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Game-changing technologies: Transforming production and employment in Europe

Game-changing technologies: Transforming production and employment in Europe

European Foundation for the Improvement of Living and Working Conditions

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Country codes

EU28

AT	Austria	**FI**	Finland	**NL**	Netherlands
BE	Belgium	**FR**	France	**PL**	Poland
BG	Bulgaria	**HR**	Croatia	**PT**	Portugal
CY	Cyprus	**HU**	Hungary	**RO**	Romania
CZ	Czechia	**IE**	Ireland	**SE**	Sweden
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Executive summary

Introduction

Eurofound studied the implications of eight game-changing technologies (GCTs) for work, employment and employment relations:

- advanced robotics
- additive manufacturing (that is, 3D printing for industrial purposes)
- Internet of Things (IoT), specifically industrial IoT (IIoT) and wearable devices
- electric vehicles
- autonomous vehicles (for example, ‘driverless’ cars)
- industrial biotechnologies
- blockchain – the underlying technology of cryptocurrencies such as Bitcoin
- virtual and augmented reality (VR/AR)

These technologies have the potential to cause significant disruption to European manufacturing and services sectors by 2030. Based on technology-specific studies, this report summarises the main characteristics of these technologies, the drivers of and barriers to their adoption and their (potential) application in business. It goes on to provide an overview of the impact these technologies may have on work and employment in Europe.

In contrast to other types of innovation, GCTs prompt bigger, more immediate changes and have a disruptive effect on the economy, labour markets and society. While some of these technologies are already operational, others may not be implemented in practice for some time; for others still, it is difficult to predict when they will reach technological and market maturity.

Although the extent to which GCTs will be applied in the future is unclear, from a policy perspective it is important to become aware of their development at an early stage and to assess their potential impact. This will enable informed policymaking in terms of timely preparation and the implementation of effective interventions.

Policy context

In the context of an increasingly globalised economy, innovation is viewed as playing a key role in maintaining and improving the EU’s economic competitiveness. According to the report *A vision for European industry until 2030*, European industry will be

> *a global leader, responsibly delivering value for society, the environment and the economy. Europe will build its competitive advantage on cutting-edge and breakthrough technologies, respect for our environment and biodiversity, investment in our people, and smart European and global alliances. Based on collaboration and common European values, this new industrial model will help to make Europe a role model for the rest of the world.*

Fostering innovation and improving companies’ competitiveness is a traditional objective of the policy agenda at both EU and Member State level. For example, in the framework of the Europe 2020 strategy, the EU has implemented policies to support and advance companies’ use of new technologies. In recent years, policy has been increasingly focused on new technologies and digitalisation, as with the establishment of the digital single market, which aims to provide fast internet connections, boost e-commerce, establish data protection rules and foster supercomputing ecosystems.

Furthermore, digitalisation objectives are increasingly combined with other strategic goals. The 2030 Agenda for Sustainable Development, for example, envisages special attention being paid to environmentally friendly policies, including the commitment to shift to electric vehicles. An array of policies related to the labour market are also being developed: policy debate centres around the potential for job creation and job loss as a result of new technologies and digitalisation, as well as the effect on job profiles and the related skills needs. Accordingly, the Upskilling Pathways initiative and the Digital Skills and Jobs Coalition aim to foster digital skills among citizens.

Key findings

- As the analysed GCTs are so new, assessments of their impact on working conditions can only be preliminary and indicative. The most significant disruption is expected for skills use and skills development due to changes in the task profiles of jobs and in work organisation (notably working time, autonomy, flexibility and control). For workers who manage this transformation well, it should represent an improvement. In contrast, issues around data protection and data privacy might be to the disadvantage of workers. Substantial change is also expected in health and safety, but the information available does not yet indicate whether this would improve working conditions.
- The explored technologies vary widely in terms of their technological and market maturity, as well as in the time lag between the introduction of the new technology and its impact on the economy and the labour market. Accordingly, the discussion is separated by technology and sector.
- Among the eight GCTs, advanced robotics has had the widest adoption in some manufacturing sectors and some early-stage deployment in services. Similarly, additive manufacturing is already being used in a range of economic activities, both in manufacturing and services. In services, autonomous vehicles, VR/AR and blockchain remain at the testing stage.
- Although there are differences in terms of technology and sector, the key elements influencing the adoption of GCTs generally comprise: financial considerations and expected return on investment; regulatory frameworks and standards; relevant infrastructure and access to input factors; social acceptance and ethical concerns; and projected impact on workers' health and safety.

Policy pointers

- The possibility of using GCTs strategically in the labour market – for instance, to enable labour market inclusion through flexible and remote working or alternative training methods – should be explored; if these strategic uses are deemed relevant and effective, operational instruments should be designed and implemented.
- Industrial policies should be updated for the digital age. The emergence of new technologies and business models, cooperation and the increased blurring of boundaries between sectors and activities need to be considered. Particular attention should also be paid to small and medium-sized enterprises (SMEs) to ensure that they are not left behind.
- The EU should focus its initiatives and actions on addressing the development of disruptive technologies across countries. Cross-border and large-scale digital projects that cannot be achieved by individual Member States might be facilitated by mobilising additional funding through public–private partnerships and other financial means. The horizontal and sector-oriented approach to finance should be integrated properly in a policy mix in which collaborative approaches are promoted (such as funding large-scale projects along with start-up micro-finance; (tax) incentives at national level; framework support through facilitating networking and contacts between technology clusters, industry and stakeholders; and legal and standardisation measures).
- Regulatory frameworks and standards should be established or revisited to ensure that they are appropriate for the adoption of GCTs. They should also address the interoperability of technologies and societal and ethical concerns, including data protection, ownership and privacy.
- In general, digital transformation should not be tackled in isolation, but in an integrated policy approach that considers other developments, such as the transition to a low-carbon economy, globalisation and demographic change.

Introduction

Background and objectives

To support informed policymaking, Eurofound studied the implications of eight game-changing technologies (GCTs) on work, employment and employment relations:

- advanced robotics
- additive manufacturing (that is 3D printing for industrial purposes)
- Internet of Things (IoT), specifically industrial IoT (IIoT) and wearable devices
- electric vehicles
- autonomous vehicles (for example 'driverless' cars)
- industrial biotechnologies
- blockchain (a verifiable record of electronic transactions, and the foundation of cryptocurrencies such as Bitcoin)
- virtual and augmented reality (VR/AR)

As of 2019, these technologies have the potential to disrupt the European manufacturing and services sectors within the next 10 years. Based on technology-specific studies (Eurofound, 2018d, 2019e), this report summarises the main characteristics of these technologies, the drivers of and barriers to their adoption and their (potential) application in business. Furthermore, it provides an overview of the potential impact these technologies might have on work and employment in Europe.

GCTs are defined as technologies that may disrupt industries, markets and societies by changing ways of working and living. Disruptive and incremental innovation differ in that a disruptive technology is not simply an improvement in a product or process but a deeper transformation that creates or expands new markets and leads companies that adopt them ahead of competitors (Bower and Christensen, 1995). According to the Oslo Manual (OECD and Eurostat, 2018), it is difficult to determine whether an innovation is disruptive; however, ascertaining an innovation's level of impact – for example, at firm, market or global level – can help grade the magnitude of potential change. As an example, extending the length of a candle's wick to improve its burning time was an incremental innovation in the lighting sector, whereas the invention of the light bulb was disruptive (Bower and Christensen, 1995).

A more recent example is additive manufacturing, which represents a disruption in the way a product is made: instead of taking material away (i.e. subtractive manufacturing) additive manufacturing adds material layer by layer, resulting in fast prototyping and the potential for creating new shapes (Eurofound, 2018d).

As of 2019, many digital technologies are emerging as a result both of technological developments and the combination of different technologies: a recent foresight study by the European Commission identifies up to 100 innovations that could result in deep technological and social transformations. Some of these innovations, such as plant communication, are not expected to be implemented operationally for a long time.[1] Others, such as medical or industrial exoskeletons, are already in use (European Commission, 2019a).

The speed at which a technological innovation will go from the research and development (R&D) stage to market maturity, as well as its effects and implications, is not easy to predict. Furthermore, the *combination* of innovations – such as artificial intelligence (AI), IoT, blockchain and quantum computing, to name a few – may open up avenues that today seem far-fetched. At the same time, there are already indications that, if a critical level of adoption is reached, GCTs have the potential for disruptions in both how business is conducted and how labour markets operate. From a policy perspective, therefore, it is recommended work start now on exploring the potentials of these technologies as well as their possible impacts in order to consider relevant interventions and to be better prepared for the future.

Due to the rather rapid nature of technological development, there is a wide range of innovations and GCTs that might have an impact on the world of work. Based on findings from the Future of Manufacturing in Europe project (Eurofound, 2019i – a pilot project proposed by the European Parliament and delegated to Eurofound by the European Commission (DG GROW)) and from similar Eurofound research on GCTs in the services sector, Eurofound selected eight technologies for in-depth analysis. This selection also took into account literature reviews, expert reports and expert interviews, as well as the technologies identified in the EU digital industry strategy (European Commission, 2016). The illustration of the expected implications is based on evidence from 10 specific technology

1 Plant communication refers to communication between plants and other organisms or other, non-plant categories. Potentially important innovations may result from innovations that combine plant, human and machine capacities, or using plants as sensors (European Commission, 2019a).

Table 1: GCTs selected for analysis

Manufacturing	Services
Advanced robotics	
IoT (IIoT and wearables)	
Electric vehicles	Autonomous vehicles
Additive manufacturing	VR/AR
Industrial biotechnologies	Blockchain

literature reviews, 60 expert interviews, 5 regional workshops and 15 brief company case examples.

The eight analysed technologies (Table 1) are deemed to be potentially disruptive within a 10-year time horizon (i.e. up to about 2025–2027) in manufacturing, services or in both sectors. Manufacturing and services have been chosen as areas of investigation for the following two reasons:

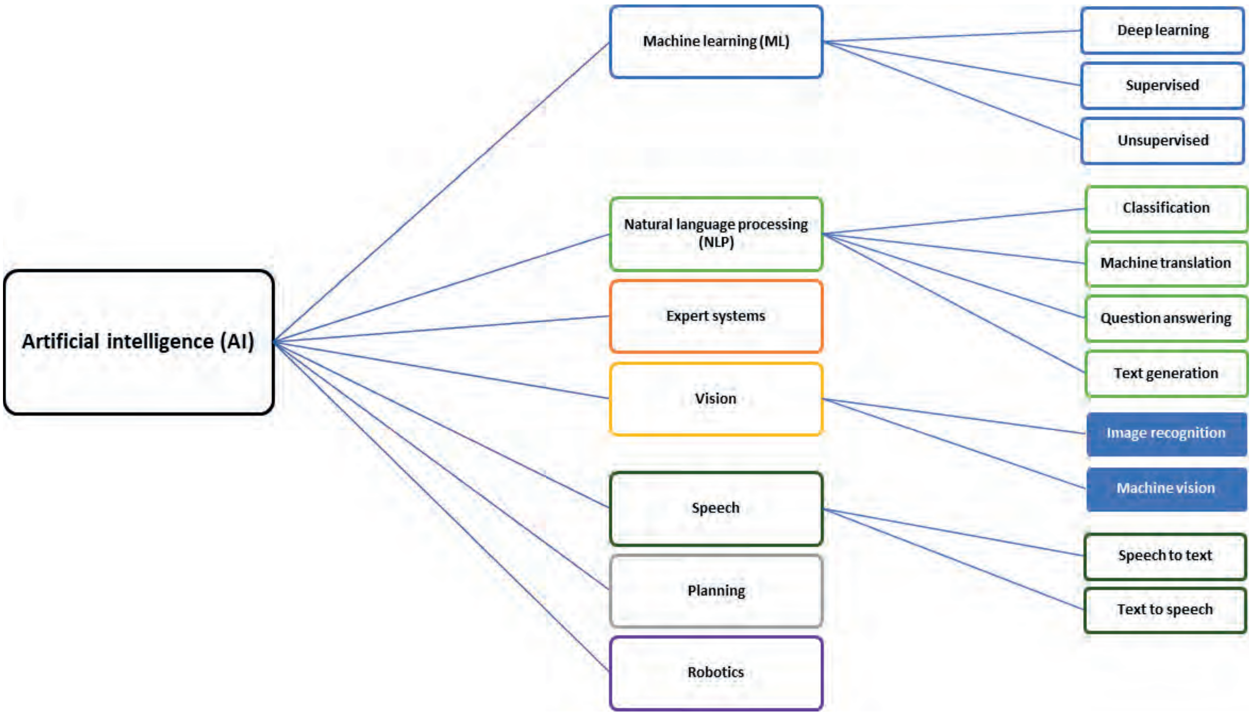
- the digitisation of manufacturing is already changing workplace practices and skills demands
- the services sector represents around 74% of the EU economy in terms of employment (Eurostat, 2019b), so potential disruptions in this sector would have a significant impact on many workers and businesses

This report investigates the level of technological and economic maturity of these GCTs – that is, their application in and across economic activities and their implications for work, employment and employment relations when they are widely adopted. The adoption and development of technology starts with an initial innovation trigger, which might raise expectations and excitement around a technology; however, the real R&D and testing period can last far longer than the 'hype' initially suggests. This is one reason why it is so valuable to gather information about new technologies early on. Insights into possible implications might help decision-makers to shape policies and ecosystems that can nurture and direct promising technologies and prepare the way for their mainstream adoption. This is the case, for example, with 5G – the fifth-generation cellular network technology – which enables ubiquitous communication and high connectivity to both individuals and objects (European Commission, 2019g). 5G is a prerequisite of a number of potential GCTs, such as IoT, which can only reach mainstream adoption and be fully exploited once 5G is deployed.

During the period 2017–2019, the discussion about technological change was dominated by AI – so much so, that the word 'algorithm' (previously used mainly by programmers and information and communications technology – ICT – professionals), has become familiar to the layperson. As defined by Brynjolfsson et al (2017), AI is a general purpose technology that enables and supports the application of many other technologies. Acknowledging that artificial general intelligence (that is sentient AI) is 'always 30 years away' (Greenfield, 2017) – that is, the idea that experts since the 1960s have considered the creation of 'general AI' a far-off achievement – this report uses the definition of 'narrow AI' (European Commission, 2018a). Narrow AI uses machine learning and deep learning tools to extract information from an enormous amount of data and to generate new value based on models built with those data; it has many fields of application (Figure 1). AI can also be used to analyse data, to maintain infrastructure used in blockchain or to create software for VR/AR. Not least, narrow AI algorithms can be applied widely in advanced robotics, IoT and autonomous vehicles applications, which could lead to the creation or destruction of tasks. The use of machine learning techniques or neural networks in work organisation may significantly alter management procedures.[2] Nevertheless, the potential of AI to increase productivity and its role in reorganising tasks or creating new labour activities is still unclear. The way in which AI applications will be adopted in the overall economy and in combination with GCTs will determine its potential benefits for society: it may empower business and workers and it may help to create new jobs, but it may also contribute to enlarging the 'digital divide' – between workers, regions and so on. Due to its vast applicability, AI is considered as an underlying enabler when looking at GCTs that will potentially be adopted into mainstream work processes by 2025–2027.

2 Neural networks consist of adaptive systems of interconnected nodes modelling relationship patterns between input and output data. Multilayered neural networks are particularly relevant for performing complex tasks, such as image recognition and text synthesis. These networks form a subset of machine learning referred to as deep learning (WEF, 2019).

Figure 1: Narrow AI: fields of application



Source: *Mills, 2016*

EU policies on innovation and technologies

In the context of an increasingly globalised economy, innovation is seen to play a key role in maintaining and improving the EU's economic competitiveness. According to the report *A vision for the European industry until 2030*, European industry

> *will be a global leader, responsibly delivering value for society, the environment and the economy. Europe will build its competitive advantage on cutting-edge and breakthrough technologies, respect for the environment and biodiversity, investment in people, and smart European and global alliances. Based on collaboration and common European values, this new industrial model will help to make Europe a role model for the rest of the world.*
>
> European Commission (2019b)

On 10 September 2019, President-elect Ursula von der Leyen appointed Mariya Gabriel as Commissioner designate for Innovation and Youth. In her mission letter, Ms von der Leyen states:

> *Education, research and innovation will be key to our competitiveness and our ability to lead the transition to a climate-neutral economy and new digital age. It is about equipping people with the knowledge, life experience and skills they need to thrive. Our world-leading science, research and innovation capacity can help us find European solutions to the most pressing global issues. (…) you should ensure sufficient investment flows to disruptive research and breakthrough innovations, notably through the European Innovation council. To stay competitive globally, we should better support our innovators to bring their ideas to the market.*
>
> (European Commission, 2019d)

The trend towards environmentally friendly practices can already be seen in the commitment to shift transport towards electric engines and a balanced environmental impact of the vehicle over its lifetime. The Directive on the Promotion of Clean and Energy Efficient Road Transport Vehicles has prompted Member States, and consequently manufacturers, to announce a reduction in the number of combustion engine vehicles by 2030 and beyond (Eurofound, 2018a). In 2018, the EU Battery Alliance (2018) called for €20 billion investment to secure the European batteries market (estimated to be worth around €250 billion per year). The Battery 2030+ manifesto, for which the research part is supported by Horizon 2020 and Horizon Europe, aims at enhancing R&D for battery technology, incorporating smart sensor functionality on batteries and improving both manufacturability and recyclability. In March 2019, France and Germany agreed to support the strategic importance of the battery market by setting up two production plants over the following four years – one in France and one in Germany – with around 1,500 employees in each (Représentation permanente de la France auprès de l'Union européenne, 2019).

Continuing the long-standing commitment to fostering innovation, the Europe 2020 strategy supports growth and jobs while promoting 'smart, sustainable and inclusive growth as a way to overcome the structural weaknesses in Europe's economy, improve its competitiveness and productivity and underpin a sustainable social market economy.' In line with this vision, the EU implemented policies in 2017 to support and advance the use of new technologies among companies, and it has now set out its vision until 2030 (European Commission, 2019b). The EU's industrial policy strategy, from which Member States' Industry 4.0 national initiatives derive, addresses the economic importance of manufacturing in the EU (Eurofound, 2019i).[3] As of 2019, however, the emerging global trend of trade protectionism threatens the EU's multilateral approach; the Sibiu Declaration (2019) states that EU Member States will stand united to defend European interests (Council of the European Union, 2019). The EU has also initiated an internal debate on global competitiveness and on internal commercial and procurement rules (EPSC, 2019). One of the main points of debate relates to trade defence instruments. Such instruments need to address the rules applied to those non-EU companies that source funds elsewhere and, disrespecting competition rules, acquire European businesses, thereby gaining an unfair advantage over EU competitors. Disadvantages stemming from this scenario include the loss of technological expertise and intellectual property rights, as well as a reduced capacity to set operational standards. Trade defence instruments, however, tend to address the manufacturing sector but not the services sector (EPSC, 2019); in services, EU companies face fierce global competition as a result of the increasing digitisation of markets and therefore need better access to funding with which they can scale up their operations.

The establishment of the digital single market aims at creating a space

> *where the free movement of goods, persons, services, capital and data is guaranteed – and where citizens and businesses can seamlessly and fairly access online goods and services, whatever their nationality, and wherever they live.*
>
> (European Commission, 2019b)

The objectives of the digital single market include the following:

- the development of fast internet connections
- improved e-commerce
- the implementation of data protection rules
- the fostering of supercomputing ecosystems

In terms of R&D, technologies are at the top of the European agenda: the EU funds the biggest R&D programme in the world (Horizon 2020) and supports R&D in specific fields such as supercomputing. Its aim is to give state-of-the-art technology to researchers, industry and businesses to develop new applications, and it will support the advancement of IoT, AI, robotics and data analytics. As part of this commitment to technology, the European Blockchain Observatory – which maps existing initiatives and acts as a hub for initiatives and projects – was established in February 2018 (European Union Blockchain Observatory and Forum, 2018).

Strong support of new technologies in the manufacturing and services sectors cannot be decoupled from labour force resources. Digital skills are fundamental for EU citizens, and various initiatives to promote such skills have been put into place (European Commission, 2017): in 2016, the EU Commission promoted the Upskilling Pathways initiative to improve the competencies of adults with poor numeracy, literacy and digital skills. The Digital Skills and Jobs Coalition brings together all stakeholders to teach digital skills:

> *Since the launch in December 2016, organisations, government bodies and businesses who are members of the coalition provided more than 3.7 million online or face-to-face trainings, one million certificates and 9,000 job placements and internships.*
>
> (European Commission, 2018b)

The Digital Opportunity traineeship programme, launched in 2017, aims to train up to 6,000 students with hands-on experience in fields such as cybersecurity, data analytics, quantum computing, and AI, as well as in programming and software development (European Commission, 2017).

Against this backdrop, this report aims to provide some first observations about the adoption of the eight selected technologies in Europe and their impact on work and employment. The following sections in this introductory chapter define the scope of the analyses by providing an overview of the selected GCTs and the classifications used to analyse them.

3 'Industry 4.0', widely regarded as the fourth – and next phase – in the digitalisation of the manufacturing sector, is the term given to production processes with fully integrated automated facilities that communicate with one another (Eurofound, 2018 https://www.eurofound.europa.eu/observatories/eurwork/industrial-relations-dictionary/digital-economy).

In Chapter 1, the report goes on to explore the drivers and barriers for the operational adoption of the GCTs in the European economy and illustrates the scope of their current and potential application in companies in the manufacturing and services sectors.

Chapter 2 indicates the potential impact of a wider application of the selected technologies on employment in the EU. As statistical data on the effects on job creation and job loss are scarce, the main part of the discussion focuses on the effects on jobs and occupational structures and related tasks and skills profiles.

Chapter 3 points towards the potential effects of the eight GCTs on working conditions and employment relations, including collective bargaining. As with Chapter 3 but to an even greater extent, the findings should be interpreted as first indications for future developments rather than hard evidence.

Finally, Chapter 4 provides concluding remarks and policy pointers.

Defining the selected technologies

Standardised and harmonised definitions of the analysed GCTs are only just emerging, and an understanding of them is not yet commonly applied in public and policy debate or research. For the purpose of this report, Eurofound has used definitions based on a literature review and expert opinions, as summarised in Table 2.

Two technologies – advanced robotics and IoT – have been analysed in the context of both the manufacturing and services sectors. Additive manufacturing, electric vehicles and industrial biotechnologies have been investigated for manufacturing only, as they are assumed to have more specific implications for this sector. Autonomous vehicles, VR/AR and blockchain are examined for their implications for the services sector.

Table 2: Definitions of the analysed GCTs

GCT	Definition
Advanced robotics	Advanced industrial robotics is the branch of robotics dedicated to the development of robots that, through the use of sensors and high-level and dynamic programming, can perform ‘smarter’ tasks, that is tasks requiring more flexibility and accuracy than those of traditional industrial robots. An example is a robot that can handle lettuce without damaging it. The term applies to digitally enabled robots working within industrial environments that are equipped with advanced functionality, for example sensors that detect potential collisions and halt or perform a programmed motion very quickly. This advanced functionality allows robots to deal with less structured applications and, in many cases, collaborate with humans (instead of being segregated from them). The term ‘service robot’ is understood as any robotics application used for anything except manufacturing (the International Organization for Standardization (ISO) definition is a robot ‘that performs useful tasks for humans or equipment excluding industrial automation applications’ (ISO 8373: 2012)).
Additive manufacturing	Additive manufacturing is a technique using the superimposition of successive layers to create a product. It is additive in the sense that products and product components are built up rather than cut out of existing materials (subtractive manufacturing). The key prerequisite of this process is that products can be digitally modelled before being physically generated. The ‘revolution is … the ability to turn data into things and things into data’ (Gershenfeld, 2016, p. 14).
IoT (and ‘wearables’)	Sensors applied within the manufacturing industry create cyber–physical systems in which the information collected from the sensors is fed, via the internet, to computers in order to gather data about the production process and analyse these data with unprecedented granularity. In advanced cyber–physical systems, a whole factory can be digitally mapped and enabled using such sensors. ‘Wearables’ are devices comprised of electronics, software and sensors, which are designed to be worn on the body (Billinghurst and Starner, 1999). Examples include smartwatches, head-mounted displays, body cameras and smart clothing.
Electric vehicles	Electric vehicles are vehicles for which the main system of propulsion depends on electricity and not on fossil fuel. Instead, the vehicle relies on the storage of externally generated energy, generally in the form of rechargeable batteries. As of mid-2019, the main example is the battery electric vehicle.
Autonomous vehicles	Autonomous vehicles (‘driverless cars’) are able to sense and navigate their environment without human input (see Rohr et al, 2016, for further details).

GCT	Definition
Industrial biotechnologies	Industrial biotechnology refers to the use of biotechnological science in industrial processes. Modern biotechnology is based on the most recent scientific insights into the specific mechanisms of biological processes within living organisms (e.g. through systems genomics and metabolomics research). These insights are used to design processes in industry using yeasts, bacteria, fungi and enzymes (biological catalysts that improve reaction processes and that are relatively easy to obtain) to produce biomaterials and biofuels.
Blockchain	Blockchain technology is one of the most well-known uses of distributed ledger technologies, in which the 'ledger' comprises 'blocks' of transactions.[4] This technology is the foundation of cryptocurrencies, such as Bitcoin (Deshpande et al, 2017). In a distributed ledger, information about a transaction is recorded onto the system permanently and the information is simultaneously held by all the 'participants' (nodes) in the system without the need for a central authority to certify that the transaction took place.
VR/AR	VR is a computer-generated scenario that simulates a real-world experience (Steuer, 1992). AR combines real-world experience with computer-generated content (Azuma, 1997).

Source: *Eurofound, 2018d, 2019e*

Automation, digitisation and coordination by platforms

Eurofound (2018b) differentiates three digital vectors of change that are influencing work and employment in Europe as of mid-2019 (Figure 2).

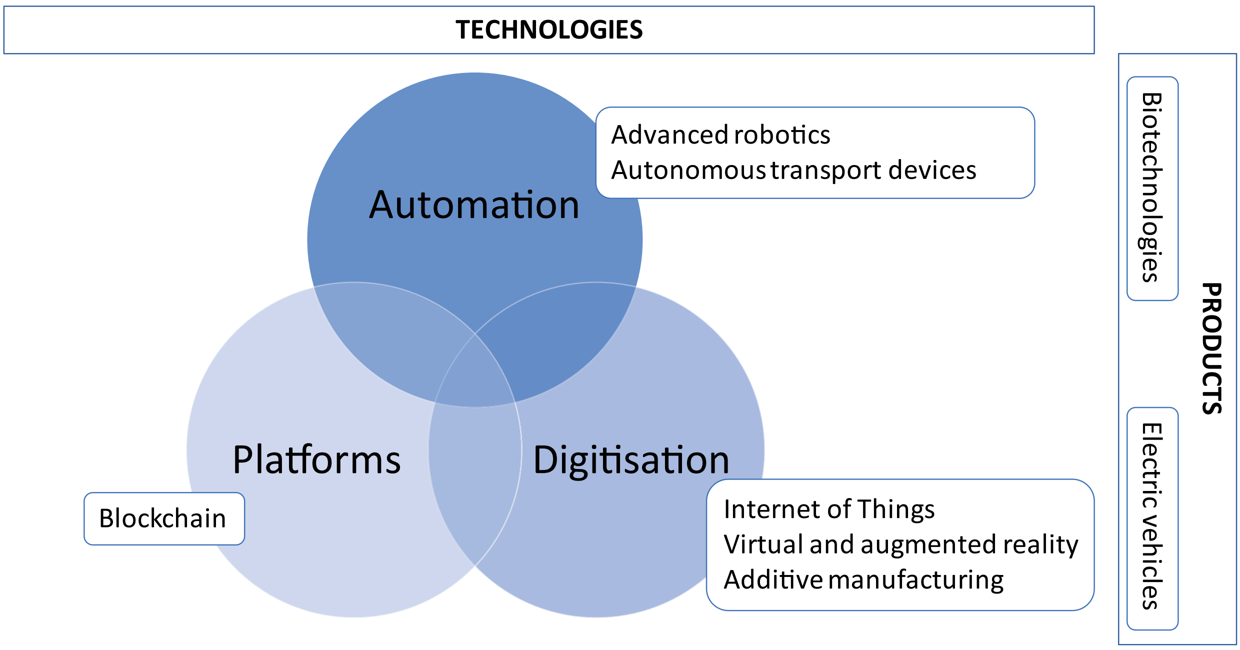
Automation: the substitution of human input by machine input.

Digitisation: the transformation of physical objects and documents into bits (and vice versa).

Coordination by platforms: the use of digital networks to organise economic transactions in an algorithmic way (such as that used by Uber).

This division of change into three broad categories is an analytical tool to help better discern work and employment implications, rather than a mirror of reality, as more often technologies are combined or interact together. For example, an autonomous vehicle can be classified both as a robot thus falling under the automation driver, and as a cluster of sensors and be classified as a device which gathers information from the external environment and digitises it (digitisation driver).

Figure 2: Vectors of digital change and analysed GCTs



Source: *Authors' elaboration, based on Eurofound, 2018b*

4 A distributed ledger is a digital ledger (a computer file used for recording and tracking transactions) that stores cryptographically authenticated information on a network of machines. Changes to the ledger are reflected for all holders of the ledger simultaneously.

Advanced robotics, both for services and manufacturing, can be grouped with autonomous vehicles under the automation vector since their ultimate application aims at substituting human input: robots or automated software performing a worker's task(s) and the vehicle guiding itself. Digitisation is the main characteristic of additive manufacturing, IoT and VR/AR. These technologies use digitised information to do the following:

- create virtual environments
- augment the experience of a visual scene by superimposing information
- gather data about machinery and processes (IIoT) or people (wearables)

Blockchain comes under the heading of coordination by platforms: blockchain transactions are enabled by algorithmic operations that substitute a wide range of workflows. These might include, for example, smart contracts where, if the software finds that all the criteria are met, payment is released. It could be argued, therefore, that blockchain also incorporates elements of both automation (as it diminishes human input) and digitisation, since all the operations take place digitally; however, for the purpose of this analysis, the most prominent vector (coordination by platforms) is selected. Other forms of coordination by platforms, such as platform-based work, are beyond the scope of this report, but further information can be found in other Eurofound publications and in its online platform economy repository (Eurofound, 2018f).

Electric vehicles and industrial biotechnology focus more on innovative transformation processes; in this regard, their scope of application is limited to a few specific economic activities. However, they are nevertheless investigated as GCTs in this report because of the potentially high levels of disruption these products could cause in both the automotive sector and the plastics and fuels sector, notably throughout the supply chains.

Box 1. Game-changing labour market effects of the platform economy

The platform economy refers to the mediation between the supply of and demand for goods and services through an online platform. It emerged in Europe about a decade ago and, since then, has developed dynamically. While it is still small in scale, an increasingly diverse range of products and services can be matched through such platforms, and a greater variety of business models and mechanisms are being used by platform providers (Eurofound, 2018c, 2018f).

Public and policy debate has paid particular attention to platform work – the matching of demand for and supply of paid labour. Although it is widely recognised for its potential contribution to innovation and the competitiveness of the economy, platform work raises some concerns regarding employment and working conditions of the affiliated workers. This concern relates to both the characteristics of this employment form and its business model: the triangular relationship between platform, client and worker; the fragmentation of jobs into tasks that are assigned on an on-demand basis; and the partly international scope of the activities. These characteristics challenge traditional concepts (such as what is understood by 'employer' and 'employee') and institutions (including labour law, industrial relations and representative bodies).

A wide range of existing research confirms the disruptive potential of platform work for employment and working conditions (for an overview, see Eurofound, 2018f, 2019d). Some of the key challenges identified refer to: the unclear employment status of the workers; potential labour market segmentation and discrimination effects; issues related to working time and rest periods; levels and predictability of earnings; health and safety standards; and algorithmic task assignment, surveillance and ratings (Eurofound, 2019f). In addition, game-changing effects can be expected as regards data protection, intellectual property rights, business regulation and competition law.

1 Application in manufacturing and services

Development and commercialisation of technology

Since the GCTs under consideration in this report have not yet been widely adopted, it is difficult to provide a comprehensive picture of where and how they have been implemented. However, some insight can be gained from R&D expenditure and patent applications in high-tech fields. In a global context, the EU ranks high in terms of R&D expenditure and patent applications; however it lags behind the United States (US) and China (Eurofound, 2019e). Eurostat data from 2009 to 2016 show an increase in R&D expenditure across sectors in the EU. The top three EU Member States by R&D expenditure are Germany, the United Kingdom (UK) and France (Eurostat, 2016). A comparison of EU-level patent data with the US, China and Japan reports a decreasing trend in high-tech fields for the EU, US and Japan, while the number of patent applications registered in China has increased fourfold since 2004 (Eurofound, 2019e).

A significant time lag might occur between the introduction of a new technology and its impact on the economy. The eight GCTs are not all new. One, in fact, dates back more than a century: electric vehicles were quite popular in the period 1880–1890 before the combustion engine became the engine of choice. Additive manufacturing was invented in 1983, but it has only been used in production since 2013–2014 (Bloomberg, 2019). And smart glasses have also previously appeared: the so-called 'Google glasses' were expected to become as common as smartphones, but their capacity to record everything the wearer sees was not welcomed by consumers. As of 2019, however, smart glasses are gaining new popularity as repurposed work tools.

Thus, before it can make a significant impact, technology must become widely available, businesses must change processes to take advantage of it and the regulatory and policy environment must keep pace. Further, new technology does not fully impact the economy until new businesses are created around the technology – rather than existing businesses adopting the new technology – and complementary 'co-inventions' are created to help realise its full potential (Eurofound, 2018b; Pollack et al, 2019). To add to the complexity of this trajectory of adoption, a technology might have different speeds of adoption in different sectors. For example, the mining and oil extraction industries have been using sensors (IoT) and advanced robotics for a long time; the scope of these technologies is only now widening to other economic activities thanks to cheaper prices and new ideas for how to apply these technologies in other sectors. As an illustrative case, El Dulze, a Spanish food processor, uses advanced robotics to run quality checks on lettuces (Fresh Produce Journal, 2017). The introduction of the robots, which have sufficient dexterity to handle lettuces without causing damage, has resulted in a lower lettuce rejection rate (from 20% to 5%) and higher standards of hygiene (McKinsey Global Institute, 2013 in Eurofound, 2018a).

Some of the technologies considered have a broad application across sectors (as discussed in Table 3 on p. 13). Within the **automation** cluster, advanced robotics is already used in mature sectors in manufacturing: electronics assembly, automotive parts manufacturing and aerospace. Robotics is also applied to services activities, though to a lesser extent. For a considerable period of time it has been fully deployed in some areas in manufacturing (such as electronics assembly and automotive parts manufacturing), but its potential applicability in other sectors (for example, handling material of different textures and shapes within the food preparation industry or warehousing within logistics) is gaining pace. Online retailer Amazon, for instance, has robotised the goods storage in its warehouses, while Spanish supermarket chain Mercadona has set up a robotised distribution centre in Jundiz (Noticias de Gipuzkoa, 2019). Advanced robotics has also reached early stages of adoption in sectors including emergency rescue services, where robots can be used in hazardous situations such as searching through earthquake debris, and in inspection and maintenance, where they can clean dangerous products from contaminated areas. Other areas in the services sector where robots are being tested include healthcare, retail and entertainment. Robots have also had an impact on R&D: 'Eve', in operation at Manchester University since 2018, is a 'robot scientist' that combines AI and physical motion to help conduct drug discovery activities. Eve can generate

> *its own hypotheses, meaning it can go beyond the 'brute force' approach to screening and testing and, instead, adapt its behaviour in order to respond intelligently to emerging findings, for example, by prioritising the screening of compounds with a higher probability of positive outcomes.*
>
> (Eurofound, 2019a, p. 59)

Nevertheless, the level of uptake of advanced robotics remains below expectations in relation to the high levels of interest it initially provoked.

Autonomous vehicles are still at the testing stage. Testing is still largely restricted to fixed spaces agreed with public authorities – usually where there is a limited human presence. Some tests have been carried out in cities in the US, but fewer such experiments are taking place in the wake of a number of fatal accidents. In practice, many self-driving vehicles will also be electric, so their commercial relevance and uptake will depend on a combination of both automation technology and electric engines. For electric vehicles more generally, improvements in their range per charge have opened up a market, which seems to be growing.

In the **digitisation** cluster, sensors have a huge variety of potential applications, some of which are already available in sectors such as oil, gas and textiles (for example, the application of radio-frequency identification – RFID – tags in clothing manufacturing and retail). Additive manufacturing is being taken up in a range of economic activities for fast prototyping and for production; this is especially the case for products whose shapes and materials challenge traditional manufacturing methods, as in the jewellery or fashion sectors. In 2017, sportswear manufacturer Adidas set up a factory in Germany where shoes are made with additive manufacturing methods and advanced robots. The factory was set up as a result of ‘reshoring’ of production from China; however the number of jobs was reduced from 1,000 in China to 160 in Germany due to the automation of the production line (Eurofound, 2018d).

VR/AR also shows a high degree of cross-sector adoption. VR-based immersive experience is already used in the arts and entertainment sector and, in terms of its work-related application, in training activities (e.g. for training police, military personnel and pilots). A wider application is expected in other services, such as design and prototyping and sales and marketing. Early research found that VR training does not differ from traditional training in terms of its effectiveness, but it includes an element of entertainment that is appreciated by workers (Eurofound, 2019e). The ability to provide real-time visual feedback makes AR highly valuable in planning surgery procedures and other types of remote collaboration involving professionals and teams in different locations. AR is also at piloting stage in logistics and in the activities of defence forces.

Wearable devices have a range of applications in both manufacturing and services. In manufacturing, they may be used to augment human capabilities and to overcome physical limitations (for example with the use of exoskeletons) and to increase safety and productivity (as with smart gloves). Such devices can collect and process data about the wearer or their environment, connecting to machines through sensors (IoT). As a result, devices can monitor a wearer’s health and performance as well as track their movements and location, which can be beneficial for workers in hazardous or emergency situations (such as miners, firefighters and field medical personnel). In healthcare, wearable devices enable remote health monitoring by both healthcare staff and service users.

In the **coordination by platforms** cluster, as of 2019, blockchain is still at the very early stages of adoption (apart from its use in cryptocurrencies). The scope of its applicability, however, encompasses so many economic activities that around 650 related projects are underway in the EU (European Union Blockchain Observatory and Forum, 2018).

In terms of **products**, the scope of industrial biotechnologies is, by its nature, focused on specific subsectors – namely, the pharmaceutical industry (as in antibiotics), biofuels, the chemical industry (specifically in the production of amino acids, biosurfactants or biolubricants) and in the production of bioplastics and biopolymers. R&D in this field is projected to be very active in the next 5–10 years as the pursuit of product improvement continues.

The way in which innovation (or disruption) takes place in the manufacturing and services sectors is notably different. In manufacturing, the US National Aeronautics and Space Administration (NASA) has developed a Technology Readiness Level (TRL) index that identifies the development stage of a given technology. There are nine levels in the index, ranging from the initial basic principle to prototyping and, finally, adoption. Though this index works well for manufacturing, the picture is more blurred for services. A service innovation starts from concept design, but once active it is generally improved through customers’ interaction with it. The innovation loop in services has only recently started to become ‘productised’, meaning that service expectations are listed and customers can be reasonably sure that services reach a certain consistent standard.

Companies test and trial a change in their processes through pilot projects: according to a World Economic Forum (2018) survey, 70% of companies looking into the adoption of Industry 4.0 technology are at pilot stage; for nearly two out of three companies, the pilot lasts one to two years. To progress from pilot to full adoption, companies face the challenges of scaling up and aligning performance with return on investment. In services, where development comes – in part – as a consequence of interaction with consumers, new ideas and their implementation are a component of the service (Den Hertog et al, 2010).

Table 3 lists the sectors in which the eight analysed GCTs are applied, differentiating between manufacturing and services, and indicates the level of market maturity of the technology. Overall, the table demonstrates that technologies have already been adopted in some frontrunner companies in manufacturing while, despite the variety of opportunities, they have not yet been widely implemented in services.

Table 3: Example applications of GCTs

<table>
<tr><th>Vector of change</th><th>GCT</th><th colspan="2">Potential applications by sector</th></tr>
<tr><td rowspan="3">Automation</td><td rowspan="2">Advanced robotics</td><td>Electronics assembly; automotive parts manufacturing; aerospace</td><td rowspan="2">Retail (public relations, customer services); transport and warehouse storage; accommodation (cleaning robots); financial services; public administration, civil services and defence (personal care robots, inspection and maintenance robots, automated devices for emergency situations); education and training (scientific investigation, lab biomedical robots); health and social work (surgery, rehabilitation and therapeutic robots)</td></tr>
<tr><td>Food preparation industry; craft and bespoke manufacturing</td></tr>
<tr><td>Autonomous vehicles</td><td colspan="2">Retail (car dealers, vehicle maintenance); transport (freight and passenger); postal service and delivery; logistics; insurance sector; real estate activities; public services</td></tr>
<tr><td rowspan="4">Processes and products</td><td rowspan="2">Electric vehicles</td><td colspan="2">Plug-in hybrid electric vehicles</td></tr>
<tr><td colspan="2">Extended-range electric vehicles</td></tr>
<tr><td rowspan="2">Industrial biotechnologies</td><td colspan="2">Pharmaceutical industry; energy industry; chemical industry; materials industry</td></tr>
<tr><td colspan="2">Application of new production processes in the industry (use of new enzymes, yeasts, bacteria and fungi to produce better materials)</td></tr>
<tr><td rowspan="6">Digitisation</td><td rowspan="2">IIoT</td><td colspan="2">Oil and gas; automotive</td></tr>
<tr><td colspan="2">Chemicals and chemical products; motor vehicles, trailers and semi-trailers; coke and refined petroleum products; repair and installation of machinery and equipment; food products; machine manufacturing</td></tr>
<tr><td rowspan="2">Additive manufacturing</td><td colspan="2">Consumer production using plastics</td></tr>
<tr><td colspan="2">Automotive; aerospace; human prosthetics; living cells; creative industries</td></tr>
<tr><td>VR/AR</td><td colspan="2">Retail (virtual sales, marketing); logistics (tracking in warehouses); professional services (psychological treatments; architecture and urban planning); public services (training); education activities; transport (driving schools); health (supporting surgery or diagnosis and remote collaboration); touristic and cultural sites</td></tr>
<tr><td>Wearables</td><td colspan="2">Marketing and advertising; smart clothing; warehousing; sports sector; public services (emergency services, police and military services); remote health monitoring</td></tr>
<tr><td>Coordination by platforms</td><td>Blockchain</td><td colspan="2">Sales (ownership tracking and supply chain management); financial and accounting (coordinated bookkeeping, recording and storing assets, automated regulatory compliance); financial and business services (smart contracts); public services (timestamping); education (encoding educational qualifications, academic records, accreditation standards); health (storing and sharing medical records, tracking of prescriptions)</td></tr>
</table>

Legend, based on TRLs

- Manufacturing: currently applied in production (TRL9)
- Manufacturing: stages up to testing and prototyping (TRL5–8)
- Services: piloting/early-stage adoption and potential uses

Source: *Own elaboration based on Eurofound, 2018b, 2019e*

Factors influencing adoption

The adoption of technology often depends on several factors. Whether these factors constitute a driver or a barrier for the adoption of the technology in practice differs from case to case, depending both on the technology and the external framework conditions and on small-scale aspects specific to the company or workers. Furthermore, these factors do not act in isolation but rather interact.

The following sections discuss some key factors influencing the adoption of the analysed GCTs in the European economy. As far as possible, it will be indicated whether they tend to act as a driver or a barrier for the specific technologies.

Financial considerations and ROI

The most relevant factor is the required investment in R&D or the purchase of the technology, as well as the projected profitability and projected increase in productivity (against assumed maintenance costs). Strategy is another driver behind businesses' adoption of GCTs, particularly early involvement in new technologies and emerging markets, as is evident with electric vehicles or self-driving cars. Table 4 displays the estimated market growth of GCTs over a 10–15 year timeline.

Access to financial markets (through private equity rounds) aimed at financing technological development, and the business capacity to maintain long-term investment in R&D, are certainly factors that need to be evaluated by companies. High investment costs could be a barrier, despite an expected high return on investment (ROI).

Table 4: Estimated potential market size of analysed GCTs

Technology	Estimates of potential market size
Advanced industrial robotics	Impact on global market of between USD 1.9 trillion and USD 6.4 trillion (€1.73 and €5.84 trillion as at October 2019) per year by 2025 (RAS 2020, 2014, p. 9). The sales of professional service robots have reportedly increased by 85% between 2016 and 2017, from approximately 60,000 to 110,000 units worldwide (IFR, 2018a).
Additive manufacturing	Estimates of the global additive manufacturing industry vary from a turnover of USD 1.7 billion (€1.56 billion) (Roland Berger, 2013) to as much as USD 500 billion (€456 billion) per year (Manyika et al, 2013).
IIoT	Deployment in the automotive industry only: a value of USD 210–740 billion (€191–€675 billion) by 2025.
Electric vehicles	Electric car stock at a global level will be between 9 million and 20 million by 2020 (10% of the market). The electric batteries market is estimated to be worth around €250 billion per year by 2025 (EU Battery Alliance, 2018).
Industrial biotechnologies	The EU market for products derived from industrial biotechnologies is expected to increase from €28 billion in 2013 to €50 billion in 2030 (BIO-TIC, 2015).
VR/AR	Value projected to be €15–€34 billion by 2020 (Bezegová et al, 2017).
Blockchain	International Data Corporation predicts that Europe will be the second largest investor in blockchain technologies between 2018 and 2022 and will increase its spending from USD 400 million (€365 million) to USD 3.5 billion (€3.19 billion) over the same time span (IDC, 2018).
Wearables	Some projections suggest that the global wearables market will grow to USD 5 billion (€4.56 billion) by 2020 (WEF, 2017). Others estimate a global growth of up to USD 70 billion (€64 billion) by 2025 (Harrop et al, 2015).

Notes: *The wide range in the values of the projections concerning the wearable technology market can partly be attributed to challenges in defining the term 'wearables'. The projections encapsulate a combination of wearables and VR/AR due to high-profile products in the market, such as Google Glass Enterprise and Microsoft HoloLens, that combine both wearable and VR/AR functionalities.*
Source: *Eurofound, 2018d, 2019e*

Box 2: Investment and funding in disruptive technologies is key for the future of the EU

Promoting the development of disruptive technologies requires time and adequate funding strategies and schemes. The digital component of the EU's current Multiannual Financial Framework amounts to €37.4 billion (3.9%) of the total budget. This strand covers several EU programmes aimed at technological change, mainly focusing on digital infrastructures. For example, the European Fund for Strategic Investments and the EU research programme Horizon 2020 have targeted investment in R&D for key digital technologies. Other EU measures include the Connecting Europe Facility, which mostly addresses cross-border transport, energy and telecommunications infrastructure between EU Member States, or the strategy on Digitising European Industry, which includes the objective of mobilising over €50 billion of investment between 2016 and 2020. Another example of a major initiative in infrastructure is the 5G Infrastructure Public Private Partnership, which amounts to €700 million of EU funding and is to be topped up with private financing to reach a total budget of €3.5 billion by 2025.

As of 2019, the new 2021–2027 Multiannual Financial Framework proposal (which is still under consideration) places digital change at the top of the budgetary agenda. For instance, the future Digital Europe Programme – the first-ever EU programme solely dedicated to digital transformation – has proposed an overall budget of €9.2 billion aimed at boosting investments, mainly in five broad areas: supercomputing, AI, cybersecurity, digital public services and advanced digital skills.

Source: *European Commission, 2019i*

Advanced robotics and industrial biotechnologies, as well as the production of electric vehicles, require substantial initial investment in sophisticated machines and equipment; this initial investment itself requires long, complex processes in terms of revised work organisation, reorganisation of production and training of the workforce (Eurofound, 2018d). These additional processes must therefore be factored into the initial investment cost. For example, Amazon is planning to deploy CMC CartonWrap (Reuters, 2019), a packing machine that can pack 600–700 products per hour, which is 4–5 times the amount that can be packed by a worker. Each machine replaces around 24 employees, which will amount to 1,300 jobs across the 55 centres in the US. Each unit costs USD 1,000,000 (€912,000) and will take two years of operation to recoup costs. This might be a feasible option for big corporations, but SMEs might struggle to source the investment necessary to acquire advanced robotics or other technologies that require significant upfront investment. One way to address the need for high initial investments could be the use of leased, pay-per-service or pay-for-availability technologies (Eurofound, 2019a). In industrial technologies, the cost of setting up a plant and investing in the R&D process are also potential barriers. In IoT and additive manufacturing, the initial investment could be less demanding since these technologies can be applied to a part of the production process and in a staggered manner. In services, upfront investment may be required for VR/AR headset and for content preparation. Furthermore, a company's ability to assess the value of a specific investment might be influential in its capacity to adopt new technology

> *while large organisations, such as hospitals or manufacturers, were experienced in conducting complex cost-benefit analyses with regard to investment in new technology, this may not be the case for small organisations or service providers.*
>
> (Eurofound, 2019a, p. 21)

Infrastructure and standardisation

Limitations stemming from technological infrastructure may result in patchy adoption, either in terms of pace or quality. This is the case for technical infrastructure, such as 5G, that serves to foster interconnectivity between different technologies and with other devices. Similarly, the availability of charging infrastructure, requiring electricity or gas, could directly affect the uptake of electric vehicles.

The spread of new technologies makes standardisation necessary to ensure quality and reliability. Standardisation processes require time and thorough investment to guarantee that all components, materials, products and services meet the requirements and specifications, usually set by the ISO. Standardisation can also facilitate the combination and interoperability of GCTs and AI,[5] enhance their performance and expand their functionalities.

5 Interoperability is the ability of products and services to work with each other. Compatibility refers to a lower level of interoperability and guarantees interaction only to a certain extent.

For technologies in the **automation** cluster, some ISO standards have been issued for certain sets of robots (including personal care robots and collaborative industrial 'cobots'). The ISO standard for personal care robots, for example, focuses on three types of robot – mobile servant robots, physical assistant (exoskeleton) robots and person carrier robots – and identifies risks such as the ergonomics of human–robot interaction, cognitive load and concerns about physical safety (Eurofound, 2019a). However, it is unlikely that a common standard for robot safety and risk management will be developed for the various applications of other service robots (as in healthcare, education, professional services, transport) (EU-OSHA, 2015).

In the **digitisation** cluster, standardisation for wearables and AR represents a challenge for cross-cutting cyber–physical technologies based on connectivity between different environments and between machines and humans. The intrinsic characteristic of IoT to function over a connected network should rely on common protocols and standards for both security and interoperability reasons – a concern that is also valid for potential uses of blockchain. Such standardisation should be implemented along the value chain, allowing the various programming languages and platforms to communicate securely with each other. Similarly, the absence of technical standardisation in the blockchain ecosystem creates fragmentation and may also hinder the adoption of this technology (Hofmann et al, 2017). For instance, it is not always possible to transfer data across platforms as they use different and incompatible protocols.[6] A standardisation roadmap for blockchain has been put forward by the ISO covering the period to 2020 (Hofmann et al, 2017).

Standards should also be developed by companies manufacturing electric vehicles – especially as regards the treatment of batteries – and, when autonomous vehicles have been fully adopted, standards should be laid out to allow interoperability for European road transport infrastructure. Industrial biotechnologies also need to apply standardisation for biomaterials and other bio-based products.

Interoperability between GCTs

Interoperability between technologies is essential to implementing them on a larger scale and maximising their potential. This could also increase competitiveness and productivity by allowing businesses, supply chains and consumers to better interact.

This challenge has been addressed as part of the EU's digital single market initiative. The combination of technologies creates technological ecosystems, which themselves enable further adoption within a virtuous loop. This is particularly the case with cross-cutting technologies such as AI and IoT. As an example, the number of IoT devices that are active is expected to grow to 10 billion by 2020 and 22 billion by 2025[7] and the European Commission is supporting the creation of IoT ecosystems through an open platform approach (IOT Analytics, 2018; European Commission, undated).

An example of interoperability in the eight GCTs studied in this report is the combination of technologies needed to enable road vehicles to act autonomously. To constantly adapt to dynamic traffic environments, these vehicles need to collect data through multiple IoT-enabled sensors. IoT-enabled interfaces are also crucial to facilitating the interaction of the vehicles with other devices when the autonomous vehicle is in motion. They then require AI and machine learning techniques to understand the captured sensor data. Analysing and updating the collected data in real time (traffic data, but also any road data and navigational pathways, including the presence of other vehicles and humans) is critical to smooth driving and is provided by both onboard analytics functions and an embedded software platform. In turn, robotics platforms contribute by performing data-specific functions (for example, GPS tracking and odometry) and helping the vehicle navigate dynamic traffic flows. In short, the integration of multiple and complex GCTs is essential to enable the existence and functionality of autonomous vehicles.

A further example is the combination of AI and advanced data analytic capabilities that can enable robots to make autonomous decisions and adapt their behaviour to their context. First, the robots need sensors with data collection capabilities and, second, large datasets are needed for training AI and applying decision-making by algorithms. Equally, the combination of 3D-printed products and advanced robotics could make substantial changes to work production and processes. The game-changing dimension of collaborative 'cobots' is likewise linked to the combination of several technologies, such as IoT (advanced sensors) and deep learning. Similarly, strong synergies between advanced industrial robotics and other manufacturing technologies, particularly IIoT, create the potential for the profound restructuring of industrial activity.

6 Hyperledger and the Ethereum Enterprise Alliance – another prominent enterprise community focusing on developing business-oriented open-source standards for the Ethereum platform (CoinDesk, 2018) – announced in October 2018 that they will collaborate on the development of open-source standards to avoid the risk of silos (Allison, 2018).

7 This number of IoT devices comprises all active connections: it does not take into consideration devices bought in the past that are no longer used.

Another example can be found in VR/AR technologies and their integration with wearable devices, smartphones and IoT-enabled devices. Smartphones can be deemed as wearable devices insofar as they make use of wireless connectivity and offer easy access to immersive environments via VR headsets. Wireless connectivity – usually in the form of Wi-Fi, Bluetooth and other systems – as well as the full adoption of 5G is particularly important for gaming and entertainment sectors to provide an interactive streaming experience. IoT combined with VR/AR technologies would provide data for analytics functions in service activities such as marketing, education and healthcare.

Wearable technologies also match perfectly with IoT capacities. Here, securing connectivity among different devices in households, companies and the public sphere is the key issue. In that sense, some researchers have approached the adoption of wearable technologies in the context of a wider connectivity trend (the 'seamless web') led by IoT and involving cloud computing and smartphones.[8] Blockchain also has the potential to be used in conjunction with several emerging technologies that require and are built on top of extensive data interaction, such as IoT, big data and other technologies that govern tangible objects, including autonomous vehicles, wearable devices and VR/AR.

Regulatory issues

Legislators are faced with the dilemma of regulating innovation without stifling it. Regulatory frameworks need to be loose enough to allow experimentation but robust enough to protect vulnerable groups of workers or citizens from extreme consequences. The development of standards and the EU-wide applicability of regulations – for example, for charging points for electric vehicles or compatible algorithmic choices in autonomous vehicles' software – are fundamental to fostering the adoption and deployment of technologies (Spöttle et al, 2018).

Legislative action should be taken to integrate automated processes in the workplace. For example, as of 2019, the EU Machinery Directive concerning harmonised safety standards for machine products in Europe is only partially applicable to the more recent and most evolved generation of robots (European Commission, undated). The European Commission has initiated the revision of this legislation, which aims to tackle the challenges that arise from technical progress (European Commission, 2019j).

The unclear legal and regulatory environment surrounding blockchain has frequently been cited as a potential barrier preventing, among other outcomes, a widespread adoption of this technology. Concern is expressed in particular by international and national financial systems that use blockchain-based cryptocurrencies. Additional concerns have been raised regarding system design (for example, the way in which data are stored on the blockchain) and the technology's specific applications, such as the legal status and enforceability of smart contracts. However, setting up a regulatory framework at any level may clash with the very nature of blockchain as a transnational, multisectoral foundational technology.

Social acceptance

Social and cultural barriers can prevent technologies from taking certain development paths. In the automation domain, where the ultimate aim is the 'lights out' factory,[9] efforts to prepare the next step of automation could be regarded as a threat to workers and their representatives, hence making them reluctant to cooperate in implementing these technologies. Autonomous vehicles and advanced robotics are the automation technologies most likely to entail labour force replacement.

In other economic activities, for example healthcare services, end-users may be reluctant to accept typically 'human' tasks being performed by machines – for instance, receiving a terminal diagnosis via a digital interface (CNN Health, 2019) [10]. The issue of human–machine interaction in services is also linked to cultural barriers; in some western countries, people are uneasy with the idea of of robots being used in patient care, while it is largely accepted in Japan. From the worker's point of view, remote communication may limit their exposure to emotional distress, but the question about how a service is delivered, which needs to take into account the provider–user interaction, may steer future developments towards identifying tasks that are 'better performed' by humans.

8 'Cloud computing' involves the storage and accessing of data over the internet ('the cloud') rather than on a local computer (PCMag UK, 2016).

9 A factory where no humans are present, so all operations can theoretically happen in the dark (except, of course, those that require some sort of visual image recognition).

10 In the United States in 2019, a patient was informed of his terminal diagnosis through a telepresence device, causing the family great distress.

Data use and privacy

A key element in the current technological transformation is the collection, storage and processing of workers' and end-users' data. If digitised technologies are to be accepted, it is vital that both workers and the public have confidence in how the data collected are used and with whom they are shared. The ease with which data can be gathered, combined and sold has deep implications for working life and society at large.

While data collected about workers (for instance their activity, performance and location) might be used to improve work processes, it could also result in strict surveillance. Wearable devices, for instance, have the potential to collect highly sensitive, personal data about employees. This increased scrutiny of employees would compromise their privacy; furthermore, the employer's ability to access such information could jeopardise employees' bargaining power (Eurofound, 2019j). On the other hand, data generated through wearable devices could empower workers by providing empirical evidence of their performance or behaviour.

Another concern relates to the unclear relationship between data privacy and blockchain applications. It has been suggested that the distributed nature of blockchain, combined with its capability to store data cryptographically, makes it more difficult for personal data to be hacked, thus reinforcing the security and resilience of the system (European Union Blockchain Observatory and Forum, 2018). However, some researchers have pointed out that, although the users' identities are anonymised, the details of transactions are transparent and thus it is not totally clear to what extent blockchain can ensure privacy (beyond simply anonymity) to its users.

The General Data Protection Regulation (GDPR), which entered into force in 2018, was designed to reach a balance between data protection and the free movement of personal data in the EU. Despite being more focused on the personal data of citizens, as opposed to workers, GDPR covers a number of workers' rights.[11] An assessment conducted by the European Commission one year after the regulation's entry into force shows that most Member States have set up the necessary legal framework and that new systems strengthening the enforcement of the data protection rules are falling into place. Businesses are developing a compliance culture and, at the same time, convergence towards high data protection standards is progressing at an international level (European Commission, 2019e).

Despite the GDPR provisions and specific safeguards to protect sensitive information (e.g. about workers' health), the flow of personal data that is enabled by the interoperability of and hyperconnectivity between different technologies tends to remain an unresolved issue (Eurofound, 2019e). Thus, the pairing of workplace robots with sensors that collect data used in AI applications might give rise to legal issues regarding the protection of workers', clients' and customers' data. Similarly, most uses of VR/AR pose digital risks in terms of the collection of personal data. These technologies can collect information about the user through different devices (cameras, microphones, headsets). Even where data are anonymised, the underlying algorithms have the potential to identify the user by cross-referencing data sources with an individual's 'digital traces'.[12]

11 Employees' rights under GDPR include the following: to receive information about the collection and processing of their personal data; to access the personal data and supplementary information held about them by the data controller; to rectify their personal data if they are inaccurate or incomplete; to request that their personal data be erased by the data controller; to restrict a data controller from processing their data if they consider it to be unlawful or that the data is inaccurate; to obtain their personal data from their employer and reuse it ('data portability'); to object to their personal data being processed for direct marketing, scientific or historical research.

12 At workplace level, many questions arise regarding the interface between workers' personal and non-personal data or, in other words, personal data and confidential or sensitive data. For example, a ruling mandating the registration of working hours (as a record of the work day) could inspire the use of biometric methods for recording, including the use of fingerprints. In this case, according to some lawyers, the employer will either have to prove that there is no less invasive registration system available or they will have to request the workers' consent. Other cases in which the employer should ask for consent refer to the provision of personal telephone numbers or email addresses, or the use of a worker's image for promotional videos or on the company website.

Box 3: Recognising the financial value of workers' data

The employment relationship can last for a long time and relates to different personal and working life dimensions. As such, it represents a permanent source and exchange of personal data.

A report from the High-Level Expert Group on the Impact of the Digital Transformation on EU Labour Markets proposes a discussion on the nature of digital ownership. The expert group highlights that data produced and handled within firms:

> *has led to standard practices of workers not being directly compensated for sharing their private data with firms. On the other hand, data sets, data development and analytics and data management skills are included and accounted for as intangible assets of firms, contributing to the knowledge-based capital in national accounts, alongside Research & Development (R&D), Intellectual Property Rights (IPR), training, software, engineering and design, marketing and branding, as their gathering, accumulation and treatment entail investments from firms.*

Therefore, to the extent that workers' and consumers' data are used to increase the firm's value, this should be recognised and compensated accordingly. The report displays a possible redistribution of the value of digital ownership through treating data either as capital (which should be subject to general taxation), labour (which should be remunerated through a wage premium for workers creating and treating data) or intellectual property.

Source: *European Commission, 2019g, p. 44*

Ethical concerns

Since AI systems need big data – and in some cases also need real-time data collection and processing – to get the most out of their capabilities, ethical risks may also arise. This may also be the case for robot applications that use advanced AI or machine-learning software. AI systems can take automatic, algorithm-driven decisions based on large datasets, meaning that there is neither human intervention nor explicit transparency in decision-making processes; the outcomes of such 'decisions' may turn out to be discriminatory or unfair. A lack of transparency about the inner workings of these 'intelligent' algorithms, and to what extent the data stored are already biased themselves, are a growing concern for citizens, trade unions and governments.

The future adoption of fully autonomous vehicles may also pose ethical challenges. For these vehicles, the automated nature of driving is based on sensors that collect and transmit data wirelessly; this is in turn processed by software platforms. The scenario could arise where the software is faced with an extreme choice, such as having to pursue a course of action which could lead to harm or to loss of human life in order to protect or save another. This dilemma indicates the ethical complexity of the societal and economic environment that results from the adoption of complex technology – particularly in the absence of any principles and values framing it. Ethical and legal frameworks should be explored and built to ensure the transparency and accountability of AI systems.

The risk of inaction in the face of such ethical questions is that companies will set their own rules – rules that may neither foster competitiveness nor meet users' needs. Implementing technological change is not inherently positive or negative and can be done in different ways. For example, the introduction of robots could lead to direct replacement of human labour or it could be devised in a way whereby existing workers are reskilled, thus changing work organisation and challenging the idea of technological determinism. For example, automation processes, robots and sensor data may be integrated into work systems and management practices with unfair consequences for employees' working conditions. Similarly, algorithm-based software in human resources management can be applied in different ways, thereby resulting in either positive or negative outcomes for workers when it comes to the implementation of human resources policies (for instance recruitment, professional development, working time). Indeed, trade unions have raised ethical concerns relating to the use of AI-based software (such as machine learning, predictive high-performing models and so on) and analytical tools in human resources management.

Occupational safety and health issues

Among the drivers of the adoption of GCTs are the projected improvements in work safety and alleviation of physical strain. Robots working in hazardous environments – such as those where workers deal with toxic elements – have the potential to improve both work efficiency and workers' safety; vehicles that have a degree of self-driving capacity, for example, could allow drivers freer movement, thus alleviating musculoskeletal issues resulting from driving for long hours.[13] The use of additive manufacturing equipment entails fewer mechanical moving parts and could therefore reduce hazards to workers. Workers' safety in many different cross-sector activities could also be improved through the use of simulated environments in VR-based training programmes, while wearable devices could monitor workers' health and potentially prevent health problems.

However, some safety issues may arise and should be given appropriate consideration: some models of advanced robots are not fixed in one place, so sensors must be able to effectively coordinate the movements of these machines with humans in the workplace. high-temperature printer nozzles, high-voltage arcs and small-particle toxicity (some of the new pastes and powders used in additive manufacturing might have effects that have not yet been studied over the long term) could pose potential threats if not properly addressed. It has been suggested that, in light of the potential negative effects of small particles, additive manufacturing machinery should be placed in well-ventilated areas within the plant. Plant or production line redesign for safety purposes might also be required in the automotive industry, as the shift to electric vehicles could pose potential hazards in the manufacturing process of electric batteries.

Environmental issues

Environmental issues act as both drivers of and barriers to the adoption of technologies. For example, the transition from fossil fuels to biofuels and biomaterials requires the adoption of electric vehicles and industrial biotechnologies. The adoption of electric vehicles, however, in turn requires that their batteries be recycled or disposed of safely.

The energy consumption required by some blockchain applications could act to hinder its adoption or, at least, its social acceptance. Despite the growing capability for software to run on local devices, algorithms still require support infrastructure and energy which might be more expensive than non-automated ways of performing that task. Similarly, in advanced robotics, for example, a cleaning device might make sense in a hospital where the energy used per unit cleaned makes it a cheap option, but it could use a disproportionate amount of energy in an average household.

Access to raw materials

The analysed GCTs will require raw material (and possibly rare earth materials) for their components; this makes businesses highly dependent on access to international markets trading these materials, and vulnerable to disruptions in supply chains. Equally, additive manufacturing may also require input materials that are not commonly available, while production plants using biotechnology would need a constant stream of biomaterial to feed their processes. In this case, the challenge could be exacerbated by the seasonality of the input, or by the distance of the input production plant (for example, the organic waste of a factory or a crop field).

Conclusion

In general, the digitisation technologies tend to be affected by fewer barriers than the automation technologies and products (electric vehicles and industrial biotechnologies) (Table 5). A key driver in most cases of the adoption technologies are the expected occupational safety and health benefits, particularly in relation to a reduction in physical effort and hazardous situations.

From a company perspective, considerable initial financial investment (in both machinery and workers' training) is required for automation and products, constituting a significant barrier to the implementation of these GCTs. Access to raw materials could also represent a barrier for the majority of the explored technologies.

Lack of standardisation is a barrier for automation technologies, IoT, blockchain and electric vehicles, because these technologies require a high level of interaction with other technological applications. Similarly, technologies at an early testing stage – such as blockchain and autonomous vehicles – need strong regulation before they are commercially implemented. It could take some time for legislation to be adopted, resulting in a barrier to the deployment of these technologies.

13 Such systems would be comparable with the autopilot system long used in commercial aviation.

Table 5: Overview of key factors influencing adoption of the analysed GCTs

	Automation		Digitisation				Coordination by platforms	Products	
	Advanced robotics	Autonomous vehicles	IoT	VR/AR	Wearables	Additive manufacturing	Blockchain	Electric vehicles	Industrial biotechnologies
Initial financial investment	Barrier	Barrier						Barrier	Barrier
Lack of standardisation	Barrier	Barrier	Barrier				Barrier	Barrier	Can be barrier or driver
Regulatory uncertainty	Can be barrier or driver	Barrier	Can be barrier or driver	Can be barrier or driver	Can be barrier or driver	Can be barrier or driver	Barrier	Can be barrier or driver	Can be barrier or driver
Social acceptance	Barrier	Barrier	Can be barrier or driver		Can be barrier or driver				
Health and safety outcomes	Driver	Driver	Driver	Driver	Driver	Can be barrier or driver		Can be barrier or driver	
Environmentally friendly practices							Barrier	Can be barrier or driver	
Access to raw materials	Barrier	Barrier	Barrier			Barrier		Barrier	Barrier

Legend: Factor as a barrier or driver

- Barrier
- Can be barrier or driver
- Driver
- Not applicable or not known

Note: *Regulatory uncertainty refers to specific sectoral or technological regulation only and does not consider the potential regulation of workers' data or privacy rights.*
Source: *Authors' elaboration, based on Eurofound, 2018b, 2019e*

2 Implications for employment

Employment effects and transformation of jobs

Technological change has been identified as one of the main drivers in many advanced economies of structural change in the labour market. This is notably the case for two main patterns of employment development that have characterised the European labour market in the last decades (Eurofound, 2017):

- upgrading (a linear improvement in the employment structure, with greatest employment growth in high-paid jobs)
- polarisation (a relatively stronger employment growth at both ends of the job–wage distribution, leading to a 'shrinking' of the middle)

On the one hand, technological advances generate relatively greater demand for higher-skilled workers (who are better able to master new technologies), but relatively weaker demand for lower-skilled workers – the so-called 'skill-biased technical change hypothesis'. On the other hand, some jobs are more susceptible to technological displacement if a high share of the tasks performed by workers are easy to automate and hence replaceable by machines (e.g. routine clerical and manufacturing or production jobs); these often dominate the middle of the job–wage distribution (Autor et al, 2003, 2006). Less routine jobs, which include personal services at the bottom of the wage distribution (such as hairdressers or restaurant workers) and knowledge-intensive professional services at the top (for example, lawyers or medical doctors), are less easy to automate and therefore less vulnerable to replacement; this is the so-called 'routine-biased' effect on labour demand.

Such a theoretical shift (from skills to tasks as a fundamental factor in the impact of technological change on workers) involves conceptualising of jobs as 'bundles of tasks', therefore allowing for the possibility that only part of a job – rather than all of it – may be substituted by technology. As a result, an increasing number of studies that seek to forecast future job losses (or creation) due to automation consider the different types of task content involved across jobs in the economy. Estimates, such as those from the OECD, that do take into account the variety of workers' tasks within occupations when considering the impact of automation (Arntz et al, 2016) are substantially lower than those provided by the pioneering work of Frey and Osborne (2013) for the US. In the case of the latter, the entire occupation is considered as a unit of analysis, and it is therefore assumed that the entire occupation, rather than individual tasks, are fully substituted by technology. On average across 21 of the OECD countries, only 9% of jobs are found to be automatable, compared with around 47% in the US. More recently, Nedelkoska and Quintini (2018) estimate that 14% of jobs in 32 OECD countries are highly automatable (having a likelihood of automation of over 70%) and a further 32% have a 50–70% likelihood of automation.[14]

Taking the EU as the main area of reference and using a sectoral approach, Eurofound (2019h) explores three different automation scenarios; the objective of the study is to determine which tasks are most susceptible to automation and then to determine in which jobs these tasks predominate. The first scenario assumes high costs and hence slow adoption of technology, the second scenario assumes low costs with quick adoption of technology and the third low costs with reduced working hours and no reduction in pay. Compared with a baseline scenario with no acceleration in automation, the expected job loss from automation by 2030 is higher in the EU (10% in the high-cost scenario, 16% in the first low-cost scenario) than in the US (9% and 14%, respectively). In the EU, manufacturing, utilities, and transport and communication show the highest proportional job losses in all scenarios (20% in the high-cost scenario, 30–35% in the first low-cost scenario). Job loss is generally expected to be lower in the second low-cost scenario (with working hours adjustments). Particularly in distribution, retail, and hotels and catering, job loss is seen to be mediated by reduction in working hours. Growth in employment is projected for only a few occupations, such as ICT, legal, social and cultural (and related associate) professionals, science and engineering associate professionals, and customer services clerks (Eurofound, 2019h).

However, the expected transformations should not only be considered from an individual worker or company perspective: there are some first indications that GCTs have effects along value chains (Box 4).

14 That said, predicting which jobs may be more at risk of automation on the basis of their current task composition and intensity only gives a partial assessment of the potential effect of digital technologies on work and employment. Technological transformations not only determine changes in the employment shares across jobs based on their task content; they can also contribute to changes in the task content itself over time. In most cases, machines replace specific tasks but not others, changing the task content of jobs and occupations (Bisello et al, 2019).

Box 4: Electric vehicles: first signals of value chain disruption

The automotive sector's switch towards electronic vehicle production is suggested as a possible cause of disruption in combustion engine manufacturing and on its related value chains. Caps on carbon emissions and bans on diesel and gasoline car sales in major markets within 10–15 years are compelling manufacturers to align with the new technology. In 2017, for example, Volvo announced that from 2019 onwards it would produce only electric or hybrid cars. The company's plan is that, by 2025, 50% of its output will be 'all electric'. Electric vehicles require fewer components than conventional cars since an electric motor is mechanically less complex than an internal combustion engine: according to estimates from UBS Bank, the number of components needed is expected to decrease by 17%.

Early signs of adjustment in value chains are evident in restructurings in the EU and worldwide. Eurofound's European Restructuring Monitor (ERM) has recorded restructuring cases linked to the switch to electric car production, especially by German manufacturers, in Germany and in other EU Member States. The German manufacturer Bosch, for instance, has announced several local restructurings to manage the decline of the diesel engine. Nearly 50,000 jobs in the automotive supplier depend on this technology, which is likely to be abandoned by consumers. In 2018, the group had already eliminated 1,100 jobs at three German sites (Bremen, Leinfelden, Hombourg). As of 2019, approximately 500 positions are threatened across three German plants (Hombourg, Bamberg, Feuerbach). The group also announced in June 2019, some 620 redundancies at its Modugno plant (near Bari, Italy) and in July 2019, a reorganisation of its French plant in Rodez (Aveyron). Another German manufacturer, Mahle, which produces combustion engine components, is planning to close two sites (Öhringen in Germany and Telford in the UK). Schaeffler, a manufacturer of clutches and camshaft adjusters, has found that demand for its products is declining due to the switch to electric car production and has announced 700 job cuts in Germany. The combination of this switch and the consequences of the diesel crisis have also prompted cable manufacturer Leoni and seal specialist ElringKlinger to announce job cuts.

On the other hand, electric car production is fostering the creation of jobs. The first half of 2019 saw the establishment of new production facilities for electric components, including batteries, and the ERM recorded the announcement of new jobs in a number of countries. The German electronic car components company Nord, for example, created 400 new positions in Poland. Instead of exporting batteries, Asian companies are establishing production facilities near the European market: South Korean automotive components manufacturer INZI Controls decided to build a battery module plant in Komárom, Hungary – the company's first European production facility. The choice is considered strategic, as major European automotive firms do not have battery production capacities yet. In fact, Hungary is increasingly becoming a prominent site of battery production, with Samsung present there since 2016 (creating 600 jobs) and two other battery plants already under construction. Japanese battery manufacturer GS Yuasa has also opened a new production plant in north-eastern Hungary. In western Europe, Forsee Power, a French manufacturer of batteries for buses and industrial vehicles, has announced that it will recruit 300 more employees by 2021. Forsee Power buys batteries on the market from Asian manufacturers and focuses on developing the electrical environment (e.g. connection technology and voltage control) that allows batteries in heavy transport vehicles to be more efficient.

Source: *Eurofound, undated*

Impact by sector

In both services and manufacturing, automation technologies have the potential not only to lead to job losses and job creation but also to transform the tasks performed within jobs. The main insight is that, in manufacturing, such tasks are likely to shift closer to monitoring and machine-control tasks, often requiring workers to upskill (Box 5). In services, the task content of jobs is also evolving; for example, the advent of online and mobile banking and the increasing requirements for fast and seamless cash-free payments through digital interfaces has already impacted the work of bank employees. In finance, the use of financial algorithms has changed the way brokers operate, resulting in a greater reliance on computers and reducing the amount of time spent dealing directly with other people (Eurofound, 2019b). A recent analysis of changes in work tasks over the last 20 years reveals that sectors such as financial intermediation, real estate, renting and business activities and public administration have recorded a significant and consistent decline in tasks involving external social interaction (e.g. with customers) (Bisello et al, 2019).

Box 5: Employment and skills upgrading in manufacturing

The manufacturing sector, which suffered the steepest employment losses during the recession, recorded a net employment growth between 2013 and 2018, amounting to two million new jobs. Interestingly, net new employment has been skewed towards better-paid jobs that are higher-skilled, professional roles and away from more traditional, blue-collar production jobs. The increase in professional engineering and management roles has been responsible for the expansion of employment (Eurofound, 2019g). This shift towards higher-skilled professional occupations was particularly evident in machinery and equipment as well as motor vehicle production (Eurofound, 2017).

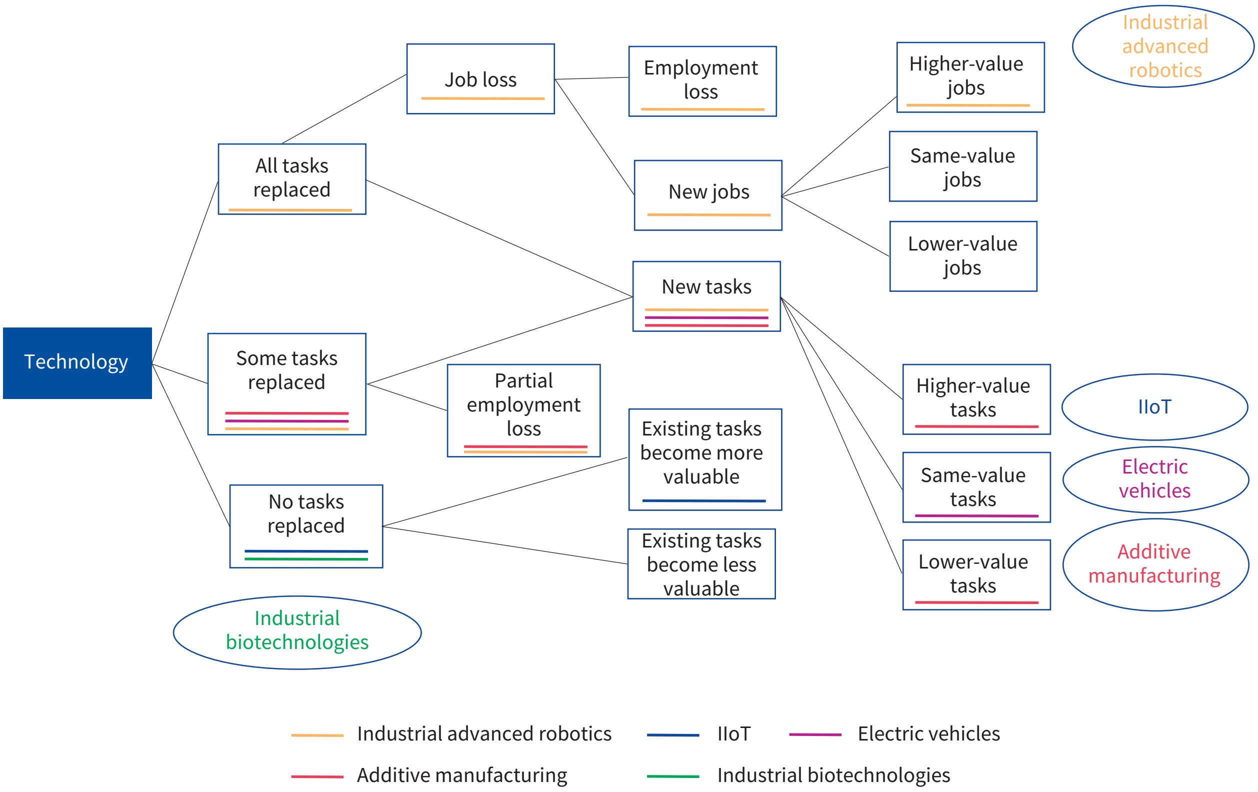
This ‘upgrading’ of employment in manufacturing is supported by findings from a recent Eurofound report that looks at the changes in the types of task performed by workers in five selected occupations: car assemblers, meat-processing workers, hand packers, chemical products plant and machine operators, and inspection engineers (Eurofound, 2018e).

Among the five key occupations analysed, the work of car assemblers has been the most significantly affected by digitalisation in recent decades, in terms of both manufacturing processes (including the development of digital factories that use sensors, algorithms and robots) and customer relationships (with cars themselves becoming more digitised, allowing user interaction and evaluating information collected through specialised applications) (Bisello and Fernández-Macías, 2018). The increasing use of digitally controlled equipment in production is one of the main factors contributing to this trend. This both requires that workers in manual, semi-skilled occupations have more developed ICT skills and increases the number of literacy- and numeracy-related tasks they have to perform, such as reading technical documentation or dealing with numerical information. The spread of automation and the use of advanced machinery in production is also boosting the importance of intellectual problem-solving tasks, with shop floor workers being increasingly tasked with troubleshooting production line and handling errors (Bisello and Fernández-Macías, 2018).

As far as GCTs are concerned, the theoretical framework by Mac Flynn et al (2019) has been used to assess and compare the impact of GCTs on task composition. While the framework was originally conceived to evaluate the potential impacts of automation technologies on the displacements of tasks and job quality, here it is applied in a wider sense to map the eight GCTs. Taking technology as an entry point, the framework looks at possible effects of the introduction of the technology in two phases. The first phase considers the replacement of tasks (complete, partial or no replacement); the second phase explores the effect on jobs (whether they are lost, become higher-value or lower-value or change to involve different tasks).

In this report, the framework is used to provide a qualitative assessment of the change in tasks and job quality for each of the selected technologies. This report also expands the scope of the framework to take into consideration the effects of technologies that relate predominantly to digitisation or coordination by algorithms. The general entry point – technology – is replaced by one of the selected GCTs and the effects are then mapped on to the framework according to findings from expert interviews and the literature reviews. The only addition to the original framework is the acknowledgement that, in cases where some tasks are replaced, the adjustment or expansion of existing tasks could also result in the creation of new tasks as well as partial employment loss.

Figure 3: GCTs in manufacturing: potential employment implications

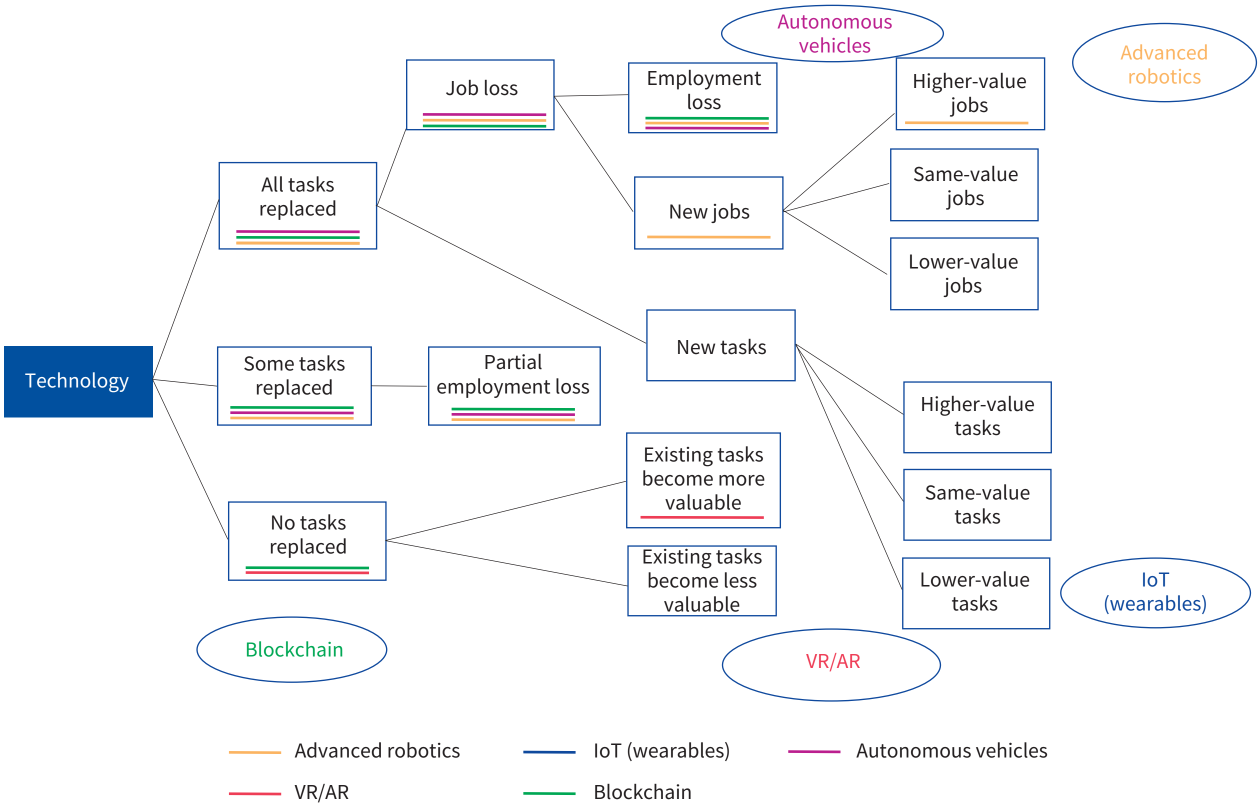


Note: *The chart starts from the technology box on the left. It represents all the possible outcomes of jobs and task creation or loss. Each technology is represented by a colour as shown in the legend.*
Source: *Adaptation of Mac Flynn and Wilson's (2019) theoretical framework outlining the potential impacts of automation technologies on the displacement of tasks and job quality*

Figure 3 and Figure 4 present the potential employment implications of technologies by sector (manufacturing and services, respectively). For example, in Figure 3, the adoption of advanced robotics (orange) could lead to all tasks being replaced. In turn, this could lead to job loss and job or task creation – for example, monitoring the robot, which could then be classified as a higher-value job. The new job may not necessarily be carried out by the same worker, however, because the level of competency and skills required might be different. Advanced robotics could also have a limited effect on tasks, therefore leading to only some tasks being replaced. This could either result in partial employment loss or in the creation of new tasks. In the case of industrial biotechnologies (green), the interviews highlighted that tasks characterised by the technology will not change much. If change occurs, the shift is likely to be to higher-value tasks – for example, R&D tasks and multidisciplinary communication among team members.

Figures 3 and 4 present a high-level conceptualisation, one based on experts' expectations and judgements. With that in mind, the figures appear to show that, in services, high-value tasks and high-value jobs are more likely to be created as an effect of the introduction of the analysed technologies. In manufacturing, the type of task displaced could lead to higher- or lower-value tasks, and this would essentially depend on decisions made at company level.

Figure 4: GCTs in services: potential employment implications



Note: *The chart starts from the technology box on the left. It represents all the possible outcomes of jobs and task creation or loss. Each technology is represented by a colour as shown in the legend.*
Source: *Adaptation of Mac Flynn and Wilson's (2019) theoretical framework outlining the potential impacts of automation technologies on the displacement of tasks and job quality*

Automation GCTs – impacts

The potential substitution of human input is found in both services and manufacturing, but its extent varies across industries and depends on several factors, including cost and comparative advantages.

In Industry 4.0 factories, the adoption of advanced robotics in manufacturing could lead to an increased demand for specialised, highly digitally skilled workers. Such workers will likely include mechatronics engineers and data scientists; apart from specialised skills, these employees will need to have highly developed communication skills to effectively collaborate with team members of other disciplines (Eurofound, 2018b). In services, where the 'working space' is perhaps not as clearly defined as the manufacturing production line, the extent of the impact of automation will depend on how capable advanced robots are of safely interacting in a setting where humans might be present or, in cases where robots might operate in an unstructured setting, on their ability to navigate a setting that is likely to change slightly with every interaction. The top three service areas that will potentially be affected by the adoption of advanced robotics are: medical and care professions (engaging with robots), engineering (developing the robots) and testing and monitoring operators, including emergency and rescue workers.

The emergency and rescue services sector seems to be the one in which task substitution is most likely to occur, and tasks are likely to shift towards robot monitoring.

The other technology that could have the strongest implications for employment from the point of view of automation is autonomous vehicles. If the transportation of goods and people can be effectively and safely outsourced to self-driving cars or drones, considerable job losses could be triggered in the transport and storage sector in the EU, which in 2016 accounted for 8% of the total workforce (more than 11 million workers) (Eurostat, 2019a). However, according to both the literature and experts, the horizon for mass adoption of fully autonomous vehicles is longer than 10 years; furthermore, the types of service performed by a driver – such as loading and unloading, monitoring passenger behaviours and so on – might not be automated at the same time. New jobs directly related to transport services could also emerge, such as autonomous transport planners, analysts, fleet managers and supply chain managers. Other services could also be indirectly impacted by the changes in the transport sector – for example, the insurance industry could need new types of expert who can understand driving algorithms and interpret the dynamics of accidents.

Box 6: Last-mile delivery

Last-mile delivery is a phase in the supply chain in which products are delivered from a local warehouse or transport hub to their final destination, such as a home or shop. In this segment of logistics, service providers' performance expectations and hopes of increased efficiency rely on the future adoption of drones or self-driving vehicles. Various pilot projects are taking place around the world. For example, the US–Estonian company Starship Technologies has developed drones that can deliver small items within a range of four to six kilometres; the drone is booked via an app and can be tracked online.

If these pilots were to be successful and legislative issues overcome, workers' employment levels in the delivery sector might be affected. Jobs characterised by small goods and single-item deliveries could potentially be lost. The impact on employment could also extend to traditional last mile jobs and platform workers, such as delivery riders. Traditional firms such as UPS and platform services such as Uber do not deny that the ultimate goal of delivery data collection is automation: collected data would feed maps and navigation guidelines for delivery with self-driving vehicles.

In relation to delivery drones, there are several challenges yet to be resolved. For example, in order to carry items and withstand unfavourable weather conditions, drones need a heavier structure; and this might pose a safety hazard in the case of accidents. The increased size of delivery drones also means they create more noise, leading to greater noise pollution. Furthermore, from the point of view of privacy, devices that can record images, location and possibly sound, particularly from heights where this was not previously possible, could prove unpopular. For self-driving vehicles (cars but also small-wheeled units), the ability to navigate an unstructured setting and the protection of the items or passengers carried are still under scrutiny.

Source: *Eurofound, 2019c*

Digitisation GCTs – impacts

IoT, in combination with advanced robotics and additive manufacturing, is the most significant innovation of Industry 4.0. The use of sensors to monitor machinery and processes means that entirely digitised models of factories known as 'virtual twins' can be created (IEEE, 2018). Virtual twins are virtual models of a physical process or product, built on the basis of sensor data. They incorporate both historical and near real-time data, and they allow manufacturers to both improve the performance of existing processes and test the performance of new ideas. Similarly to advanced robotics, this new technology creates a need for new specialised professional roles such as data scientists, software engineers and other profiles that sit between machinery and data. This will affect domains beyond manufacturing: the idea of 'virtual twinning' is already expanding to hospitals and cities (IEEE Future Directions, 2019). In particular, for job profiles in which data analysis is required, the demand for AI experts continues to rise. Private companies are offering highly enticing packages to PhD students and lecturers, provoking a 'brain drain' from universities to private-sector companies (Eurofound, 2019j).

These developments offer an insight into the predictions of Baldwin (2019), who describes a scenario in which deeply transformative changes could occur in the structure of employment: the possibility of working remotely online – performing not only small tasks but entire jobs – could make competition for jobs global. Jobs that do not require a physical presence can be performed remotely thanks to fast broadband services, efficient online translation tools, VR environments and data flows. Baldwin also predicts that white-collar jobs are at risk of automation, though it could be argued that in certain roles the knowledge of the local context or of local laws – for example, for lawyers – would limit this risk.

Additive manufacturing enables fast prototyping, as the design of a prototype can be quickly 'printed', examined, and adapted instead of producing the prototype in the traditional way – that is having to rearrange part of the machinery and process to manufacture a part. Additive manufacturing can also enable shapes and structures which might require fewer assembly tasks. At the same time, depending on the degree of automation involved in these processes, new tasks – such as machine loading and unloading and machine-cleaning tasks – could be created as a result.

There is no evidence of job creation or loss as a consequence of the adoption of wearables, except for the monitoring aspect of the technology. If workers' movements and actions are tracked, those workers whose performance falls below the average could be at risk of losing their job on the basis of metrics that might not always be in their favour, depending on the sample used to create those averages. For example, in logistics, workers in their 50s might not be able to keep pace with a walking rhythm based on a sample of workers in their 30s. In terms of job creation, manufacturers and companies providing services related to wearables might need more skilled workers – not least, to analyse data flows.

The impact of VR/AR on employment should be small. Tools using VR/AR enhance the working environment and can make information manipulation and acquisition faster; however, so far there is little evidence that these changes will have an effect on workforce numbers. Potential job creation seems more likely to take place: technology experts, software developers and instructors could be needed.

Other GCTs – impacts

Its role in the cryptocurrency market aside, blockchain is very much still at the piloting stage. The services most affected by it would be any type of service where intermediation is necessary, ranging from legal and notary roles to professionals who certify educational and academic credentials. While there is a potential high risk of job losses, therefore, this cannot be generalised, and it will depend on how each economic activity uses and customises the technology. On the positive side, adoption of blockchain could lead to increased demand for engineers and software developers as well as forensic blockchain analytics experts and other professions related to cybersecurity and data processing.

For industrial biotechnologies, changes occur at product innovation level and, for this reason, experts predict that the type and number of jobs and skills needed in the next few years will be in line with the requirements as of mid-2019, albeit with slightly more emphasis on communication and teamwork skills due to the need to liaise with local stakeholders to source input materials.

Summary of potential job creation and loss

In both manufacturing and services, all of the analysed GCTs show some potential for both job creation and job loss. For the time being, no assessment can be made in terms of whether job loss will outweigh job creation or the other way round.

In general, job creation is expected among higher-skilled occupations and specialised professions. Furthermore, some new occupations are predicted to emerge, notably related to data handling, data analysis and algorithms (see Table 6).

Job loss is less clear-cut, as is often discussed. While some low-skilled routine jobs are likely to be affected, some higher-skilled and specialised professions are also expected to be less in demand due to the opportunities offered by the new technologies.

Table 6: Potential job creation and job loss by sector and GCT

Sector	GCT	Potential job creation	Potential job loss
Manufacturing	Advanced robotics	ICT-skilled professionals; mechatronics engineers; data scientists	Low-skilled routine jobs in manufacturing
	IIoT	ICT-skilled professionals; data scientists; software engineers; and other roles that sit at the interface between machinery and data	White- and blue-collar jobs that can be performed online
	Electric vehicles	Technical experts in electric and high-voltage items	Combustion engine professionals
	Additive manufacturing	ICT-skilled professional experts in additive manufacturing; engineering and new material experts; possible rise of post-production tasks	Reduction of pre-processing manual tasks
	Industrial biotechnologies	R&D professionals	
Services	IoT (wearables)	ICT-skilled professionals; data scientists; software engineers; and other roles that sit at the interface between machinery and data	White- and blue-collar jobs that can be performed online
	Autonomous vehicles	‘Forensic algorithm’ insurance workers; engineers; data scientists	Drivers; delivery riders; insurers (indirectly affected)
	VR/AR	VR/AR instructors; software developers; content creation artists; creative arts content creators	Tour guides (tourism)
	Blockchain	ICT experts (specifically, software engineers, programmers and database experts)	Intermediary professions (e.g. notaries, people involved in certificate production in education and financial sector workers)

Source: *Eurofound, 2018d, 2019e*

3 Implications for working conditions and employment relations

Overview

As the analysed GCTs have been adopted in practice to only a limited extent, their impact on working conditions can only be assessed through qualitative indicators. The survey data that might illustrate, for example, workers' experiences of the analysed GCTs, is – for now – lacking. For the following discussions, therefore, Eurofound's framework on job quality indicators (Eurofound, 2013) has been taken as a starting point. The individual factors affecting workers' overall job quality are explored as far as the available qualitative information will allow. For this reason, the report focuses on those for whom the expected impact is assumed to be most disruptive. In this context, it has to be remembered that disruption can be both positive and negative for the affected workforce and that the level and kind of impact depends on the technology, how it is adopted in practice and workers' individual characteristics (Figure 5). The following section looks at where the greatest disruptions are anticipated.

Skills use and skills development: In line with the anticipated changes in job tasks discussed above, the greatest disruption is foreseen in the skills use and skills development of staff working with these technologies. The observed tendency towards higher-skilled tasks in combination with other potential changes, such as in work organisation (see below), is expected to be slightly positive for the working conditions of the affected workers – if they are able to adjust to the changed work environment and requirements.

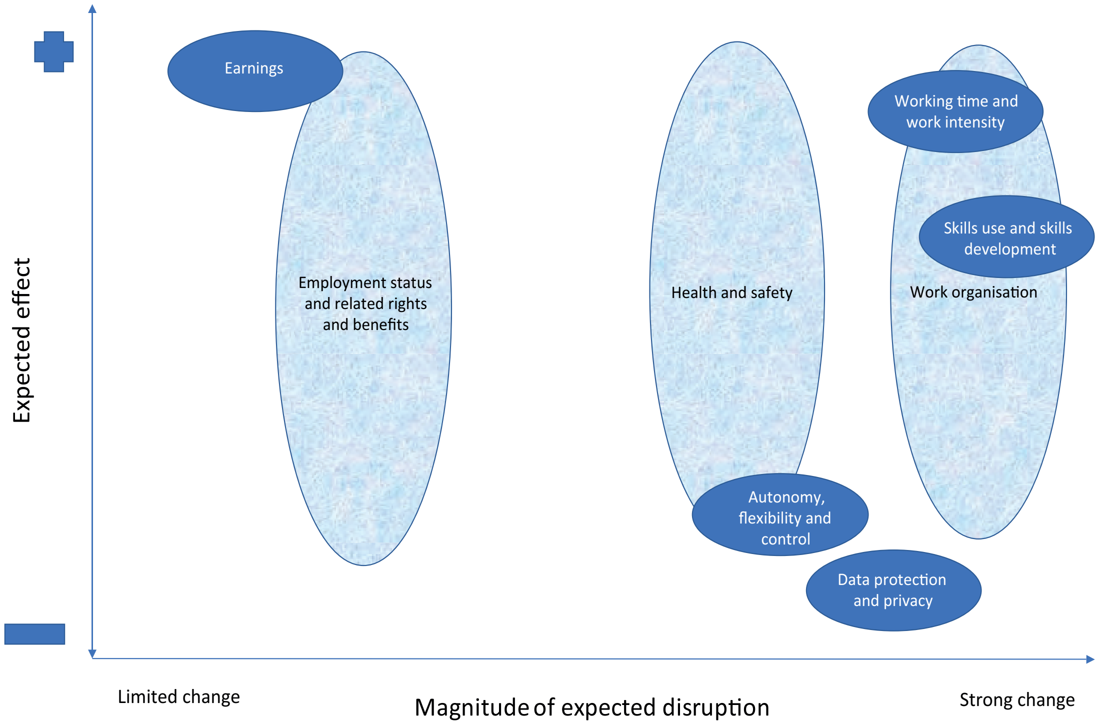
Elements of work organisation: Working time, work intensity, autonomy, flexibility, control and health and safety are strongly related to work organisation, that is workflows and cooperation within the production and service provision process. Each of these factors is expected to change significantly following the adoption of the explored GCTs. At the time of publication, the information available regarding the GCTs' potential impact on health and safety is not sufficient to assess whether the effects will be positive or negative. Available indicators point towards improvements (e.g. if physical tasks are replaced by machines) and increased risks (e.g. exposure to higher voltage), and it cannot yet be said which will predominate. It is assumed that working time will grow shorter and work intensity will diminish, while autonomy and flexibility have the potential to decrease, and surveillance of workers to increase.

Data protection and privacy: Control by employers is related to data protection and data privacy; considerable disruption is also expected in this area, mainly to the disadvantage of the affected workers. The main, widely discussed, risk is the potential for the gathering of large amounts of data, which could be used for performance monitoring and result in decisions by the employer that are to the disadvantage of the worker.

Earnings: Highly skilled specialists in the fields of advanced robotics or industrial biotechnologies might see an increase in their earnings; however, this could affect only a comparatively small number of workers.

Employment status: Limited change is expected with regard to employment status and the related rights and entitlements (including, for example, social protection and representation) of the affected workers. There are early indications that some digitisation technologies (such as blockchain and IIoT) could result in a shift towards more self-employment and cooperation with freelancers at a medium to high level of education. For the time being, it cannot be judged whether such a shift would be perceived positively or negatively by the affected workers – that is whether the self-employment would be experienced as an opportunity to avail of as opposed to a decision taken in the face of necessity.

Figure 5: Overview of potential impact of the analysed GCTs on selected working conditions



Notes: *For lighter shaded elements, the available information is mostly limited. Notably, some indicators point towards positive and some towards negative effects, so their overall direction is not known. For the time being, it is unclear which will predominate.*
Source: *Authors' elaboration based on Eurofound, 2018b, 2019e*

In the following sections, some of the working conditions factors for which more information is available are discussed in more detail.

Skills use and skills development

Overall, there is a strong tendency observed among the analysed GCTs of a decrease in manual tasks and an increase in the need for intellectual skills. This is the case for all three vectors of change (automation, digitisation and coordination by platforms) as well as the products (industrial biotechnologies and electric vehicles).

Across the analysed GCTs, some differences regarding the direction (positive or negative) of their effects on the workforce are assumed. For staff working with advanced robotics, wearables and VR/AR, task changes are expected to be positive. In some areas, specific skills might be required to make use of possibilities for cross-discipline cooperation. For example, the application of VR/AR to the domain of psychology to treat psychological trauma requires a team with programming, psychological, creative and sound and music skills. The demand for skills when using wearable devices indicates a need for digitally educated workers who can work with data flows from wearables – not only to monitor workers but also to monitor their own performance or interact with machines.

As regards advanced robotics, the shift towards higher-skilled tasks such as advanced engineering, data analytics, materials science or programming is considered to result in better job quality: a greater potential is expected for the involvement of creativity, problem-solving and decision-making as well as a reduction in physical effort. However, the automation of certain tasks could contribute to a further fragmentation of tasks in order to adapt them to robot and AI resources, which could eliminate some skills from job profiles (e.g. some cleaners' tasks). A similar effect which, as of 2019, seems to extend beyond a 10-year horizon, could potentially occur in scenarios where blockchain is adopted. For wearables and VR/AR, the developments are considered positive because the use of these technologies usually involves more efficient and effective training, which can generally be considered advantageous for the workers.

In contrast, the expected change in skills use can be considered negative for workers dealing with autonomous vehicles: it will be a challenge for drivers to adapt to the changed job profile, which requires more creative and social skills – skills that tend not to be the core strength for this type of workforce. In the case of a transition to vehicles that are *fully* autonomous, workers would need to reskill to fill vacancies in other occupations.

Table 7: Expected effects of analysed GCTs on skills use and skills development

Vector of change	GCT	Expected effect on skills use and skills development
Automation	Advanced robotics	Shift from manual towards intellectual skills; expectation that jobs will be more interesting
	Autonomous vehicles	Shift in skills demand is expected to be difficult for affected workers to fulfil
Digitisation	Wearables	More demand for supervisory skills; potential for use in training
	IIoT	Shift from manual towards intellectual skills
	Additive manufacturing	Shift from manual towards intellectual skills; focus on interdisciplinarity
	VR/AR	Shift from manual towards intellectual skills; potential for use in training
Coordination by platforms	Blockchain	Demand for higher skill levels
Products	Industrial biotechnologies	More demand for social and intellectual skills, with a focus on interdisciplinarity and adaptability
	Electric vehicles	More demand for social and intellectual skills, with a focus on adaptability

Notes: *Green cells refer to expected positive effects on affected workers, while red cells refer to expected negative effects on affected workers. Yellow cells do not allow for a general assessment but depend, for example, on workers' individual characteristics.*
Source: *Authors' elaboration based on Eurofound, 2018b, 2019e*

For the majority of the analysed GCTs, it is difficult to judge whether the changes in skills use will result in positive or negative effects. At the time of publication, the available information does not indicate whether the general requirement for a higher level of skills makes the work more interesting and meaningful for the staff or whether (if they cannot fully adapt to the changed demands) it will affect them negatively. It can be assumed, however, that those technologies that will likely require specialised skills (engineering, software development and data analytics for blockchain) or those requiring interdisciplinarity (the simultaneous combination of extensive scientific, technical, business/management and interpersonal skills) and a high level of adaptability (industrial biotechnologies and electric vehicles) will result in polarisation: higher-skilled workers will further benefit from these developments while lower-skilled ones are more likely to suffer. Table 7 presents the expected effects of the analysed GCTs on skills use and skills development.

Work organisation

Workflows and cooperation within the production and service provision process – in other words, work organisation – are highly likely to change due to the analysed GCTs. Beyond the purely technical feasibility of replacing human input for the performance of specific tasks, the way work is organised has a significant influence on which specific tasks can be automated. If work is organised in a way that reduces the importance of key human labour attributes by centralising, standardising and breaking tasks down, the possibilities for its automation may significantly increase. Some of the digital labour platforms are a clear example of how possibilities for automation can be expanded by more discrete and granular tasks, algorithmically centralised decision-making and a standardisation of processes and outputs (Bisello et al, 2019). The importance of work organisation in the process of task automation should therefore not be underestimated.

Early attempts at automation were preceded by an organisationally driven routinisation of tasks: Taylorism [15] and bureaucratic management routinised – respectively – manufacturing and administrative activities. If new technologies and management principles have the effect of expanding the range of routine work processes, they may also lay the foundations for further waves of automation (Bisello and Fernández-Macías, 2016). Data from Eurofound's European Working Conditions Survey (EWCS) suggest that, in the last 20 years, standardisation has also increased considerably for high-skilled occupations, such as professionals and managers, which previous research had viewed as being at less risk of automation (Bisello et al, 2019).

Whether the expected disruptive effect of the analysed GCTs on work organisation will positively or negatively affect workers is difficult to judge, mostly because this will greatly depend on the individual characteristics and preferences of the workers. For example, there is an assumed higher level of collaboration, particularly in

15 Also known as scientific management, Taylorism is a management theory relating to workflows.

Table 8: Expected effects of analysed GCTs on work organisation

Vector of change	GCT	Expected effect on work organisation
Automation	Advanced robotics	Human–robot interaction, increased complexity, reduced team size, more remote working
	Autonomous vehicles	More variation, change in use of time
Digitisation	Wearables	More efficient and optimised workflows
	IIoT	More use of ICT, more collaboration, more remote working, increased complexity
	Additive manufacturing	More collaboration
	VR/AR	More task-driven organisation
Coordination by platforms	Blockchain	More remote working
Products	Industrial biotechnologies	More collaboration
	Electric vehicles	Change in processes

Notes: *Green cells refer to expected positive effects on affected workers, while red cells refer to expected negative effects on affected workers. Yellow cells do not allow for a general assessment but depend, for example, on workers' individual characteristics.*
Source: *Authors' elaboration based on Eurofound, 2018b, 2019e*

relation to the analysed digitisation technologies: bringing manufacturing and service processes into the digital sphere involves an inherently cooperative element, often extending beyond the company level. This can be positive if the worker is in favour of close interactions with colleagues or external stakeholders; however, this can be negative if a greater need for teamwork and increased engagement with different kinds of people – potentially on a global scale and from different disciplines – is challenging for the worker. The outcomes of such increased cooperation will likely be even more influenced by personal preferences and capabilities if the collaborator is not a human being but the technology itself, as is the case in advanced robotics.

Similarly, the anticipated increased task complexity and variability as well as the potential to work more remotely, as expected with advanced robotics or IIoT, can improve the quality of working conditions for some workers but reduce it for others, depending on personal capabilities and preferences. For example, workers may or may not enjoy more challenging jobs, flexible changes in roles and greater decision latitude and responsibilities.

A topic not yet widely discussed in relation to the expected impact of GCTs on work organisation is their effect on human resources and line management. Advanced robotics in particular is expected to affect people management due to the complexities of human–robot interaction, which may result in the supervision of robots (and possibly supervision by robots) as well as greater diversity within teams in additive manufacturing.

Interestingly, the only two developments that show a clearer direction in terms of the effects of GCTs on work organisation are based on similar drivers but result in different outcomes. For wearables, it is expected that workflows will be more data driven. This is assumed to result in more efficient and optimised workflows, which will benefit the workers. In contrast, for VR/AR, the shift towards a task-driven work organisation is likely to lead to workers becoming passive recipients of task assignments which they complete mechanically, thereby losing the wider perspective. Table 8 shows the expected effects of the analysed GCTs on work organisation.

Working time and work intensity

The analysed GCTs related to both automation and digitisation are generally expected to have positive effects on working time and work intensity. This either relates to anticipated shorter working hours due to reduced workload, changes in the work organisation (as found for advanced robotics, wearables, VR/AR and industrial biotechnologies) or to an improved quality in working time in terms of more consistent work schedules (as mentioned for autonomous vehicles).

Risks of higher levels of overtime and increased work intensity, however, are expected in relation to electric vehicles. The positive expectations for advanced robotics may also become negative if work organisation includes a 24/7 production process and workers are called in at unsocial hours to check or fix failures in the automated processes. Table 9 displays the expected effects of the analysed GCTs on working time and work intensity.

Table 9: Expected effects of analysed GCTs on working time and work intensity

Vector of change	GCT	Expected effect on working time and work intensity
Automation	Advanced robotics	Potential for shorter working weeks and more part-time work, but workers may need to be ‘on call’ for 24/7 production processes
	Autonomous vehicles	More consistent work schedules and more regular working hours; less commuting time
Digitisation	Wearables	Reduction in workload as technology complements the human workers’ activities
	IIoT	n/a
	Additive manufacturing	n/a
	VR/AR	Reduction in workload as technology complements the human workers’ activities and decreases complexity
Coordination by platforms	Blockchain	n/a
Products	Industrial biotechnologies	Improved work–life balance
	Electric vehicles	Potential for increased work intensity and need for overtime

Notes: *Green cells refer to expected positive effects on affected workers, while red cells refer to expected negative effects on affected workers. Yellow cells do not allow for a general assessment but depend, for example, on workers’ individual characteristics.*
n/a = no information available
Source: *Authors’ elaboration based on Eurofound, 2018b, 2019e*

Autonomy, flexibility and control

The effects of GCTs on workers’ autonomy , flexibility and control cannot be considered in isolation, but are closely related to other working conditions factors – notably, work organisation and data issues.

A positive outcome is expected only for blockchain. This is due to the tendency of blockchain to decentralise the steps of the manufacturing or service provision process, hence enabling more remote and individualised working.

For advanced robotics and wearables, a decrease in workers’ autonomy is expected, as the data gathered through the technology could be used for greater monitoring of workers’ performance. Similarly, for VR/AR, the above-mentioned shift towards a more task-driven work organisation is assumed to result in less autonomy for workers. Table 10 displays the expected effects of the analysed GCTs on autonomy, flexibility and control.

Table 10: Expected effects of the analysed GCTs on autonomy, flexibility and control

Vector of change	GCT	Expected effect on autonomy, flexibility and control
Automation	Advanced robotics	Less autonomy due to the potential for increased monitoring through the technology; less flexibility to manage staffing and planning issues
	Autonomous vehicles	n/a
Digitisation	Wearables	Less autonomy due to the potential for increased monitoring through the technology
	IIoT	Increased decision-making on the shop floor, but reduced levels of control by the worker
	Additive manufacturing	n/a
	VR/AR	Less autonomy due to task-driven work organisation
Coordination by platforms	Blockchain	Increased autonomy due to remote and decentralised work organisation
Products	Industrial biotechnologies	n/a
	Electric vehicles	n/a

Notes: *Green cells refer to expected positive effects on affected workers, while red cells refer to expected negative effects on affected workers. Yellow cells do not allow for a general assessment but depend, for example, on workers’ individual characteristics.*
n/a = no information available
Source: *Authors’ elaboration based on Eurofound, 2018b, 2019e*

Occupational safety and health

It is difficult to provide an overall assessment of the effects of GCTs on workers' health and safety as the adoption of most analysed technologies is expected to have both positive and negative impacts. For the time being, information is not sufficient to judge which will predominate.

In general, most of the analysed technologies are assumed to result in less physical strain as physically burdensome tasks can be conducted by machines (in the case of the automation technologies) or are supported by them (in the case of digitisation). However, experts point out that an important precondition for this positive development is to inform employers and employees about the particularities and potential dangers when working with the technologies and how to avoid accidents. This is especially crucial for the services sector as work environments tend to be less structured compared to manufacturing and, hence, human–machine interactions involve more safety risks.

Similarly, some of the explored digitisation technologies (notably IoT and VR/AR) can be used to improve workers' physical safety by monitoring the work environment and detecting potential hazards at an early stage. Furthermore, VR/AR could be used to familiarise workers with dangerous situations and enable them to practise suitable responses in a sheltered training environment, thereby preparing them for potential emerging hazards.

Interestingly, however, the GCTs are expected to bring about negative psychosocial effects related to increased stress or decreased quality of relationships at the workplace (e.g. in advanced robotics) in addition to the assumed negative impact of automated performance control (e.g. in wearables). As regards work intensity and workers' monitoring, on the other hand, it must be noted that GCTs could also be used as an early warning tool, resulting in an adjustment of workload or workflows to the benefit of the workers. Accordingly, health and safety factors should be considered in combination with developments in work organisation.

In relation to autonomous vehicles, positive effects are expected – notably, a reduced risk of road accidents (though this might not be the case in the early phase of adoption), and a reduction in the traditional challenges in the transport sector (such as posture problems and the need for break times, which create a disruption in service). Similarly, industrial biotechnologies are expected to make the work environment safer as they generally involve less harsh working conditions in terms of temperature and pressure compared to, for example, petrochemicals. In contrast, additive manufacturing and electric vehicles are expected to make the work environment more dangerous as workers are exposed to higher voltages and temperatures or toxic materials, which are characteristic features of these GCTs.
Table 11 shows the expected effects of the analysed GCTs on workers' health and safety.

Table 11: Expected effects of analysed GCTs on workers' health and safety

Vector of change	GCT	Expected effect on health and safety
Automation	Advanced robotics	Lower physical strain and reduced risk of injury, but greater risk of negative psychosocial effects
	Autonomous vehicles	Lower physical strain and reduced risk of accidents
Digitisation	Wearables	Lower physical strain, but greater risk of negative psychosocial effects
	IIoT	Lower risk of accidents, but greater risk of negative psychosocial effects
	Additive manufacturing	Potential for both safer and more dangerous work environments
	VR/AR	Lower physical strain, but greater risk of negative psychosocial effects
Coordination by platforms	Blockchain	n/a
Products	Industrial biotechnologies	Potential for safer work environments
	Electric vehicles	Lower physical strain, but greater risk of more dangerous work environments and negative psychosocial effects

Notes: *Green cells refer to expected positive effects on affected workers, while red cells refer to expected negative effects on affected workers. Yellow cells do not allow for a general assessment but depend, for example, on workers' individual characteristics.*
n/a = no information available
Source: *Authors' elaboration based on Eurofound, 2018b, 2019e*

Employment relations

Contractual stability and career development

As most of the GCTs analysed are not yet widely adopted in business and the degree of their implementation is uneven across economic activities, hardly any evidence has been found regarding their effects on employment relations.

It has been suggested that automation may influence individual employment status as far as it introduces more flexibility in work organisation and more labour instability. Furthermore, the fragmentation of jobs into tasks – as brought about by automation and blockchain, for example – could lead to a decrease in contractual stability if assignments become shorter and more specific. It has also been acknowledged that GCTs could cause some tasks, and even parts of work processes, to be subcontracted or outsourced, which may contribute to the increase of atypical forms of employment (e.g. self-employment). The evidence relating to the effect of digitisation on employment stability shows a less clear picture.

Contractual instability would have repercussions for the opportunities for career development available to workers: if the company does not see them as a long-term resource, training and career prospects would be limited. On the other hand, if workers possess a high level of digital skills and the ability to communicate well across different disciplines, they could have a higher probability of long-term employment.

Challenges for industrial relations and social dialogue

The digital transformation has the potential to impact core elements of employment relations and working conditions. As a result, industrial relations as a whole and, in particular, social dialogue at sectoral and company level, could be affected by technological change. Furthermore, during the transition period towards the adoption of GCTs, a core component of collective employment relations will be to ascertain how the expected productivity gains will be distributed between employer and employee.

One way in which technological change is thought to potentially disturb labour markets is by increasing the disparity between highly skilled workers and those who lack the skills to keep pace with the changes. In this context, the industrial relations system could play a constructive role in managing transition periods in order to help companies and sectors restructure and adapt accordingly, dealing with the risks of increasing wage inequality and polarisation in working conditions.

From the analysis carried out in the selected GCTs, it can be assumed that the effects of automation-related technologies (notably advanced robotics and autonomous vehicles) are greater than those of digitisation (such as wearables or VR/AR). Some researchers have noted the risk that the greater potential to automate tasks within jobs – for example, by using robots – could reduce the wages of workers in low-skill sectors (McKinsey Global Institute, 2017); in so doing, this would weaken the position of organised labour in relation to employers (Freeman, 2015, in Went, 2015). And the impact of IoT cannot be underestimated: as a cross-cutting technology, it can interact with other technologies in the automation processes. Similarly, while there is very limited evidence of the potential implications of blockchain on collective employment relations, it is thought that blockchain could enable the further development of the platform economy and other forms of decentralised working. With that in mind, the increase in remote working facilitated by blockchain would further challenge the bargaining power of employees (Johnston and Land-Kazlauskas, 2018).
In any case, the implications of blockchain adoption are likely to differ significantly across sectors, job roles and tasks – though, so far, it is not expected to have a broad impact on large companies.

Automation – in particular, robotisation – may also result in both the fragmentation of supply chains (for example, the outsourcing of robot maintenance to remote companies) and greater servitisation in work production and the economy. Automation also blurs company boundaries and creates more complex organisational forms of production, both of which impact collective employment relations. In combination with developments related to work organisation – for example, greater remote working (Johnston and Land-Kazlauskas, 2018) – these shifts resulting from automation could compromise the minimum threshold for consultation rights and thus the ability of employee representatives' to engage in negotiations (IBA GEI, 2017). Overall, therefore, these tendencies will diminish opportunities for workers to organise into trade unions and, consequently, reduce collective bargaining rights and workers' participation in the decision-making processes that affect working conditions.

In light of this, collective bargaining and social dialogue at company level may indicate a way to manage the effects of automation: carmakers in Germany such as Daimler, Volkswagen, BMW, Audi, and Bosch, as well as automotive parts manufacturers like Continental, have introduced ambitious remote working programmes for hundreds of thousands of employees (where, for instance, robots can be managed remotely). Based on an agreement reached between management and the central works council, Daimler has gone one step further by giving 100,000 German workers the right to work outside of the company's official premises. SAP's 22,000 employees in Germany also have the same right to work wherever they want in the country.

It can be concluded that the more disruptive the technology, the greater the impact it has on the labour force and on working conditions, and thus on social dialogue. The above developments in collective agreements stress the key role of a strengthened process of social dialogue in dealing with changes in work organisation as a consequence of technological change and the impact of automation and GCTs. Change needs to be implemented step by step, using social dialogue and tailored approaches, as the adoption of GCTs is a complex process that requires continuous monitoring and problem-solving.

Technological change also therefore prompts the need for effective human resources management approaches, which should involve worker representatives or trade unions. Human resources management policies are increasingly expected to be able to ease technological change through people management. In particular, policies should consider the increasing diversity of the workforce: ageing workers with limited potential for reskilling will likely have different attitudes towards technological change compared to younger workers. Companies focusing exclusively on technical change, rather than on the people working with the technologies, are pursuing a short-term strategy that is unlikely to foster workforce cohesion. Social dialogue involving employees affected by GCTs therefore becomes a crucial way to create new, more appropriate agendas for negotiation and identify new areas for employer–employee cooperation.

Following the implementation of GDPR and national legislation focused on workers' data rights, the issues of privacy rights and the collection of personal data by employers have become priorities in the labour relations agenda. Staff now need to know how their personal data are collected, stored, processed and disseminated. Collectively, worker representatives and unions should start to include issues (such as data control, surveillance, profiling, geo-tracking) arising from this in workplace or company discussions and negotiations. In Italy, for example, the two main union federations for metalworkers have signed a collective agreement for 2019–2022 at Lamborghini to establish a bilateral commission aimed at negotiating the availability of big data: in other words, the commission will assess who has access to the data produced by the company's ICT systems – whether it is solely the company or company and workers (Planet Labour, 2019).

4 Conclusions and policy pointers

Role for EU investment and policies

Despite accounting for only about 7% of the world's population, Europe accounts for 20% of global R&D investment. However, statistics relating to the number of patents and other indicators suggest that the EU is lagging behind other regions – notably the US and China – in technological development, including those technologies that are considered potentially more disruptive. Several factors can explain this gap. For one, the political and economic nature and structure of the EU means that, despite the single market, its markets are fragmented. This is essentially a disincentive for European entrepreneurs targeting a large market at an early stage. Another reason is that differences in language, culture, market size and regulations constrain innovation more so than in other parts of the world.

EU policy has started to address this gap, for example by financially supporting the development of disruptive technologies such as AI and biotechnologies, although further efforts and more holistic approaches might be needed. Technological change goes hand in hand with innovation, but a certain scale is required for innovation to reach business and society. Silicon Valley or Seattle in the US, for example, are technological ecosystems that offer opportunities to innovative entrepreneurs and, crucially, they are wealthy financial systems. Indeed, businesses, big technology companies and funding rounds in the US are able to finance much more than the €11.66 billion investment in growth-stage technology generated in Europe in 2018. Nevertheless, the EU is now producing more high-tech start-ups than the US and both public policies and public and private partnerships should provide the necessary means for innovative ideas and organisations to mature and scale. As suggested by Eurofound (2012), research on 'born globals' (start-ups facing the challenges of simultaneously establishing a business, innovating and internationalising), possible solutions might include enhancing access to finance beyond traditional bank loans (such as business angels or venture capital options) or non-monetary options (such as tax benefit schemes that can be postponed until the company starts making a profit).

The issue of scaling up – helping a start-up achieve sustainable growth – is already discussed in the policy arena and should be enacted upon (EPSC, 2019).

Efforts are also needed to close the financing gap between R&D grants and private investment. With sufficient support for innovation and the development of technologies, including GCTs, Europe could bounce back as a technology innovator.

EU regulations supporting GCTs

Many policies support the development and adoption of GCTs. However, regulatory frameworks, especially in the area of standardisation and interoperability, need to be established and fine-tuned both for companies and workers. For companies, IoT, blockchain and electric vehicles fall under this category.

Legislative action should also be taken to integrate automated processes in the workplace. For example, as of mid-2019, the EU Machinery Directive concerning harmonised safety standards for machine products in Europe is only partially applicable to the latest and much more evolved generation of robots (European Commission, undated). The European Commission has begun to revise this legislation in an attempt to tackle the challenges arising from technical progress in digitisation.

Changes introduced in production lines by electric vehicles and additive manufacturing should be monitored and, if necessary, regulated to prevent potential hazards. Additionally, employers and workers need to be aware of the potential risks and options to tackle them.

The ownership of workers' data, in particular related to performance and behaviour, should be regulated. Furthermore, although GDPR protects personal data, the types of data produced during working time need to be defined more specifically. It should also be recognised that workers' and consumers' data are used to increase a firm's value, and they should be compensated accordingly. A possible redistribution of the value of digital ownership might be considered – for example, through treating data as either capital (which should be subject to general taxation), labour (which should be remunerated through a wage premium for workers creating and treating data) or intellectual property (European Commission, 2019g).

Strategic use of GCTs for labour market purposes

The new capabilities of GCTs should be exploited to improve labour markets. GCTs falling under the digitisation cluster (i.e. IoT, additive manufacturing and VR/AR) can foster flexibility through remote working. VR/AR can also provide alternative training methods for hazardous occupations.

Advanced robotics, or the use of exoskeletons, can reduce physical strain and hazardous tasks, which could enable the integration of disabled or older workers into the workplace. Furthermore, there should be a focus on research into hazardous tasks that can be carried out by machines in order to make workplaces safer. VR training can similarly be promoted as a potentially safer alternative to training on-site.

A European vision for technology and digitalisation

Digital transformation involves a wide range of challenges and choices for companies, including contextual forces such as environmental policies and internationalisation. Hence, digitalisation entails more than solely implementing new technologies in work processes: it requires a long-term strategic vision be taken for organisations, and that the implications of digitalisation for both human capital and the value chain be taken into consideration. Usually, digitalisation will involve reorganisation at company level, driven by competition in an increasingly technological and globalised environment.

The way in which technology is adopted and implemented is highly significant. Technological transformation does not take place overnight, and the pace of change should be tailored to help manage the transition period. Organisations need to identify early on the strategic vision driving the adoption of technology and, consequently, the overall effects for the organisation and for the staff. This is particularly important for those organisations adopting robotisation in combination with other general purpose technologies such as IoT and AI, which are usually run from the cloud. Such combinations of technologies enable the implementation of smart factories or digitised networked workplaces, with profound impacts on production and work organisation.

Automation is not new. In fact, automated work processes have been applied for a long time in some sectors with already high levels of technological maturity. EU companies thus have significant experience in dealing with transformative automation, and lessons learned should be applied to the current technological transition. A narrow approach to technological change, which mostly takes advantage of automation to reduce the workforce and labour costs, should be avoided. Instead, labour-friendly strategies, which seek to reskill the workforce in line with efficiency and productivity gains, should be applied. Implementing technological change is not a neutral choice, and the EU should seek to make the most of knowledge and expertise in social dialogue and labour institutions. In this way, research on the implications of technologies for work and employment can help in monitoring the situation and enable policymakers to better prepare for and guide technological change.

An EU-wide industrial policy for integrated digital manufacturing

The services sector has grown significantly over the last few decades, while mass customisation and servitisation are the new paradigms in manufacturing, ultimately blurring the boundaries between manufacturing and services. IoT, in combination with other disruptive technologies such as additive manufacturing and advanced robotics, facilitates these digitised processes, boosting value chains and enabling customers to access additional services. Interaction, digital interoperability and networking are thus key principles in integrated digital manufacturing.

EU companies are already seeing the impact of such changes; what is needed are industrial policies that take into account new business models and manufacturing requirements. Such policies could build upon existing regional industrial policy approaches – for example, in the context of Smart Specialisation.[16] Policies should also ensure that SMEs are not left behind, as they are an essential part of the EU's capacity for lean and flexible production; policies should also seek to mitigate the disruptive effects of the uneven implementation of IoT through the value chain.

16 'The smart specialisation approach combines industrial, educational and innovation policies to suggest that countries or regions identify and select a limited number of priority areas for knowledge-based investments, focusing on their strengths and comparative advantages' (OECD, undated).

Employment and skills

After the first wave of near-dystopian predictions about the impact of automation on job losses, more recent estimates confirm the limited quantitative effects of automation on employment. It is widely accepted that a job is composed of a set or 'bundle' of tasks to which workers apply their skills in exchange for wage; some of these tasks can be automated, but others cannot. Presently, estimates suggest that automation will thus replace only very few jobs completely (automating all task content in a given job).

The increase of remote working enabled by GCTs could pose serious challenges to policymakers and workers alike. If jobs can be done remotely, they may not be performed – and therefore paid – at local level. Solutions could be put in place to direct customer demand towards European businesses, for instance by clearly labelling where products are made or by whom a service is provided. Examples could be initiatives like 'Made in Europe' or call centres asking if the caller wants to speak with somebody based in the same country from which they are calling.

As workers' jobs could be put at risk by competition on a global scale, continuous professional development and lifelong learning courses should respond to this challenge. Other possible mitigation strategies to ensure a level playing field in a globalised labour market could include occupational licensing (Eurofound, 2018b), which makes access to certain jobs dependent on specific requirements such as formal qualifications.

Technological change should be viewed as an opportunity to adjust work processes and reorganise the production process and the provision of services to improve, rather than replace, workforce capacity. As more tasks become automated over time, tasks that are not replaced by machines are likely to change and could increase in value, while other new creative tasks requiring human talent may be created. In this transition period, further public and private research and monitoring is needed to ensure that workers and machines work together effectively.

Significant investment in skills at all levels is essential in this technological transition. As future jobs in the technological sphere will be constantly evolving, continuous and lifelong training should be at the core of a renewed EU strategy to address technological change. To stay ahead of global competition, the EU needs to solve two issues in particular: how to equip the new generation of workers with the right skills, both transferable and specific, and how to help workers whose jobs might be lost through the adoption of GCTs. A job might also not be lost entirely, but its task content might change to the degree that, for some workers, the new skills required are beyond the scope of a short-term course. A positive example of bridging the gap between vocational apprenticeships and higher-level jobs is the so-called 'higher apprenticeship' for advanced manufacturing. These apprenticeships are provided by higher education institutions in collaboration with companies that often fund these courses which are recognised by national qualification frameworks (Eurofound, 2019i). Notably, apprentices gain not only a valuable degree but also technical and soft skills necessary for their jobs. Another aspect that could be improved, according to the research, is the involvement of trade unions.

As of 2019, there is no consensus on whether education pathways should support the teaching of 'learning to learn' skills or whether they should focus on the acquisition of the skills demanded by the market (Cedefop, 2018). The latter option poses some significant problems: first, the market-driven skills currently in demand could become obsolete in a short time, and the work required to rearrange curricula often has a negative impact on the resources of education institutions. Second, as the onus of learning and upskilling is on the worker, lower-skilled workers are at risk of not engaging in learning opportunities and therefore being excluded from an evolving labour market.

Training policies should be based on close collaboration and synergies between industrial environments, social partners and governments, as well as education and training providers. Companies and research institutes also need to look ahead and work together in order to identify the skills and competencies needed in a constantly changing environment. Apprenticeship systems and vocational education and training need to be reoriented in line with these changes, and collective bargaining at all levels can play an important role in anticipating and managing change by establishing agreed training and skills policies.

Finally, public policies must intervene to ensure that technological change is a positive opportunity, rather than a source of inequality and a 'digital gap' on the labour market, but also in the society. If digital transformation is well organised, it can contribute to upwards convergence among EU countries and, ultimately, strengthen cohesion.

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Innovation and technological advancement are natural features of developed economies, and they are necessary to maintain and improve sustainable competitiveness in an era of globalisation. However, while most innovation tends to be incremental, some has a disruptive effect on production and service provision, the labour market and social dialogue. This report discusses a selection of eight so-called 'game-changing technologies' (advanced robotics, additive manufacturing, the Internet of Things, electric vehicles, autonomous vehicles, industrial biotechnologies, blockchain and virtual and augmented reality). Each of these has the potential to substantially change business activities, work and employment in Europe. Looking at both the manufacturing and services sectors, this report gives an indication of how these technologies might be adopted and how they are expected to affect the labour market.

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