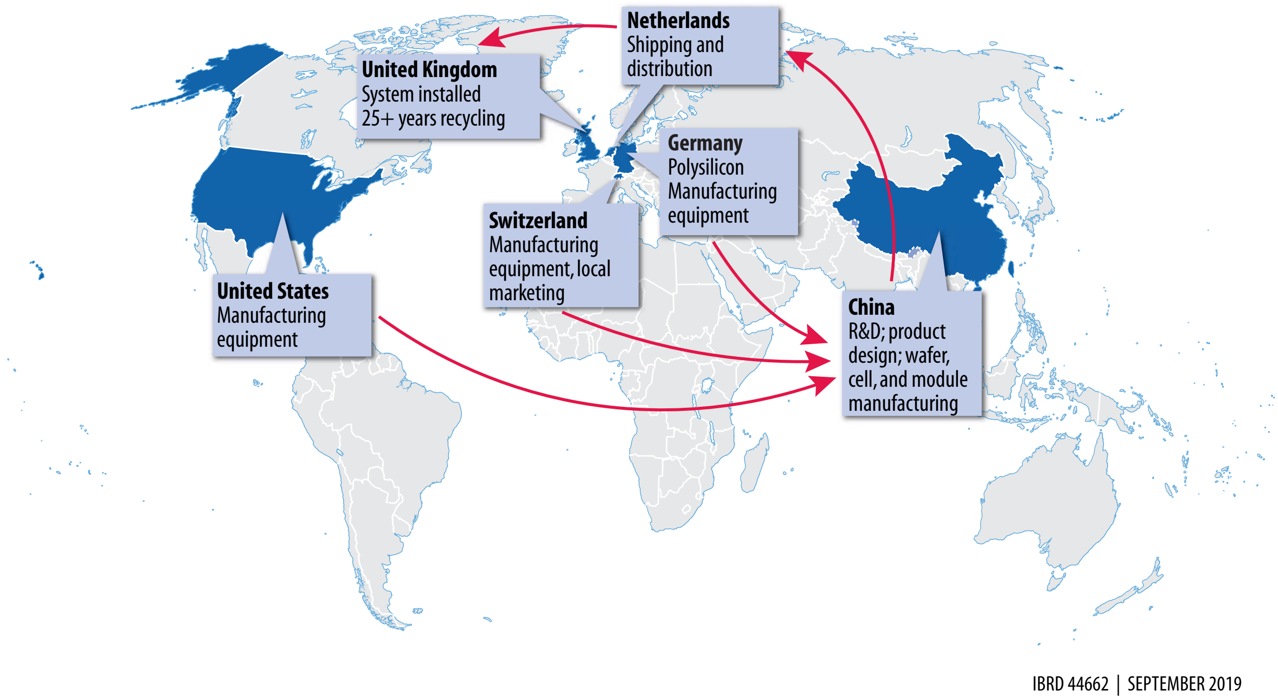
One of the biggest contributions of GVCs to the environment may be the many new and innovative environmental products they make possible. Trade and GVCs have a positive impact on the environment by promoting innovation and by making these clean technologies and environmental goods more affordable. This section describes some of the most important green goods value chains.[37]

Solar energy

The solar value chain relies on innovation and complex production systems. Countries may be part of the value chain through producing silicon, manufacturing solar cells, or assembling modules, inverters, mounting systems, combiner boxes, and other components.[38] Older companies appear to be more vertically integrated, whereas newer entrants tend to source from multiple locations for assembly on-site.

Solar photovoltaic (PV) products are generally tradable. Map 5.1 illustrates the supply chain of a PV company. Solar cell production is concentrated

Map 5.1 Supply chain of a solar photovoltaic company



Source: European Commission 2016.

Note: Solar cell production is primarily concentrated in China and elsewhere in Asia and is dependent on the production of components from several countries. Europe and the United States lead upstream service provision, including shipping, distribution, installation, and recycling. R&D = research and development.

primarily in China and elsewhere in Asia and is dependent on the production of components from several countries. Europe and the United States lead upstream service provision, including shipping, distribution, installation, and recycling.

Large parts of the supply chain have generally been located in countries or regions with strong demand, such as the European Union. Low labor costs, natural resources, and government policies have driven some production to China. Meanwhile, policies to encourage deployment have expanded in other countries.[39]

Value created along the solar value chain starts with polysilicon and ends with the PV module (table 5.1). Downstream activities generally account for a large share of value added, especially for services such as installation, system design, and research and development.

Other examples of green goods

The wind energy supply chain, though not as globalized as solar, has grown increasingly complex and fragmented. A single wind turbine has more than 8,000 parts. And major components include rotor blades, towers, and nacelles. In the U.S. supply chain, only about 50 percent of the value of components is from domestic sources. Several European countries, such as Denmark and Germany, used to be the main manufacturing hubs, but the sector is growing increasingly diverse geographically, with more than 50 percent of suppliers from China, India, and other Asian countries, as well as Brazil.[40]

In the electric vehicle industry, global sales of new vehicles passed a million units for the first time in 2017. On current trajectories, this figure could quadruple by 2020, to about 5 percent of the total global light vehicle market.[41]

China is the largest global market for electric vehicles, and it is dominated by independent domestic firms. China's electric vehicle industry showcases how trade liberalization and greater access to foreign suppliers, combined with government intervention and strong competition in the traditional automotive market, allow independent domestic companies to enter the niche market of electric vehicles and become both innovative and cost-competitive. In the years after China joined the World Trade Organization, the import volumes of parts for electric motors and generators picked up, as exports of electronic motors also increased.

Table 5.1 Estimation of value added at stages of the supply chain of a solar photovoltaic (PV) module

US$ per kilowatt

Stage of production	Sales receipts (turnover or gross output)	Cost of intermediate products and services	Value added
Polysilicon	150	50	100
Silicon wafer	330	150	180
Solar cell	460	330	130
Final product (PV module)	660	460	200
Total	1,600	990	610

Source: Jha 2016.

Notes

1. Roosevelt (2018).
2. This phenomenon, known as the pollution haven effect (PHE), is different from the pollution haven hypothesis (PHH). The empirical literature provides much more support for the PHE than for the PHH (Copeland and Taylor 2004; He 2006; Kellenberg 2009; Levinson and Taylor 2008). The PHE and the associated problem of "carbon leakage" hold even when the PHH does not. Although environmental policy is not a predominant determinant of comparative advantage, it does matter at the margin, particularly for countries whose competitiveness is based on producing at low cost.
3. The environmental Kuznets curve (EKC) describes a relationship between per capita income in a location and environmental outcomes. See Grossman and Krueger (1991, 1995).
4. Copeland and Taylor (2004); Stern (2017).
5. ITF (2015).
6. ITF (2015).
7. UNCTAD (2017, 2018).
8. IMO (2015).
9. UNCTAD (2017).
10. ETC (2018); European Parliament (2015).
11. The initial strategy, launched in April 2018, envisages reducing total greenhouse gas (GHG) emissions from international shipping, which should reduce the total annual GHG emissions by at least 50 percent by 2050 compared with 2008, while pursuing efforts toward phasing them out entirely by that date (IMO 2018b).
12. Sims et al. (2014).
13. Keen, Parry, and Strand (2012).
14. Dominioni, Heine, and Martínez Romera (2018).
15. Anenberg et al. (2019).
16. For more information, see IMO (2018a).
17. Holgate (2018).
18. UNU (2018).
19. UNU (2018).
20. Lepawsky (2015).
21. Ryder and Zhao (2019).
22. Brooks, Wang, and Jambeck (2018).
23. Center for Biological Diversity (n.d.).
24. See Copeland and Taylor (2004) for a formulation of the pollution haven hypothesis.
25. Cherniwchan, Copeland, and Taylor (2017); Dechezleprêtre and Sato (2017); Ederington, Levinson, and Minier (2005).
26. Demsetz (1967).
27. Levinson and Taylor (2008).
28. Shapiro and Walker (2018).
29. Shapiro and Walker (2018).
30. Jackson et al. (2001).
31. van der Werf and Petit (2002).
32. Kroeger et al. (2017).
33. Kroeger et al. (2017).
34. Impact Valuation Roundtable (2017).
35. Lanoie et al. (2011).
36. Kummritz, Taglioni, and Winkler (2017).
37. Not all green goods have a positive environmental footprint. In some cases, such as in the mining of rare minerals, this is not the case.
38. Jha (2016).
39. Jha (2016).
40. Jha (2016).
41. Hertzke et al. (2018).

References

Andersson, Jens, Reza Iftekhar Patwary, Weronika Rehnby, and Emilie Pellby. 2018. "Evaluation of STWI Projects 2014–2018: Final Report." November 19, NIRAS Sweden, Stockholm.

Anenberg, Susan, Joshua Miller, Daven Henze, and Ray Minjaresicct. 2019. "A Global Snapshot of the Air Pollution–Related Health Impacts of Transportation Sector Emissions in 2010 and 2015." International Council on Clean Transportation, Washington, DC.

Brooks, Amy L., Shunli Wang, and Jenna R. Jambeck. 2018. "The Chinese Import Ban and Its Impact on Global Plastic Waste Trade." *Science Advances* 4 (6). doi: 10.1126/sciadv.aat0131.

Center for Biological Diversity. No date. "Ocean Plastics Pollution: A Global Tragedy for Our Oceans and Sea Life." Center for Biological Diversity, Tucson, AZ. https://www.biologicaldiversity.org/campaigns/ocean_plastics/.

Cherniwchan, Jevan, Brian R. Copeland, and M. Scott Taylor. 2017. "Trade and the Environment: New Methods,

Measurements, and Results." *Annual Review of Economics* 9 (August): 59–85.
Copeland, Brian R., and M. Scott Taylor. 2004. "Trade, Growth, and the Environment." *Journal of Economic Literature* 42 (1): 7–71.
Dechezleprêtre, Antoine, and Misato Sato. 2017. "The Impacts of Environmental Regulations on Competitiveness." *Review of Environmental Economics and Policy* 11 (2): 183–206.
Demsetz, Harold. 1967. "Toward a Theory of Property Rights." *American Economic Review* 57 (2): 347–59.
Dominioni, Goran, Dirk Heine, and Beatriz Martínez Romera. 2018. "Regional Carbon Pricing for International Maritime Transport: Challenges and Opportunities for Global Geographical Coverage." Policy Research Working Paper 8319, World Bank, Washington, DC.
Ederington, Josh, Arik Levinson, and Jenny Minier. 2005. "Footloose and Pollution-Free." *Review of Economics and Statistics* 87 (1): 92–99.
Ellen MacArthur Foundation. 2017. *A New Textiles Economy: Redesigning Fashion's Future*. Cowes, Isle of Wight, U.K.: Ellen MacArthur Foundation. https://www.ellenmacarthurfoundation.org/publications/a-new-textiles-economy-redesigning-fashions-future.
ETC (Energy Transitions Commission). 2018. *Mission Possible: Reaching Net-Zero Carbon Emissions from Harder-to-Abate Sectors by Mid-Century*. London: ETC. http://www.energy-transitions.org/sites/default/files/ETC_MissionPossible_FullReport.pdf.
European Commission. 2016. *Trade Sustainability Impact Assessment on the Environmental Goods Agreement*. Final report. Brussels: Directorate-General for Trade, European Commission.
European Parliament. 2015. "Emissions Reduction Targets for International Aviation and Shipping." Report IP/A/ENVI/2015-11 (November), Policy Department A: Economic and Scientific Policy, Directorate General for Internal Policies, European Parliament, Brussels.
Frothingham, Steve. 2018. "Pedego Shifts Some E-Bike Production to Vietnam in Response to Tariffs. *Bike Retailer and Industry News,* September 12. https://www.bicycleretailer.com/international/2018/09/12/pedego-shifts-some-e-bike-production-vietnam-response-tariffs#.XVrgOpNKiCd.
Grossman, Gene M., and Alan B. Krueger. 1991. "Environmental Impacts of a North American Free Trade Agreement." NBER Working Paper 3914 (November), National Bureau of Economic Research, Cambridge, MA.
———. 1995. "Economic Growth and the Environment." *Quarterly Journal of Economics* 110 (2): 353–77.
He, Jie. 2006. "Pollution Haven Hypothesis and Environmental Impacts of Foreign Direct Investment: The Case of Industrial Emission of Sulfur Dioxide (SO_2) in Chinese Provinces." *Ecological Economics* 60 (1): 228–45.
Heine, Dirk, and Susanne Gäde. 2018. "Unilaterally Removing Implicit Subsidies for Maritime Fuels." *International Economics and Economic Policy* 15 (2): 523–45.
Hertzke, Patrick, Nicolai Müller, Stephanie Schenk, and Ting Wu. 2018. "The Global Electric-Vehicle Market Is Amped Up and on the Rise." *Our Insights* (blog), May. McKinsey and Company, New York. https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/the-global-electric-vehicle-market-is-amped-up-and-on-the-rise?.
Hettige, Hemamala S., Paul Jonathan Martin, Manjula Singh, and David R. Wheeler. 1995. "The Industrial Pollution Projection System." Policy Research Working Paper 1431, World Bank, Washington, DC.
Holgate, Peter. 2018. "How Do We Tackle the Fastest Growing Waste Stream on the Planet?" *Global Agenda: Circular Economy*, February 9, World Economic Forum, Geneva. https://www.weforum.org/agenda/2018/02/how-do-we-tackle-the-fastest-growing-waste-stream-on-the-planet/.
Hook, Leslie, and John Reed. 2018. "Why the World's Recycling System Stopped Working." *Financial Times,* October 25. https://www.ft.com/content/360e2524-d71a-11e8-a854-33d6f82e62f8.
IMO (International Maritime Organization). 2015. *Third IMO Greenhouse Gas Study, 2014*. London: IMO.
———. 2018a. "Marine Litter." In Focus, IMO, London. http://www.imo.org/en/MediaCentre/HotTopics/marinelitter/Pages/default.aspx.
———. 2018b. "UN Body Adopts Climate Change Strategy for Shipping." Press Briefing 06, April 13, IMO, London. http://www.imo.org/en/MediaCentre/PressBriefings/Pages/06GHGinitialstrategy.aspx.
Impact Valuation Roundtable. 2017. "White Paper: Operationalizing Impact Valuation: Experiences and Recommendations by Participants of the Impact Valuation Roundtable." Geneva, World Business Council for Sustainable Development.
ITF (International Transport Forum). 2015. "The Carbon Footprint of Global Trade: Tackling Emissions from International Freight Transport." Policy Brief, November 30, ITF, Paris. https://www.itf-oecd.org/carbon-footprint-global-trade.
Jackson, Jeremy B. C., Michael X. Kirby, Wolfgang H. Berger, Karen A. Bjorndal, Louis W. Botsford, Bruce J. Bourque, Roger H. Bradbury, et al. 2001. "Historical Overfishing and the Recent Collapse of Coastal Ecosystems." *Science* 293 (5530): 629–37.
Jha, Veena. 2016. "Building Supply Chain Efficiency in Solar and Wind Energy: Trade and Other Policy Considerations." Issue Paper (May), International Centre for Trade and Sustainable Development, Geneva.
Keen, Michael, Ian W. H. Parry, and Jon Strand. 2012. "Market-Based Instruments for International Aviation and Shipping as a Source of Climate Finance." Policy Research Working Paper 5950, World Bank, Washington, DC.
Kellenberg, Derek K. 2009. "An Empirical Investigation of the Pollution Haven Effect with Strategic Environment and Trade Policy." *Journal of International Economics* 78 (2): 242–55.
Kroeger, Alan, Haseebullah Bakhtary, Franziska Haupt, and Charlotte Streck. 2017. "Eliminating Deforestation from the Cocoa Supply Chain." March, World Bank, Washington, DC.
Kummritz, Victor, Daria Taglioni, and Deborah Elisabeth Winkler. 2017. "Economic Upgrading through Global

Value Chain Participation: Which Policies Increase the Value Added Gains?" Policy Research Working Paper 8007, World Bank, Washington, DC.
Lanoie, Paul, Jérémy Laurent-Lucchetti, Nick Johnstone, and Stefan Ambec. 2011. "Environment Policy, Innovation, and Performance: New Insights on the Porter Hypothesis." *Journal of Economics and Management Strategy* 20 (3): 803–42.
Lepawsky, Josh. 2015. "The Changing Geography of Global Trade in Electronic Discards: Time to Rethink the e-Waste Problem." *Geographical Journal* 181 (2): 147–59.
Levinson, Arik. 2010. "Offshoring Pollution: Is the United States Increasingly Importing Polluting Goods?" *Review of Environmental Economics and Policy* 4 (1): 63–83.
Levinson, Arik, and M. Scott Taylor. 2008. "Unmasking the Pollution Haven Effect." *International Economic Review* 49 (1): 223–54.
Mekonnen, Mesfin M., and Arjen Y. Hoekstra. 2011. "National Water Footprint Accounts: The Green, Blue, and Grey Water Footprint of Production and Consumption." Value of Water Research Report 50 (May), IHE Delft Institute for Water Education, Delft, the Netherlands.
Muntean, Marilena, Diego Guizzardi, Edwin Schaaf, Monica Crippa, Efisio Solazzo, Jos G. J. Olivier, and Elisabetta Vignati. 2018. *Fossil CO_2 Emissions of All World Countries, 2018 Report*. JRC Science for Policy Report EUR 29433 EN. Luxembourg: Joint Research Center, European Union.
Roosevelt, Margot. 2018. "Can Southern California's Electric Bike Industry Survive Trump's Tariffs?" *Orange County Register*, September 10. https://www.ocregister.com/2018/09/10/can-southern-californias-electric-bike-companies-survive-trumps-tariffs/.
Ryder, Guy, and Houlin Zhao. 2019. "The World's e-Waste Is a Huge Problem: It's Also a Golden Opportunity." *Global Agenda: Digital Economy and Society*, January 24, World Economic Forum, Geneva. https://www.weforum.org/agenda/2019/01/how-a-circular-approach-can-turn-e-waste-into-a-golden-opportunity/.
Shapiro, Joseph S., and Reed Walker. 2018. "Why Is Pollution from U.S. Manufacturing Declining? The Roles of Environmental Regulation, Productivity, and Trade." *American Economic Review* 108 (12): 3814–54.
Sims, Ralph, Roberto Schaeffer, Felix Creutzig, Xochitl Cruz-Núñez, Marcio D'Agosto, Delia Dimitriu, Maria Josefina Figueroa Meza, et al. 2014. "Transport." In *Climate Change 2014: Mitigation of Climate Change; Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by Ottmar Edenhofer, Ramón Pichs-Madruga, Youba Sokona, Jan C. Minx, Ellie Farahani, Susanne Kadner, Kristin Seyboth, et al., 599–670. New York: Cambridge University Press.
Stern, David I. 2017. "The Environmental Kuznets Curve after 25 Years." *Journal of Bioeconomics* 19 (1): 7–28.
UNCTAD (United Nations Conference on Trade and Development). 2017. *Review of Maritime Transport 2017*. Report UNCTAD/RMT/2017 (October 25). Geneva: UNCTAD.
———. 2018. *Review of Maritime Transport 2018*. Report UNCTAD/RMT/2018 (October 3). Geneva: UNCTAD.
UNU (United Nations University). 2018. "E-Waste Rises 8% by Weight in 2 Years as Incomes Rise, Prices Fall." Press release, December 14, UNU, Tokyo. https://unu.edu/media-relations/releases/ewaste-rises-8-percent-by-weight-in-2-years.html.
van der Werf, Hayo M. G., and Jean Petit. 2002. "Evaluation of the Environmental Impact of Agriculture at the Farm Level: A Comparison and Analysis of 12 Indicator-Based Methods." *Agriculture, Ecosystems, and Environment* 93 (1–3): 131–45.