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Abstract

Notwithstanding increasing policy and academic debate around the 'twin' digital and ecological transitions, there is no systematic assessment of their linkages, potential synergies and trade-offs. Most fundamentally, the full extent of challenges that their interaction poses for the prospects of a 'just transition' is not fully understood. This paper discusses the role and impact of digital technologies on two key objectives of a just sustainability transition, namely (1) the creation of decent-quality employment in (2) the pursuit of climate change mitigation and, more broadly, sustainability. In addition, it also discusses (3) whether and how digitalisation affects society more broadly, with a particular focus on how digital technologies can contribute to or reduce existing inequalities, as well as promote social dialogue at all levels. For each of these three aspects, evidence is presented regarding either the negative or positive effects of a number of digital technologies in several key sectors. Based on this evidence, the rationale for jointly addressing these transformations is explained and key policy implications are put forward.

Keywords: Just transition, digital transformation, ecological transition.

JEL Codes: O33, Q52, O15, H23.

1. Introduction

There is increasing talk and policy discussion around the concept of 'just transitions' (in the plural), meaning 'just' for both the ecological and the digital transition. This joint focus on the 'twin just transitions' is a relatively recent one, but one that is attracting increasing attention (IndustriALL 2018). Both transformations will not only bring about fundamental and disruptive changes to our economies and societies, but are also likely to affect each other as well as the achievement of broader long-term environmental, economic and societal goals. To date, there is, however, no systematic assessment of the linkages, potential synergies and trade-offs between the digital and the ecological transitions. Most fundamentally, the full extent of the challenges that their interaction poses for the prospects of a 'just transition' is not fully understood. Gathering evidence on these aspects is crucial to informing the drafting of future industrial, climate and social policies.

In this paper, I bring together evidence from several parallel and, until now, separate streams of literature. First, I briefly describe how the just ecological transition concept has been combined with that of the digital transformation into what is currently known as the 'twin just ecological and digital transitions' (Section 2). Second, I present a framework detailing the links and the feedback between the ecological and the digital transitions and how these, in turn, affect the prospects of a just transition (Section 3). These links and this feedback have been discussed and analysed separately, but a comprehensive approach is currently missing from both the academic and policy debates; nor have implications for a just transition been fully conceptualised. Third, by drawing on this framework and on the available evidence, I summarise five key implications of digitalisation for the just ecological transition (Section 4). Fourth, based on this summary, I identify the rationale for addressing the two transitions as twin processes and in the light of the need to promote a just transition (Section 5). Fifth, based on this evidence, I distil a set of broad recommendations to shape the debate and guide policy-making (Section 6).

2. Just transition, climate action and digitalisation

The origins of the just transition. The 'just transition' concept gained widespread recognition in the 1990s through the work of North American trade unions. By 2015, it had become a core component of the global union agenda (Stevis et al. 2015). The term was initially used to refer to specific programmes and interventions to support workers who faced job losses as a result of environmental protection policies regulating hazardous sectors, such as some chemicals and asbestos (JTC 2017; Stevis et al. 2015). Over time, the concept evolved from this narrower interpretation to indicate a much broader, deliberate effort to plan for and invest in a transition to environmentally and socially sustainable jobs, sectors and economies (JTC 2017). Recognising that the economic and social costs of industrial restructuring (e.g. job losses) would likely fall on specific segments of the workforce, to which the benefits of the restructuring (e.g. new, high-quality jobs possibly created) would not accrue, the transition towards sustainability should be based on a series of principles and institutional arrangements designed to limit negative impacts on vulnerable workers and communities, either by providing the necessary skills and competences or through social protection (Stevis et al. 2015).

In the 'Guidelines for a just transition towards environmentally sustainable economies and societies for all', published by the ILO in 2015 following the adoption by the UN of the Sustainable Development Goals, a just transition framework is defined as one that 'promote[s] the creation of more decent jobs' in the context of the transition towards environmentally sustainable economies and societies for all, 'including as appropriate: anticipating impacts on employment, adequate and sustainable social protection for job losses and displacement, skills development and social dialogue, including the effective exercise of the right to organize and bargain collectively' (ILO 2015). This definition stresses two key aspects: on the one hand, the need for measures promoting the creation of new, green and decent jobs in emerging sectors; on the other hand, the importance of measures to limit negative impacts on workers and communities resulting from industry phase-out, including job losses (JTC 2017). The ILO guidelines, which represent a systemic approach with a view to jointly addressing environmental, social and economic issues in the pursuit of sustainability, call for a clear strategy, building on a comprehensive policy framework, and for engagement in a meaningful and functioning social dialogue at all levels (Galgóczi 2018).

Just transition in the context of climate action. In response to the growing understanding of, and concerns about, the climate crisis, the international trade union movement began specifically to extend the just transition discussion to the climate change debate. Climate change differs from other environmental challenges because of its global nature, as well as its long-term horizon. In this context, the just transition is the path towards a low-carbon and climate-resilient economy that 'maximises the benefits of climate action while minimising hardships for workers and their communities' (ITUC 2015). This approach focuses on fulfilling the criteria of equity and redistribution by cushioning the negative social effects of greening the economy and promoting decent-quality employment (Galgóczi 2019; Sabato et al. 2021; Sabato and Fonteddu 2020). The concept of a just transition was put forward by the unions and their partners in several international climate negotiations and conventions, including the United Nations Framework Convention on Climate Change (UNFCCC). In 1997, the International Confederation of Free Trade Unions (ICFTU) included 'just transition' in its statement to the Kyoto Conference (Stevis et al. 2015). The turning point in the debate, however, was around 2007, when the International Trade Union Confederation (ITUC) and the European Trade Union Confederation (ETUC) started to engage specifically in the discussion around the labour market impacts of the EU long-term climate goals and of the policies implemented to support them (Dupressoir et al. 2007). The 'just transition' concept was also mentioned in the final agreement of the 16th UN Conference of the Parties to the Climate Change Convention in Cancún (COP16) in 2010, effectively marking its inclusion in international regimes and its establishment as a prominent policy tool in global climate politics (Galgóczi 2018; Newell and Mulvaney 2013). The outcome declaration of the Rio+20 Earth Summit in 2012 also contains the term 'just transition' and emphasises the need for 'programmes to help workers adjust to changing labour market conditions' (UNEP 2012). More recently, the non-binding preamble to the Paris Agreement takes into account 'the imperatives of a just transition of the workforce and the creation of decent work and quality jobs in accordance with nationally defined development priorities' (UNFCCC 2015).

Over time, the 'just transition' concept has been taken up by environmental justice groups and indigenous rights groups, but also by businesses and national governments. The most prominent example is its inclusion as one of the pillars of the European Green Deal (European Commission 2019), which is discussed later in this article. Importantly, as the Just Transition Research Collaborative points out (JTRC 2018), as the term 'just transition' became more popular, it was increasingly used in a variety of different contexts and by a variety of different stakeholders. As a result, the term started to reflect the broader political and ideological beliefs of those using it. Indeed, the understanding of 'just transition' varies in several dimensions, such as the kind of justice that should be sought (social, environmental, etc.), whether the debate should be about distributional, procedural, restorative or recognition justice or a combination of them, the type of governance structures, institutions and policies that are called for, the subjects whose justice should be considered (i.e. particular groups or broader society, or even nature more in general). Demands linked with just transition principles may, in fact, range from the simple request for job creation to a radical critique of capitalism and markets (Barca 2015, as cited in JTRC 2018).

Galgóczi (2018) argues that two key features of the original 'just transition' demand had a lasting effect on the framing of the just transition concept in the context of climate mitigation: on the one hand, the fact that pursuing a just transition amounts to more than simply providing ‘welfare’, and that actively supporting a transition is in the common interest and is a public responsibility; and, on the other hand, the fact that decarbonisation is a planned transition that emerged as a response to climate worsening resulting from the use of fossil fuels. Its objectives are clearly identified and pursued through policy. As such, it is currently fundamentally different from other transformations, such as globalisation or digitalisation, and should be addressed through the definition of a holistic policy approach. Furthermore, while a ‘just transition’ approach needs to take full account of local conditions, a key set of policies and approaches rests at its core. These include sound investments in low-emission and job-rich sectors and technologies respecting human and labour rights and ‘decent work’ principles; social dialogue and democratic consultation of social partners (trade unions and employers) and other stakeholders (communities); research and early assessment of the social and employment impacts of climate policies, training and skills development; active labour market policies and social protection, as well as local economic diversification plans (ILO 2013).

The digital revolution. In parallel, the digital revolution is dramatically reshaping how we produce and consume goods and services. Digitalisation is the adoption and increased use of information and communication technologies (ICTs) by all actors, and the consequent restructuring of several domains of social life and of the economy around digital technologies and infrastructures (Brennen and Kreiss 2016). Developments in digital technologies, many of which resulted from massive publicly funded research programmes (Block and Keller 2011; Mazzucato 2013), have fuelled the creation of new products and customer markets since the 1970s. Although initially limited to a few sectors at the margin of established markets, such as computers and video games (Fernández-Macías 2018), digital technologies are now radically changing the world of work, for instance through increased automation and the development of platform economies. Overall, the digital revolution has been driven by rapid technological developments, such as cost reductions and improved performance of computing devices, digital communication, sensors and the rapid expansion of internet infrastructure and access worldwide (World Bank 2014). In recent years, the pace of the use of digital technologies and services, as well as the exchange of data between humans, machines and devices, has accelerated dramatically (Hammond 2018). This is the result of an increased ability to use digital data to produce useful information and insights (i.e. analytics) and to exchange information between humans, devices and machines (i.e. connectivity), and of higher technical performance, widespread applicability and declining costs (Masanet et al. 2020). Furthermore, many digital technologies, such as handheld devices or computers, are neither bulky nor capital-intensive products; as a result, they are adopted rapidly by consumers (Wilson et al. 2020). As an illustration, in OECD countries, market saturation for cell phones was reached in 13 years. In non-OECD countries, they started to spread a few years later, but market saturation was reached in 11 years (TWI 2018: Figure 9). Several experts now claim that we are, once again, on the verge of an even faster surge in the applicability and widespread use of digital technologies in all aspects of our economies and societies.

These trends in digitalisation promote disruptive change and major societal transformations (Brynjolfsson and McAfee 2014; European Commission 2020a), which affect both the energy/sustainability transition and the prospects of a just transition. On the one hand, an increasingly rich literature shows mixed expectations about the impact of digital technologies on energy demand, energy efficiency and the deployment of renewable energy (Inderwildi et al. 2020; Ficarra et al. 2021). On the other hand, a parallel stream of discussion revolves around the relevance of digital technologies also in the context of broader sustainability challenges, including those of increasing social inclusion, reducing inequality and promoting newer forms of political and societal participation through digital devices (UN 2021). A specific concern addressed in the literature relates to the impact of digital and smart technologies on the future of work. According to a Gallup survey, three in four workers in the United States fear that new technologies will foster unemployment, while 23% believe that their own jobs are at risk (Reinhart 2018). Yet it has also been suggested that digital technologies will lead to more qualified and better-paid jobs and more flexibility in the workplace and will open up new opportunities and business models (OECD 2016). Furthermore, it has been argued that digitalisation can lead to reshoring of production to countries with a high-skilled labour force, reversing the offshoring trends of the past few decades, which were driven by low labour costs as well as lower environmental regulation (Faber et al. 2020).

The missing link. Notwithstanding the significant potential impact that digital technologies can have on both the sustainability transition and the just transition, a strong connection in the policy debate between the digital revolution and sustainability has only recently been adopted. By 2017, while a large number of countries had high-priority policy objectives focusing on the development of the digital economy and society, almost no country specifically linked these objectives to higher-level goals on climate mitigation or sustainability. The two notable exceptions in this respect were Sweden and Switzerland. Responses to the OECD Digital Economy Outlook Policy Questionnaire indicate that the national digital strategies of both these countries made explicit mention of the fact that promoting digitalisation was instrumental to addressing climate change and sustainability objectives. Other countries perceived digital technologies as crucial for other ancillary benefits – competitiveness (e.g. the Netherlands), jobs (e.g. Denmark and Germany), growth (e.g. Brazil), inclusiveness and inclusion (e.g. People's Republic of China), but not decarbonisation (OECD 2017). By 2022, the picture had significantly changed, reflecting a recognition of the disruptive nature of the digital revolution and its potential implications for a just green/sustainable transition.

The twin challenge of a just ecological and digital transition. The most notable example of such change took place in the EU, where the concepts of just ecological transition and digital transformation were linked in a matter of months. In 2019, the newly established von der Leyen Commission proposed the EU Green Deal, namely a new 'just and inclusive' 'growth strategy that aims to transform the EU into a fair and prosperous society, with a modern, resource-efficient and competitive economy where there are no net emissions of greenhouse gases in 2050 and where economic growth is decoupled from resource use' (European

Commission 2019). The political guidelines the von der Leyen Commission proposed for potential adoption mentioned both a just green transition (EU Green Deal) and the goal of making the EU fit in the digital age, but the two objectives were still separate. Conversely, a link between the two appears in the EU Green Deal Communication, where digital technologies are specifically mentioned as a critical enabler for attaining the sustainability goals of the Union in many different sectors; furthermore, a specific call is put out for Europe to leverage the potential of the digital transformation. Contextually, the European Green Deal proposed a Just Transition Mechanism, including a Just Transition Fund, to leave no one behind; the Just Transition Mechanism was established in January 2020. In February 2020, the Commission's Strategy on Shaping Europe specifically mentions the twin challenge of a green and digital transformation, and briefly mentions the needs for the digital transformation to be 'fair and just'. On 10 March 2020, the EU adopted the New Industrial Strategy, which more forcefully stated the need for the twin transition to 'leave no one behind' and included a reference to the Just Transition Fund.

> The twin ecological and digital transitions will affect every part of our economy, society and industry. […] The breadth and depth, the scale and speed, the nature and necessity of the twin transitions are unprecedented. […] As the transition picks up speed, Europe must ensure that no one is left behind. (European Commission 2020b)

The EU New Industrial Strategy thus effectively brought the discourse around the just ecological and digital transition together. On the next day, the WHO declared the novel coronavirus (Covid 19) outbreak a global pandemic.

3. Framing the analysis of the just ecological and digital transitions

The focus on the twin challenge of the just ecological and digital transitions emerged from the widespread and increasingly disruptive impact of digitalisation on economies and societies, and the urgency of addressing climate and sustainability concerns. The Covid-19 pandemic strengthened this link, as the digital transformation was accelerated as a result of the world moving online to perform some of the most basic activities (Sabato et al. 2021). Children attended classes remotely, many employees worked remotely, and businesses adopted digital business models to preserve some revenue flows. Digital applications also helped set up a system for tracking and tracing the development of the pandemic. Internet traffic in some countries increased by up to 60% shortly after the outbreak (OECD 2020). However, a large digital divide both within and across countries highlighted that those unable to access digital technologies would be even more likely to be left behind.

This notwithstanding, there is no systematic understanding of how the ecological and digital transitions influence each other, and what challenges they raise separately and jointly for the achievement of a just transition. While the literature highlights several potential channels through which digitalisation may affect the prospects for the sustainability transition and for a just transition, these discussions are often parallel and not mutually informed. This is true for both academic literature and, until recently, for the policy discourse. Most recently, a number of institutions and interest groups – prominently the trade unions (IndustriALL 2018) – have pushed for these two debates to be linked.

From a theoretical point of view, the development of a framework to assess the impact of digital technologies on the prospects of a just ecological transition is complicated by the fact that the term ‘digital technologies’ encompasses a very wide range of technological solutions, ranging from robotics to the Internet of Things (IoT) and the industrial IoT, sensors, cloud services, big data and analytics, blockchain, artificial intelligence, augmented reality and many more. Not only are these technologies and their applications extremely heterogeneous, but they also perform very different functions in different sectors. Mobility as a Service (MaaS), unmanned vehicles and trucks and big data will find widespread application in the transport sector. Optimised process control through sensors, industrial automation through robots and additive manufacturing are relevant in the context of industry; occupancy and daylight sensors, remote control and smart thermostats and appliances have high potential in the buildings sector (IEA 2017b). A further difficulty arises from the fact that the geographical concentration of these heterogeneous digital technologies varies greatly in different regions of the world. While cell phones and handheld devices are now widespread in all countries of the world, independent of the level of their economic development, the application of digital technologies to the productive sector is still very much concentrated in developed countries, while developing countries lag behind. This limits the ability to compile the available results.

To overcome these challenges, the present section builds on previous studies (Verdolini 2021; Alacevic and Verdolini 2022) and discusses the role and impact of digital technologies on the objective of promoting 'the creation of more decent jobs' in the context of the transition towards environmentally sustainable economies and societies for all (ILO 2015). To this end, this section summarises recent academic evidence on the impact that digital technologies have on (1) decent-quality employment, as well as on the prospects of (2) promoting climate change mitigation and sustainability in the economic domain. In addition, it also presents broader considerations regarding (3) whether and how digitalisation affects society more broadly, with a particular focus on how digital technologies can contribute to or reduce existing inequalities, as well as promote social dialogue at all levels. This is relevant to understanding the contribution of digitalisation to a more broadly defined just transition, which goes beyond consideration for affected workers and communities, and rather focuses more in general on distributional, procedural, restorative or recognition justice. For each of these three aspects, evidence is discussed regarding either the negative or the positive effects of several digital technologies in several key sectors. Wherever possible, I highlight implications for key sectors: industry, buildings and transportation.

Digital technologies and decent-quality employment

Digital technologies can affect the prospects of promoting decent-quality employment both positively and negatively. On the one hand, they can reduce overall demand for labour, particularly for jobs that can be automated or are characterised by routine tasks; digital technologies and business models are often associated with low-quality and precarious jobs. On the other hand, they can promote high-quality employment by raising the demand for high-skill workers, as well as contribute to the backshoring of jobs. While the academic literature presents results supporting both theses, a question that is only recently being tackled is the extent to which these two opposing effects are geographically localised and sector-specific. In other words, the potential benefits associated with digital technologies in terms of the quality of jobs may not accrue to those workers who risk becoming redundant as a result of digitalisation. Below, we discuss these opposite effects in turn.

A large body of literature puts forward evidence that digital technologies will substitute workers, and reduce both overall employment and the quality of jobs. Several analyses show that digital automation has contributed to a decline in employment among manual and routine-intensive occupations (e.g. Goos and Manning 2007; Autor and Dorn 2013). Along similar lines, the adoption of information technology affects employment and wages differently across occupations. Specifically, information technologies replace routine middleeducation jobs while complementing abstract jobs and high-education, high-skilled jobs (Autor et al. 2008). Acemoglu and Restrepo (2020) study the impacts of the adoption of industrial robots in US local labour markets. According to their framework, technologies have both a 'displacement' effect – as they substitute workers in performing tasks – and a productivity effect – as they make it easier to complete certain tasks or to create new jobs. The overall impact of robots on the level of employment and on the average wage (one of several proxies for quality of jobs) will depend on the relative magnitude of the displacement and productivity effects.

In the case of industrial robots, which are automatically controlled, reprogrammable, multipurpose machines that can autonomously perform a variety of tasks like welding, painting and packaging, both effects arise, but the displacement effect is stronger and results in adverse effects on wages and employment. The authors find that one additional industrial robot per thousand workers reduces both the employment rate by two percentage points and workers' wages by 42%. Given the current installation levels of robots in the manufacturing sector in the USA – approximately 126 robots per 10 000 employees (IFR 2021) – this loss has been estimated at about 400 000 jobs (Brown 2020). Job losses and downward pressure on wages are greater in sectors with higher exposure to digitalisation, that is to say sectors in which repetitive tasks can be more easily automated. In point of fact, industrial robots are more likely to affect routine manual occupations and lower- and middle-class workers, particularly blue-collar workers, such as machinists, assemblers, material handlers and welders. Similarly, Acemoglu et al. (2020) find negative overall impacts on employment in the industrial sector in France. Robot-adopting firms, which account for 20% of manufacturing employment, experience higher productivity and value added and lower shares of production workers, while expanding overall employment. However, their non-adopting competitors experience a reduction in both value added and employment. The net effect is that a 20 percentage point increase in robot adoption is associated with a 3.2% reduction in total industry employment.

Importantly, industrial robot adoption is very heterogeneous across sectors and countries. Graetz and Michaels (2018) use data from the International Federation of Robotics (IFR) and from the EU KLEMS Growth and Productivity Accounts database (Jaeger 2017) to estimate robot density—the stock of robots per million hours worked—in 14 industries in the US, 14 European countries, South Korea and Australia from 1993 to 2007. They show that, in their sample, robot density increased over this period by more than 150%, from 0.58 to 1.48. In 1993, robot densities measured as robots per million hours worked were highest in Germany (about 1.7), followed by Sweden (about 1.4), Belgium (1.2) and Italy (about 1.1). The US density was just above two thirds of the 17-country average. Four of the 17 countries (Australia, Greece, Hungary and Ireland) had either no or almost no industrial robots. Over the period 1993 to 2007, Germany led the growth in robot density, followed by Denmark (about 1.6) and Italy (about 1.4). By 2007, industrial robots were employed in all the 17 countries in the sample, and mean robot density across the 17 countries that were analysed increased by more than 150%. Among the industries, the transport equipment, chemicals and metal industries led the way in increasing robot density.

Specific dynamics between robots and labour have been highlighted in different sectors and countries. For instance, US automakers are one of the world's biggest users of industrial robots. According to the International Federation of Robotics, the US car industry had 127 000 industrial robots installed in 2016, up 70% from 2006. It has been reported that, in the wake of the global financial crisis, General Motors and other automakers held back on investment in new plants, instead focusing on raising productivity. They did this mostly with robots. While national statistics show that the US automotive industry generated record added value in 2016, the industry's employment was only at 70% of its peak in 2000. Industrial robots increasingly replaced human workers after the financial crisis (Nakanishi 2017).

Conversely, some contributions point to the fact that, overall, digital technologies promote high-quality employment. Digital technologies, for instance, expand production possibilities (Kunkel and Matthess 2020); smart technologies enhance workers' productivity and foster the demand for new skills and the creation of new occupations. Graetz and Michaels (2018) show that increased robot use within industries in 17 countries from 1993 to 2007 contributed approximately 0.36 percentage points to annual labour productivity growth, raised total factor productivity and lowered output prices. Their estimates also suggest that robots did not significantly reduce total employment, although they did reduce low-skilled workers' employment share. This indicates that digital technologies may, in fact, promote better-paid occupations at the expense of low-skilled jobs. Similar conclusions are reached in a number of other studies. Koch et al. (2021) use administrative longitudinal data of firms in Spain between 1990 and 2016 to find that robot adoption leads to increases in output by 20 25% within four years, reduces the labour cost share by 5 7 percentage points and results in a 10% increase in jobs. In this specific case, evidence of employment gains exists for all types of workers, including low-skilled occupations and employment in manufacturing establishments. A negative effect on labour emerges only in firms that do not adopt the new technology.

This evidence, which may seem contradictory, highlights the complexity of the dynamics that characterise digitalisation and its impact on the labour market. One common finding of the literature is that the effect of digitalisation varies by occupation. This suggests that what ultimately matters in terms of a just transition is not only the net effect of digital technologies on the labour market, but rather the fact that the displacement effect hurts some specific workers and sectors, while the productivity effect generally benefits others. That is to say, the workers being displaced by new technologies, including digital ones, lack the opportunities and the skills to benefit from the newly created jobs. Without upskilling or reskilling programmes, displaced workers cannot benefit from the new jobs. De Vries et al. (2020), for instance, focus on a panel of 19 industries in 37 high-income and emerging market and transition economies (EMTEs) from 2005 to 2015 and show that increased use of robots is associated with positive changes in the employment share of non-routine analytical jobs and negative changes in the share of routine manual jobs. These patterns are proof against a series of changes in the empirical estimation approach, although they are stronger in high-income countries and weaker in EMTEs. Furthermore, there is no evidence that industrial robot adoption increases aggregate employment (de Vries et al. 2020). Humlum (2021) uses data from Denmark and shows that, while industrial robots have lowered real wages of production workers employed in manufacturing by 5.4%, overall, average real wages have increased by 0.8%. Furthermore, the analysis shows that welfare losses resulting from robots are concentrated on older production workers. Conversely, younger workers benefit, as they have the chance to enter tech and higher-skilled occupations, and their wages rise, as they are complementary to robots. The analysis concludes that, since 1990, industrial robots in Denmark have accounted for about 26% of the fall in the employment share of production workers, but also about 8% of the rise in the employment share of tech workers. Overall, what emerges from the available literature is that the impact of industrial robots on labour market outcomes depends on a given sector's exposure and the extent to which a given specific technology can replace humans in tasks that they perform.

Another important result put forward in the literature relates to the role of labour market institutions in mediating the effects of digitalisation on the labour market. For instance, Dauth et al. (2021) analyse German administrative data and do not find evidence of negative effects of automation on overall employment. This is the opposite of what is found in the US. They show, however, that this result masks displacement and reallocations across occupations, with heterogeneous effects across sectors. Importantly, this effect is mediated by the interaction with labour market institutions. Relatively strong labour protection has the effect of shifting the incidence of adoption of digital technologies onto young workers and labour market entrants. Incumbent workers whose tasks are automated often switch to different occupations at the same workplace, softening the potentially negative impact of digital technology adoption. Several measures indicate that the new jobs are of higher quality than the previous ones. The analysis also shows that skills upgrading is a successful strategy to this end; this is observed also for young workers and labour market entrants, who adapt their educational choices and turn away from vocational training towards colleges and universities. Finally, industrial robots have benefited workers in occupations with complementary tasks, such as managers or technical scientists.

Most of the available evidence discussed so far is focused on automation; the extent to which these results and insight can be extended to other digital technologies as a basis to inform policy-making is questionable. Other digital technologies, such as the IoT, machine learning and artificial intelligence, differ greatly from automation or robotisation: they can perform multipurpose, reprogrammable, self-learning and interconnected tasks (IFR 2021). Empirical evidence in this respect is scarce: these technologies are less well-researched because of their novelty and an overall lack of data. One of the few available estimates indicates that developments in machine learning, in which efforts are explicitly dedicated to the development of algorithms that allow cognitive tasks (including data mining, machine vision, computational statistics and other sub-fields of artificial intelligence) to be automated can put 47% of jobs in the US at high risk of automation (Frey and Osborne 2017).

In addition to threatening routine and low-skilled jobs, digital technologies also have low-quality and precarious jobs. The platform economy, enabled by widespread digitalisation, relies on private individuals who, through the platform, become independent contractors and carry out jobs. This has introduced a new business model based on flexible, lean and cost-efficient work for both clients and independent contractors. For many workers, this has emerged as an alternative to conventional full-time employment. However, these jobs are often not economically viable in the long run; furthermore, their flexibility is frequently an indication of precarious working conditions and has undermined existing legal and social standards of good work (Schmidt 2017). In this respect, it is important to distinguish between two different dynamics. On the one hand, platforms mean that the traditional reliance on employment relationships versus self-employment is changed. This has a radical transformative potential, but one that has not been observed extensively so far. For example, platforms like Uber have reorganised sectors that were already largely characterised by self-employment. On the other hand, platforms may facilitate offshoring of work from local labour markets – and, importantly, beyond the reach of local taxation and regulatory frameworks – as a result of the remote provision of services. Graham et al. (2017), for instance, show that digital workers hired in Sub-Saharan Africa and South-East Asia have low bargaining power in the global labour market and suffer from economic exclusion, discrimination and limited opportunities for skill and capability development. Furthermore, only a small fraction of platform workers attain the equivalent of the local minimum wage; the majority of platform transactions are not taxed, and social insurance is not provided. The latter is particularly relevant in the case of food-delivery platforms, as accidents for cyclists are common (Drahokoupil and Jepsen 2017).

It has also been argued that digital technologies may contribute to reversing the trend of production relocation towards low-wage countries. If advances in digital technologies reduce production costs independently of the location where production happens, then digitalisation will increase the attractiveness of producing domestically, as opposed to offshoring. Faber et al. (2020), for instance, show that US robot adoption lowers labour demand in Mexican export-producing sectors. Dachs et al. (2019) assert that Industry 4.0 and local manufacturing strategies could have a substantial impact on backshoring in the coming years. But the evidence is small and mixed (Ancarani et al. 2019). Indeed, Kamp and Gibaja (2021) provide evidence to the contrary: backshoring is a rare phenomenon, and it is questionable whether there is a correlation, let alone causality, between the adoption of digital technologies in home-based manufacturing sites and backshoring. Furthermore, the impact of backshoring dynamics should not be judged solely on the basis of the potential benefits for more developed countries boosting their employment, but also in the light of the negative impact they may have on foreign labour markets, most of which are in developing countries.

Digital technologies and sustainability

Similarly to the case of the labour market, digital technologies have been linked with both positive and negative impacts on sustainability. On the one hand, digital technologies affect climate mitigation and sustainability negatively, because they directly increase energy and material demand, as well as indirectly promoting increased production and consumption; this, in turn, tends to increase greenhouse gas (GHG) emissions in a context where the penetration of renewables is lagging behind. Digital technologies can also promote the deployment of fossil fuel energy and technologies. On the other hand, digital technologies can affect climate mitigation and sustainability positively when they enable the dissemination of key low-carbon technologies in the energy sector and increase energy and material efficiency. These different impacts are discussed in turn below.

Digital technologies, devices and processes consume energy to operate, and thus have a tendency to increase energy demand. In the next five years, an estimated threefold increase in connected digital devices will take place, from 25 billion in 2019 to roughly 75 billion in 2025 (Ali et al. 2015; TWI 2018). Forecasts suggest that the digital economy, currently consuming around 7% of the world's electricity, will experience high growth rates in energy consumption (Morley et al. 2018). As a result, the percentage share of global greenhouse gas emissions associated with digital technologies is estimated to rise from 2.5% in 2013 to 8% in 2025 (Efoui-Hess 2019). Demand for data centre services increased by 550% between 2010 and 2018 and is now estimated at 1% of global electricity consumption (Masanet et al. 2020; Avgerinou et al. 2017; Stoll et al. 2019; Vranken 2017). However, the associated energy demand increased only modestly, by about 6% from 2000 to 2018. This is due to significant efficiency improvements over the same time period (Masanet et al. 2020). Strubell et al. (2019) estimated the carbon footprint of training a large natural language processing (NLP) model: training this single artificial intelligence (AI) model produced 300 000 kilograms of carbon dioxide emissions. This is roughly the equivalent of 125 round-trip flights from New York to Beijing. While increases in GHG emissions may be decoupled from electricity use, thanks to reliance on renewables, this is currently not the case in the energy system. Even when digital technologies and services such as data centres are coupled with renewable electricity production, a significant portion of the electricity they require still comes from fossil sources.

Digital technologies put pressure on rare-earth materials and generate waste. Demand for digital devices has led to an increase in the extraction of natural resources — particularly rare-earth metals — in harsh working conditions, subject to exploitation and with negative implications for marginalised communities and fragile ecosystems (Ilankoon et al. 2018; Sovacool et al. 2022). The short lifetimes of many digital devices aggravate the situation. Cell phones, computers and other small or handheld devices, for example, quickly become obsolete or are substituted very fast as a result of practices linked with consumerism. Recycling and upgrading is not available. This generates digital waste. For instance, over 30% of the appliances that were substituted in Germany in 2012 were still in good working condition (TWI 2018). To compound the problem, reuse of products and material has not been sufficiently promoted (Ilankoon et al. 2018). Enacting legislation to counter the linear production model for digital technologies is possible (Patil and Ramakrishna 2020), but to date not sufficiently widespread across countries. Currently, there are strong concerns that a universal and rapid uptake of short-lived digital devices will accelerate the depletion of rare metals that are required in the manufacture of these devices and significantly exacerbate the growing problem of digital waste (TWI 2018).

Digital technologies promote increased production and consumption. First, digital technologies can increase energy and material demand, because they give rise to substitution dynamics in production. By increasing energy efficiency, digital technologies effectively make energy comparatively less expensive than other production inputs, and may promote substitutions towards a higher share of energy in total production (Greening et al. 2000). Higher energy efficiency makes energy and energy-intensive goods and inputs comparatively less expensive than other goods and inputs, all other things being equal. For a given level of consumption (production), the demand for energy and energy-intensive goods (inputs) and their accessories will increase compared to that for relatively more expensive, non-energy-intensive substitutes. Hence, an X% increase in energy efficiency will not translate into an X% reduction in the demand for energy. Furthermore, production is not likely to remain at the pre-efficiency improvement level; rather, it will increase, as it will then be possible to produce more output with the same amount of energy inputs. The 'rebound' or 'take-back' effect (Saunders 1992) measures the percentage of potential engineering energy savings that were not realised following an efficiency improvement, due to the forces described above. The existence and magnitude of rebound effects has crucial implications for future energy demand and security, for mitigation efforts and for sustainable development. If rebound effects are indeed present, the emission reduction potential associated with energy efficiency, especially as promoted through efficiency policies, may be overstated. In the worst-case scenario, some studies suggest that energy demand may actually increase as a result of energy efficiency policies and efficiency improvements, leading to 'backfire' effects (Greening et al. 2000; Gillingham et al. 2016). Similar considerations, although not explored extensively in the available literature, apply to energy efficiency promoted by digitalisation. Rebound effects associated with the adoption of digital technologies are a potential concern in the context of decarbonisation pathways, in so far as fossil fuels are the main source of energy worldwide. In the current fossil-based energy system, increasing energy demand will translate into more GHG emissions. However, if the energy sector increasingly relies on renewable energy sources, concerns related to rebound effects in energy demand may be lower.

Second, digital technologies can promote increased consumption by consumers. The 'platform economy' – namely online economic and social activities and interactions facilitated by digital matchmakers – has grown in the past decade and now includes a large number of digital platforms with varying functions, such as the provision of services (e.g. Uber and Airbnb), products (e.g. Amazon and eBay), payments (e.g. Square and PayPal) and software development (e.g. Apple and Salesforce). The platform economy, which gained centre stage during the Covid 19 pandemic, has been associated with higher demand for both existing and new goods and services. Note that the platform economy has been and still is being used as a tool to promote post-pandemic recovery. China, for example, has recently promoted specific measures to boost consumption as an instrument of economic recovery (China Daily 2022). If sustainability considerations are not included in such efforts, increased consumption will translate into higher pressure on the environment (Deloitte, 2019). Switching from traditional retail to e-commerce also changes how products are delivered to the consumer. This may increase energy use if purchased goods are imported from afar, possibly through air freight, as opposed to other means of transportation. Furthermore, e-commerce is associated with greater package density (Williams and Tagami 2002; Horner et al. 2016). Increased consumerism arising from changes in business models, human activities and preferences is a threat to sustainability even if energy is fully produced through renewable sources, because it raises already high pressure on the earth's natural resources, such as water, minerals and food (Rockström et al. 2009; Steffen et al. 2015; WWF 2020).

Digital technologies can be applied to increase the availability and deployment of fossil-based energy and solutions. Digital technologies are considered to be general-purpose technologies, that is to say technologies with a protracted impact on a large range of sectors and applications (Jovanovic and Rousseau 2005). As such, they do not only benefit renewable and low-carbon technology options. Digital technologies such as machine learning have also been applied to the benefit of fossil fuel production, for instance to predict the location of new oilfields and to increase fossil fuel extraction or enhance the efficiency of fossil fuel transportation (Peranandam 2018; Greenpeace 2020). The prospects of a transition towards a green, sustainable economy would be reduced if digital technologies resulted in increased production of fossil fuels or the generation of fossil energy at lower costs. This would counter any effort towards sustainability and mitigation of climate change.

Notwithstanding the negative impacts described so far, there is also evidence that digital technologies can support the transition towards sustainability. To begin with, digital technologies have enabled and are enabling the diffusion of novel low-carbon solutions in all sectors. Digital technologies are a fundamental precondition for the deployment of renewable technologies and the establishment of an integrated renewable energy system, including power-to-X solutions (WEF 2021; Clean Energy Wire 2018), as well as the spread of both electric vehicles and Mobility as a Service through the integration of different means of transport (IEA 2017a). Digital technologies also play a pivotal role in accelerating innovation in renewable energy supply through simulations and deep learning (Rolnick et al. 2023). Furthermore, digital technologies such as sensors, smart meters and data analytics allow the efficient integration of variable renewable energy in the (smart) grid and promote demand management practices (Naylor et al. 2018). Digitalisation plays a particularly important role for energy-intensive sectors such as industry, transportation and buildings, because these sectors face the biggest mitigation challenges, and the adoption of digital technologies could contribute to offsetting mitigation costs (Luderer et al. 2018). While decarbonising these sectors is crucial to achieve the energy transition, currently there are very few, if any, cost-competitive low- or zero-carbon technologies that can be readily applied. In the transportation sector, electric vehicles are becoming a viable option, although significant barriers exist in terms of infrastructural constraints and social acceptance. In the buildings sector, digital technologies could be game-changers by improving energy management and bringing novel solutions to the market.

Digital technologies also contribute considerably to energy and material efficiency through real-time sensing, connectivity and prediction, the reorganisation of production and additive manufacturing (Watanabe et al. 2000; Sarc et al. 2019; Sun et al. 2021). There are several analyses in the literature supporting this point with evidence on different digital technologies in different sectors. For instance, in all sectors, digital technologies, such as smart devices, currently allow users to perform functions that were previously provided by a large number of other devices. This convergence in functionality, brought about by increased connectivity, is accompanied by a dramatic increase in energy efficiency. For example, a smartphone requires 100 times less energy to operate than previous devices. Furthermore, it gives rise to increased controllability, and opens up opportunities to achieve strong coordination in energy demand management for both firms and individuals (Grubler et al. 2018). The use of additive manufacturing (AM) by aircraft component manufacturing has been proven to increase materials efficiency, reduce life-cycle impacts and achieve greater engineering functionality as compared to conventional manufacturing processes. In point of fact, AM is increasingly being used in the airplane industry to develop lightweight, cost-effective designs for specific parts. As a result, by 2050, cumulative fleet-wide primary energy savings through the aircraft life cycle are estimated at between 1.2 and 2.8 billion gigajoules (GJ). This would translate into a cumulative reduction of 92.1 to 215.0 million tonnes of associated GHG emissions. Furthermore, sizable reductions in primary raw materials – such as aluminium, titanium and nickel – could be achieved (Huang et al. 2016). Sensors, remote control digital technologies and automation improve the energy intensity of production throughout manufacturing, because they lower waste and inefficiencies. Similar dynamics also emerge in the buildings sector, in which digital technologies reduce construction waste and the demand for construction material, as well as increase the salience of demand-side management practices (Serrenho and Bertoldi 2019). The use of ambient intelligence has major potential for energy management in buildings, enabling localised energy generation and control, thanks to occupancy sensors, remote ambient control, predictive maintenance and system control (Naylor et al. 2018). Estimates indicate that, on average, US residences waste around 40% of their primary energy consumption due to inefficiency (Meyers et al. 2010). Much of this energy waste could be reduced by using digital solutions (Horner et al. 2016). The IEA estimates that smart appliances, devices that provide feedback on energy consumption and devices pertaining to energy management could reduce energy demand and associated GHG emissions by at least 5 to 10%, with no decrease in the quality of energy services (IEA 2020). In 2017, McKinsey reported that tech giants and digital native companies such as Amazon, Apple, Baidu and Google were investing billions of dollars in the various technologies known collectively as artificial intelligence (Bughin et al. 2017). Digitalisation also holds high potential for coordination in the transport sector, which is moving towards the business model of Mobility as a Service (MaaS). MaaS is an emerging option exploiting digitalisation to integrate and coordinate different public and private modes of transport (public transport, railways, taxis, shared biking services, self-driving shared vehicles, on-demand electric cars, individual drivers) into one easy-to-use customer package (European Commission 2018). MaaS could reach 20% of German individual car transport by 2027 (Accenture 2018). It offers the potential advantage of higher occupancy rates and intensified usage of transport technologies, likely reducing private car ownership. This, in turn, has strong climate and environmental implications: the potential fuel savings in the UK are estimated at around 2.9 million barrels of oil per year (ITS 2017). Currently, MaaS is seen as a business opportunity even by car manufacturers, which are investing to retain a share in a changing mobility market.

Overall, the literature on the sustainability implications of digital technologies appears very polarised. Many claim that digital technologies will promote the ecological transition; others argue precisely the opposite. This polarisation in the debate is partly emerging from the lack of comparative assessments of cases in which digital technologies have supported, or have failed to support, sustainability. This, in turn, is partly due to the novelty of these technologies, as well as the difficulty in measuring digitalisation across countries and across sectors. A relevant question, which has not received enough attention to date, relates to the role of governance structure for digitalisation, and the extent to which different governance choices of the digital revolution can help ensure that it is synergistic with the ecological transition, rather than act as a barrier.

Digitalisation and broader societal impacts

In addition to influencing the prospects for decent-quality employment and sustainability, digitalisation also influences societal transitions more generally. In this case too, examples of both positive and negative impacts can be found. One the one hand, digital technologies can compound existing inequalities, making it hard to cushion the negative social effects of greening the economy, and hindering meaningful social dialogue. On the other hand, digital technologies can help overcome inequalities, providing alternative ways to mitigate the negative social effects of greening the economy, contributing to meaningful social dialogue and pursuing distributional, procedural, restorative or recognition justice.

As digitalisation becomes more pervasive in all sectors and countries, the ability to reap the benefits associated with these technologies rests on the assumption that they are accessible to all. Yet there is ample evidence suggesting the existence of a digital divide. This term originated in the 1990s to indicate the divide between those with access to new digital technologies and those without (NTIA 1995; Gunkel 2016). Over time, the literature has identified three distinct layers of the digital divide. The first-level digital divide indicates lack of access to digital technologies. The second level focuses on lack of the digital skills and digital usage necessary to operate the digital technologies. The third-level digital divide focuses on differences in the ability to use digital technologies to achieve given benefits or outcomes (van Dijk 2020). The ability to reap the benefits associated with digitalisation depends on the extent to which given communities and countries can overcome the digital divide, which is greater for low-income and low-skilled individuals and regions. These are also individuals and regions that are both more exposed to climate risks and more at risk of suffering the economic and social effects of greening the economy. The compound effect of the digital divide and exposure to negative social effects suggests that any support measure would have to be designed to address both issues. There is indeed a growing body of literature pointing to digitalisation contributing to both local and global inequality, including across the gender dimension, and raising fairness concerns (Kerras et al. 2020; Vassilakopoulou and Hustad 2021). Furthermore, it has been argued that digital technologies can lead to further concentration of economic power; Rikap provides an example of this (Rikap 2020). In addition, digital technologies sometimes benefit certain regions less than others. For example, integrated mobility services do not hold the same benefit for rural and peripheral areas as they do for cities (OECD 2017). Overall, van Dijk (2020) draws the conclusions that current digital inequality not only reflects but also tends to reinforce existing social inequality. The Covid 19 pandemic has brought to light the challenges associated with a digital economy in a context where stark digital divides exist. Policy actors have argued in favour of renewed efforts to address digital inequalities, but the links between technology and inequality are highly complex and multifaceted, and digital technologies per se are not necessarily a positive thing (Eynon 2022).

Countering these potential negative social effects, an increasingly rich literature shows that communication technologies (such as mobile phones) can enable more active participation by actors in the economy, including in rural communities and developing countries; they also promote technological leapfrogging, such as through the deployment of decentralised renewable energies and smart farming (Ugur and Mitra 2017; Foster and Azmeh 2020; Arfanuzzaman 2021). Digital technologies also play a role in engaging citizens in social dialogues, most notably in relation to climate and sustainability actions (Segerberg 2017; Westerhoff et al. 2018). Eynon (2022), for instance, provides evidence from interviews with digitally competent individuals, but who came from lower socio-economic backgrounds, that, in some cases, the internet offered a way for users to express their views and engage in a broad array of civic activities, including signing petitions or emailing complaints about poor services to companies and local government, or becoming engaged in civic and political actions.

4. Discussion

The previous section identified whether and how digital technologies can (1) promote decent-quality employment while (2) contributing to the sustainability transition. It also discussed the broader role that digital technologies may have in the context of promoting distributional, procedural, restorative or recognition justice. The evidence presented suggests that digital technologies can be enablers of or barriers to the just ecological transition, with both positive and negative examples across sectors and geographies. While the overall effects are far from clear, a few key implications can be drawn from this often contradictory body of research.

First and foremost, digital technologies are still very concentrated geographically and in certain sectors, and so are their potential benefits and trade-offs. A recent report by the IFR shows that the total worldwide operational stock of robots almost tripled between 2009 and 2019, increasing from 1 021 000 to 2 722 000. China accounts for about one third of all robot purchases, followed by Japan and the US. At global level, the electronics and automotive sectors are those in which most new robots were installed in recent years (2017-2020). However, robot density (i.e. the number of robots per 10 000 workers) is higher in Germany (346) and the USA (228), as opposed to China (187) (IFR 2021). Similar heterogeneous patterns can be identified for many other key digital technologies, including additive manufacturing, IoT and AI in all sectors. For instance, the deployment of AI in buildings faces barriers related to the upgrading of the existing building stock, while MaaS penetration varies widely across countries, and is more relevant in cities and metropolitan areas (TWI 2018; IEA 2017b). Such heterogeneity illustrates the fact that the impact of digitalisation on the ecological transition in several sectors will vary, depending on the sector's exposure to digitalisation. Furthermore, it is worth noting that robotisation is still progressing very slowly in most developing countries, where there have been the most significant increases in energy demand.

Second, digital technologies will positively impact the transition towards a low-emission economy only if the benefits they bring about due to increased energy and material efficiency are not offset by increases in overall energy and material demand. As illustrated in Section 3, digital technologies are associated with energy savings at the micro level due to sharp increases in energy, material and production efficiency. However, the widespread deployment of digital technologies may offset benefits arising from increased efficiency and coordination. Digital technologies could, in fact, increase overall energy demand even while increasing overall efficiency, as a result of the rebound effect, or as a consequence of increases in overall demand for goods and services (Coroamă and Mattern 2019). Altogether, the pace at which different sectors are embracing the digital revolution and at which the potential benefits of this transformation are materialising is still an open question. Consequently, the extent of aggregate energy saving brought about by the digital revolution has yet to be understood. Furthermore, there are strong concerns supported by evidence that the increased adoption of digital technologies may not be sustainable from a climate perspective (TWI 2018).

Third, it is not clear whether digital technologies will have a positive or a negative impact on the level of employment, nor whether they will stimulate higher-quality jobs. Considering reallocation dynamics between low-skill, repetitive tasks and high-skill, intellectual tasks, which are discussed below, it is an open question whether digital technologies will render workers obsolete overall. As explained in Section 3, digital technologies can displace workers in manufacturing occupations through automation. This negative effect can be counterbalanced through the creation of newer, higher-quality jobs. However, the ability to reap the benefits associated with the new jobs largely depends on workers' skill endowment and how they adapt to upskilling and retraining. In fact, these new high-quality jobs are often not accessible to workers who have become obsolete, either because the jobs are too far away or because they require different skills and competences. To date, evidence shows that ICT investment has led to job losses in some sectors (manufacturing, business services and trade, transport), while leading to job creation in others. In sectors where labour has been negatively affected, the decrease has been stronger for medium-skilled workers than for high- and low-skilled ones ('Just Transition: A Report for the OECD', 2017). Furthermore, the digital economy has been associated with an increase in low-quality, precarious jobs.

Fourth, the use of digital technologies requires specific skills which are currently not common in low-skilled workers or most high-skilled traditional occupations. While the digital revolution opens up new work possibilities in these jobs, it also negatively impacts traditional and low-skilled occupations. Substantial reallocation dynamics between low-skill, repetitive tasks and high-skill, intellectual tasks can arise. To transition towards new, higher-quality jobs and to be competitive on the job market, workers will need to develop technical and digital skills. This is true for older workers, but also for younger, school-age individuals. Importantly, it has been noted that many sustainable and green technologies are also digital, and in order for these to be developed, installed and operated, science, technology, engineering and mathematics (STEM) graduates and trained technicians are needed.

Fifth, digital technologies are not necessarily green, and they have also been shown to compound existing inequalities and injustices. A key research and policy question is whether the digital revolution will able to promote social and economic benefits across the board (Khan 2008) in different countries and sectors (Ugur and Mitra 2017; Mehrabi et al. 2020). Overall, digitalisation could increase local production (as in the case of additive manufacturing), strengthening regional economies and entrepreneurship. However, digitalisation has been shown to benefit certain regions, areas and socioeconomic groups more than others, as in the case of integrated mobility services, which benefit cities more than rural and peripheral areas (OECD 2017). Digital technologies raise fairness concerns: they can lead to additional concentration of economic power as well as increased inequality. Sovacool et al. (2022), for example, examine how improved cooking stoves and heating, battery electric vehicles, household solar panels and food-sharing, which are four innovations in technology and behaviour, generate trade-offs in different equity dimensions. They show how such technologies and behaviours can both introduce new inequalities and reaffirm existing ones.

5. Is there a rationale for addressing the digital and the green transitions jointly?

The framework proposed in Section 3 and the discussion presented in Section 4 provide strong rationales for addressing the ecological and digital transitions as twin processes.

The first strong, simple and straightforward rationale is the following: the one conclusion on which almost all contributions, in a very heterogeneous body of work, agree is that digitalisation will impact in some way the achievement of an ecological transition, and that, together, these two transformations will affect our ability to promote just societal transitions. This is the one common message emerging from all voices. Given this, the potential impacts of digitalisation on the achievement of a just ecological transition need to be taken into account. A positive contribution of digital technologies to sustainability and to the promotion of fair jobs through social dialogue would reduce the burden associated with the just ecological transition. A negative impact would imply that achieving the just transition goals will be harder than expected. Given the overwhelming evidence of the links between these two transformations, a failure to consider their interaction would lead, in both cases, to the implementation of inefficient and ineffective policies.

A second, subtler, but equally strong rationale for the joint consideration of these transformations lies in the differing role that policy-making currently plays for sustainability and digitalisation. It can be argued that just ecological transitions are the result of decades of engagement by several stakeholders demanding that negative environmental and climate impacts be recognised, addressed and managed. This transition should address imbalances that emerge from market forces alone, namely pressure on natural systems beyond what is feasible, given planetary boundaries as well as the unequal distribution of both costs and benefits across and within countries and regions. In this process, consensus building has played and should play a critical role in moving forward.

Conversely, the digital revolution today is still a largely ungoverned process, a mega-trend that is strongly fuelled by market forces and powerful interest groups, as well as consumer preferences for digital services. In point of fact, while public support has played a crucial role in the development of digital technologies, the ubiquitous application of these technologies (such as sensors and the Internet of Things) and the digital business model is currently strongly promoted by private entrepreneurs and early technology adopters. This is possible because markets are largely unregulated and ungoverned, so that the negative impacts that digital technologies may impose on certain social groups or countries are not factored into business decisions, giving rise to what are known as negative externalities. As a result of this strong asymmetry, digitalisation has the potential to hinder agreed processes and targets to achieve the sustainability transition.

Both transitions will require significant proactive agency and policy support moving forward, in order to achieve societal goals. Yet the nature and extent of this support varies, as does the ability that policy-making currently has to drive these transitions. On the one hand, (more stringent) decarbonisation policies will need to be implemented to promote dramatic changes in our energy system and in the way in which we produce and consume (IPCC 2022). This will have to be achieved in a way that, at the very least, addresses the negative implications that these policies will have on specific workers and communities, or that, more broadly, promotes distributional, procedural, restorative or recognition justice. On the other hand, policies and institutions to govern digitalisation are a necessary requirement to ensure that the benefits of digital technologies accrue without imposing costs on the weakest parts of societies, both within and across countries. They are also needed to ensure that digital technologies contribute to emission reductions (Blanco et al. 2022).

In this respect, ungoverned digitalisation will have similar, albeit arguably more disruptive, effects compared to other previous instances of industrial revolutions, the benefits of which were accompanied by both environmental cost and, more broadly, societal injustices. Policy mixes to promote the twin ecological and digital transitions will necessarily have to balance these fundamental differences. If this is not the case, digital technologies may lead to significant negative environmental and social consequences, while economic gains will accrue to a small share of the world's population, highly concentrated both within and across countries. In this context, governance is necessary to ensure that digitalisation and decarbonisation unfold in a mutually supportive way that promotes a just transition.

6. Policy recommendations

Both digitalisation and decarbonisation are seen as unprecedented economic and industrial opportunities for today's economies, because they could bring about major co-benefits in terms of jobs, competitiveness and overall well-being. Even if one were to overlook the imperative of decarbonisation, it remains true that many countries are facing key economic challenges in the next decades, exacerbated by recent economic crises and the Covid 19 pandemic. These include the need to renew an ageing infrastructure, to reduce energy dependence and to sustain economic growth.

In this context, digital technologies can become multipliers of sustainable change, potentially making it easier to achieve the co-benefits associated with decarbonisation. These include positive labour market outcomes – in particular, decent-quality jobs, increased competitiveness and fairer access to economic resources. Yet these and other potentially positive benefits of the digital transition are unlikely to accrue autonomously or uniformly, nor are they to be taken for granted. Rather, they will come about only if this transformation is appropriately governed and digital technologies are regulated to ensure that their dissemination does not result in burdens for vulnerable communities or in an increase in existing inequities.

The analysis presented so far suggests that addressing the digital and the green transitions as related and joint challenges can support the pursuit of a just transition and, more broadly, of distributional, procedural, restorative or recognition justice. A fundamental question then needs to be addressed: what are the necessary building blocks of a strategy to ensure that digital technological developments and breakthroughs offer a win-win solution to the potential tension arising between decarbonisation processes and economic growth in the context of a just transition? The analysis presented so far, while not exhaustive, suggests two sets of policy recommendations.

The first set of recommendations tackles the need for a better understanding of the interplay between digitalisation and the sustainability transition:

1. *Measure the progress of digitalisation and its benefits and barriers*. As illustrated by this analysis, the full extent of the consequences that the digital revolution will have on our economies and societies, including on the prospects for the ecological transition, is not fully understood. A clear lack of statistics on several key aspects of the digital revolution emerges. While this is due to the fact that digital technologies are very

recent and heterogeneous, filling this measurement gap is a crucial first step towards informing policy-making in the context of a just transition.

2. *Improve the understanding of the interactions between digitalisation and the just ecological transition*. The link between these two major trends in our society has only recently been highlighted. While available evidence on this topic is growing, many studies are limited to a few digital technologies and specific sectors, and are mostly concentrated in advanced economies. Further cross-country, cross-sector analysis, as well as specific case studies, will provide much-needed insights into context-specific barriers to ensuring that digitalisation acts as an enabler towards sustainability. Importantly, successes, as well as failures, can provide important insights into how to govern digital low-carbon pathways towards sustainability.

A second set of recommendations, on the other hand, is specifically related to the governance of digital technologies and investment in digital infrastructure:

3. *Support and regulate digital technologies and markets to ensure that their potential benefits are also distributed to more vulnerable households, workers and firms, and that their potential negative impacts are managed*. As argued by Creutzig et al. (2022), digitalisation 'alter[s] information flows and controls, rules of the system, the power structures and dynamics that uphold existing rules, and the mindsets that define them'. As such, digitalisation influences consumption, political and economic power, equity and trust. Public policy should focus on ensuring that these powerful general-purpose technologies operate within regulatory boundaries, protecting the interests of the many over those of the few. Examples include regulations on data use and protection, promoting an open-source approach and sharing for non-sensitive data, and taxing data rents through the establishment of taxation systems for the digital economy. Unless such a governance architecture is put in place, the benefits and costs of digital technologies will accrue to different people, and digitalisation is very likely simply to compound existing inequalities. Another important role of governments in this respect is ensuring access to digital technologies and targeting the digital divide that prevents poorer and more vulnerable households from accessing, using and benefiting from digital technologies.

4. *Invest in digital infrastructure to grant access to digital technologies*. Both digitalisation and the ecological transition will require fundamental changes to our economies and societies. Digital infrastructure plays a key role in enabling the sustainable provision of services, as well as the changes in human behaviour necessary to reduce our footprint on the earth's resources and GHG emissions. It also plays a pivotal role in ensuring widespread access to digital technologies, addressing the first level of the digital divide. For this reason, public investment should be devoted to this type of investment through long-term planning. A major barrier in this respect relates to the fact that governments' time horizons

are generally short-term rather than long-term. In this respect, specific earmarking of funding for sustainable digital infrastructure should be introduced, along the lines of what has been done at EU level in relation to the Structural Funds aligned with the Multiannual Financial Framework 2021-2027, on which the EU Green Deal rests.

A third set of recommendations specifically relates to the outcomes and processes of the just transition, whether defined more narrowly or more broadly, as discussed in Section 2:

5. *Support the creation of sustainable, digital and decent-quality jobs through government investment*. In this context, governments should play a leading role in providing strong signals of commitment to the ecological transition as well as fostering the creation of new, better jobs in all sectors of the economy. Importantly, government investment can also help to leverage private investment, notably in areas like infrastructure and housing.

6. *Train the workforce in digital skills*. In addition to creating new jobs, significant effort needs to be devoted to developing training programmes that are relevant in the context of the digitalisation of the production process and business models and aimed at training workers, as well as upskilling and reskilling them, where needed. These programmes are fundamental to ensure that all workers can transition to more sustainable and decent-quality digital jobs and take advantage of the opportunities arising from the twin digital and ecological transitions.

7. *Enhance social safety nets*. The transition towards a digital low-carbon economy will represent a challenge for vulnerable parts of the workforce and of society, such as those in low-paid jobs and older workers. For these groups, overcoming barriers will be harder. Social safety nets have to be enhanced to ensure support for those who may find it particularly difficult to adjust to new technologies and transition towards different jobs.

The above three points relate to specific elements of the just transition, albeit in its narrow definition. Conversely, the recommendation below specifically tackles the need to engage citizens and stakeholders in the definition of what a just transition should look like in a given community, thus embracing a broader approach that could encompass distributional, procedural, restorative and recognition justice.

8. *Embed procedural justice considerations in the ecological and digital transitions through just and inclusive processes of citizen and stakeholder engagement that promote the co-design of policies and measures*. Embedding justice and equity considerations in both the ecological transition and the digital transformation requires, first and foremost, a shared, strong and actionable vision of what a just transition looks like (Meadows 1996). To create such a vision, public bodies, industry, civil society and academia should engage in extensive dialogue

on how to provide ‘a just transition of the workforce and the creation of decent work and quality jobs’ (preamble to the Paris Agreement). Such dialogue should also acknowledge and embrace considerations on the economic and social effects of the twin transitions on households, energy-intensive industries and regions; opportunities to support upskilling, promote regional development and address pre-existing inequalities; and impacts on countries beyond the EU (Jakob et al. 2020a; Jakob et al. 2020b). Non-monetary aspects should also be given appropriate consideration, given that any transition deeply affects relationships, attachments (e.g. to particular places) and projects (jobs, life plans) that are central to people’s identities (Elliott 2018). Participatory societal dialogue helps identify and manage different interests and expectations; equip vulnerable groups with the capabilities to embrace and implement change; and ensure that policies resonate with diverse stakeholder groups. A shared vision ultimately inspires all societal actors towards the common goal of achieving climate neutrality and promotes the achievement of ‘just transitions’ in which no stakeholder is or feels left behind.

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