6

Greening Global Value Chains: A Conceptual Framework for Policy Action

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6.1 Introduction

The greening of a global value chain (GVC) is the process that results in the reduction of its ecological footprint, such as the impact on greenhouse gas (GHG) emissions, biodiversity loss, and overexploitation of existing natural resources (De Marchi et al. 2019). Reducing global GHG emissions is fundamental to achieving the Paris Agreement objective of keeping warming below 1.5°C. However, the fact that international production, trade, and investment are increasingly organized in GVCs, with different production stages located across different countries, makes it more challenging to coordinate the multiple actors involved in the chain towards this common goal (ADB forthcoming).

To analyze how greening can occur along the value chain, one must first understand the impact that GVCs have on the environment. There are three main channels through which GVCs affect the environment: a *scale effect*, a *composition effect*, and a *technique effect* (World Bank 2020). The scale effect is described as an increased level of production, leading to increased transport volumes and travels, waste production, and overexploitation of scarce resources, resulting in increased GHG emissions. As GVCs involve multiple cross-border flows of intermediate goods, an increase in economic activity leads to additional emissions from transportation and packaging of intermediate inputs. Indeed, Chapter 5 shows that GVCs have led to a surge in CO_2 emissions from international production-sharing through trade and investment. The international transport sector, in particular, was estimated to account for more than 10% of global emissions in 2018 (OECD 2022), and although overall carbon emissions from international transport dipped during the COVID-19 pandemic,

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they are now rebounding to pre-pandemic levels (Crippa et al. 2023). Maritime transport is the type most closely linked to GVCs, since more than 80% of the volume of international trade in goods is carried by sea (UNCTAD 2021). The share of shipping emissions in global emissions is estimated at 2.89% in 2018, and depending on the size of the scale effect, overall GHG emissions from international shipping are projected to increase up to 130% of 2008 levels by 2050 (IMO 2020).[1]

The composition effect reflects changes in the composition of production within a country because of international trade. In the case of GVCs, the production process is broken up into tasks that can be shifted from one location to another. This leads to environmental benefits when production tasks are relocated where it is the most efficient, or environmental costs when carbon-intensive tasks are relocated to jurisdictions where environmental regulation is lax (i.e., ”pollution outsourcing“). The latter scenario also results in environmental inequality, as some countries benefit from shifting economic activity away from carbon-intensive tasks, whereas others pay the cost (ADB forthcoming). Empirical evidence does not support a major reconfiguration of GVCs towards countries with lax climate policies, likely because emission abatement represents a smaller fraction of a firm’s total operating costs compared to capital, labor, and transport costs (Copeland, Shapiro, and Taylor 2021; WTO 2022). It is worth noting that the available empirical evidence may refer to a time when emission permit prices were relatively low. With the increasing diffusion of carbon price initiatives and permit prices increasing, the incentives for carbon leakages are likely to increase (World Bank 2022).

The technique effect refers to firms getting access to production methods that reduce emissions per unit of output through trade. In the case of GVCs, knowledge flows among firms along the value chain to facilitate the development, adoption, and adaptation of ”green” products and processes at different supplier levels (Altenburg and Rodrick 2017). GVC participation can be a powerful incentive for firms to ‘clean up’ their production processes to comply with lead firm requirements, with those who can’t adapt being left out of the value chain.[2]

To sum up, the scale effect results in increased GHG emissions (holding composition and technique constant); the composition effect is negligible; and the technique effect leads to a decrease in emissions per unit of output. Therefore, the technique effect must override the scale effect to reduce the environmental impact of a GVC. Empirical evidence at the macro level shows that the net effect depends on multiple factors, such as the type of pollutant, a country’s development stage, sector composition, and the energy sources used. (WTO 2022).

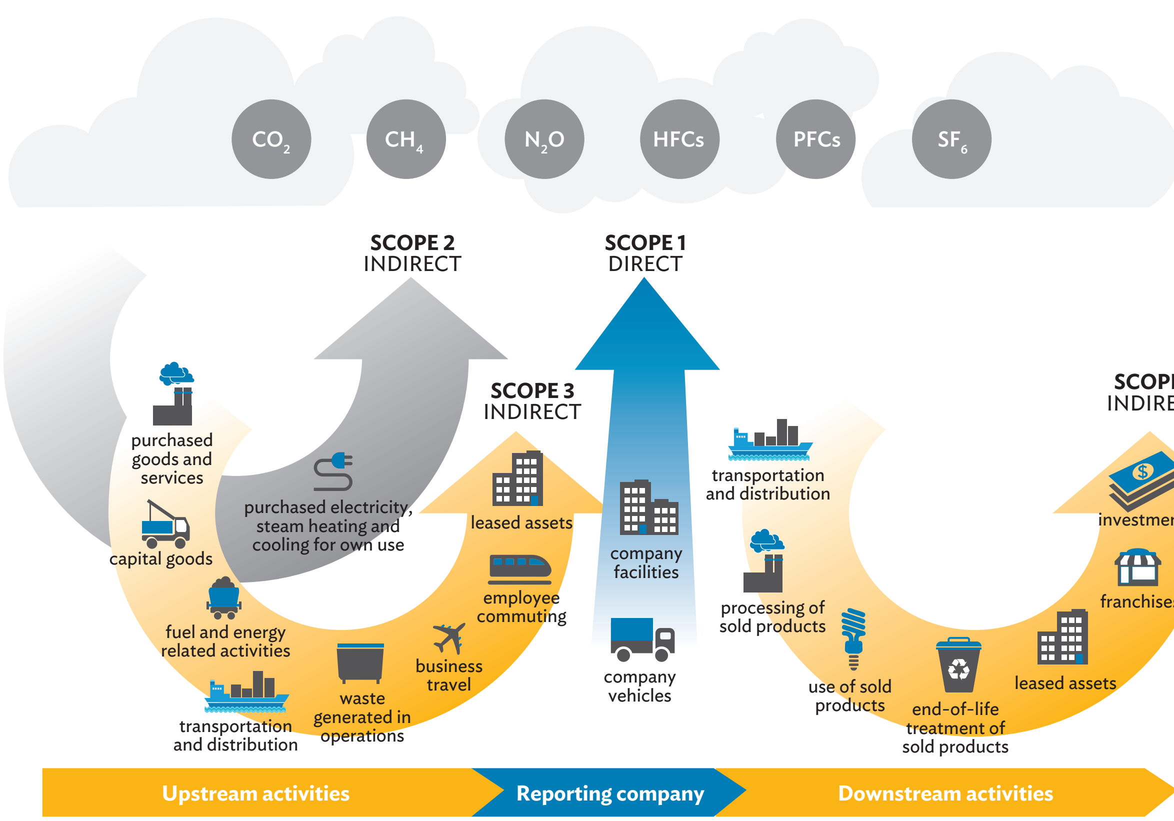
1 At the time the study was conducted, it was too early to assess the impact of the COVID-19 pandemic on emission projections (IMO 2020).

2 Lead firms, such as Toyota, Apple, or Nike arrange their networks of suppliers to produce a given product. They tend to control access to key resources and activities, such as product design, international brands, and access to final consumers. This usually gives them considerable influence over the other suppliers in the production network (Chang, Bayhaqi, and Zhang 2012).

The focus of this chapter is the potential policy levers to incentivize GVC greening at the firm level. A conceptual framework is presented to investigate (i.) why GVC greening occurs, (ii.) the types of environmental innovation undertaken in GVCs, (iii.) the actors involved, (iv.) how the greening occurs in GVCs and the different stages, and (v.) the outcomes of GVC greening. Table 6.1 offers a detailed description of the different elements included in the conceptual framework, which is accompanied by case studies for evidence-based policy implications.

A GVC is a web of independent, yet interconnected enterprises where lead firms tend to specialize in high value-added activities, relying on external suppliers to perform production tasks. The implication for GHG emissions across the value chain is shown in Figure 6.1. Assuming the "reporting company" shown in the figure is a GVC lead firm, the direct emissions from company-owned and controlled resources, known as *scope 1 emissions*, are shown at the center. To the far left, there are the indirect emissions from the generation of purchased electricity, steam, heating, and cooling for the firm's own use, i.e., *scope 2 emissions*. Finally, the indirect emissions that occur in the value chain of the reporting company, including both upstream and downstream emissions, are known as *scope 3 emissions*.

Figure 6.1: Overview of Greenhouse Gas Emissions Across the Value Chain



Source: WRI and WBCSD 2011.

The case of global technology lead firm Apple illustrates the relevance of scope 3 emissions: less than 1% of the firm's CO2 emissions are directly from the corporation itself. No emissions are produced from energy use, since energy is sourced from renewables. However, the products' lifecycle emissions in upstream and downstream production and use are significant: more than 75% of emissions are from products manufacturing in supplier firms, 14% from product use, and 5% from product transport (Apple 2022a). Hence, it is important for lead firms to be accountable for the environmental footprint of their entire value chain.

As shown in Chapter 5, emissions from production tasks are increasingly concentrated in developing economies to produce goods and services for export to high-income economies. Therefore, GVC greening can also help redress the environmental inequality arising from the geographical distribution of tasks along the value chain.

The rest of the chapter is organized as follows: The next five sections examine the five elements of the conceptual framework shown in Table 6.1. This is followed by a three-pronged strategy for policy action based on (i.) creating and amplifying the driving factors, (ii.) leveraging the identified enabling mechanisms, and (iii.) monitoring outcomes and addressing environmental inequality. The chapter concludes by drawing lessons from evidence and findings presented.

6.2 The Driving Factors of Global Value Chain Greening

GVC greening has institutional, market, and technological drivers that have spillover effects on one another. Institutional drivers typically derive indirectly from societal pressures and political decisions to reduce negative externalities in home economies. For example, as of 2022, 46 countries were pricing emissions through carbon taxes or emission trading schemes (Black, Parry, and Zhunussova 2022). Denmark currently has the highest enterprise carbon tax scheme, which will reach USD 160 per ton of carbon dioxide emitted by 2030 (Jacobsen and Skydsgaard 2022). However, as the cost of emissions becomes increasingly expensive in certain countries, there is a risk that firms based in those countries will move carbon-intensive production to countries with less stringent climate policies, a phenomenon known as "carbon leakage."

In order to stem carbon leakage from countries without a carbon price, the European Union is phasing in the Carbon Border Adjustment Mechanism (CBAM), which will take effect in 2026, with reporting starting in 2023. The CBAM is a carbon tariff targeting goods deemed at most significant risk of carbon leakage—cement, iron and steel, aluminum, fertilizers, electricity, and hydrogen—designed to ensure the carbon price of imports is equivalent to the carbon price of domestic production. However, as discussed in Chapter 5, the CBAM is not without criticism from those who see it as further exacerbating global trade tensions and unfairly affecting developing economies with lower historical emissions (ADB forthcoming).

Table 6.1: The Conceptual Framework for Global Value Chain Greening

Key question	Why is GVCs greening occurring?	What type of environmental innovation is involved in GVCs greening?	Who are the actors involved in environmental innovation?	How is environmental innovation implemented in the value chain?	What are the biophysical outcomes?
Description	The main drivers of GVC greening	The main forms of environmental innovation in GVCs	The key actors in GVC greening	The enablers of GVC greening	The outcomes of GVC greening
Main categories	**Institutional drivers** • At national level » Introduction of sustainability standards » Introduction of carbon taxes » Introduction or changes in national environmental legislations • At global level » Environmental provisions in trade agreements » International environmental agreements **Market drivers** • Changes to green preferences among consumers or professional users in existing markets • Shift of market demand to green lead markets **Technology drivers** • New green technology in manufacturing • Digital technologies to minimize waste, energy use, enforce traceability	**Environmental process innovation** • Substitution of energy-sources, energy intensive materials, scarce natural resources, toxic inputs • Reduction of waste from the production process • Reduction of energy consumption • Optimization of the material flow **Environmental product innovation** • New designs replacing environmentally harmful components • Designing of recycled products • Designing for durability • Substitution of complete environmentally harmful product • Recycling • Re-use of waste **Environmental organizational innovation** • Lean production • Green Supply Chain Management	**Chain internal actors** • Lead firms: buyers and producers • Suppliers (different tiers) **Chain external actors** • National/Local governments • NGOs, • Civil society organizations	• **Enabled by lead firms** » Standard-driven » Mentorship driven • **Enabled by suppliers** Autonomous building of internal knowledge • **Collectively enabled** Business associations, consortia • **Enabled by the state** i.e., local, and national governments	• Climate change mitigation • Mitigation of biodiversity loss • Sustainable use of territorial and marine ecosystems • Diffusion of affordable, reliable, and sustainable energies • Diffusion of sustainable consumption and production patterns
Additional questions	• Can the drivers be traced to specific structural changes associated with the green transformation? • Are the drivers mainly national or global?	• Did the innovations involve several types of innovation at once, cross-cutting between product, process and organization? • In which stages of the GVC is the green innovation taking place?	• Is there mainly one driving actor or are several actors jointly responsible for environmental innovation? • How do internal and external actors interact with one another?	• Does learning take place at the collective or individual level? • In which areas have capabilities been built? • Which incentives should be set across the chain to foster the diffusions of environmental innovations?	• Does innovation result in greener GVCs overall? • Have efforts at greening GVCs largely resulted in improved reputations of lead firms rather than improved environmental outcomes? • Are there any trade-offs between positive and negative outcomes? • Who are the beneficiaries of GVC greening? Who are the losers?

Institutional drivers may also arise in multilateral settings. This applies, for example, to trade agreements where detailed environmental provisions are included in the charters with the effect of increasing green exports from developing countries, particularly pronounced in countries with stringent environmental regulations (Brandi et al. 2020).[3] Moreover, private governance mechanisms—whereby environmental concerns become part of a broader multilateral network of cooperation and standardization driven by corporate initiatives—are increasingly becoming relevant. For example, the Carbon Pact agreements that the global shipping company Maersk enters into with its customers form the basis for a value-chain-spanning approach to mitigating the carbon emissions from transport. Through the Carbon Pact, Maersk is provided transparency into the logistical flows of its customers' production network, thus unlocking possibilities for optimization of transport emissions (Salminen et al. 2022).

The market drivers of GVC greening are rooted in changes to green demand preferences amongst consumers or professional users in existing markets or to the shift of market demand to green lead markets, i.e., markets with more stringent environmental protocols. For example, concerns about climate change amongst consumers may lead global buyers to introduce fair trade labels that include a certification process to ensure environmental standards, such as the introduction of the Forest Stewardship Council (FSC) label to wood products to ensure sustainable sourcing or the climate label introduced by the British multinational corporation Tesco in 2007, although this was discontinued in 2012 due to unforeseen costs and lack of take-up by other businesses (Lucas and Clark 2012). British retailer Marks & Spencer's 'Plan A' initiative, discussed in Box 6.1, is an example of consumers successfully driving the lead firm to greening its value chain.

Aggregate demand patterns may shift from locations with lax environmental regimes to green lead-markets (Beise and Rennings 2005). Foreign regulations have stimulated renewable energy innovation in the energy domain due to the foreign demand inducement effect. Foreign climate and environmental policies can thus spur green innovation in other countries. GVCs may act as an important channel whereby foreign environmental regulatory stringency signals are conveyed to induce domestic renewable energy innovations (Herman and Xiang 2022). These are typically diffused through the efforts to meet more environmentally demanding customer requirements. Lead firms may respond to customer and institutional pressure by transferring environmental requirements upstream in the supply chain, either by collaborating or monitoring the suppliers' environmental performance (Laari et al. 2016).

A different demand effect is seen when the final demand for sectoral products shifts from one market to another, where the latter is part of the green economy. For example, when demand for lithium shifted from ceramics and glass to lithium-ion batteries—a

3 For an overview of the environmental provisions included in preferential trade agreements (PTAs), see the TRade and ENvironment Database (TREND) (IDOS 2022).

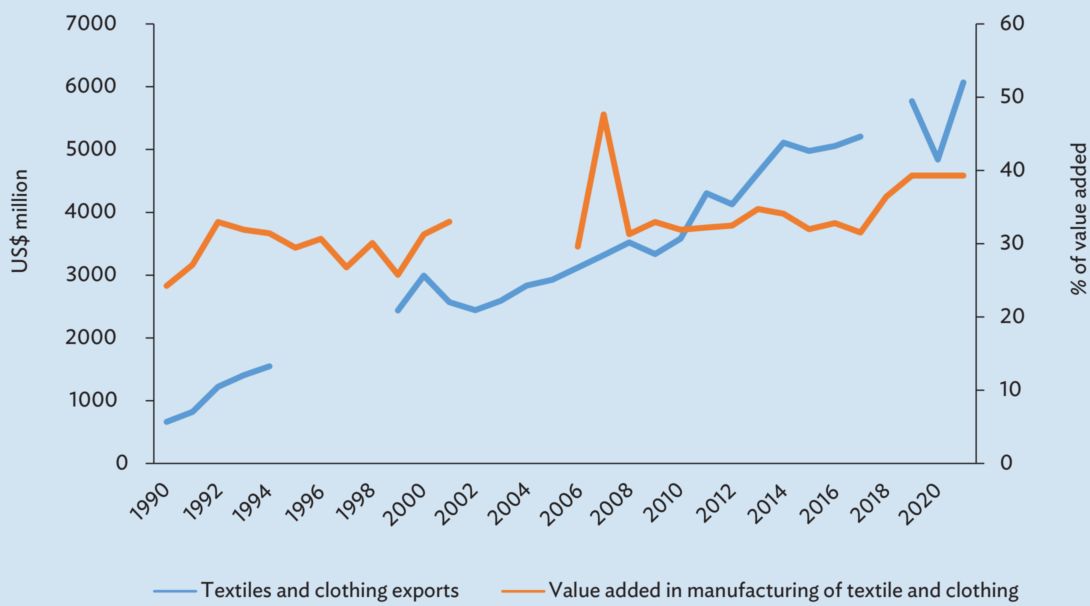
market with significantly higher environmental attention—it induced environmental innovations to reduce mining waste at the source of GVCs (Tabelin et al. 2021).

Box 6.1: The (Un)Willingness to Pay for Green: Textile Suppliers in Sri Lanka

The textile industry has a high environmental impact because of its intensive use of natural resources, energy, and chemicals (European Parliament 2023). It is also one of the "light industries" where the barriers to entry in production are relatively low, serving as a springboard for export-oriented industrialization for developing economies (OECD, WTO, and IDE-JETRO 2013). Figure 6.2 presents the case of Sri Lanka. Between 1990 and 2021, the country saw a steady growth in textiles and clothing exports and an increase in value added in manufacturing, albeit at a slower pace.

Sri Lankan exporters on the textile value chain are typically first-tier suppliers to international apparel brands, exporting finished garments manufactured with imported materials. One of those international brands is British retailer Marks & Spencer (M&S). In 2006, M&S conducted a survey that showed their customers' growing expectations for the company to focus on climate change. However, they did not want to pay a premium for it, and they did not want to know all the details of what the company was doing to fight climate change and how it was doing it (Goger 2013). To align its strategy to the survey findings, in 2007 M&S launched the M&S Plan A, with the tagline: "Plan A because there is no Plan B for the one planet we have" (M&S 2015). Plan A included 100 ethical commitments to be achieved within 5 years, implemented both internally and among roughly 2,500 suppliers around the world, based on the idea that environmental upgrading could enhance supplier competitiveness in the long run.

Figure 6.2: Sri Lanka's Performance in Textile and Clothing Manufacturing, 1990–2021



Source: World Integrated Trade Solution and World Development Indicators (accessed 26 September 2023).

As one of the first Plan A projects in 2007, M&S decided to pilot four model environment-friendly factories for apparel in Sri Lanka, partly because the Sri Lankan suppliers had well-established relations of trust with M&S after 20 years of doing business together (Goger 2013). The pilot projects involved green designs for the plants and work processes such as rainwater catchment, solar power, waste reduction, and an energy-efficient cooling system (Figure 6.3).

Although building the model eco-factories cost approximately 30% more than a conventional factory, M&S contributed a very small share of the overall cost in seed funding. Furthermore, it did not offer a price premium, did not commit to higher orders, and did not offer long-term contracts to its suppliers. It is not surprising, then, that the model eco-factories were built by firms that had substantial financial and managerial resources and were well positioned to benefit from early mover advantages (Goger 2013).

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Box 6.1: continued

In a different study, Khattak et al. (2015) interviewed three textile firms in Sri Lanka that had embarked on an environmental upgrading trajectory in one or more of their factories. All firms held the Leadership in Energy and Environmental Design (LEED) certification standard, were International Standards Organization (ISO) 14001 certified, and were signatories of the Global Compact, a policy initiative for businesses committed to aligning their operations and strategies with 10 principles in the areas of human rights, labor, environment, and anticorruption. Compliance with these standards is necessary to get procurement from global buyers, namely European and United States-based retailers.

Figure 6.3: The Plan A Model Eco-Factories

a. Green Uniforms in a Model Eco-Factory

b. Plants on the Shop Floor and Natural Lighting

c. a Green Roof on a Model Eco-Factory

d. Solar Panels and Rainwater Catchment Systems

Source: Goger (2013).

The three firms studied by Khattak et al. (2015) engaged in environmental upgrading through a combination of technological, organizational, and social initiatives. Because of the substitution of fossil energy sources and the shift towards biogas, solar PV, and hydroelectric power for steam production, all firms included in the study were able to reduce their carbon emissions. Some of the factories had also introduced rainwater harvesting facilities and waste recycling systems to divert waste from landfills. The firms transformed their organizational processes by incorporating policies and regulations consistent with the standard of their environmental certifications and implementing monitoring tools. Finally, they organized programs to foster a green culture across all levels of employees.

In all three cases examined by Khattak et al. (2015), lead firms played a key role in the environmental upgrading process. They encouraged their local suppliers to upgrade, set the standards, and offered future contracts in exchange for compliance. They shared knowledge not only on certification standards to help their suppliers upgrade, but also on future industry trends. It is also worth noting that all three factories manufactured and exported high value-added products for which specifications and production processes are not easily codified; hence, frequent interactions between lead firms and suppliers were required to transmit the tacit knowledge required.

For all three local suppliers, lead firms did not provide any low-cost funding nor grants to support environmental innovation, and most of them did not offer higher prices for products manufactured in an environmentally sustainable manner. Because improving the eco-efficiency of production lowered operating costs, the three suppliers stayed competitive by offering lower prices to international buyers.

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Box 6.1: continued

In addition to asking suppliers to improve environmental compliance without any financial support, lead firms are known to pressure them for a lower price, a practice known as "squeezing." While already capable and financially sound suppliers can absorb the initial investment in greening their operations, firms facing capacity and financial constraints may be left out of the value chain (Goger 2013; Ponte 2020).

This case study shows that shifts in consumer demand can lead to GVC greening. However, when consumers are unwilling to pay a premium for products from sustainable manufacturing and lead firms are unwilling to reward suppliers for such compliance, only the more advanced firms with considerable financial resources can participate.

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The technology drivers of GVC greening arise when new technologies induce efficiency savings with a greening effect or innovations to meet greener demand requirements. Innovations may spread beyond individual firms through entire value chains, and such diffusion, especially between the Global North and Global South, is key to greening GVCs (Glachant et al. 2013).

The major technological shift that occurred at the turn of the 21st century, known as the Fourth Industrial Revolution (4IR), is characterized by the convergence of a wide range of breakthroughs—not just digital (e.g., artificial intelligence), but also physical (e.g., new materials) and biological (e.g., bioengineering). Particularly relevant to GVC greening are Smart Manufacturing and Service Technologies and Data Processing Technologies (Lema and Rabellotti 2022).

Smart manufacturing and service technologies are involved in automating and decentralizing production tasks. They include advanced robotics, 3D printing, wireless technologies, and sensors (e.g., the Internet of Things [IoT]). Examples of this class of technologies include RFID tags, which can improve logistics efficiency and thereby reduce global trade's overall carbon impact; fixed and mobile sensors in harvesting and logging equipment and satellite data that provide precise information on matters of interest such as tree species, biodiversity counts, or illegal logging and fishing; and wireless sensors and GPS tracking systems that generate data used to optimize logistics and significantly reduce carbon emissions (Caldeira Pedroso et al. 2009, Gale et al. 2017, Mangina et al. 2020). In the case of smart factories that already employ IoT and robots, improvements in the algorithms could result in continuous optimization and increases in energy efficiency. For example, in a case study of a smartphone manufacturer that uses robots, based in the People's Republic of China, algorithm changes to optimize the robot operation increased the productivity of these machines

(Fuoco 2018). Finally, the savings in using 3D printing instead of traditional production methods can be substantial. For example, a study found that additive manufacturing on the production of less flight-critical lightweight aircraft parts could reduce the weight of these parts, thus reducing the weight of an airplane, its fuel consumption, and the related carbon emissions in air travel (Huang et al. 2016).

Data processing technologies enable interconnection and data exchange within and between firms. They include big data, blockchain, cloud computing, and Artificial Intelligence (AI). Blockchain can enhance sustainability both upstream and downstream. In upstream supply chain management, for example, blockchain can track faulty products or components to reduce reproduction, with recalls resulting in decreased resource consumption and reduced GHG emissions; it can also increase traceability to ensure that designated green products are environmentally friendly, such as in the case of the blockchain-based Supply Chain Environmental Analysis Tool (SCEnAT) system to trace the carbon footprint of products or the Programme for the Endorsement of Forest Certification (PEFC) to ensure that wood is sustainably sourced (Saberi et al. 2019). Downstream, blockchain can be used to enhance incentives to recycle, such as with the RecycleToCoin system that enables people to return plastic containers for a financial reward, and to provide information to buyers on the origin of products and guarantees authenticity of the information.

AI is relevant across environmental domains such as energy, production, and natural resource management (Toniolo et al. 2020). For example, to reduce energy consumption in operations, firms are starting to adopt technologies that can optimize green energy use in smart grids. In agriculture, supply chain professionals can draw on AI inputs to plan shipping and the delivery of perishable goods by monitoring and forecasting the state of the cargo. This is often aided by AI that draws on data from sensors and other technologies involved in smart supply chain systems and intelligent food logistics. Measures such as certifications, codes of conduct, supply chain reporting, lifecycle assessments, supplier audits, smart packaging, and eco-efficiency programs may all be aided by AI. In this respect, machine learning and intelligent automation improve environmental management.

Box 6.2 presents the famous case study on the sourcing of tuna from the Eastern Tropical Pacific (ETP) purse seine fishery, which resulted in high dolphin mortality due to entanglement in the nets. The tuna caught in the ETP was then processed, canned, and sold to consumers in the United States. Dolphin mortality was a negative biophysical outcome in the canned tuna value chain that was greatly reduced in the thirty-year period going from the early 1970s to the early 2000 through a convergence of market, institutional, and technology drivers. It is also a case where legislation at the national level resulted in ”leakage” of the environmental cost, with subsequent attempts by the national legislator to address the problem. Finally, it emphasizes the importance of multilateral action to create common rules and standards.

Box 6.2: The "Tuna-Dolphin Problem" and the Drivers of Global Value Chain Greening

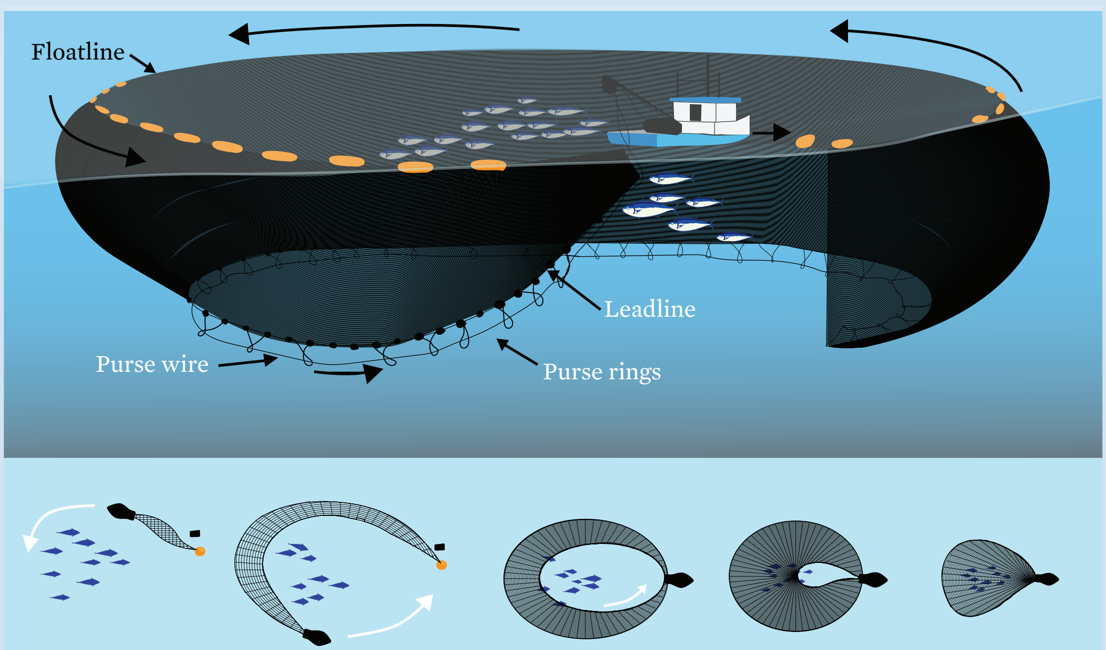
The Eastern Tropical Pacific (ETP), a large swath of the Pacific Ocean extending from Mexico to Peru, is the only region in the world where large pods of dolphins are prevalent above schools of tuna, accompanied by flocks of seabirds. This gathering makes it possible to visually locate large schools of tuna by searching for the seabirds, which closely track the tuna. Once the dolphins are sighted closer to the ocean surface, they are chased and encircled with purse seines to capture the schools of tuna underneath them. A purse seine is a large surrounding net that hangs vertically in the water with its bottom edge held down by weights and its top edge buoyed by floats. Once the school of tuna is encircled, the net is "pursed" at the bottom, capturing the dolphins that follow the tuna (Figure 6.4).

It has been estimated that more than 7 million dolphins were killed by ETP tuna purse seiners since the late 1950s (IMMP 2022), and this is just due to entanglement. Research suggests that chase and encirclement may also have many other negative impacts on dolphins, such as increased fetal and calf mortality, separation of nursing females and their calves, decreased fecundity, increased predation, disruption of mating and other social systems, and ecological disruption (Ballance et al. 2021).

In the mid-1960s, the high dolphin mortality in the ETP tuna purse seine fishery came to widespread public attention in the United States, resulting in calls on the government to take action that ultimately led to the Marine Mammal Protection Act (MMPA) being enacted in 1972 with the goal of reducing dolphin mortality to "insignificant levels approaching zero" (NOAA 2023). Since dolphin mortality continued to be high after the passage of the MMPA, the legislation was tightened in subsequent amendments that led many US vessels to register under flags of other countries or to fish for tuna in other geographic regions, using other methods (Ballance et al. 2021).

Modifications to purse-seine fishing methods were identified relatively early to reduce dolphin mortality from entanglement. They range from simple solutions such as using swimmers and divers to disentangle and release dolphins and using high-intensity floodlights to illuminate dolphins in the nets at night, to more technical solutions. For example, the "backdown," whereby the vessel is run in reverse after the seine has been pursed and approximately two-thirds of the net brought on board the vessel, which releases the dolphins while the tuna tend to remain below the dolphins in a deeper part of the net. Sawing a "dolphin safety" panel of relatively small mesh netting into the purse seine to surround the apex of the backdown area where dolphins are most likely to gather has also proven very effective (Ballance et al. 2021).

Figure 6.4: A Purse Seine Net



Source: Authors based on AFMA 2023.

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Box 6.2: continued

As US vessels left the ETP fleet due to the stringent MMPA requirements, vessels from other countries entered in larger numbers, so that the number of vessels using purse seines in the ETP continued to increase. The 1984 amendments to the MMPA introduced embargoes on tuna imports from fleets with dolphin mortality above that of the US fleet, due to concerns that US gains in lowering dolphin mortality were being offset by increased mortality from non-US vessels. In 1988, dolphin mortality requirements on tuna imports were further tightened. At the same time, environmental public opinion pressure led to voluntary action by the three largest US tuna canners to buy only tuna caught using methods other than purse seine fishing.

The US embargo on the sale of tuna caught with purse seine nets was lifted in 1997 after challenges by Mexico and other nations under the General Agreement on Tariffs and Trade (GATT). Meanwhile, a 1990 amendment to the MMPA established the "dolphin-safe" label, which mandated that during the entire trip for which tuna were captured no purse seines were deployed that targeted dolphins at the sea surface, as verified by a certified observer. The labels, combined with environmental activism to pressure major US retailers, effectively excluded tuna caught on dolphins from the large and lucrative US market (Ballance et al. 2021). Mexico challenged the dolphin-safe label multiple times under the WTO non-discrimination rule and the WTO's appellate body ruled against the US in 2012 and 2015, arguing that the label did not take into account the risk to dolphins of other tuna fishing methods. After the US adapted the label, the appellate body upheld the measure in 2019 and ruled that it is fully consistent with WTO rules (WTO 2019).

In the early 1990s, before the embargo on non-MMPA compliant tuna was lifted, the foreign fleets' desire to re-enter the US market formed the basis for a series of multilateral initiatives (Ballance et al. 2021). In 1992, with the La Jolla Agreement, 10 fishing countries (including the US and Mexico) established the International Dolphin Conservation Program with a focus on comparability of dolphin mortality to the US fleet under the MMPA and the dolphin-safe label. The agreement introduced two key features: (i) the non-transferable Dolphin Mortality Limit (DML) per vessel, whereby once a vessel reached its own DML, it was required to cease purse seine fishing targeting dolphins, and a vessel changing flags would still retain its DML; and (ii) an International Review Panel (IRP) tasked with the review of cases of apparent non-compliance with the La Jolla Agreement based on fisheries observer reports. In addition to representatives of the Parties to the Agreement, the IRP included elected industry and NGO representatives, thus increasing transparency and accountability.

In 1995, the Declaration of Panama was signed by 12 nations. It reaffirmed a commitment to reduce dolphin mortality to levels approaching zero, declared the nations' intention to formally establish strict stock-specific DMLs on a per-vessel basis, and agreed to place fisheries observers on every large purse-seine vessel to verify dolphin mortality. Finally, in 1998 features of the La Jolla Agreement and the Declaration of Panama were formally incorporated into the Agreement on the International Dolphin Conservation Program (AIDCP), a legally binding multilateral agreement with three primary objectives: (i.) progressively reduce incidental dolphin mortalities in the tuna purse-seine fishery in the Agreement Area to levels approaching zero, through the setting of annual limits; (ii.) seek ecologically sound means of capturing large yellowfin tunas not in association with dolphins with the goal of eliminating dolphin mortality in this fishery; and (iii.) ensure the long-term sustainability of the tuna stocks in the agreement area, as well as that of the marine resources related to this fishery, taking into consideration the interrelationship among species in the ecosystem (IATTC 2023).The AIDCP also made periodic attendance of informational seminars to educate fishing captains on bycatch mitigation a requirement for certification to engage in purse-seine fishing under the agreement.

Together, these institutional, market, and technological drivers reduced dolphin mortality due to entanglement by more than 99%. However, it is unclear whether and to what degree dolphin populations have recovered. That is because conducting comprehensive repeated surveys to derive rigorous estimates of dolphin populations requires significant funding, not to mention the logistical challenges of such a large and remote area, and the multinational nature of the fishery, which complicate data collection, regulation, and enforcement (Ballance et al. 2021). Multilateral action is needed to monitor the biophysical outcomes of countries' joint action.

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6.3 Types of Environmental Innovation

Environmental innovation is defined as a radical or incremental change in processes, products and organizational models that results in a reduction of the chain's ecological footprint – such as its impact on greenhouse gas emissions, biodiversity losses, and natural resources overexploitation (De Marchi et al. 2019). In this section, we distinguish between environmental process innovation, environmental product innovation, and environmental organizational innovation, although in the real world there is a lot of overlap among the three categories. For example, it may be difficult to distinguish between process and product environmental innovations; the two often take place together since a change in the production process is often needed to modify a product. Process and organizational innovations could also overlap because process improvements can be the result of fulfillment of environmental management standards such as ISO 4000 (De Marchi and Di Maria 2019). Nonetheless, the evidence presented in this section is useful to get a more concrete grasp of what type of innovation is making GVC greener.

Environmental process innovation occurs when eco-efficiency increases along the different stages of the value chain through the reorganization of the production process or the use of superior technology. An example of environmental process innovation in the logistics of PET plastic bottle recycling is described by Bjorklund et al. (2012). The large volume of collected PET bottles creates challenges in terms of increasing requirement of storage space and rising emissions from transportation. To tackle these issues, Returpack, a Swedish recycling company, introduced a new equipment to compress the bottles in collecting trucks, reducing the transported volumes throughout the entire flow. This innovation led to a reduction in the number of trips, an increase in the volume of recycled bottles, and a decrease in the company's carbon footprint.

Kunkel et al. (2022) explore the greening of Chinese companies in the electronics industry due to the introduction of Big Data Analytics (BDA) for sustainable supply chain collaboration. The adoption of BDA for tracking suppliers' environmental footprints has made it possible to: (i) track CO2 emissions along the supply chain; (ii) predict whether companies were at risk of not meeting sustainability targets; (iii) calculate carbon footprint along the chain; and (iv) track fleet routes in logistics processes. This has also resulted in more efficient tracking and tracing of containers and reusable packaging material, with a reduction in the amount and cost of packaging.

The tannery district in Arzignano, Italy, is an example of suppliers within GVCs as proactive actors in environmental innovation (Box 6.3). The local government supported creation of the baseline infrastructure to reduce the cluster's ecological footprint; that enabled the firms to leverage funding from the EU for environmental innovation.

Environmental product innovation takes place with the development of environment-friendly products (i.e., designed for durability, using recycling inputs, recycling, reduced

Box 6.3: Environmental Innovation in Industrial Clusters—The Arzignano Tannery District

In the leather production process, several steps to produce the final output entail a high level of water consumption and pollutants that in the final stage produce emissions like dust and organic compounds. Consequently, the leather industry has experienced a growing flow of investments in environmental sustainability.

Arzignano is an industrial town of about 25,000 people in northeastern Italy. Its industrial district specializes in leather production and the local tanneries are suppliers in different value chains, such as IKEA in the furniture industry, LVMH in the fashion industry, and Audi and BMW in the automotive industry. Within the leather GVC, tanneries usually perform low value-added tasks at the production stage (Figure 6.5). The higher value-added tasks in pre-production, such as research and development, are generally performed by chemical firms (including large multinationals such as BASF), whereas lead firms handle higher value-added tasks in post-production, such as marketing and branding (De Marchi and Di Maria 2019).

Figure 6.5: Leather Production in an Arzignano Tannery

Source: Gruppo Mastrotto SpA

In response to environmental pressure and stringent regulation, the cluster has undertaken intense environmental upgrading activities since the early 1970s, acting both at the cluster and firm level, with a gradually more systemic approach. With support from the local government, the consortium built a water treatment plant and an industrial sewage system to collect sludge and water refuse from the tanneries. These investments represent a baseline infrastructure for the improvement of the local environmental situation and the foundation for further cluster development; that is precisely what happened with the GreenLIFE project, funded by the European Commission, which ran from 2014 to 2017. Five local companies developed several process innovations to make the leather production process more sustainable (European Commission 2021). A first innovation introduced in the local tanneries was aimed at reusing water, also leading to a reduction in electricity use. A further area for innovation was the optimization of material flow in the liming process using oxygenated water instead of pollutants, thereby reducing the use of toxic inputs. Finally, the local firms developed a new tanning agent from renewable sources based on natural polymers instead of chrome.

While the creation of the baseline infrastructure was mostly in response to local pressures, the tanneries' participation in GVCs provided a powerful incentive for them to engage in environmental innovation. First, by demonstrating the ability to develop such advanced processes, the tanneries wanted to signal to their international buyers that they are ready to perform higher value-added activities, including co-development of new product lines. Second, large international buyers, especially in the automotive and fashion industries, are demanding increasingly sustainable inputs of their suppliers in response to pressure from consumers and policymakers. Third, when it is not possible to compete on costs with suppliers from emerging markets (e.g., the People's Republic of China), then environmental sustainability is key to maintaining a competitive advantage (De Marchi and Di Maria 2019).

The new processes tested under the GreenLIFE project demonstrated up to 70% less water consumption due to bath recovery; reduced consumption of chemicals (up to 80% of sulfates, 20% of chlorides and complete elimination of chromium and formaldehyde compounds); lower energy consumption (up to 10% less electricity and 10% methane); lower waste production (up to 50% of the waste produced in weight can be recycled); and reduced odorous emissions from the tannery district (European Commission 2021). The achievements of the project have also contributed to a wide range of EU legislation.

The case of the Arzignano leather cluster highlights several aspects of GVC greening. First, is the role suppliers take as drivers of environmental innovation within GVCs as opposed to lead firms, which do not have technical knowledge in the tannery process (De Marchi and Di Maria 2019). Second, it is an example of collectively enabled innovation, which is commonly found in industrial clusters (Giuliani, Pietrobelli, and Rabellotti 2005). Finally, the case highlights the role of the local government as an actor enabling innovation by supporting the creation of the local infrastructure that propelled further cluster development, as well as the role of supranational organizations such as the European Union in supporting environmental innovation.

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packaging, and waste reuse). An example is provided by Aquafil, an Italian company specializing in nylon yarns for carpeted floors (De Marchi et al. 2013b). In addition to investing in energy production and a more efficient energy management through a co-generation plant, the company developed a new yarn named Econyl, made by recycling carpets, which reduces the use of raw materials and waste at the end of the product lifecycle.

Box 6.4 presents the case of Valcucine, an Italian company producing high-end, design-driven kitchens. Because of its continuous research and development efforts, the company introduced several environmental features to differentiate itself from the competition, thus obtaining a premium price (De Marchi et al. 2013a).

Box 6.4: Valcucine: A Mentoring-Driven Approach to Product Innovation

Valcucine is an Italian company in Northeastern Italy that specializes in the production and commercialization of kitchens for high-end markets. Its business model is based on attractive design, technological innovation, and attention to quality and sustainability. The firm does not perform any manufacturing activity except for assembly and relies on a network of roughly 300 suppliers, with first-tier suppliers mostly located in the surrounding area. Design and marketing are the major activities performed in-house, while sales are carried out by specialized retailers worldwide and through a few flagship stores. Valcucine is responsible for the marketing and design of almost all new products and cooperates with suppliers on technical features.

Valcucine's environmental goals of reducing the materials used in the production process, reducing the environmental impacts of furniture disposal, and improving recyclability are achieved through extensive product innovation. Kitchens are designed to be technically and aesthetically durable, and highly recyclable (up to 100%)— attributable to the selection of raw materials (e.g., glass and aluminum), and the use of one-material components that are put together solely by mechanical joints. Accessories, such as lights and appliances, are considered to be among the most environment-friendly available on the market.

The typical supplier In Valcucine's network is a small family-run operation for which the cost of obtaining and maintaining an environmental process certification can be prohibitively high. Therefore, the company typically does not ask for certifications as a prerequisite to do business. Instead, compliance with the environmental features of the product is guaranteed by a tough internal control system based on first-hand knowledge of the processes used by suppliers achieved through frequent on-site visits and by co-developing process innovations. The firm also actively looks for second-tier suppliers that can match its requirements and join the collaboration with first-tier suppliers to develop new products. This is the case, for example, of the air emission and health improvements achieved through the co-development of a new waterborne varnish in close cooperation with its first-tier supplier, a varnish producer, and a machinery company (De Marchi et al. 2013a).

Valcucine fosters the environmental upgrading of its suppliers by sharing knowledge on the product, processes, or organization, and at times through joint investments or other favorable financial conditions. It suggests how to reduce environmentally harmful products and processes and collaborates with suppliers in developing new solutions. In addition, the company works to sensitize its suppliers on why it is important to reduce environmental impacts and how this process can yield important economic benefits for them.

The Valcucine case shows that a mentoring approach based on close collaboration of the lead firm with its suppliers can lead to environmental innovations that go beyond mere compliance with environmental process certification standards. However, this approach is likely facilitated by the physical proximity of the lead firm with many of its key suppliers.

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Environmental organizational innovation happens when organizational changes reduce the environmental impact of companies (i.e., introduction of lean production tools). An example of organizational innovation with environmental implications is "lean manufacturing" practices aimed at reducing production costs by avoiding overproduction and excessive inventory, reducing transportation, defects, delays, and overprocessing.

Chiarini (2014) presents a study of five European manufacturers of motorcycle components for customers including Piaggio, Aprilia, BMW, and Honda. All companies share similar assembly lines and do not treat chemical products; their main concerns are energy consumption, oil spillage, and emissions of fumes and dust in production processes. To address environmental concerns, they adopted lean manufacturing. The study shows that an organizational innovation as simple as positioning machines closer to one another reduces handling and transportation of materials within the plant, and introducing new technology to press plastic products reduces the amount of garbage produced. In this case the incentive for these suppliers to adopt lean manufacturing practices was twofold: operating in the EU means that these companies are committed to environmental strategies such as ISO 14001 and publishing their environmental balances and impact yearly; and increasing efficiency and minimizing waste can curb production costs.

Laari et al. (2016) investigate the adoption of customer-driven Green Supply Chain Management (GSCM) in 119 Finnish manufacturing companies. GSCM manages upstream and downstream supply chains for minimizing the overall environmental impact. It is a combination of environmental and supply chain management techniques, involving both the internal dimension of firms (i.e., green transport and green marketing) as well as external transactions with suppliers and customers. The study finds that manufacturers with strong internal GSCM practices combined with arm's length environmental monitoring of suppliers are likely to perform well in environmental issues and that if a firm seeks to improve financial performance, it needs to form more collaborative relationships with customers to achieve environmental goals.

6.4 Actors Involved in Environmental Innovation

The GVC literature stresses the role played by the lead firms in transferring knowledge and introducing innovations along the chain. With respect to GVC greening, lead firms are described as the main driving actors of environmental innovation. As further elaborated in the next section, lead firms can adopt different governing mechanisms to facilitate or impose the greening of suppliers. They can, for example, impose standards on their suppliers and expect them to comply, or they can provide mentorship support, transferring knowledge and reinforcing the learning process needed to become greener (De Marchi et al. 2019). Case 1 on the Sri Lankan textile suppliers provides an example of buyer-driven environmental innovation.

Suppliers may also autonomously introduce environmental innovations contributing to GVC greening. The case study on the Italian leather value chain discussed in Box 6.3 shows that tanneries involved in the automotive and fashion value chains introduced environmental innovations without a specific request by the lead firms, but rather proactively anticipating the introduction of new technical standards in the industry.

Actors external to the chain include policymakers, customers, NGOs, and civil society organizations (CSOs). While the institutional drivers of GVC greening are discussed in section 6.2.1, the Hawassa Eco Park case discussed in Box 6.5 shows how policymakers can go beyond their regulatory role and become direct actors in the GVC greening process, in this case by collaborating with private actors in policy design.

De Marchi et al. (2019) refer to two examples of independent third-party organizations playing a role in sustaining the development of socio-environmental standards: Oxfam's Behind the Brands campaign (2013-2016) followed by the Implementation Initiative (2016-2020) and Greenpeace's Detox campaign in the fashion industry. Oxfam challenged 10 of the largest food and beverage companies to improve their social and environmental policies. The companies introduced a scorecard system measuring the strength of sustainability and human rights policies and commitments, not only at the level the company itself but within its supply chain. Following the Greenpeace campaign, 80 companies, including retailers and suppliers in the fashion industry, pledged to reduce or eliminate toxic chemicals from their products.

Box 6.5: When private actors and government come together: The Hawassa Industrial Park

Hawassa is a city in Ethiopia of about half a million people that hosts a 300-acre industrial EcoPark. The inception of the EcoPark is the result of the synergy between the private and public sector, more specifically, the cooperation between the Government of Ethiopia and the Phillips-Van-Heusen (PVH) company.

Based in New York City, PVH is one of the biggest holdings in the fashion industry, owning brands such as Calvin Klein and Tommy Hilfiger. In its efforts against climate change, PVH pledges to (i.) drive a 30% reduction in its global supply chain (Scope 3) emissions by 2030, (ii.). eliminate single-use plastics by 2030, and (iii.) achieve zero hazardous chemicals and harmful microfibers in textile wastewaters by 2025 (PVH 2019).

The objective of the Government of Ethiopia was to attract investors by establishing a sustainable textile and apparel industry in the country at the supplier level. The government acted through the Industrial Parks Development Corporation (IPDC), an initiative devoted to attract foreign direct investment in key strategic manufacturing industries. Public investments facilitated job creation and technology transfer in areas such as waste management.

When PVH showed interest in Ethiopia, the government built the Hawassa Industrial Park. PVH indicated that all the environmental and safety regulations and the characteristics of the data-driven monitoring system were based on the standards developed within the Sustainable Apparel Coalition (SAC), of which PVH is a member, as conditions for sourcing from Ethiopia. The EcoPark offers infrastructure such as a solid waste management system, 100% renewable energy, and LED lights, which are needed for companies to qualify as certified suppliers.

In 2012, PVH became an early mover in Ethiopia. Currently, the park hosts 18 apparel and textile companies from the US, the People's Republic of China, India, Sri Lanka, and six local manufacturers (Hawassa Industrial Park 2023).

The Hawassa Industrial Park is a case of policymakers going beyond their regulatory role to become direct actors in the GVC greening process (Jensen and Whitfield 2022); thus, it is an example of environmental upgrading enabled by the integration of private actors and government in policy design. The project provides the basic infrastructure for the suppliers located there to meet the standards set by the SAC and hence participate in textile GVCs. However, due to delays, lack of funding, and difficulties in completing and staffing the EcoPark, Jensen and Whitfield (2022) conclude that so far, the main beneficiaries of the public investment in green infrastructure are foreign buyers, whereas the domestic capacity to create new industries through vertical integration using sustainable resources is quite limited.

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Other third-party institutions playing a key role to ensure that suppliers in the chain correctly implement environmental standards (e.g., ISO 14001) are independent certification bodies, such as the Société Générale de Surveillance (SGS), Intertek, and Bureau Veritas. They verify suppliers' compliance with such standards, and their reports decide whether the supplier can remain in the value chain. Several third-party standards—such as Registration, Evaluation, Authorization and Restriction of Chemicals (REACH); Global Recycle Standard (GRS); Better Cotton Initiative; ISO 14001; and Leadership in Energy and Environmental Design (LEED) —focus primarily on environmental issues. Others, such as the Worldwide Responsible Accredited Production (WRAP), Sedex, and FairTrade focus on social issues and provide environmental guidelines (Khan et al, 2019). However, as sustainability becomes more mainstream and brands are increasingly incentivized to display third-party "green" certifications, consumers should investigate any green certification labels they see on products to ascertain whether or not they are valid (EarthTalk 2016).

6.5 The Enabling Mechanisms of Environmental Innovation

Within GVCs, there are different enabling mechanisms for implementing environmental innovations. How knowledge circulates within the chains and how environmental innovations are developed and introduced could change depending on the actors involved. We document these diverse mechanisms by distinguishing those (i) enabled by lead firms, (ii) enabled by suppliers, (iii) collectively enabled, and (iv) enabled by the government.

Lead firms are the main actors responsible for the introduction of environmental innovations in GVCs. De Marchi et al. (2013b) identify two main approaches adopted for greening GVCs: a standard-driven approach and a mentoring-driven approach.

A standard-driven approach is when the lead firm introduces specific rules and codes of conduct aimed at reducing the chain's environmental impact, which suppliers must satisfy. Standards and certifications can be developed by third-party organizations or by the lead firm itself.

De Marchi et al. (2013a) present the case of IKEA, which requires both kinds of certifications from its suppliers: they must be ISO 4001 certified, use wood certified by the Forest Stewardship Council (FSC), and abide by IKEA's own IWAY supplier code of conduct (IKEA 2019). IKEA's suppliers are also responsible for the environmental conduct of their second-tier suppliers, and the lead firm offers incentives when first-tier suppliers buy from second-tier ones that also respect the IWAY code of conduct. IKEA has a verification and peer learning system in place to ensure the code requirements are fulfilled by its suppliers. It also established formal projects to transfer know-how in eco-efficiency and help suppliers get access to renewable energy and negotiate affordable contracts with renewable electricity providers. Similar programs have been launched by many other companies in different industries; another notable example is Apple, which adopted the Supplier Clean Energy Program (Apple 2022b).

The standard-driven approach works well for large firms that aim at achieving eco-efficiency in the production process together with cost efficiency in a price-sensitive market. With the implementation of standards and a strong control system, IKEA selects suppliers capable of complying with those standards, and both the lead firm and the suppliers have gained from cost reductions in the manufacturing process (De Marchi et al. 2013a).

The limitations of an approach mainly driven by standard compliance are documented by Krishnan et al. (2022), who present evidence on the Kenya-United Kingdom (UK) horticulture value chain. The authors show that UK supermarkets impose very stringent standards on Kenyan exporting firms, which in turn enforce compliance with these conditions on farmers. Farmers then adopt environmental practices such as integrated pest management and soil testing, which are complex and seldom used in that region. Occasionally, the exporting firms provide some training and access to extension services, also in collaboration with training associations and NGOs, but only in a few demonstration farms and a few times a year. Moreover, the contracts signed by farmers are very rigid in terms of standard compliance and quantity purchased, and the price paid does not account for the increased costs of production and the impact on soil and water quality. The study concludes that the Kenyan farmers' biophysical outcomes are negative across all the indicators investigated: quality of soil and water, biodiversity, and sustainable use of resources. The Kenyan exporting firms and UK supermarkets, on the other hand, benefited in terms of "green" reputation and increasing market share for eco-friendly products.

A mentoring-driven approach is when certifications are not available, or suppliers need support, and the lead firm directly transfers knowledge to its suppliers and sustains their greening process. In their study on digitalization in the Chinese electronics supply chain and its implications for its sustainability, Kunkel et al. (2022) find that collaboration between buyers and suppliers has a fundamental role in pushing forward the digitalization for sustainability in the value chain. Continuous interaction between buyers and suppliers is key to building trust, which is essential for allowing mutual access to data about energy use. Case 1 describes how the three Sri Lankan green textile manufacturers interviewed by Khattak et al. (2015) had frequent interactions with their international buyers to acquire the tacit knowledge for environmental innovation in production of complex products. Box 6.4 discusses how Italian kitchen designer Valcucine works in close cooperation with a small number of very committed suppliers to meet environmental goals rather than imposing standards, leading to co-development of environmental innovation.

A crucial factor for the success of a mentor-driven approach is suppliers' competencies and strategic intent in engaging in environmental upgrading (Khattak et al. 2015). Because suppliers that can deliver environmental upgrading are larger in scale and already have higher capabilities, the end result could be consolidation of the supplier base with fewer opportunities for smaller, more marginal suppliers (Khan et al. 2019).

In their study of the Pakistani apparel chains, Khan et al. (2019) highlight a trend of proactive environmental upgrading whereby suppliers anticipate future environmental requirements to leverage their upgrading initiatives as a competitive factor to access new buyers and markets. More commonly in clusters, innovation is a collective effort given that firms, often characterized by a common specialization, are used to collaborate on innovative activities (Box 6.5). Finally, a key enabling role is played by national or sub-national public actors when they provide the basic infrastructure that contributes to GVC greening (Boxes 6.3 and 6.5).

6.6 The Outcomes of Global Value Chain Greening

While a substantial body of literature exists on the impact of GVCs on workers and society, which is the subject of Chapter 7, the literature on environmental sustainability is much more recent, with only a handful of studies so far conducted, as reviewed in the earlier sections of this paper. This section continues to seek insights from this literature, with the attention now turned to the biophysical outcomes of GVC greening, that is the effect on the environment seen as comprising flora and fauna; land, soil, water, and air; and the atmosphere (Mackie 2021). We start by briefly bringing together the types of greening outcomes identified in the literature, then we discuss the key issues in interpreting these outcomes. This discussion is subject to considerable uncertainty, incomplete knowledge, and lack of robust quantitative evidence because most studies tend to focus more on environmental innovation rather than on biophysical outcomes.

Overall, the biophysical outcomes of GVC greening processes can be divided into the following types:

- GHG emissions: studies focusing on environmental innovation and potential emission reduction from lead-firm schemes (De Marchi et al. 2013a; Jensen and Whitfield 2022; Khattak et al. 2015; Bjorklund et al. 2012).
- Biodiversity: studies about the uptake by companies in deforestation-linked GVCs for environmental monitoring and improvement (Gallemore et al. 2022) and schemes to ensure sustainable wood harvesting (von Geibler et al. 2010).
- Sustainable land use: studies about the introduction of certification and standard schemes to reduce or avoid soil degradation, for example, in cocoa (Fold and Neilson 2016), palm oil (Dermawan and Hospes 2018), and beans and avocado (Krishnan et al. 2022).
- Energy use: renewable energy initiatives such as that of Walmart, which provides education and advice on power purchase agreements to its network of suppliers (Walmart 2022).
- Toxic materials: studies about the reduction or elimination of chemical hazards in products or services or water pollution (e.g., through discharging wastewater without regard to adequate wastewater infrastructure) in response to voluntary standards (Mackie 2021).

Table 6.2 lists the biophysical outcomes that the studies discussed in this chapter investigate. It shows the complexity of accounting and collecting quantitative information for many diverse dimensions, which can have either positive or negative environmental impacts. The greening of the GVCs happens when the net environmental impact is positive.

Table 6.2: Biophysical Outcomes of Global Value Chain greening

Industry	Indicator	Reference
Agriculture	Soil erosion Fresh water availability Leaching (loss of water-soluble nutrients) Wind erosion Number of local flora and fauna Level of pollination Availability of water table Inorganic waste generation Electricity use	Krishnan et al. (2022)
Fisheries	Dolphin stock status	Ballance et al. 2021
Apparel	Carbon footprint (LEED-certification) CO_2 emissions Solid waste landfill Production costs: energy and water High Index Facility Environment Module (FEM) Environmental management systems Energy use and greenhouse gas emissions Water and electricity consumption Wastewater Emissions to air Waste management Chemical management	Khattak et al. (2015) Jensen and Whitfield (2022)
Leather	Electricity use Water recycling Chemical management	De Marchi et al. (2019)
Furniture	Recycling of raw materials CO_2 emissions Water consumption	De Marchi et al. (2013a)
Logistics	Volume of recycled material Number of travels CO_2 emissions Recycling of raw materials	Bjorklund et al. (2012)
Automotive	Waste reduction Reduction of oil leakages Electricity consumption	Chiarini (2014)

A thorough assessment of claims of environmental impact is challenging because systematic measurement efforts are scarce, and the outcomes are highly complex to measure. Many studies are single cases of firm-level or sector-level initiatives where it is difficult to isolate, generalize, and attribute causal factors. Several quantitative studies focus on the potential environmental benefits of GVC participation rather than the process of GVC greening.[4] For example, Batrakova and Davies (2012) find that manufacturers inserted into GVCs adopt more energy-efficient technologies, especially among energy-intensive firms. They measure the effect of exporting, but the environmental innovations that led to emissions reductions is a ”black box” in these studies.

When specific metrics are sometimes defined, they are often firm or GVC metrics (what the firm does, e.g., its sourcing of wood) rather than environmental outcome measures as such (e.g., how biodiversity is affected). In general, “the scarcity or incompleteness of data has thus far limited the ability to accurately assess the impact of environmental upgrading processes on actual outcomes” (Krishnan et al. 2022). In addition, reputational outcomes for individual firms may sometimes outweigh biophysical outcomes. In other words, given the above-mentioned difficulty in specifying environmental impact, firms may exaggerate claims of reduced environmental harm or increased environmental benefit, while receiving a perceived image boost, a phenomenon known as ‘greenwashing.’ Coen et al. (2022) studied 725 corporate sustainability reports with machine-aided textual analysis to test whether climate claims translated into verifiable performance measured by changes in GHG emissions over a 10-year period. They found that while some climate commitments were genuine, most were producing symbolic rather than substantive action.

There are also several important tradeoffs in terms of different green outcomes, such as tradeoffs between the carbon emission effect of bioproducts as petroleum substitutes versus nitrogen pollution or the environmental impact of renewable energies, such as solar or wind, producing large amount of waste for the decommissioning of obsolete systems (Lema et al, 2023). Finally, these biophysical outcomes are also experienced heterogeneously by different GVC actors: certain actors can reap benefits by appropriation, whereas others experience a drainage of their environmental resources (Krishnan et al. 2022).

6.7 A Three-Pronged Strategy for GVC Greening

Table 6.3 presents a three three-pronged strategy to promote and sustain GVC greening derived from the conceptual framework: (i.) policies for creating and augmenting the driving factors; (ii.) policies to strengthen and support environmental innovations acting on the identified enabling mechanisms and (iii.) policies aimed at monitoring outcomes and addressing environmental inequalities.

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4 For an overview of the literature on the potential environmental benefits of GVC participation, see Delera (2022).

The first column in Table 6.3 lists policies for creating and augmenting the driving factors of GVC greening. Governments must on the one hand put in place environmental regulation and standards as a measure for incentivizing and supporting environmental innovations, eliminating barriers, and creating new markets; on the other hand, they must use taxation—or more broadly fiscal policy—to modify price signals so that firms internalize externalities and properly value environmental resources. Governments must also promote and sustain the development of green technologies by investing in research and innovative activities. Another critical action at the national and subnational level is increasing awareness among consumers in schools, workplaces, and public spaces to promote environmentally sustainable consumption patterns.

Table 6.3: A Three-Pronged Strategy for GVC greening

Create and amplify the driving factors	Leverage the identified enabling mechanisms	Monitor outcomes and address environmental inequality
National and subnational level • Regulations and standards • Taxation • Consumption patterns • R&D activities **Global level** • Agreements to avoid environmental dumping • Agreement to control transboundary toxic movements • Agreements to lift tariff and non-tariff barriers to trade in environmental goods and services • Global initiatives to support R&D collaborations	**Policies involving lead firms** • Make lead firms responsible for the environmental impact of their suppliers • Provide support to lead firms that contribute to GVC greening • Introduce green procurement policies • Create a green supplier database • Create incentives for cooperation on green innovative activities between lead firms and suppliers • Strengthen sustainable innovation ecosystems **Policies involving domestic suppliers** • Strengthen knowledge infrastructure • Strengthen sustainable innovation ecosystems • Develop local specialized scientific, technological, managerial, and organizational capabilities • Introduce green procurement policies • Provide financial support to environmental innovations **Policies supporting collective initiatives** • Support activities aimed at driving the green agenda in business organizations • Support R&D activities taking place in consortia **Policies aimed at building and strengthening infrastructure** • Provide basic green infrastructure and logistics • In clusters and industrial parks, invest in specific infrastructure for GVC greening in the dominant industry • Encourage investment and linkages in recycling industries	• Introduce measures to address the unequal impact of greening within chains • Introduce appropriate forms of regulation to orchestrate private sustainability initiatives to achieve fair and just environmental protection • Increase knowledge about biophysical outcomes and develop monitoring system to measure complex outcomes • Track the environmental performance of firms within the chains that receive subsidies to adopt environmental innovations

Because the salient feature of GVCs is that they span national boundaries, action at the global level is critical for GVC greening. Environmental agreements are needed, for example, in dissuading arbitrage between jurisdictions and environmental dumping across countries, and in controlling transboundary movements of hazardous waste and its disposal.

Trade agreements are also necessary to lift tariff and nontariff barriers to trade in environmental goods and services. The recent resurgence of protectionism can prevent the spreading of new environmental solutions and thus poses a danger to achieving GHG reduction targets.

Global initiatives to support R&D collaborations across countries and institutions can boost environmental innovation. Furthermore, they can facilitate the adoption and adaptation of frontier technologies in developing economies to foster environmental equality.

The second column in Table 6.3 focuses on actions that leverage the identified enabling mechanisms to strengthen and support environmental innovation. As discussed in Section 6.4, lead firms play the key role in greening the entire value chain, although suppliers are increasingly taking the initiative to increase their involvement in GVCs or in response to public pressure.

Strengthening sustainable innovation ecosystems—by building human capabilities, establishing standard and metrology organizations, developing technical and advisory services, investing in domestic R&D in research centers and universities, and strengthening university-industry linkages—helps both lead firms and suppliers. Similarly, the introduction of green procurement policies that can either add the condition of meeting specific environmental standards to tender for government contracts or exclude firms not certified by certain environmental standards can be a powerful incentive for both lead firms and suppliers. For example, certain green public procurement guidelines require that a firm's products contain a minimum amount of recycled content or achieve specified levels of energy efficiency.

For lead firms, regulation that makes them explicitly responsible for the environmental impact of their suppliers should be paired with support for lead firms that contribute to GVC greening. That would incentivize other foreign and domestic firms to shift toward sustainable practices to gain the same support.

Enabling connections between lead firms and sustainable domestic companies, for example by creating a green supplier database, can boost GVC greening. Beyond traditional information, such as production capacity, goods and services offered, and contact information, the database can offer information regarding the sustainability of operations, such as environmental protection and carbon offset activities, the social impact of the operations, and supply chain management.

Governments can also create incentives for cooperation on green innovative activities between lead firms and domestic suppliers. For example, special categories for green investment and green innovation can be created under policies to incentivize foreign direct investment and knowledge transfers.

Empowering domestic suppliers to drive GVC greening requires strengthening the knowledge infrastructure, enhancing local skills development, and providing information and skills to anticipate the future impacts of environmental legislation, carbon taxes, and new standards. A forward-looking approach would also include developing local specialized scientific, technological, managerial, and organizational capabilities to absorb, adapt, and eventually develop the relevant knowledge for facilitating environmental innovation.

Financial incentives are perhaps the most powerful for suppliers: it can be difficult to persuade firms and financial intermediaries to invest in green innovation when there is limited business evidence on the return on investment. Therefore, innovation and technology funds financed by the public sector, international donors, and development banks are key to piloting new approaches.

Governments can also support collective initiatives for GVC greening. Industry associations can be important allies in driving a green agenda. Consortia aggregating firms specializing in similar and complementary stages along the value chain can also implement environmental innovation with government support.

A crucial enabling mechanism for GVC greening is the provision of basic infrastructure and logistics, such as renewable energy sources and waste management systems, that can serve as a platform for further innovation. In the case of clusters and industrial parks, specific infrastructure may be needed to enable GVC greening in the dominant industry. Facilitating investments in the recycling industry and the creation of linkages to other industries (i.e., chemicals) is also part of building this infrastructure.

Finally, the third column in Table 6.3 focuses on policies aimed at monitoring outcomes and addressing environmental inequality. Inequality along value chains is a product of the power asymmetries intrinsic to actors within the GVC. Addressing these inequalities requires the full spectrum of policies discussed in Table 6.3, from strengthening national and multilateral institutions, to providing core infrastructure, to building capacity.

Monitoring should be iterative and integrated into any greening initiative from the start. It helps to identify any potential issues, track progress, and measure outcomes. The increased transparency also leads to better accountability. This is particularly relevant for firms within the chains that receive subsidies to engage in environmental practices. A regulatory framework that fosters environmental accountability is also conducive to private sustainability initiatives to achieve fair and just environmental protection.

Conclusion

In this chapter, we introduce a framework addressing five related questions: (i) Why is GVC greening occurring? (ii) What type of environmental innovation is undertaken in GVCs? (iii) Who are the actors involved? (iv) How is environmental innovation taking place? And (v) What are the outcomes? The evidence collected on the five dimensions of the framework provides three main findings that point to challenges for both policy action and future research.

First, while GVC greening has institutional, market, and technological drivers, institutional drivers play a major role because of the public good nature of the green transition. New policies and legislation related to domestic or global sustainability transformation agendas are central to GVC greening. Market and technological drivers are also essential, but they ultimately tend to be driven by institutional drivers. Therefore, GVC greening is characterized by endogeneity, complementarity, and interaction effects among the different drivers.

Promoting such drivers may require a shared effort among institutional actors at national and global levels. However, as advanced and emerging economies are increasingly competing to gain competitive advantage in new green technologies, domestic policies play a greater role than global concerns (Aklin and Mildenberger 2020). The Inflation Reduction Act that the US enacted in 2022 is a good example of a climate policy that aims to address both domestic competitiveness and sustainability issues.

Multilateral policies acting as driving factors, such as multilateral climate agreements, have been pivotal in the last decades (i.e., the United Nations Framework Convention on Climate Change [UNFCCC] in 1992, the Kyoto Protocol in 1997, and most recently the Paris Agreement in 2015). The notion that the public will support expensive climate policies more if other nations adopt them is one of the reasons for securing cooperation among multiple states. This is true both because it increases the likelihood that important sustainability goals will be achieved and because such efforts are consistent with widely shared fairness norms. Research suggests that multilateralism increases public acceptance of costly climate action, and it makes it more appealing and 'fair" (Bechtel et al. 2022). However, multilateral negotiations appeared to be stalled after the 2022 UN Conference of the Parties (COP27) because of geopolitical tensions arising from the energy crisis and sparring between the Global South and high-income economies (Masood et al. 2022).

Governments turning sharply away from multilateral cooperation may pose a major challenge to GVC greening. A way forward to safeguard multilateralism and global institutional drivers sustaining GVC greening is to invest in initiatives developed among smaller groups of like-minded economies such as the Breakthrough Agenda, involving 45 economies and the private sector to accelerate the shift to green technologies in industries such as agriculture, transport, steel, cement, and energy (Dworking and Engström 2022). Coordination at the global level might also help promote the energy transition towards the net-zero goal (e.g., a single international carbon tax rate).

The second key message is that several actors, not only lead firms but also suppliers, national and local governments, and often a combination of them, contribute to GVC greening. There is evidence showing that suppliers, proactively anticipating the introduction of new technical standards in the industry, introduce environmental innovations as a competitive factor to access new buyers and markets.

However, the greening opportunities within the chain may not unroll evenly among the suppliers. Several studies show that lead firms do not always provide enough financial, managerial, and knowledge resources for their suppliers to implement green strategies, leaving them out of the chain if they are unable to meet such requirements. This risk is particularly high for small firms in developing countries and in developed ones because implementing environmental standards in own operations and monitoring sustainability in suppliers has economies of scale—that is, the cost of sustainability per unit of output reduces with increasing size of operations (Görg et al, 2021).

The uneven distribution of costs, benefits, and rewards for greening the value chain poses a challenge for policymakers to address this supplier-squeeze (Krishnan et al., 2022). Actors external to the GVC, such as national or local governments, NGOs, and independent certification bodies, can provide technical and financial support to suppliers in GVCs to implement environmental innovations. National or subnational public actors can provide the basic infrastructure that contributes to GVC greening. Effective support of actors with more limited capacities will need further investigation about how GVC greening affects various actors operating in and beyond GVCs, the damage and benefits caused, and the possible tradeoffs between different types of environmental and socioeconomic outcomes.

Finally, there is very limited evidence on the biophysical outcomes (De Marchi and Gereffi 2023). Among the indicators considered in the literature are CO2 emissions, biodiversity, sustainable land use, energy use, and use of toxic materials. However, firms may exaggerate claims of reduced environmental harm or increased environmental benefit to receive an image boost, sometimes concealing greenwashing practices. Moreover, there are important tradeoffs between environmental and socioeconomic outcomes, and therefore the final assessment of whether GVC greening happens generally remains a research gap in most of the existing studies.

Therefore, accounting, monitoring, and disclosing the environmental outcomes and the possible tradeoffs with socioeconomic outcomes are not only challenging but are also essential dimensions to investigate along the entire value chain. Firms in different business sectors implement different organizational capabilities to track their greening progress. Yet, raising knowledge about biophysical outcomes and the several tradeoffs and developing monitoring systems to measure them is key. For instance, the US clothing company, Levi Strauss & Co., publishes on its website a detailed description of its environmental life cycle assessment (LCA), a quantitative method for evaluating the impact of a product along the value chain and at various stages. It is a tool used to assess the stages and impact of a product's entire life, from raw material extraction (cradle) to waste treatment (grave), and it informs consumers and actors involved in the chain about their environmental impact. However, the LCA does not account for economic or social impacts.

A GVC perspective on monitoring activities is also being implemented by policymakers as in the case of the Extended Producer Responsibility (EPR) laws introduced by many countries to make producers responsible for the post-consumer stage of a product's life cycle or in presence of due diligence rules in case of commodities associated with deforestation (De Marchi and Gereffi 2023). However, multilateral efforts to orchestrate and harmonize private and national initiatives are strongly needed to make environmental-outcome tracking systems more effective, again pointing at the inevitability of a multilateral approach in GVC greening due to its intrinsic global, transboundary nature.

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