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The Green and Digital Transition in Manufacturing Global Value Chains in Latecomer Countries

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Abstract

This paper is based on a review of the literature that brings together GVCs, green and digital transformations. Or to be more precise, the analysis is based on three main components: (a) the greening of GVCs and environmental upgrading; (b) the digital transformation of manufacturing GVCs and (c) an initial exploration of the green and digital joint transformations in GVCs. The aim is to provide a framework bringing together environmental upgrading and digital technologies in manufacturing GVCs.

We find that the greening of the global value chains in manufacturing industries unfold in analytically separable steps: a) new patterns of demand preferences and consumer behaviours, b) new green strategies by lead firms and global buyers and c) enforcement of environmental standards and associated patterns of upgrading and downgrading across global supply bases.

Digitalization in manufacturing GVCs have differentiated effects across the Global South. The importation and adoption of advanced digital technologies is still limited to a small number of countries (the so-called emerging economies) and their production at any scale is limited to an even smaller set of advanced economies plus China. Across most of the Global South, adoption rates of smart manufacturing and service technologies as well new technologies for data processing and analysis are very low and many firms still face challenges with adopting much older manufacturing and service technologies.

Still very little is known about the extent to which key enabling digital technologies support the process of environmental upgrading in the Global South firms that are inserted into GVCs. This is because these techno-institutional waves are still concentrated geographically and the full extent of the ramifications across the Global South remains to be seen. This also means that synergy-creation is challenging. The small pool of literature identified for this study suggests that potentials are mainly limited to certain digital technologies and specific types of environmental upgrading. These insights are anyhow useful because they may help to early direct the efforts of policymakers towards the more likely opportunities.

Note and acknowledgements

This paper was produced as a background study for the UNCTAD Technology and Innovation Report 2023.[1] It has been published previously on the UNCTAD website.[2]

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Comments on an earlier draft received from experts attending an ad-hoc informal expert consultation held online in October 2022, and the online peer review meeting of the Technology and Innovation Report 2023 organized in October 2022, are gratefully acknowledged.

[1] https://unctad.org/publication/technology-and-innovation-report-2023

[2] https://unctad.org/system/files/non-official-document/tir2023_background1_en.pdf

Content

1 Introduction

Globalization is currently confronted by the emergence of several remarkable obstacles, starting from the trade dispute between China and the US to the COVID-19 outbreak and more recently the invasion of Ukraine and all the consequent economic sanctions inflicted to Russia. Despite all these challenges, Global Value Chains (GVC), characterized by firms specializing in specific tasks and breaking up the production process across different countries, have marked the evolution of the global economy since the early 1990s and are still a cornerstone of the world economic system. As a matter of fact, about two-thirds of international trade involves transactions taking place within supply chains (OECD, 2020) and the most recent available statistics on the world exports of intermediate goods (IG), which are parts, components and accessories used to produce final products and are therefore an indicator of the activity within supply chains, show that after a decline in 2020, IG exports have continuously raised in 2021, surpassing the level of 2019 before the COVID-19 pandemic struck.[3]

While it is too early to evaluate the impact of these combined challenges, there is a reasonable consensus that even if GVCs are undergoing a profound reconfiguration and diversification process, international supply chains are quite resilient (Gereffi et al, 2021; Miroudot, 2020). According to UNCTAD (2021a), in the long-term global value chains will be interested by a gradual rebalancing with resilience becoming a key consideration in location decisions for new investments: "*the drive to increase supply-chain resilience will not lead to a "rush to reshore" but could become a "drag on development", with new investments in international networks no longer looking for locations offering low cost factors of production to the same degree*" (177). Therefore, even in these difficult and uncertain times for globalization, GVCs are likely to remain an important component of world trade.

The rise of GVCs has allowed many emerging and developing countries to enter the global market, based on their specific advantages and on their specialization in tasks rather than final goods. But entering in GVCs is not sufficient to guarantee sustainable growth, because it is by scaling the value-added ladder and moving, progressively, to more sophisticated forms of participation that high growth rates can be reached (World Bank, 2020). Moreover, beyond economic upgrading it is essential to account also for the other key dimensions of upgrading: the social component – i.e., the process of improving rights and entitlements of workers and their employment conditions (Rossi, 2019) and the environmental component – i.e., the process that results in the reduction of the firms' ecological footprint, such as impact on greenhouse gas emissions, biodiversity losses and natural resources overexploitation (De Marchi et, 2019).

[3] Data is available at wto.org.

This paper focuses on environmental upgrading addressing it from a very specific perspective, which is whether and how the adoption of digital, frontier technologies associated with smart manufacturing or in other words, Industry 4.0 (4IR – Fourth Industrial Revolution), can lead to greener GVCs. It investigates how and to what extent the combined green and digital transition, sometimes also defined as the 'twin transition'[4], takes place in globally organised manufacturing in latecomer countries. It is clear that whereas the general 'age of ICT' – the techno-economic paradigm driven by information and communication technologies (Perez, 2013) – has become ubiquities across rich and poor countries alike, the specific technologies associated with the digital transformation (e.g. Internet of Things, blockchains, additive manufacturing and robots) (UNCTAD, 2022) are still concentrated in advanced economies and a few emerging economies, such as China, Brazil and India. While it is usual that technological waves start in a restrict group of countries, the current digital transformation is more far-reaching than earlier techno-economic paradigm shifts and therefore it is important for GVC-stakeholders in all countries to understand the dimensions of this process of digitalization of economic processes as well as the relationships with the greening phenomenon.

We focus on the opportunities and the challenges for latecomer countries involved in manufacturing GVCs based on a systematic literature review of the more recent and thematically relevant English language publications in scholarly journal articles, reviews, and book chapters of social sciences as indexed in the Scopus database. The methodology and the challenges faced with the literature survey are presented in Section 2. Section 3 reviews the literature on environmental upgrading and greening GVCs and Section 4 discusses digitalization in manufacturing GVCs focusing on latecomer countries. Section 5 disentangles how the greening of GVCs, and environmental upgrading may benefit from digitalization, and discusses the challenges faced by latecomer countries involved in GVCs to undertake the green digitalization. Section 7 concludes with some policy implications.

2 Methodological issues and challenges

We have undertaken a systematic survey of the literature aimed at mapping the key articles on the greening and digitalization in global value chains, identifying potential overlaps (or lack of it) of the

[4] The twin transition refers to the simultaneous transformation of the global economy towards both environmental sustainability and digitalization. It involves two key transitions that are taking place simultaneously: the shift towards a low-carbon economy to address climate change and the increasing use of digital technologies in all aspects of life and work. While widely used by organizations such as the World Economic Forum, (2019) and the European Union (2019) there is some criticism about the use of the term 'twin transition' because the digital transition and the green transition are not equal twins as the former is a means and the latter is an end. Therefore, the green transition should guide digital innovations and their application to serve sustainability goals (Digitalization for Sustainability, 2022). In the rest of this report, for the sake of brevity, we will sometimes use the term twin transition, but we share the above criticism and in the final section of the report we return to the criticism and argue that the potential interactions between the green and digital transformation remain unfulfilled in cross-continental GVCs.

two separate strands of literature. We have focused on the Scopus database, which includes peer review articles, conference proceedings and books in English. The survey has been centred on studies on latecomer countries and on traditional manufacturing industries, such as agri-food, leather, shoes, textile, apparel, and furniture.

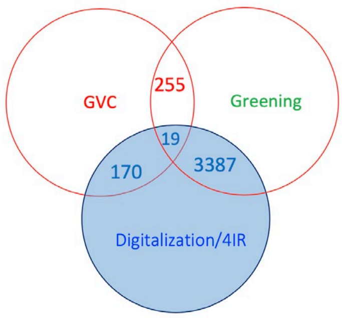
To identify the thematically relevant publications on the greening and digitalization of manufacturing GVCs in developing countries, as well as potential overlaps between the two strands of literature, we have searched for the combination of three sets of search words in the title, abstract, and author keywords fields. The resulting list of publications has been further qualitatively checked for relevance through reading of titles and abstracts. Finally, more in-depth analysis of the selected literature is conducted in terms of the main theoretical orientation, major findings, as well as the geographic and sectoral coverage. Figure 1 shows the results of the survey without filtering for latecomer countries and for the specific industries of interest and the list of all the keywords used in the survey is available in the Appendix (Table A.1). As it can be seen, the overlap between the three literature strands is limited to 19 papers, which after a careful reading reduce to only 5 articles, which are relevant in our analysis. The list of the 19 papers is provided in the Appendix (Table A.2). Adding the filters for latecomer countries and traditional manufacturing industries, the results of the literature survey show in Figure 2 indicate that the number of articles decreases very significantly.

Given the very limited number of articles found with the systematic literature review, we have widened our survey and qualitatively identified additional studies dealing with digitalization in the manufacturing industry in latecomer countries. This literature is the basis for the discussion presented in Section 5. One additional challenge is that most of the existing contributions about the topic mainly discusses the challenges faced by developing countries in adopting digital technologies or presents possible solutions to technical problems. There is very limited empirical evidence available in the literature discussing actual case studies about the adoption of digital technologies with some positive (or negative) impacted on the greening of GVCs in latecomer countries.

3 The greening of GVCs

The section provides an overview of the empirical literature on the greening of GVCs, not least the greening of final demand preferences and how these transpire down through the chain and result in altered forms of governance with new requirements, including various types of standards, traceability obligations and certifications. We discuss the main drivers of environmental change in GVCs, which range from external factors, such as reputation and consumer pressures, to approaches taken by the lead firms to reduce internal costs through private and public standards, which may raise entry barriers and induce different types of environmental upgrading,

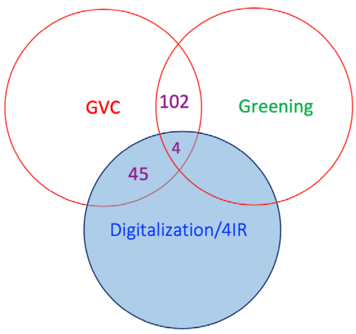
Figure 1. Literature survey: GVC & GREENING & DIGITILIZATION/4IR*



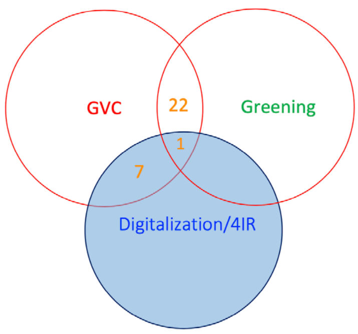
*The list of keywords is available in the Appendix, Table A.1

Figure 2. Literature survey: GVC & GREENING & DIGITILISATION/4IR in latecomer countries and traditional manufacturing industries*

Latecomer Countries



Latecomer Countries AND Traditional Manufacturing Industries



*The list of keywords is available in the Appendix, Table A.1

3.1 The globalization of the green economy versus the greening of GVCs

At the general level, global value chains may contribute to the greening of economies through two routes. The first is through the globalization and increasing fragmentation of production in sectors central to the green economy, which have become increasingly organised along GVCs, not least in the sustainable energy sector such as solar PV and wind energy industries (Surana et al., 2020; Zhang and Gallagher, 2016; Amendolagine et al., 2021). The second is through the greening of GVCs in sectors that are not belonging to the green economy, including manufacturing sectors of crucial importance to low- and middle-income countries, such as traditional manufacturing industries, including food production, garment and textiles, leather and shoe, and furniture. The focus of this paper is on this second route.

Before proceeding, it is relevant to note that in the green economy itself, customers, investors, policymakers are increasingly seeking disclosure and transparency on the environmental management of green supply throughout product life cycles. A process of greening is thus currently occurring within sustainability-oriented production systems. This regards, not only backward linkages to such as sourcing of rare earth materials in electric vehicles and wind turbines (Alves Dias et al., 2020) and reduction and management of chemicals of concern in solar PV manufacturing (Greening solar supply chains, 2021) but also concerns of circular economy considerations including re-use after decommission (Gallagher et al., 2019). These trends will have profound implications for the transformation of the green economy GVCs in the coming years.

3.2 The greening of GVCs and environmental upgrading

The greening of the global value chain in manufacturing industries unfold in several steps that can be separated analytically. First, at the root, the green transformation imperative leads to new patterns of consumer behaviour, new demand preferences changing policy landscapes and increasing NGO activism that also change consumption and reduce the environmental footprint of production and trade. In addition to changes driven by environmental concerns, there are also drivers rooted in the profit motive, not least costs savings derived from decreased material use. Changing demand for less resource-intensive and environmentally friendly products and services has ramifications as new requirements are transmitted through GVCs.

Second, these requirements are typically enforced in the value chains through various types of demand conditionalities such as new designs, standards, and specifications. They are typically defined and enforced in 'green lead markets', countries that are pioneers in environmentally benign products, processes and services (Beise and Rennings, 2005). Many of these new requirements are 'private standards' defined and enforced by lead firms, which also internalise several public environmental regulations and semiprivate environmental certifications, such as the Technical Regulations (TRs) Certification (i.e., Round Table on Responsible Soy) which, beyond the core private sector firms and organizations, includes authorities and governmental agencies and public donors. In other words, the introduction of sustainability requirements has implications for the entire value chain, including its governance.

The notion of value chain 'governance' is used to describe how some firms in the chain set and/or enforce the parameters under which others in the chain operate (Humphrey and Schmitz, 2001). It thus refers to relationships among the buyers, sellers, service providers and regulatory institutions that operate within or influence the range of activities required to bring a product or service from inception to its end use. Gereffi et (2005) identified five main types of GVC governance: market, modular, relational, captive and hierarchy. Table A-3 in the appendix describes the five governance types in more detail.

Third, these changes in the governance regime of GVCs create both 'green entry barriers' and 'green windows of opportunity' (GWOs) for suppliers in the Global South. This is because changing governance patterns arising from greening may translate into new constraints in meeting these requirements for suppliers, thereby making entry into GVCs more difficult, or forcing exit from GVCs for existing suppliers. This is what Ponte (2020) refers to as the sustainability-driven supplier squeeze. However, certain suppliers may be able to develop sustainability capabilities leveraging them to their advantage, provided that certain preconditions are in place and appropriate strategic actions are taken (Lema et al., 2020) (Lema and Rabellotti, 2022). The embeddedness of suppliers in well-functioning production and innovation systems is of crucial importance (Pietrobelli and Rabellotti, 2011).

Fourth, provided that the requisite capabilities and support requirements are in place, green windows of opportunities in GVCs may be effectively utilised and foster 'environmental upgrading' which can be defined as any change that results in the reduction of the ecological footprint of the firm, e.g. reduced greenhouse gas emissions, natural resources use and biodiversity loss (De Marchi et al., 2019). In more concrete terms, environmental upgrading may take three forms: (a) process improvement, e.g., reduction of energy or materials used per unit of output which can be achieved with the introduction of new technology; (b) product improvements: taking on circular economy features such as improving recyclability, eliminating harmful chemicals reducing material use; and (c) organizational improvements: such as the introduction of environmental management systems (De Marchi et al., 2019).

In this paper, we focus on the first two types of environmental upgrading and in Table 1 (Section 5.1) we consider: 1) *process upgrading* (a) of the upstream inputs needed for production and (b) of the production process and 2) *product upgrading* (a) of the product and (b) of downstream consumption. For a detailed description of the different types of upgrading see Section 5.1

3.3 Effective seizing of green windows of opportunities in GVCs

The case of the apparel industry in Sri Lanka shows how lead firms use environmental standards (e.g., LEED; ISO 14001) as an element of chain coordination. Khattak et al., (2015) show how, in this case, changes in GVCs represented drivers of environmental upgrading as supplier firms engaged in the process to comply with environmental standards, to increase their competitiveness. The incentive for firms to increase environmental performance is a competitive advantage arising from reduced costs, for example savings associated with minimisation of materials and waste. They thus show how apparel firms 'embrace' environmental upgrading and trace the successful seizing of the opportunity to strengthen competitiveness to strategic intent and pre-existing capability of the suppliers to assimilate knowledge about certification transferred from lead firms.

Golini et al. (2018) draw on the database on International Manufacturing Strategy Survey (IMSS) and examine material, water and energy consumption reduction, as well as pollution emission and waste reduction in assembly industries. They show that insertions in GVCs support such measures in general, but upgrading patterns depend on the mode of value chain governance. Moreover, suppliers and buyers in GVCs are not affected in a uniform way when it comes to green upgrading. Buyers tend to upgrade more along the environmental dimensions when GVCs are characterised by 'relational' governance patterns, i.e., when frequent interactions and knowledge sharing occurs between buyers and suppliers, supported by reciprocal trust and long-term relationships. Suppliers, on the other hand, tend to upgrade environmentally when chains are characterised by captive governance, i.e., when there are high switching costs. In such chains, powerful lead firms tend to control activities in the chain and provide suppliers with the conditions under which they operate. In this latter case, buyer firms may invest substantial resources in the upgrading of their input and assembly service providers, both for reputational and cost-saving reasons.

De Marchi et al. (2013) show that GVC-inserted businesses are enhancing their environmental performance to drive competitive advantages in the Italian home-furnishing industry. Based on case studies, they address environmental management in GVCs by examining types of environmental upgrading and their implications in terms of product, process, and functional upgrading and hence, economic performance, as well as the greening of the industry. They demonstrate that the businesses advance green strategies to reduce the environmental footprint of products and processes while achieving economic benefits and competitiveness, which may be internal to the firm but also apply to the value chain, with different implications in terms of bargaining power and value appropriation. On this basis, the article develops a theoretical framework to analyse environmental upgrading trajectories and their implications in terms of firms' green strategies.

The same authors, in another study, explore further the role of suppliers in the process of environmental upgrading within global value chains in the leather industry. They approach such upgrading through the looking glass of 'agency' of suppliers in implementing various types of product and processes innovations. Through their examination of such innovations developed within the leather GVC they show how suppliers can independently develop sustainability strategies to maintain their competitiveness and achieve functional upgrading and better value capture in the GVC. This paper therefore adds to the literature by showing how environmental upgrading can be facilitated from below, by suppliers as proactive actors within GVCs, and with only a limited role played by global buyers in supporting the green upgrading of products and processes. Furthermore, the authors suggest that environmental sustainability is encapsulated by different visions along the value chain, i.e., for suppliers and lead firms. For example, leather producers support that tanning with chrome production is the process with the lowest environmental impacts along the entire chain, but branded buyers opine that leather without chrome is the best way to achieve a sustainability image (De Marchi and Di Maria, 2019a).

Another example of seizing GWOs in GVCs is the case of maritime ports in the greening of global trade routes studied by Poulsen et al. (2018). Given their role as key nodes in global trade and the substantial CO2 emissions by the shipping industry, ports have a key role to play in facilitating the reduction of carbon emissions across maritime transport networks. They study selected European and North American port authorities, which are considered frontrunners in environmental management and identify results and future potentials of a range of voluntary initiatives implemented by these ports. They suggest that ports can upgrade in two main ways to advance the environmental performance of maritime transport. The first is through stronger collaboration within the GVC by lowering the complexity of implementation of emissions reduction tools such as voluntary vessel speed reductions, whereby fuel emissions are reduced as slow ocean-going vessels reduce emissions significantly. Also, information sharing to reduce vessel turn-around-time in the port and virtual arrival systems that reduce delays in entering ports, resulting in decreased fuel consumption and emissions while they idle at anchorage.[5]. The second is by increasing emission visibility through alliances with cargo-owners and regulators such as real-time monitoring equipment onboard ships. However, the authors also show that voluntary environmental measures by ports only have limited leverage to improve data availability and reporting from ships at sea and there is further potential which may reaped with additional regulation.

3.4 The supplier squeeze: Failed attempts at seizing GWOs in GVCs

Ponte (2020), drawing on insights from the wine and coffee sectors, suggests that lead firms may push 'hidden costs' of sustainability compliance onto suppliers in GVCs. They increase demands from their suppliers and achieve consolidation of their supply base by enacting several sustainability

[5] Virtual vessel arrival systems offer a low-cost strategy to reduce these emissions by informing vessel operators of expected delays and aligning arrival times with berth availability.

measures. This has important redistributive implications since they increase entry barriers for developing country firms. The almost ubiquitous nature of sustainability measures along GVCs has thus allowed lead firms to capture new rents and reinforce and deepen imbalances of power between lead firms in the North and South respectively.

Achabou et al. (2017), in their study of 24 Tunisian olive oil companies found that although exporting companies did benefit from environmental upgrading compared to non-exporting firms the extent of upgrading was limited. Buyer firms in European export markets did impose standards but due to a lack of financial and technical assistance, the extent of environmental upgrading remained limited to the minimum threshold levels and dynamism effects were few and far between. This research thus shows the role that lead firms may have on environmentally responsible corporate behaviour in developing countries and confirms that under conditions of market governance, environmental upgrading may be limited in resource constrained firms in developing countries unless new challenges (environmental standards) is combined with support for more deeply rooted environmental upgrading.

Further evidence of the supplier squeeze is provided by Khan et. al (2020) in their study of Pakistani apparel firms. They show that Pakistani apparel suppliers are required both to absorb the consequences of global buyers' unsustainable purchasing practices (all buyers examined in the case study prioritize their own financial goals over environmental impact in their global sourcing) and to reduce their own profitability as sustainability standards are introduced. They point to the existence of a 'factory manager dilemma' in terms of the balances that enterprises are confronted with regarding environmental upgrading requirements on the one hand and everyday purchasing practices of their buyers on the other. Executives see environmental upgrading mainly as a cost since it has become a new 'entry ticket' to GVC and depends on investment in fixed assets, new technology, certifications, system modifications and skills development and these investments are not compensated.

Before we consider how the combined digital and green transition is taking place in globally organised manufacturing, in the next section we turn to the digitalization of manufacturing GVCs in latecomer countries.

4 The digitalization of manufacturing GVCs

4.1 The diffusion of digital technologies in latecomer countries

Digital technologies, such as the Internet of Things (IoT), cloud computing, artificial intelligence (AI), additive manufacturing (e.g., 3D printing) and advanced robotics, are changing the manufacturing process across global value chains (GVCs). Technologies associated with smart manufacturing or in other words, Industry 4.0 (4IR – Fourth Industrial Revolution) can be grouped into two categories, considered in Table 1 (see Section 5.1): 1) *Smart Manufacturing and Service Technologies* leading to automation and decentralization of tasks and including advanced robotics, 3d printing, wireless technologies, and sensors (e.g., Internet of Things - IoT); 2) *Data Processing Technologies* allowing interconnection and data exchange and including big data, blockchain, cloud computing, machine learning and AI (De Marchi and Di Maria, 2019b). What makes these technologies novel is the combination and integration of hardware, software, and connectivity in complex production systems (Andreoni and Anzolin, 2019).

The production and adoption of these technologies is still extremely concentrated in few leading economies (UNCTAD, 2022). UNIDO (2020) considers the global distribution of patents in the digital technologies and concludes that more than 90% of all patenting activities take place in 10 countries, all high income except for China.[6] Exports are also very concentrated and the top 10 countries, again including China, account for 70% of the global market. The import market is somehow less concentrated with the top 10 countries, comprising China, Mexico, India and Turkey and accounting for 46% of global imports of these technologies.[7] Based on a combination of information about patenting, exports, and imports UNIDO (2020) identifies as frontrunners in emerging digital technologies 10 countries, which are all high-income, except for China and as followers 40 countries: 23 producer economies, among which there are Brazil and India and 17 users comprising Algeria, Argentina, Bangladesh, Columbia, Indonesia, Iran, Malaysia, Mexico, South Africa, Thailand, Turkey, and Vietnam. All the remaining countries show low (latecomers) or very low to no activity (laggards) in the field of digital technologies.[8] Therefore at present, a large part of developing countries is completely excluded from the ongoing digital revolution in the manufacturing value chains, but of course this does not mean that these countries will not be impacted by the growing adoption of digital technologies in the more advanced countries (Auktor, 2022). These technologies may seem in the distant future for many countries, but all will be affected sooner or later, and it is therefore vital that countries at different level of development understand the implications of the

[6] The countries are USA, Japan, Germany, China, Taiwan, France, Switzerland, UK, Korea, and The Netherlands (UNIDO, 2019).

[7] According to UNIDO (2020) the top 10 exporting countries are Germany, Japan, China, Italy, Taiwan, Austria, USA, Korea, Switzerland, and France. The top importing countries are China, USA, Germany, Mexico, Russia, Italy, India, UK, Turkey, and France.

[8] Frontrunners are countries with 100 or more global patent family applications in digital technologies. Followers in production are identified based on their patenting or export activities while followers in use based on import of digital related technologies. Three more groups of countries are identified: latecomers in production including 16 economies, latecomers in use with 13 countries and laggards (88 countries) showing no or very low engagement with I4R technologies. For details about the classifications see UNIDO (2020).

fourth industrial revolution on various dimensions of their economic and social systems (UNCTAD, 2022).

The large heterogeneity among countries also reflects their sectoral specialization because digital technologies are more common in some manufacturing industries such as computers and machinery and transport equipment. According to UNIDO (2020) the computer and machinery industry shows the highest use of cloud computing and 3D printing technologies while the transport equipment industry is at the top for adoption of industrial robots. A lot of heterogeneity also exists at firm level within countries, with only a minority of firms adopting some I4R technologies, while the majority is still involved only in analog production. Typically, firms in developing countries are yet at the stage of Industry 2.0 and even automation through adoption of industrial robots (Industry 3.0) is not very advanced (Lee, 2019). This is empirically confirmed by a firm level survey undertaken by UNIDO (2020) in Argentina, Brazil, Ghana, Thailand, and Vietnam. For instance, in Ghana 90% of firms surveyed are characterized by analog or rigid production, which implies adoption of technologies such as CAD only in product development and machines operating in isolation. This share is 84% and 74% in Vietnam and Thailand while it goes down to 37% in Argentina and 29% in Brazil, where respectively 17% and 25% of firms operate with Industry 3.0 technologies. The adoption of digital technologies takes place in only 3% of firms in Argentina and 4% in Brazil, which represent *technological islands* characterized by few advanced firms surrounded by a large majority of companies operating at a lower and, in most of the cases, much lower technological level. This suggests that even when a minority of firms invests in advance manufacturing technologies, they are unable to establish significant backward and forward linkages within the domestic economy given the existence of a large digital capability gap between the leading most digitalized companies and their suppliers (Andreoni and Anzolin, 2019). The weak linkages between firms within and across industries also impact on the limited spillover and learning opportunities deriving from the adoption of digital technologies to the rest of the economic system (Matthess and Kunkel, 2020).

A very recent survey undertaken in Ghana on a sample of 500 firms adds some information about the adoption of specific digital technologies such as robots, cobots, 3D printing, big data, and augmented/virtual reality (Esseqbey et al, 2022). According to the survey results, the adoption rates are as low as 3.6% for industrial robots, 5.2% for cobots, 5.6% for 3D printing, 9.6% for big data and 4.6% for virtual reality. Besides, there are big differences among industries with the ICT sector having the highest weighted average of technology adoption rate, which could be explained by the availability of infrastructures, followed by Tourism, Agro-processing, Pharmaceuticals and Textiles in decreasing order of frontier technology adoption.

4.2 *The impact of digital technologies on Global Value Chains*

The implications of increasing digitalization in manufacturing are expected to be wide-ranging in global value chains (Strange and Zucchella, 2017). The diffusion of digital technologies in advanced countries is anticipated to reduce the importance of low labor cost, which is a key comparative advantage for many industrializing countries, possibly reducing offshoring from industrialized to developing countries and inducing reshoring towards high income economies (Rodrick, 2018). A recent ILO study (2020) concludes that reshoring remains a rare phenomenon but also finds an association between the adoption of Industry 4.0 technologies in developed countries and reshoring. Evidence about the limited diffusion of reshoring in Europe is confirmed by the European Union (2021), which underlines that the phenomenon is so far modest and dependent on the type of industry, as well as on the type of technology. UNIDO (2020) presents evidence from 2,500 firms in eight European countries confirming that reshoring is not common and pointing out that the main reason for reshoring from latecomer countries is flexibility in logistics rather than labor costs.

Considering technologies, the adoption of robots and computerized manufacturing could reduce the advantage of producing in low labor cost countries while additive manufacturing technologies such as 3D printing could shorten and reinforce the trend towards regionalization of value chains, maintaining production closer to markets, as we have seen during the COVID-19 pandemic when 3D printing technologies were used to remedy shortages in medical supply. 3D printing can democratize manufacturing allowing companies in latecomer countries to engage in manufacturing without large investments, opening opportunities for distributed local production processes (Fu and Shi, 2022), but it can also allow high-income countries to produce closer to their demand (Akileswaran and Hutchinson, 2019).

If low labor costs may not be enough anymore to get developing countries involved in GVCs, many will suffer by a digital divide in both production and use of digital technologies, which is expected to increase entry barriers in terms of know-how, skilled human resources, and capital investments to enter, participate, and upgrade in GVCs (Banga, 2022). For instance, the introduction of IoT will imply that manufacturing will become less reliant on low skilled labor and more dependent on engineers, programmers, and other specialized professions, which are in short supply in many latecomer countries (Akileswaran and Hutchinson, 2019).

4.3 *The opportunities for latecomer countries*

Digital technologies could also open opportunities for at least, some developing countries involved in GVC. Based on the above-mentioned firm level survey undertaken by UNIDO in 5 latecomer countries, Delera et al (2022) find that, although the diffusion of Industry 4.0 technologies is still extremely limited and on average less than 5% of the surveyed firms are aware of them, the participation in GVCs is an important channel for learning and acquiring the adequate digital capabilities to integrate these technologies in the manufacturing process. They conclude that through GVC integration, firms in developing countries may in part compensate for the lack of domestic capabilities and for the underdevelopment of their local ecosystem. Moreover, in the 5 countries investigated they also show the existence of a productivity premium for firms adopting digital technologies, a result which persists controlling for several factors traditionally considered as productivity enhancing.

The adoption of digital technologies such as IoT and AI could also encourage the participation of more SMEs from developing countries in GVCs by bridging distances and reducing costs related to trade, such as tracking of shipments and inventory (World Trade Organization, 2019). The AI can help to benefit from the fastest, cheapest, and most sustainable routes for shipping goods around the world.

Another possible effect of Industry 4.0 technologies could be the decentralization of advanced activities across the regional networks of production, increasing the opportunities for peripheral locations of stages such as engineering, design, and software development to reduce the concentration in headquarters and increase flexibility in serving regional markets (UNIDO, 2020). An interesting case is represented by the subsidiaries opened in Nepal and Kenya by Cloudfactory, a US company offering data processing services for AI and automation. This a case of slicing up of the value chain with the higher end of the activities undertaken in the headquarters and other lower end activities, such as data input, quality control and processing, taking place in developing countries, offering employment opportunities for, mainly young, well-trained workers.[9]

The introduction of blockchain technologies can be used to improve transparency, traceability along the value chains by reducing information asymmetries, tracking inventories, and attributing ownership rights, enabling faster and cost-efficient delivery of goods and enhancing coordination among stakeholders (UNCTAD, 2021b). Blockchain provides a technological support for tracking the supply chain route of products from their origin to the final destination, increasing the trust mechanism and supporting the choice of a product by considering its whole life cycle and its impact on social and environmental sustainability (Tseng and Shang, 2021). In general, the blockchain technology allows SMEs to access digital marketplaces and online services, as well as to interact with other firms in value chains on a trusted basis (Menon and Fink, 2019).

[9] For more information about Cloudfactory and its presence in Nepal and Kenya see cloudfactory.com.

Blockchain for tracking products along the supply chain has been experimented in Ethiopia with coffee in a project involving the Ministry of Science and Technology and the Swiss-based Cardano Foundation.[10] Another experience of adoption of blockchain technologies for tracing coffee beans sold in the growing Chinese market is in Indonesia, where ALKO, a cooperative producing and processing coffee, in collaboration with EMURGO, a multinational providing blockchain solutions, among the founders of Cardano, has adopted a mobile application for storing into the blockchain information about sourcing origin, processing dates and other logistics data to offer each stakeholder in the value chain transparent access at any given time into the journey of the coffee.[11]

UNCTAD (2021b) provides two other interesting examples of blockchain adoption outside the food industry. A platform built by Everledger, a technology company, to record the origin of diamonds along the supply chain, preventing possible fraud and a promising application in the pharmaceutical industry to identify counterfeit pharma products.

Another key advantage of blockchain is the disintermediation of financial intermediaries, including payment networks, stock exchanges and money transfer services, making trading processes among partners more efficient. Moreover, blockchain technologies provide a connection for secure transactions between different currencies from multiple sources in global supply chains (Saberi et al, 2018). This application is particularly relevant for facilitating the access to financial services for small firms, largely unbanked, based in latecomer countries. Blockchain usage provides SMEs with an affordable and efficient technology to make and receive payments, access investments and savings and build a credit history (Bizama, 2022).

As a matter of facts, some African countries, such as Nigeria, Kenya, Togo, South Africa, Ghana and Tanzania are ranked among the top 20 countries in the adoption of crypto money in 2021 (Chainanalysis, 2021).[12] The reason for this African boom in the diffusion of blockchain technology is that it allows money transfer across countries within and outside the continent with the simple access to the internet, ensuring privacy and security for transactions and without incurring the high foreign exchange fees from the traditional money transfer services. Notably, the diffusion of these technologies opens job opportunities in field such as blockchain designers and crypto traders for young skilled Africans (Africa Blockchain Institute, 2022).

[10] The Cardano Foundation is related with Cardano, an open source blockchain platform. More information is available at cardanofoundation.org.
[11] More information is available at emurgo.io.
[12] The top 3 countries are Vietnam, India, and Pakistan (Chainanalysis, 2021).

4.4 Conditions for taking advantage of digital technologies

Digital technologies are highly biased towards capital and high-skilled labor and require significant R&D investments so to transform them in windows of opportunity, latecomer economies need to build up a certain level of production and innovation capabilities, including absorptive capacity to not get stuck in the development trap (Lee, 2019). According to Fu and Shi (2022) to truly seize this technological window of opportunity, latecomer countries should develop and implement pertinent policy strategies aimed at addressing key challenges in the field of digital competency, infrastructures, and institutions, building innovation capacity, and overcoming financial barriers.

The above-mentioned survey undertaken in Ghana identifies lack of finance, attachment to existing practices and traditional ways of doing things, and insufficient government support as the three main barriers to digital technology adoption. The strategic role of the government as facilitator and enabler of effective adoption of frontier technologies is strongly underlined in the survey (Esseqbey et al, 2022).

Concerning capabilities, the development of basic and intermediate production capabilities are pre-conditions to absorb and deploy the new digital technologies. The above mentioned UNIDO (2020) survey has emphasized that in many developing countries many firms have yet to acquire and adopt Industry 3.0 technologies, such automation and ICT in the manufacturing process. Moreover, it has been stressed that in developing countries more advanced companies often operate in ecosystems characterized by an extreme digital gap and it is therefore very difficult for them to integrate with potential backward or forward suppliers. Therefore, the digital capability gap needs to be addressed to facilitate the positive cascade effect along the supply chain deriving from the adoption of I4R technologies.

It is also stressed that the adoption of digital technologies requires the development of complementary, specific skills to the new technologies, such as analytical skills, including science, technology, engineering and math, ICT related skills and soft skills (UNIDO, 2020). UNCTAD (2019) identifies four different levels of digital skills: a) those required for adopting digital technologies; b) those needed for a basic use; c) those necessary for a creative use and adaptation of technologies and d) those essential for the creation of new technologies. In the context of developing countries, the skills for adapting and modifying existing digital technologies are particularly important because many of these technologies are designed to be used in contexts where infrastructures and natural and social resources are quite different from those common in latecomer economies.

There are consolidated experiences of countries such as Malaysia and Thailand which have invested in building up key enabling institutions essential to develop the competencies for taking advantage of Industry 4.0 opportunities (Lee et al, 2020). In Malaysia, the Penang Skill Development Centre, established in 1989, is a non-profit institution that provides technical knowledge and organize training programs, which are key for the adoption of advanced industrial operations. Another relevant institution is CREST, an R&D consortium, established in 1999 to host multinationals, local firms and universities which has been key to create a network of actors doing research on topics related with 4IR technologies as well as for providing scholarships for advanced degrees in the field. In Thailand, in response to the increasing automation in the car industry in 2006 the government has established the Automotive Human Resource Development Program in collaboration with Japan with the aim of upgrading the digital capabilities of local suppliers. Besides, investments have been undertaken in domestic universities and research institutes to train engineers and technicians with the adequate skills and knowledge in AI, robotics, and mechatronics.

Another key area to address is the removal of possible infrastructural and institutional bottlenecks, such as electricity and connectivity failures as well as clear rules for data ownership and intellectual property protection regulations. The adoption of some technologies may need specific regulations in place as in the case of drones, which could help to deliver lightweight high value goods, such as medical supplies, to remote areas with poor transport infrastructures. So for instance, Rwanda has introduced a regulation allowing airspace to be accessed by pilotless aircrafts, making possible the use of drones to deliver critical supplies (Adhikari, 2019).

Key in this respect is also the choice of appropriate technologies and standards. The case of 5G technology is a very good example showing that the standard setting is not only an issue concerning speed or efficiency, but also reflects the political struggle between the US and China, and to a lesser degree, Europe.[13] The possibility of diverse 5G standards might be crucial for the adoption and diffusion of Internet of Things technology and all the related products and services.

5 The green and digital transition in manufacturing GVCs in developing countries

Enhancing the synergies between the two aspects of the green and digital transition has now become a key priority in international communities. These two transformations have so far developed largely in parallel, with their own trajectories and with separate drivers and separate policy domains. However, this is now beginning to change. The policies of the United Nations around the Sustainable

[13] For details see the article *China, US and Europe vie to set 5G standards* on the Financial Times (February 6th, 2022).

Development goals explicitly point to the potential of digital technologies when it comes realising several of the goals. And there is increasing realisation that functional synergies may exists across several areas of the economy.

The digital transformation has for long being promoted to enhance economic competitiveness, while there is increasing recognition that digitization can contribute to sustainability goals and enable the changes needed for a just green transition. The twin green and digital goals are increasingly seen to complement each other and digital technologies such as AI, cloud computing, IoT are expected to help the economy to become greener. Digital technologies are expected to open green windows opportunities, such as improving green efficiency, reducing the carbon footprint of current production and consumption modes, facilitating the introduction of new green technologies and eco products, enhancing the diffusion of business models based on circular economy. At the same time, digital technologies may also pose serious environmental threats, which span from the use of rare materials in their production to the high energy consumption in their utilization.

But to what extent will key enabling digital technologies support the process of environmental upgrading in GVCs? To facilitate the discussion, we introduce Table 1 which distinguish on the rows between two types of environmental upgrading:

- *Process upgrading*
    - ProcU-1 of the upstream inputs needed for production including substitution of energy-sources, substitution of energy intensive materials or scarce natural resources and substitution of toxic inputs.
    - ProcU-2 of the production process including reduction of waste from the production process, introduction of technology to reduce energy consumption and optimization of the material flow.
- *Product upgrading*
    - ProdU-1 of the product including new designs substituting environmentally harmful components, designing recycle products, designing for durability and substitution of complete environmentally harmful products.
    - ProdU-2 of downstream consumption including recycling and re-use of waste.

On the columns, we consider two types of enabling technologies, which is possible to separate analytically, although they often overlap to a great extent:

- *Smart Manufacturing and Service Technologies* leading to automation and decentralization of tasks and including advanced robotics, 3d printing, wireless technologies, and sensors (e.g., Internet of Things - IoT); 2

- *Data Processing Technologies* allowing interconnection and data exchange and including big data, blockchain, cloud computing, machine learning and AI.

In the following section, based on the very small body of literature available we sought to provide example of how the enabling digital technologies support the process of environmental upgrading in GVCs.

5.1 Digital technologies and environmental upgrading

Smart Manufacturing and Service Technologies and Environmental Upgrading in GVCs

With respect to environmental upgrading of the upstream inputs needed for production, Gale et al (2017) emphasise the important role of new hardware technologies in formal sustainability standard-setting organizations (SSOs) across agro-industrial sectors such as food, forestry and fisheries. Old verification systems that utilized annual field audits are being replaced by ICT collected data in real time with the utilisation of new technologies. For example, fixed and mobile sensors, e.g., in harvesting and logging equipment, and/or satellite data provide precise information on matters of interest such as tree species, biodiversity counts, or illegal logging and fishing are now being adopted for monitoring environmental standards by organisations such as FAO and the World Bank. With respect to inbound logistics, Mangina et al (2020), drawing on data from EU and EFTA, explore how the IoT affects the sustainable transformation of global supply chains in the logistics sector. They show that new data collected from online-connected sensors and GPS tracking systems can reduce carbon emissions significantly as physical internet algorithms perform better than other methods in terms of reducing emissions

Data Processing Technologies and Environmental Upgrading in GVCs

These are new data processing technologies, including big data analytics, cloud computing; artificial intelligence and blockchain technology. Many of these technologies have a bearing on environmental upgrading of the upstream inputs needed for production. For example, several of the papers identified in Section 2 deal with blockchain technology in this respect. Nikolakis et al (2018) stress that blockchain, is useful tool for dealing with the growing complexity of global value chains and can improve methods for securing adherence to environmental standards in GVC. Blockchain can enhance sustainability by providing information to buyers on the origin of products and guarantees as to the authenticity of the information. Similarly, Saberi et al (2019) described several ways that blockchains will impact on environmental upgrading in GVCs. Two of those are concerned with upstream supply chain management: (a) tracking faulty products or components (with systems such as Echchain, ElectricChain, and Suncontract) to reduce reproduction and recalls results in decreased resource consumption and reduced greenhouse gas emissions; (b) increasing 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 carbon footprint of products or the Endorsement of the Forestry Certification to ensure that wood is sustainably sourced. However, the authors also emphasize downstream implication in the form of enhancing incentives to recycle, such as with the RecycleToCoin system that enables people to return plastic containers for a financial reward.

Another type of software technology is artificial intelligence, which has also important implications for greening in GVCs. Toniolo et al (2020) emphasize that this technology is relevant across environmental domains such energy, production and natural resource management and that firms may implement AI to improve environmental performance.[14] In energy, for example, to reduce energy consumption in operations, firms are starting to adopt technologies that can optimize green energy use in smart grids. AI may facilitate decision-making that can increase energy efficiency and reduce cost. 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. Dauvergne (2020) adopts a critical perspective on the possibility of AI to provide greener supply chains, arguing that it is clear that AI is not advancing sustainability to the extent that companies are sometimes claiming. It is noted that lead firms are increasing adopting sustainability tools to cut operational costs, increase product value, and coordinate GVCs. 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 are certainly improving environmental management. However, firm managers have "*strong incentives to exaggerate the value of any new technology*" because this may boost brand and stock values.

In summary, digital technologies have important implications for GVCs, both for lead firms and suppliers. Most opportunities accrue to resourceful firms located in high-income economies. In principle, the same opportunities apply to firms in the global south, but in practice these opportunities are limited to a select number of firms in few emerging economies such as China and India. The literature on green upgrading (see Section 3) does not point out to a very important role of digital technologies and the literature on digitalization in manufacturing in developing countries (see Section 4) also suggests that technology adoption is limited. In this section we have nevertheless reviewed

[14] AI is relevant to addressing several targets across the SDGs but it is also an obstacle in certain cases. In the energy field the data centres used to power AI have a very high energy demand (Vinuesa et al., 2020).

insights from the (still small) pool of literature that examines the contribution of digital technologies to environmental upgrading in GVC, most of which is concentrated on GVC within OECD.

5.2 Challenges for developing countries

The evidence provided in Section 4 shows that the adoption of frontier digital technologies in manufacturing is limited to a minority of developing countries. Opportunities and challenges for adopting such technologies are also quite heterogeneous among different industries and companies, more feasible in high tech industries and for firms with larger financial resources than in labour intensive industries and in smaller firms with resource constraints (Abdul-Hamid et al., 2021). A study on the plastic industry confirms that in a country with a large predominance of SMEs like Brazil investments in I4R technologies are hindered by financial constraints as well by the large technological gap characterising smaller companies (Nara et al., 2021). In these companies changing manufacturing technologies can pose a significant challenge because implementation of new technologies can incur large costs. Besides, in the same study it has been observed that investments in digitalization in developing countries are still mainly driven by economic motivation rather than social or environmental reasons. Nara et al (2021) refer to a report of the Brazilian National Confederation of Industries confirming that domestic companies have mainly introduced digital technologies with the aim of increasing productivity, whilst social and environmental benefits are not among the top priorities.

In this section based on the results of some surveys undertaken in developing countries such as Bangladesh (Dwivedi et al, 2022), India (Lutra and Mangla, 2018) and Brazil (Cezarino et al, 2019; Nara et al, 2021), we analyse the main emerging challenges, faced by firms in adopting digital technologies to increase sustainability in the economic systems and in the supply chains.

Lack of adequate digital skills

This is a major limitation as already discussed in Section 4.4 because very often in latecomer countries there is a lack of the specific analytical skills needed to adopt, use, and adapt the new technologies as well as of soft skills which play a key complementary role. This is for instance identified as a major challenge by the managers in the footwear industry in Bangladesh by Dwivedi et al (2022). Also in the Brazilian case, Cezarino et al, (2021) stress that the lack or the difficulty in finding qualified professionals is a major problem also due to deficiency in the domestic training system.

Table 1. Environmental upgrading and digital technologies in manufacturing GVCs

Environmental upgrading				**Smart Manufacturing and Service Technologies (e.g., robotics; 3D printing, IoT, Sensors)**	**Data Processing Technologies (e.g., big data, cloud computing; AI, Machine Learning; Blockchain)**
Type	**Sub-type**	**Indicator**	**Example**		
Process upgrading	**ProcU-1**: Environmental upgrading of the upstream inputs needed for production	Substitution of energy sources	Sourcing renewable energy	• Smart meters for buying and selling electricity to enhance renewable energy uptake	• Big data analytics of energy consumption patterns • AI-enhanced corporate energy systems
		Substitution of energy intensive materials or scarce natural resources	Reducing or replacing scarce or energy-intensive materials with eco-friendly alternatives	• Internet of materials for access to raw material information and obtain material certificates • Control systems for end-to-end tracking of the material flow (using sensors and data analytics), to improving secondary raw materials • Blockchain-powered platforms for peer-to-peer trading in environmental commodities • 3D printing-enabled materials parsimony	• Supply chain mapping augmented for blockchain tracking for better product traceability for responsible sourcing of raw materials
		Substitution of toxic inputs	Elimination of sources of pollution such as solvents		• Block-chain systems to increase efficiency and transparency between producers of raw materials and intermediary goods
	ProcU-2: Environmental upgrading of the production process	Reduction of waste from the production process	Finding productive uses for formerly unused inputs	• Digital replicas of physical assets • Processes and systems, which include information on composition, health & safety, environmental data, facility information, procurement data and product usage • Reduction of waste with 3D printing	• AI-enabled technology equipped with machine vision used to analyze and sort material streams
		Introduction of technology to reduce energy consumption	Introduction of machinery or systems that use less electricity or fuel	• IoT and sensors to reduce electricity consumption	
		Optimization of the material flow	Introduction of production planning system	• IoT and sensors for optimizing material flow	• Cloud enabled infrastructure substantially saving costs, energy and materials otherwise needed to produce assets physically

Product upgrading	**ProdU-1**: Environmental upgrading of the product	New designs substituting environmentally harmful components	Introducing eco-friendly parts		• Cloud computing utilizing virtualization to encapsulate collaborative design and manufacturing resources as services, thereby allowing for resource sharing
		Designing recycle products	New product architectures for easy disassembly	• Computer aided design (CAD) to assist in the creation, manipulation, analysis, or optimization of a design	
		Designing for durability	Longer lasting products and maintenance services	• Predictive maintenance allows to replace only the required part at the required time	• Machine learning to develop the algorithms to save maintenance costs, while extending product life and improving supply chain flows
		Substitution of complete environmentally harmful product	Phasing out of old product and introducing alternative		
	ProdU-2: Environmental upgrading of downstream consumption	Recycling	Partnerships with input providers for deposit arrangements and backfilling	• RFID tags for smart waste management). • Robots detecting parts within products for refurbishment/recovering valuable materials	• Digital sourcing platforms facilitating exchange of products and materials at their highest value reuse opportunity • Cradle to cradle (or digital) passport helps to identify different material types and grades during disassembly process
		Re-use of waste	Using consumed material for a new purpose	• Robotic recycling system designed to reclaim raw materials from construction and demolition waste	• Design of product lifecycles for easier material collection, sorting and looping back into the manufacturing process

Sources: De Marchi et al. (2019), Rennings (2000) and Barteková & Börkey (2022)

Lack of awareness about the potentialities of digital technologies in terms of increasing sustainability

In the above-mentioned study on Bangladesh, the local managerial staffs interviewed have also shown very limited knowledge about how the introduction of digital technologies could impact on resource saving, support cleaner production processes, and facilitate the introduction of business models inspired by circular economy concepts (Dwivedi et al, 2022). The potentialities of digital technologies in terms of sustainability are also underrated and little understood among Brazilian companies in the plastic industry, especially the smaller ones, as emphasised by Nara et al (2021).

Lack of financial resources

In Industry 4.0, financial constraints are a very important challenge among firms, particularly relevant for smaller companies. In a study on India undertaking a survey in several manufacturing industries as diverse as automotive, metals and machinery, food, textile and electrical equipment, financial constraints are considered the most important challenge due to the very large investments needed for the acquisition of new frontier technologies, especially for small and medium enterprises (Lutra and Mangla, 2018). The lack of investment capacity has been also emphasised in the case of the Brazilian manufacturing industry by Cezarino et al (2019), based on the analysis of a wide collection of technical reports from key stakeholders.

Lack of government support and adequate legislative frameworks towards sustainability

In several latecomer countries there are national strategies aimed at strengthening the adoption of frontier digital technologies in the manufacturing industry and some examples could be the Make in India and the Made in China 2025 programs, as well as the Industry 4.0 Agenda in Brazil. Nevertheless, these strategies are very often not coordinated with interventions and initiatives in the environmental and energy domains, with the aim of unlocking the sustainability potential of digital technologies. For instance, with a focus on the footwear industry in Bangladesh, Dwivedi et al (2022) emphasise that the lack of environmental regulations and the low environmental awareness result in low motivation to adopt digital technologies in the industry with the objective of increasing sustainability in the sector. In the case of Brazil, Cezarino et al (2019) explain that the country has good environmental laws but there is not communication with industrial policies as well as a low level of coordination between private and public actors. To create opportunities with the adoption of digital technologies to sustainable solutions in the supply chains, such as renewable resources production methods and reduction in the use of energy and raw material, Brazil will require specific support from public policies.

Lack of adequate infrastructures

In the Brazilian context, Cezarino et al (2019) stress another important challenge, common to most latecomer countries, concerning structural problems (e.g., energy supply, fast internet access) that influence the implementation and dissemination of digital technologies. In the Indian case Lutra and Mangla (2018) indicate that internet connectivity should be improved especially in the rural regions if the diffusion of new digital technologies should be enhanced in the manufacturing industry.

Lack of global standards and data sharing protocols

In the same study, Lutra and Mangla (2018) identify a challenge in the lack of global standards and data sharing protocols and in the Indian case there is a problem of limited knowledge among the domestic companies as well as of adoption of standards recognised at global level. Related with data sharing there is also a problem with privacy regulations and there are security issues which need to be accounted and regulated. Security is the prime requirement to transform a factory into a smart company and a supply chain into a smart value chain.

6 Conclusions and policy recommendations

This paper started by noting that although GVCs across geographies and sectors have received several external shocks over the last decade, the fragmentation of trade and its organisation across borders is remarkably resilient. While GVCs are thus adapting to changing external political and institutional frameworks conditions, they are also changing from within by lead firms and suppliers' networks that engage in cross-border trade. Two such strategic priorities have become 'megatrends' in the world of business and society at large: the digital and green transformations. Although these trends are widely acknowledged in research and policy communities, very little is known about how they intersect in GVCs. This paper set out to shed light on whether how the twin green and digital transition take place in globally organised manufacturing in latecomer countries. A particular area of interest is to explore whether and how the adoption of smart manufacturing and data processing technologies can lead to greener GVCs and environmental upgrading of enterprises in the Global South. This section brings together the key findings and provide recommendations to policymakers.

6.1 Summary of the main findings

The paper is based on a review of the literature that brings together GVCs, green and digital transformations. Or to be more precise, the analysis is based on three main components: (a) the greening of GVCs and environmental upgrading; (b) the digital transformation of manufacturing GVCs and (c) an initial exploration of the combined green and digital transition in GVCs providing a framework which brings together environmental upgrading and digital technologies in manufacturing GVCs. Here we summarise the key conclusions.

First, the greening of the global value chains in manufacturing industries unfold in analytically separable steps: a) new patterns of demand preferences and consumer behaviours, b) new green strategies by lead firms and global buyers and c) enforcement of environmental standards and associated patterns of upgrading and downgrading across global supply bases. In other words, the greening of GVCs can open green windows of opportunities for developing country suppliers, but the seizing of these opportunities is not automatic and the failure to do so may leave enterprises worse off than before. The literature provides examples of both cases. It is important to recognize that the greening of GVCs can result in 'supplier squeeze' situations where new performance and compliance criteria provide new entry barriers, reduce profitability or force firms, and particularly suppliers from the South, out from GVCs. On the other hand, if certain conditions are met, greening may lead to environmental upgrading which can enhance both competitiveness and profitability.

Second, digitalization in manufacturing GVCs have differentiated effects across the Global South. The import and adoption of advanced digital technologies is still limited to a small number of countries (so-called 'emerging economies') and the production of them at any scale is limited to an even smaller set of advanced economies plus China. Across most of the Global South, adoption rates of smart manufacturing and service technologies as well new technologies for data processing and analysis are very low and many firms still face challenges with adopting much older manufacturing and service technologies. Hence, the digital transformation in advanced economies may further delink already struggling firms and economies in the South from GVCs, due to this increasing technology gap. Furthermore, this is compounded by the fact that the digital transformation alters the labour/capital equation of offshoring decisions because new technology can sometimes reduce the cost of manufacturing in advanced economies while in other situations it facilitates globalization of production further.

Third, still very little is known about the extent to which key enabling digital technologies support the process of environmental upgrading in the Global South firms that are inserted into GVCs. This is because these techno-institutional waves are still concentrated geographically and the full extent of the ramifications across the Global South remains to be seen. This also means that synergy-creation is challenging. In the Global South the digital transition and the green transition not only are not equal twins (Digitalization for Sustainability, 2022), but merely they are related through the 'extended family'. Nevertheless, and based on still thin empirical evidence, in Section 5 we provide a framework for examining their interaction, in particular the contribution of 4IR technologies to environmental upgrading. The small pool of literature identified for this study suggests that potentials are mainly limited to certain digital technologies and specific types of environmental upgrading. These insights are anyhow useful because they may help to early direct the efforts of policymakers towards the more likely opportunities.

6.2 Policy recommendations

This section discusses the role that the Governments, the private sector, and other stakeholders can take for latecomer countries to be able to take advantage of the windows of opportunities opening from the twin, digital and green, transition in manufacturing GVCs, overcoming the many challenges they faced, as described in the previous sections. The levels of industrialization, digital infrastructure, technological and productive capacities as well as the involvement in GVCs are highly contextual, therefore the strategic responses will be different for emerging developing economies and for less technological advanced countries. In what follows, we provide a list of critical policy areas that stakeholders in latecomer countries should consider, accounting for their technological level, for the existing preconditions and for their different involvement in specific GVCs.

Developing a digital infrastructure

A digital infrastructure is a precondition for promoting the adoption, adaptation of I4R technologies and for their use to make value chains greener. Digital infrastructure, including ICT networks and digital connectivity, platforms and data centres, submarine cables and cloud infrastructure are required for the deployment of industry 4.0 technologies (UNCTAD, 2022). The quality and speed of Internet connection affects the ability of firms in developing countries to use digital technologies. The divide in the quality of Internet connection is very significant between the developed economies and other economies. Concerning the fixed broadband connection, the observed average speed in developed economies was almost eight times that of the least developed countries (LDCs), reflecting infrastructure and technological gaps (for example, in the diffusion of optical fibre) (UNCTAD, 2021c). The technology divide is also visible within the same groups of countries, between rural and urban areas. According to UNCTAD (2021c), in LDCs 16 per cent of the rural population had no access to any mobile network, and 35 per cent could not connect online with a mobile device which implies that in these countries rural firms are quite far from the adoption of any digital technologies. In addition, according to the World Bank Enterprise Surveys[15] more than 20 per cent of the interviewed companies in South Asia and 15 per cent in Sub Saharan Africa have identified electricity access as their biggest obstacle and consequently this also impacts on their ability to use the Internet.

[15] Data are available at enterprisesurveys.org.

To constraints related with quality and access to digital infrastructure, it should also be added the high cost of connectivity relative to income, given that in LDCs ICT services remain prohibitively expensive (ITU, 2021).

Governments in developing countries should invest for providing to the business sector affordable, high-quality access to the Internet. Key policy aspects include the mobilization of public and private investments in ICT infrastructure, and the development of a regulatory environment facilitating competition in the telecommunications sector. Within countries, governments should also address the connectivity gap between small and large firms and urban and rural regions.

Building capability for green and digital manufacturing chains

Different countries find themselves at different levels of readiness in terms of capabilities and most of them need to build their capacities to adopt and adapt digital technologies for greening GVCs. Education policies should work for the enhancement of data literacy and digital skills as there are significant shortages of these skills. Policies should also support firms and other stakeholders in the provision of training of digital competencies, and in programs for the development of lifelong learning capabilities and entrepreneurship skills. Governments need to support businesses, including SME, to have the digital skills needed to use ICT efficiently in different business functions such as market research, product development, sourcing, production, sales, and after-sales services (UNCTAD, 2022). Countries need to develop incentive schemes for reducing brain drain, retaining skilled professionals and attracting skilled expatriates. An interesting example is the NerUzh program in Armenia designed to attract potential tech entrepreneurs from the diaspora, offering a start-up funding.[16]

Aligning digital and green strategies

Many developing countries have recently adopted national strategies for the green and digital transformation. For instance, according to the IEA/IRENA policy database, in Africa there are currently 83 strategic plans involving renewable energies, in Central and South America there are 65 plans and in the Middle East 15.[17] UNIDO (2020) and UNCTAD (2022) document the existence of national strategies to enhance digitalization in many different developing countries such as Thailand, Vietnam, South Africa; Chile, Argentina, Brazil and Mexico. Such strategies are critical for investing in physical infrastructures and skills; for identifying key sectors requiring strengthened capacity; and for setting the regulatory environment for firms to adopt and adapt digital technologies. To address opportunities for environmental upgrading, it is critical to align innovation and industrial policies to

[16] More information about the NerUzh program is available at diaspora.gov.am.
[17] Information is available at iea.org.

environmental policies. Besides, digital and green objectives should also be accounted in global value chain-oriented policies aimed at increasing participation and improving value capturing in GVCs (Pietrobelli et al, 2021).

In the EU, as well as in countries such as Canada and the Nordic Baltic countries, there is an increasing awareness about the importance of investing in appropriate initiatives to exploit the opportunities offered by digitalization for environmental protection and climate action, and to limit the negative environmental impacts of digitalization itself.[18] To take advantage of the windows of opportunities opening from the twin, digital and green, transition in manufacturing GVCs it requires that policies, typically developed in separate policy domains, are co-created across the energy-environmental, industrial and foreign investment spheres.

Building international partnership

Participation in projects involving international organizations, national governments, and non-governmental organizations across the world, is key for promoting access to external knowledge in developing countries. UNCTAD (2022) illustrates several examples of international collaborations aimed at promoting digitalization, at the adoption of frontier technologies and the qualification of the workforce. An example is Prospecta Americas, a regional program aimed at improving knowledge about technologies such as big data, AI, IoT, robotics, blockchain and at evaluating their economic, social, and environmental impact on the countries of the Organization of American States (OAS). The long-term goal of the project is to create a regional network of experts capable to share good practices, support capacity building and training in the field, provide technical assistance and lead joint collaborative projects across the OAS member states.[19] Another example is the multi-stakeholder knowledge-sharing platform promoted by UNIDO to create awareness of industry 4.0 and of opportunities and challenges in pursuing inclusive and sustainable industrial development in developing countries.[20] The platform enables the sharing of available tools and methods for innovation management; information on training curricula for new skills requirements; methods and best practices to support digital transformation among SMEs (UNCTAD, 2022).

Among international organizations the awareness about the interlink between the digital and the green transformation is raising. In the EU, 26 member states, Norway and Iceland have signed a declaration to accelerate the use of green digital technologies for the benefit of the environment with the commitment to use the NextGenerationEU and InvestEU funds to develop and deploy application of digital technologies in areas such as energy efficient AI solutions and digital passports to track

[18] For more information see consilium.europa.eu and Nordic Council of Ministers (2021).
[19] More information is available at prospectaamericas.org.
[20] More information is available at unido.org.

products to improve circularity and sustainability.[21] UNDP is supporting projects aimed at building cross-sectoral ecosystems of partnerships across governments, companies and NGOs to promote the digital transformation for a green economy. One example is the establishment of ImpactAim Venture Accelerator in Armenia in cooperation with the Enterprise Incubator Foundation, Innovative Solutions and Technologies Center Foundation. The Accelerator is supporting tech ventures focused on energy efficiency and renewable energies, exploring the application of technologies like AI and data science in the environmental field. The project is currently accelerating 33 start-ups in Armenia, 2 in Belarus and one in the Philippines.[22]

These demonstration projects are also crucial in terms of raising awareness in the business sector about the potentiality of the digital technologies to promote the green transformation. Accelerators and incubators can be used to facilitate learning and diffusing knowledge though best practices and demonstration projects.

Setting standards and regulations

In the context of digital transformation, the harmonized adoption of standards is key to ensure interoperability, productivity, and innovation as well as the successful scale up of solutions to be implemented globally. Standardization offers obvious benefits in international trade networks and within global value chains. According to UNIDO (2021), standard setting activities related to digital technologies are mainly concentrated at the national level and there is still plenty of work for international harmonization. Regarding AI, big data, blockchain, IoT, robotics, 3D printing and autonomous vehicles, UNIDO (2021) recommends following seven key principles: trustworthiness, inclusiveness, sustainability, interoperability, safety and security, data privacy and international collaboration. These principles account for concerns about the impacts of new technologies on people and the planet, in terms of well-being and ethics. UNIDO (2021) stresses that the transformative capabilities of digital technologies should be made evident in the development of standards to leverage their potential role in strengthening SDG pillars, and their impact on the environment.

The International Communication Union (ITU) has established several focus groups on industry 4.0 technologies and their environmental impacts, including on environmental efficiency for artificial intelligence and other emerging technologies; artificial intelligence for autonomous and assisted driving; and autonomous networks. The focus groups develop technical reports and technical specifications to address the environmental efficiency, as well as water and energy consumption of

[21] More information is available at digital-strategy.ec.europa.eu.
[22] More information is available at impact.aim.com.

emerging technologies, and provide guidance to stakeholders on how to operate these technologies in a more environmentally efficient manner.[23]

ITU publishes international standards related to industry 4.0 and associated technologies such as the Internet of Things. These standards are available free-of-charge for downloading and use in developing countries. Moreover, ITU organizes events in different regions that enable countries to obtain new knowledge and works with developing countries to bridge the standardization gap and assist them to become more involved in standardization activities (UNCTAD, 2022).

Providing financial support

The lack of financial resources for R&D programs in the field of digital and green technologies is a persistent problem in developing countries. A further challenge is that in this pioneering area it could be rather difficult to convince firms and financial intermediaries to invest because there is limited business evidence about returns on investments. Therefore, innovation and technology funds financed by the public sector, international donors and development banks are key to start demonstration projects (UNCTAD, 2022).

A complementary role is played by foreign direct investments (FDI) which can be attracted by introducing policy measures targeting technology and environmental oriented investments. According to UNCTAD (2022), developing countries should formulate strategies for investment promotion targeting specific investment activities and business functions to facilitate the adoption and adaptation of green and digital technologies. An example is the Green Channel initiative in Latvia offering fast track for FDI in field such as ICT, bioeconomy, smart materials, smart energy and mobility.[24]

6.3 Future research

Although there is widespread agreement that the green and digital transition and its manifestation in GVCs will have profound implications across the Global South, it is also clear that it difficult to study this emergent, indeed embryonic, phenomena. In this paper we have sought lay out what is already known, but we have also shown how there is a lot that we still need to investigate. In fact, there are significant knowledge needs when it comes to each of the twins, let alone their interactions. For example, while we have described a positive association between insertion into GVC and adoption of advanced technologies, what is the direction of causality? Do GVC participation facilitate technology adoption or is it the other way around? Similarly, what are the conditions on which the

[23] More information is available at itu.int.
[24] More information is available at investinlatvia.org.

green strategies improve competitiveness and when this is just an additional cost that accrue to suppliers? We have described anecdotal evidence to substantiate each scenario in these papers, but what are the wider patterns across sectors? Lastly, we know that irrespective of GVCs, processes of greening are surging ahead, and several latecomer countries are faced with green windows of opportunity. How important are new technologies to firms and local systems of production and innovation to seize these GWOs?

While qualitative case studies, surveys and other quantitative approaches have begun to provide some preliminary evidence of certain aspects pertaining to these questions, such as patterns of digital technology adoption, there is also a need to reflect upon how new data-science methods can help to bring the research agenda forward. Furthermore, there is a need to systematically contrast cases to inform policy-tools that can aid stakeholders in the effort to leverage digital technologies for exploiting green windows of opportunities in GVCs, when and where they arise.

Appendix

Table A.1 – Keywords used in the systematic review literature on GVC, GREENING, DIGITALIZATION/4IR

Global Value Chains	Global Value Chain(s); GVC(s); Global Production Network(s), International Production Network(s); Global Industrial Ecosystem(s); Global Supply Chain(s); Supply Chain(s); Global Value Chain Network(s)
Greening	Green windows of opportunity(ies); Greening; Sustainability Transition; Green Transformation; Environmental Upgrading; Green Innovation; Eco-innovation; Environmental Sustainability; Circular Economy; Climate Change; Sustainable Development
Digitalization/4IR	4IR; Fourth Industrial Revolution; Industry 4.0; Automation; Robot(s); Sensor(s); Artificial Intelligence; AI; Machine Learning; Internet of things; IoT; Industrial IoT; Data Analytics; Big Data; Big Data Analysis; Cloud Computing; Digitalization; Digitalized; Digital Technologie(s); Digital Industrialization; Digital Readiness; Digital Skill(s); Digital Platform(s); Digital Infrastructure(s); Digital capability(ies); Digital Economy; Advanced Manufacturing; 3-D printer(s); 3-D printing; Drone(s); Learning Machinery; Blockchain(s); 5G
Latecomer countries	Latecomer Countrie(s); Developing Countrie(s); Middle Income Countrie(s); Lower-Middle Income Countrie(s); Low Income Countrie(s); Leat Developed Countrie(s)
Traditional manufacturing industries	Food; Food Production; Agro-industrial; Agri-food; Agrifood; Agro Industry; Garment; Textile; Clothing; Apparel; Shoes; Leather; Furniture

Table A.2 - 19 articles identified with the systematic review literature on GVC, GREENING, DIGITALIZATION/4IR

Relevant for the analysis	
1	Dauvergne, P. (2020). Is artificial intelligence greening global supply chains? Exposing the political economy of environmental costs. *Review of International Political Economy*, 1-23.
2	Gale, F., Ascui, F., & Lovell, H. (2017). Sensing reality? New monitoring technologies for global sustainability standards. *Global Environmental Politics*, *17*(2), 65-83.
3	Mangina, E., Narasimhan, P. K., Saffari, M., & Vlachos, I. (2020). Data analytics for sustainable global supply chains. *Journal of Cleaner Production*, *255*, 120300.
4	Nikolakis, W., John, L., & Krishnan, H. (2018). How blockchain can shape sustainable global value chains: an evidence, verifiability, and enforceability (EVE) framework. *Sustainability*, *10*(11), 3926.
5	Saberi, S., Kouhizadeh, M., Sarkis, J., & Shen, L. (2019). Blockchain technology and its relationships to sustainable supply chain management. *International Journal of Production Research*, *57*(7), 2117-2135.
6	Oldekop, J. A., Horner, R., Hulme, D., Adhikari, R., Agarwal, B., Alford, M., ... & Zhang, Y. F. (2020). COVID-19 and the case for global development. *World Development*, *134*, 105044.
Off topic	
7	Bechtsis, D., Tsolakis, N., Iakovou, E., & Vlachos, D. (2021). Data-driven secure, resilient and sustainable supply chains: gaps, opportunities, and a new generalised data sharing and data monetisation framework. *International Journal of Production Research*, 1-21.
8	Fox, S. (2019). Moveable production systems for sustainable development and trade: Limitations, opportunities and barriers. *Sustainability*, *11*(19), 5154.
9	Kolmykova, T., Merzlyakova, E., & Kilimova, L. (2020). Development of robotic circular reproduction in ensuring sustainable economic growth. *Economic Annals-XXI*, *186*.
10	Kucukvar, M., Onat, N. C., Abdella, G. M., & Tatari, O. (2019). Assessing regional and global environmental footprints and value added of the largest food producers in the world. *Resources, Conservation and Recycling*, *144*, 187-197.
11	Mugauina, R., Madiyarova, D., & Shishmanov, K. (2020). Using the supply-chain management for developing oil industries in the Republic of Kazakhstan. *International Journal of Supply Chain Management*, *9*(2), 1086-1094.
12	Mateus, A., & Martins, L. (2021). Building a mineral-based value chain in Europe: the balance between social acceptance and secure supply. *Mineral economics*, *34*(2), 239-261.
13	Moore, S. B., & Manring, S. L. (2009). Strategy development in small and medium sized enterprises for sustainability and increased value creation. *Journal of cleaner production*, *17*(2), 276-282.
14	Ndubisi, N. O., Nygaard, A., & Chunwe N, G. (2020). Managing sustainability tensions in global supply chains: specific investments in closed-loop technology vs 'blood metals'. *Production Planning & Control*, *31*(11-12), 1005-1013.
15	Sendlhofer, T., & Lernborg, C. M. (2018). Labour rights training 2.0: the digitalization of knowledge for workers in global supply chains. *Journal of Cleaner Production*, *179*, 616-630.
16	Tseng, C. T., & Shang, S. S. (2021). Exploring the sustainability of the intermediary role in blockchain. *Sustainability*, *13*(4), 1936
17	Ting, S. L., Tse, Y. K., Ho, G. T. S., Chung, S. H., & Pang, G. (2014). Mining logistics data to assure the quality in a sustainable food supply chain: A case in the red wine industry. *International Journal of Production Economics*, *152*, 200-209.
18	Turner, J. A., Klerkx, L., White, T., Nelson, T., Everett-Hincks, J., Mackay, A., & Botha, N. (2017). Unpacking systemic innovation capacity as strategic ambidexterity: How projects dynamically configure capabilities for agricultural innovation. *Land use policy*, *68*, 503-523.
19	Vadarnikjoo A., Badri Ahmadi, H., Liou, J. J., Botelho, T., & Chalvatzis, K. (2021). Analyzing blockchain adoption barriers in manufacturing supply chains by the neutrosophic analytic hierarchy process. *Annals of Operations Research*, 1-28

Table A.3: Five types of GVC governance

Type	Description
Market	This type has a low degree of explicit coordination and power asymmetry. Market linkages do not have to be completely transitory, as is typical of spot markets; they can persist over time, with repeat transactions. The essential point is that the costs of switching to new partners are low for both parties.
Modular,	Typically, suppliers in modular value chains make products to a customer's specifications, which may be more or less detailed. Often, 'turn-key services' suppliers take full responsibility for competencies surrounding process technology, use generic machinery that limits transaction-specific investments, and make capital outlays for components and materials on behalf of customers.
Relational	In these GVCs interactions between buyers and sellers ae complex, which often creates mutual dependence and high levels of asset specificity. This may be managed through reputation or more trust-based ties. Spatial proximity may support relational value chain linkages, but trust and reputation might well function in spatially dispersed networks where relationships are built-up over time. This type has an intermediate degree of explicit coordination and power asymmetry
Captive	In these networks, small suppliers are transactionally dependent on much larger buyers. Suppliers face significant switching costs and are, therefore, 'captive'. Such networks are frequently characterized by a high degree of monitoring and control by lead firm
Hierarchy	This governance form is characterized by vertical integration. The dominant form of governance is managerial control, flowing from managers to subordinates, or from headquarters to subsidiaries and affiliates. This type has a high degree of explicit coordination and power asymmetry.

Source: adapapted from Gereffi et (2005)

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