JRC SCIENCE FOR POLICY REPORT

Digital Transformation
in Transport, Construction, Energy,
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DIGITAL TRANSFORMATION

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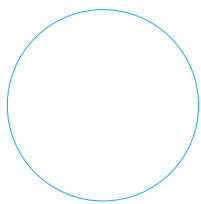
ABSTRACT / FOREWORD / EXECUTIVE SUMMARY

Abstract

This report provides an analysis of digital transformation (DT) in a selection of policy areas covering transport, construction, energy, and digital government and public administration. DT refers in the report to the profound changes that are taking place in all sectors of the economy and society as a result of the uptake and integration of digital technologies in every aspect of human life. Digital technologies are having increasing impacts on the way of living, of working, on communication, and on social interaction of a growing share of the population. DT is expected to be a strategic policy area for a number of years to come and there is an urgent need to be able to identify and address current and future challenges for the economy and society, evaluating impact and identifying areas requiring policy intervention. Because of the very wide range of interrelated domains to be considered when analysing DT, a multidisciplinary approach was adopted to produce this report, involving experts from different domains. For each of the four sectors that are covered, the report presents an overview of DT, DT enablers and barriers, its economic and social impacts, and concludes with the way forward for policy and future research.

Foreword

The present report was produced in the context of the project on "Digital Transformation and Artificial Intelligence" (DT&AI) launched by the JRC in 2018. The report analyses digital transformation in transport, construction, energy, and government and public administration.

Because of the very wide range of interrelated domains to be considered, a multidisciplinary approach was adopted, involving JRC and external experts in the different relevant domains.

In the context of the DT&AI project, JRC is also producing analyses focused on specific aspects of digital transformation, for example on artificial intelligence, internet of things, digital platforms, data ecosystems, etc.

Executive summary

This report provides an analysis of digital transformation in a selection of policy areas covering transport, construction, energy, and digital government and public administration. The report presents an overview of development of digital transformation in these sectors, its enablers and barriers, and its socio-economic impacts. It includes when feasible initial recommendations for more coherent policy development.

Digital transformation (DT) refers in this report to the profound changes that are taking place in the economy and society as a result of the uptake and integration of digital technologies in every aspect of human life. Digital technologies have become the foundation of all modern innovative economic and social systems. The transformation that results from the uptake of digital technologies is affecting all sectors of the economy and society. It is a cross-sector global transformation with both positive and negative effects. Besides the direct transformation of economic sectors, digital technologies are having increasing impacts on the way of living, on communication and on social interaction of a growing share of the population.

The consequences of DT will therefore affect almost all European policies, and DT is expected to be a strategic policy area for a number of years to come. DT is furthermore happening at increasing speed and there is an urgent need to be able to identify and address the current and future challenges for the economy and society, evaluating the impact and identifying areas requiring policy intervention.

Within this context, the present report was produced by the Joint Research Centre (JRC) of the European Commission (EC) to observe current DT developments and to explore future developments and their impacts, in line with JRC's role as the European Commission's science and knowledge service. To produce this report, we adopted a multidisciplinary approach that involved JRC researchers from different policy domains and external experts. A

related more focused report that provided a "European perspective on Artificial Intelligence" was published by JRC in December 2018 (Craglia et al., 2018).

In order to address DT potential and challenges with a systematic approach we developed a conceptual framework that includes four main sets of interacting components: EU values & objectives, policies, digital technologies, and socio-economic players. These socio-economic players can, either be impacted by DT, or themselves have an impact on the development of DT, or both. This simple yet comprehensive conceptual framework enables us to provide a map of the DT dynamic landscape, to organise the multidisciplinary analysis of DT around relevant topics, areas and actors, and to communicate more effectively. Our intention is to show to policy makers the need to study the interactions between digitalisation and the impacts on society and economy to be considered when new policy interventions are designed.

DT policies can be considered either in the context of specific "vertical" sectors, for example, transport, energy, construction, digital government, health, or agriculture, or "horizontally", for example in the domains of cybersecurity, privacy, data, IPR, telecom infrastructure, standardisation & interoperability, R&D & innovation, labour, skills, etc., since many DT policies have an impact on several sectors.

In the first part of the report we address several horizontal DT policy areas that are relevant to several sectors, such as, the legal debates raised by data ownership and access questions, the flourishing of online digital platforms, the evolution of cybersecurity, and recent territorial innovation developments in support of DT of industry across the EU. The following four parts of the report address DT policies in the context of four vertical sectors: transport, energy, construction, and digital government and public administration.

Overview of several horizontal Digital Transformation policy areas

DT, regardless of the sector concerned, goes together with an increased production of -and reliance upon- data, and this has triggered legal debates and new questions about *ownership of data*, in particular of machine-generated

data, and about *access to such data by others*. We observe that there is currently no legal or statutory title providing for ownership of data as such and that in practice data access, use and sharing are regulated at the contractual level on

the basis of a *de facto* (rather than legal) ownership; in general in this area "contract is king". We note that no recent economic research makes a clear case for creating new IP rights for data, and that many commentators agree that such creation would be premature in view of the numerous uncertainties about the consequences that such new right could have. Many consider however that some rules on access to data should be introduced. It seems that market operators view issues of access to (and re-use of) data as more important and more impacting for them than data ownership issues, and that sector-specific regulations should be preferred to a general "one size fits all" regime of access to data, at least as a first step. We argue that in the particular domain of data ownership and access, more economic research is needed in order to be able to offer suitable policy conclusions. This need for more research also applies to the more specific cases of access to data for scientific research or statistical purposes.

DT has led since the early nineties to the flourishing of *online –or digital- "platforms"* in many sectors of the economy. Notorious B2C and B2B examples are for example Amazon, Booking.com, or SAP. We observe that a key driver of the success of these new economic organisations is their ability to use data and algorithms to match users on two or more sides of the market and to lower transaction costs. Online platforms address a fundamental economic problem: how to coordinate supply and demand when information is imperfect, to reach the highest possible efficiency. We note that despite the large attention online platforms are given in media, policy and scientific research, they remain hard to define because they have characteristics of both firms and markets, they may be involved in both production and exchange, and they implement different co-ordination mechanisms. We observe that the competitive landscape of online platforms is determined by several factors, such as network effects, economies of scale, capacity constraints, degree of differentiation, and the possibility for users to use or not several competing platforms. We also observe that online platform ecosystems are prone to the appearance of leading players and that the above factors, if left alone, would lead to closed ecosystems. We argue that alternatively open platform ecosystems may achieve the full benefits of network effects and economies of scale, would increase intra-ecosystem competition, and would stimulate market entry through innovation. However, there is as yet no clear benchmark for efficient digital platform market structures. "Platformisation" of the economy is still a new, quickly developing, phenomenon. We note that, to date, most scientific contributions have been of a theoretical nature, that empirical research faces the problem of lack of appropriate data, and that, at best, evidence is still based on case studies, all of which complicate evidence-based policy-making.

DT and *Cybersecurity* co-evolve and influence each other in several aspects. We observe that DT exerts a deep influence on the threat actors that are behind cyberattacks, not only in their underlying motivations, but also in making their processes, businesses and attack vectors cheaper and more effective. Cyber-enabled crime has been profoundly transformed due to DT. We note that the increased digitalisation of society, governments and industry results in an enlargement of the global attack surface. It is nowadays hard to find a service or a product that does not contain a software layer or that does not depend on a digital service. In this globalised cyber-physical world, it is easier for cyberattackers to find and exploit vulnerabilities. Furthermore, increased digitalisation and global interconnections and dependencies result in higher potential impacts in case of successful cyberattacks, as experienced for example in 2017 with the WannaCry global ransomware outbreak that notably caused serious disruptions in the UK's heath system (NHS) with an estimated cost of GBP 92 million. Cyberattackers now have bigger potential rewards, which translates into higher motivations to conduct cyberattacks. For these reasons, we observe that cybersecurity is now a top priority for governments and businesses world-wide. Fortunately DT has also the potential to help mitigate cybersecurity risks by assisting those forces that act against cyber threats (e.g. deterrent actions, such as prosecution of cybercrime), vulnerabilities (e.g. identification of the vulnerabilities and software patching to correct them) and impacts (i.e. increased resilience). We argue that the challenge ahead lies precisely in ensuring that the positive effects of DT in cybersecurity will outweigh the negative ones.

European industry's level and pace of digitalisation vary considerably depending on company size, sector and country. The need to accelerate DT of the European industry led to the Digitising European Industry (DEI) policy initiative launched by the Commission in 2016. A key priority is to support the development of *Digital Innovation Hubs (DIH)* across the EU, to provide testing facilities, digital skills and training, support for investments and networking. In view of the already more than 260 fully operational DIHs (as of March 2019) and based on positive results, we can argue that even with a variable presence across EU countries and regions, DIHs technical competences and portfolio of services can effectively contribute to the DT of businesses, and in particular of SMEs. The DIH policy initiative is ongoing and in full development with an increased territorial focus and plans to have at least one DIH per EU region.

Digital Transformation in Transport

Digital technologies, together with connectivity and social media are currently transforming traditional concepts of mobility. In particular, new technologies and transport trends add new levels of interaction with the society and users, and may have considerable influence on people mobility and freight transport services. New business models are emerging and giving rise to innovative mobility services including new on-line platforms for freight operations, car-pooling, car or bicycle sharing services, or smartphone applications offering real-time analytics and data on traffic conditions. Vehicles themselves are also being transformed by digital technologies. They are becoming increasingly smart as new on-board connected and cooperative services and increased levels of automation become available, aided by Artificial Intelligence (AI) and the development of the Internet of Things (IoT). The advent of Connected and Automated Vehicles (CAVs) with advanced sensing and wireless communication abilities could represent the standard in private transportation by 2050. CAVs can contribute to increasing the efficiency and safety of the transport system. They can improve traffic flows, optimise infrastructure and public transport usage, and foster multi-modal transport solutions.

In the other transport modes (aviation, railway and maritime), connectivity and partial automation have been present in different forms, and have gained passengers' and stakeholders' trust. In aviation, automation has changed the roles of both pilots and air traffic controllers, now assuming the roles respectively of strategic managers and hands-off supervisors. Automatic train operation is well established on metro systems in Europe and around the world, and a further expansion is expected in main railway lines. In addition, autonomous ships are under development.

Parallel to the development of these technologies, a paradigm change in road mobility use is already on the way. Traditional ownership of petrol-powered cars is challenged by Mobility as a Service (MaaS), which represents a shift away from personally owned means of transport towards on-demand pay-per-use mobility solutions. The impact of MaaS is accelerated by societal,

economic and technological drivers. The sharing economy, big data and urbanisation are additional MaaS enablers. Widespread ownership-based car mobility remains however motivated by the high value given by people to the perceived reliability and accessibility of the transport service, rather than just its cost-effectiveness.

DT may also help developing Autonomous Mobility on Demand (AMOD) services that could supplement public transport networks where they are too expensive to operate (e.g., in sparse, peri-urban areas, but also at off-peak/night times). AMOD could have a synergistic impact on public transport, as it saves money and resources and can support the optimal operation of the system in other, core areas.

DT has enabled fundamental reinvention of the old production processes and service delivery. DT is already revolutionising manufacturing and the supply chain. New forms of more sustainable freight delivery (e.g. bicycle-based delivery services) appear as viable alternatives for (last-mile) delivery of goods. Sidewalk-based autonomous solutions are being developed and if scaled up to the city level could have a big impact. Delivery robots (ground drones) also seem to be making much progress at a city level. Air drones are promoted and supported by a growing number of firms nowadays as a valid alternative for last mile delivery in rural and suburban areas, with much progress made at legislation level.

Transport electrification assisted by DT can contribute to breaking transport dependency on oil and decrease tailpipe emissions. Network and traffic management systems based on digital technologies are used for the optimisation and management of the transport networks' operation.

Predicting future transport developments, whether they are on new transport technologies, new mobility approaches, demand changes, etc., is a constant challenge. Many of today's transport trends did not exist a few years ago. Ride-hailing service companies that use online platforms to connect between passengers and local drivers using their personal vehicles, did not exist 10 years ago while nowadays serve tens of millions of trips every day.

It is clear from the above that the transition to a new era of transport systems assisted by DT in the sector has a great disruptive potential. Nevertheless, there are potential issues such as data collection, and related challenges such as privacy and cybersecurity that need to be addressed through an appropriate policy framework, integrated with R&I actions

and the development of standards. Furthermore, the path to the digital transport era will not be quick and without pitfalls. Many technological, social and legislative barriers will need to be addressed. Standardisation issues for technologies that have not reached maturity (e.g. hyperloop technologies) and legal aspects for others (liability of automated vehicles, air-drones etc.) need to be addressed meticulously, in order to avoid future pitfalls, assist technology diffusion and achieve future safety and security goals. As in other domains, the challenge for regulators is to balance the need for technological progress and its many benefits with the safeguard of the fundamental rights and safety of the citizens.

To this aim, the European Commission (EC) is taking concrete steps. It launched the Cooperative Intelligent Transport Systems (C-ITS) initiative in 2016 to foster cooperative, connected and automated mobility, which lead to the adoption of five principles about granting access to in-vehicle data and resources. In May 2017, the second Mobility Package introduced the Strategic Transport Research and Innovation Agenda (STRIA), which has as an aim to determine the needs and set the objectives for what needs to be achieved in Europe's transport innovation system. The Transport Research and Innovation Monitoring and Information System (TRIMIS) is the analytical support tool for the establishment and implementation of STRIA. In May 2018, the EC presented the third Mobility Package with the objective to allow citizens to benefit from safer traffic, less polluting vehicles and more advanced technological solutions, while supporting the competitiveness of the EU industry. Particular focus is given in autonomous mobility that has the potential to make transport safer, more accessible, inclusive and sustainable. In March 2019, the EC adopted new rules stepping up the deployment of C-ITS in the form of a delegated act, which is based on the ITS Directive. The specifications establish the minimal legal requirements for interoperability between the different cooperative systems used. On 8th July 2019 the Council of the European Union however adopted a decision to object to the EC proposal for delegated regulation on C-ITS.

The design and implementation of governance, regulatory and public procurement strategies is required in order to support and strengthen the development of integrated planning tools and open, real-time data systems to allow for the validation and optimisation of integrated mobility eco-systems. The appropriate tools combined with the necessary data can indeed catalyse the transport system reform at all spatial levels.

Digital Transformation in Construction

The Architecture, Engineering, and Construction (AEC) sector is a key industry in the EU accounting for up to 9% of EU gross domestic product and providing 18 million direct jobs, i.e., more than 6% of European employment. However, this strategic sector for the world economy is lagging behind in terms of adoption of ICT and digital innovation compared to other sectors such as telecommunication or manufacturing industries. Whereas the design of buildings and infrastructures already relies on digital tools (e.g. computer-aided design (CAD) and structural analysis programs as well as budget and resource management software), the construction phase in particular lacks many of the potential benefits of more recent digital technology. The same adoption lag applies across the whole value chain in the AEC Sector (e.g. starting from Strategy and all the way up to Operation, Maintenance, and Repair - OM&R phases).

This report considers how new digital technologies can improve and change the AEC sector and the limitations that affect widespread adoption of innovative systems and methodologies.

Despite the seemingly low adoption rates, the potential of digital transformation in the AEC Sector is significant for the whole value chain. New technologies can disrupt the future of construction both due to the advent of Smart Buildings and Infrastructures as well as novel construction processes and business models. This will lead to significant improvements in terms of efficiency, competitiveness, and optimal use of resources. DT in the AEC sector is not only related to smoothing production processes by providing more efficient data handling, but also encompasses novel production technologies (e.g. additive manufacturing) that would not exist without the advent of ICT technologies.

The *disruptive technologies* for the AEC sector can be identified as follows:

— Sensors
— Internet of Things (IoT)
— Mobile Internet
— Additive manufacturing
— Automation
— 3D scanning
— Drones

— Building Information Modelling (BIM)
— Virtual and Augmented reality Artificial intelligence

These technologies can be disruptive in the way they introduce new business models while providing considerable advantages in terms of cost savings, productivity, improved quality and innovative services. The modern construction sector is already changing with companies shifting their core business from the physical construction process to reconfiguring their structure as service providers.

Adoption of alternative technologies, which include new materials (composites, hybrids and engineered materials), new construction technologies (such as 3D printing and robotized assemblies), and distributed sensor networks will shape the drive for more sustainable, inter-connected buildings and infrastructures. In tandem with these, artificial intelligence (AI) will deal with the massive amounts of data generated for more effective management of resources.

The real flow of disruptive digital technologies in the AEC Sector can therefore be represented as: data acquisition, digital information and analysis, and automation of processes. The availability of unprecedented amounts of data from sensors and connected devices (IoT) in the construction sector along with georeferenced data (i.e. implementation using GIS) will allow an ever increasing number of analysis services to improve productivity in the construction process as well as in real estate, commerce, urban dynamics and services.

Data Science (or Data Analytics) is therefore crucial to linking all of the innovative technologies in this sector and so the availability of data during construction or operation of the infrastructure will be crucial and will lead to significant improvements and transformations in the way work is done. The added value of knowing exactly what is happening in a site through data collation and matching it to complementary databases and data sources will be very valuable.

Automation of the construction process by adopting robotics, additive manufacturing, 3D measuring systems, and drones are key technologies for the sector.

The installation of sensor networks for monitoring buildings and infrastructures and the adoption of IoT devices, mobile Internet, and drones with integration into AI based management systems are essential for the paradigm shift of construction into services offering novel opportunities for the efficient management of buildings and lower energy consumption.

The digitisation of the physical dimensions of real world structures (3D scanning) contributes to the digitalisation of the whole process when associated to Building Information Modelling (BIM). BIM is fundamental for the digital transformation of AEC: from the initial investment and call for tenders, to the design phase and planning, the construction phase (procurement and supply chain, construction site management) and, after completion, the OM&R phase (asset, property, and facility management).

Despite its importance, the AEC sector is facing challenges in innovation, increasing productivity, and attracting new skilled workforce. This sector has been a slow adopter of new technologies, in particular, ICT and innovation has suffered from past economic crises, and the fragmentation of the market, with a small number of large enterprises investing in R&D and a large group of SMEs with too small profit margins to invest in modernization, represents a major obstacle. Moreover, the sector is facing low attractiveness to younger professionals (more technology oriented) and ageing skilled workers, both inducing problems of workforce recruitment and availability to meet current and future demand.

Education is one of the key factors for the European AEC sector to prevent skill shortage. Scarcity of training and higher education profiles really knowing the technology in the construction sector is high. University programs must be modified to include these specialities in Digital Technologies. These needs are currently covered by industrial or telecommunications engineers but ICT and novel hub technology skills must be learnt by civil engineers and architects in the AEC Sector.

The expected increase in the construction market in the next few years calls for increased productivity that can only be achieved through a paradigm shift away from the traditional approach to a fully exploited digital transformation of the sector throughout the whole value chain. The European AEC sector is already adopting digital innovation, but the EU construction industry is calling directly for policy makers to support and lead the digital transformation of the European AEC sector, develop a specific regulatory framework on data policy, and support in the development of digital skills, research, and IT infrastructure.

However, the implementation of ICT and new technologies in general requires initial investment in IT infrastructure whereas the fragmentation of the European AEC market (consisting of a multitude of SMEs and a handful of very large big players) creates another barrier to broadening and homogenising digitalisation of the sector. New technologies are being supported at national and EU level—the Digital Single Market among others—but the high initial investments tends to reflect the sector fragmentation leaving the major companies as the only innovators. Programmes to support SMEs in the adoption of ICT technologies will be strategic in homogenising the level of digitalisation in the AEC.

Furthermore, the legal aspects of shared use of BIM must be clearly addressed to ensure data ownership and avoid disputes. Legal barriers for the full adoption of BIM must be addressed by specific legislation and solutions harmonized across Member States. Moreover, the need to ensure data privacy and confidentiality would suggest that the implementation of EU Cloud systems for both sensors and BIM projects would be highly beneficial.

The adoption of new technologies in itself cannot provide the AEC sector with improved productivity and efficiency: the business model must also change and be innovative. The construction industry business model has primarily been based on industrial logistics but is progressively transforming into a service model. A clear example of the digitally driven change in the sector is represented by the advent of digital platforms and a radical change in the business model.

Finally, and importantly, innovation methods and new technologies for workers must be assessed in terms of safety and security by developing new procedures, legislation, certification, and testing to address their uniqueness. Moreover, the development of new construction techniques (e.g. 3D printing) and automatization should be anticipated by appropriate testing, dedicated standards, and building codes. The JRC is active in supporting policies in the construction

sector with ongoing scientific research in the field (smart buildings, wireless sensor networks, safety, and security of buildings) supported by unique testing facilities, and it can contribute to smoother introduction of innovative technologies in AEC.

Considering the rapid evolution of new technologies and the critical need to adopt them in the construction sector, Governments should ensure constant and effective communication with companies and innovators and facilitate the elimination of barriers to innovation.

Digital Transformation in Energy

The European Union is moving towards the creation of a fully-integrated internal energy market to ensure a safe, viable, accessible to all and climate neutral energy supply.

The EU's Energy Union strategy is made of five dimensions:

— Security, solidarity and trust
— A fully-integrated internal energy market
— Energy efficiency
— Climate action and decarbonising the economy
— Research, innovation and competitiveness.

The Energy Union aims at diversifying Europe's energy sources as a way to enhance energy security, and at eliminating regulatory and technical barriers that prevent frictionless flow of energy in within Union.

To achieve the Energy Union, a transformation of the energy system is necessary. Decarbonisation and climate action require a gradual phase-out of fossil energy sources and the integration of renewable energy sources in the energy mix. This will also reduce EU dependency on energy imports and create a market for research and innovation to boost growth and competiveness.

The transformation of the energy system will affect the way in which energy is produced, transmitted, distributed and consumed. The system must become more "intelligent" and flexible in order to integrate energy sources that have different behaviours and technical characteristics compared to traditional ones.

New functions such as time-decoupling of production and consumption though storage, demand side management, flexibility, efficiency, exploitation of distributed resources, and market clearing at prosumers' level are necessary. These new functions, in turn, require the use of new technologies and infrastructures. Smart meters, power electronics, smart grids at the distribution and transmission level are only some of the pre-requisites for the implementation of the functionalities needed for the energy transition. The new infrastructure must cater to the communication needs of prosumers, Distribution System Operators, Transmission System Operators, aggregators and of the devices that participate in the system.

The combination and interconnection of these new technologies, paradigms, services and devices require an energy distribution infrastructure and data exchange channels and platforms. Not only energy, but also data must flow freely in the system. All players and devices in the new energy system need to be able to communicate bi-directionally.

To support this, a new consistent European framework must be developed. It must consider the technological aspects but also matters of social acceptance and business models. The framework will allow the management of interactions with all energy commodities and non-energy sectors like water, finance and transport. New technologies such as Advanced Metering Infrastructure, electronic ledgers, the Internet of Things, Artificial Intelligence must be integrated in the new framework.

In this context, DT of the energy sector, in terms of technologies, infrastructures and services, is emerging as the crucial enabler of the energy transition.

Digital Transformation in Government and Public Administration

DT of government and public administration is nowadays often referred to as "digital government" (rather than simply "eGovernment") in order to highlight the potential of digital technologies for contributing to a more open,

participatory, trustful and innovative government and public administration. Contrasting with the case of industrial and commercial sectors, the constitutional roles and functions that public institutions fulfil in the society under the rule of law and the legal, financial and political dimensions that characterise government and public administration require adequate approaches and terminology, in line with these characteristics. This report provides an overview of policy initiatives, concepts, benefits and challenges regarding DT in government and public administration, and suggests multidisciplinary scientific research to adequately support policies and to understand impacts.

The main functions of governments are policy design, implementation and administration, through policy instruments encoded in law by the relevant national or regional legislators. Public administration executes the law provisions under the rule of law. DT occurs in governments and public administrations in the general context of exercising their legislative, executive and judiciary powers, which incidentally also include design of specific policies underpinning DT of the entire economy and society.

By its attributions and responsibilities, the public sector is a major economic actor in society, contributing to growth, delivering goods and services (roads, parks, broadcasting, utilities, health, education, security, etc.), regulating behaviour (law, permissions, information campaigns, etc.), and redistributing income between citizens, public or private entities (subsidies, grants, etc.). DT does not change the nature of the public functions, but it changes their costs, the way of doing, processing, communicating, and adds new requirements and partnerships. The approach to explore, analyse, plan or measure DT in this sector should then be from the perspective of policy design and implementation, where technology-enabled policy instruments are put in place at the design phase, considering which technology development fits better each different instrument type and aim, under the specific policy goal and socio-economic context.

DT in the public sector is also confronted with the complexity characterising the necessary alignment and coordination of a variety of public bodies at all levels of governance under a common strategy, recognised leaderships and acknowledged collaborative culture, while keeping accountability, stability and citizens' engagement. Good governance rules are fundamental for DT of governments and public administration, although there is no leading model of governance for digital government,

as demonstrated by the analysis of several national governance structures.

In line with the EU principles of subsidiarity and proportionality, the main responsibility for implementing digital government practices lies with the Member States. However the EU plays an important role by associating DT to the broader policy objectives of realisation of the Digital Single Market, putting in place common policies enabling DT and innovation, removing barriers, while promoting the development of technological and conceptual solutions and guarantying the policy coherence across sectors regarding digitally transformation in society.

Public sector reform is a constitutional policy and legal matter to which DT must contribute without friction in order to effectively support change. Innovation relates to how to positively incorporate digital technology into this specific environment. Opportunities resulting from DT of the public sector are potentially huge but technology cannot be uncritically applied. New technologies adoption in the public sector raises challenges that policy and research have to address with robust and rigorous evaluation, looking at the legislative, political, accountability, transparency, scrutiny and non-discrimination aspects. Implementing solutions based on emerging technologies also require from governments and regulation bodies the protection and respect of citizens' rights, freedoms and values. The research agenda in this domain is therefore significant.

Examples include the use of AI and data sharing. AI solutions hold remarkable potential benefits for both the public and the private sector, also helping to address societal and environmental challenges, but expected benefits may be negated by the variety of risks for individuals (discrimination, unfair practices, loss of autonomy, etc.), for the economy (unfair practices, limited access to markets, etc.), and society as a whole (manipulation, threat to democracy, etc.), if these risks are not addressed. Data is a fundamental asset for policy making and a fundamental resource within DT. Different data sets can be governed by different legislation and their use have different political accountabilities, determined legally or constitutionally. This consideration is important in data governance, as well as regarding open data policies.

Digital technologies are introduced in policy making, in design of policy instruments, and in the interaction, communication and engagement with citizens, private

entities and NGOs, where they enable innovation at different levels, new partnerships and new business models. Empowering beneficiaries and communities by informing and engaging them through online channels, social media platforms, or smartphones, or in providing feedback on services' content and quality, has a social impact not yet measured.

Government and public administration take measures to avoid digital exclusion, reducing this gap with various specific solutions, while acting on other related policies like reforming the national education system. Converting the digital challenges in opportunities for the society can be addressed by the policy makers and research.

DT of government services and public administrations can also result in higher potential cybersecurity risks.

Different speeds and paths for DT inevitably occur from country to country. Also within a country DT may not happen equally in all administrative regions and at all levels of administration. Therefore, at a certain point in time, the impact of digital government differs between countries but may also differ within them.

DT generates new relationships and dynamics, involving actors and resources outside public organisations, and modifying the ways by which the value embedded in the services is produced. Economic impacts of DT can be seen within the functioning and efficiency of the public sector, including all its attributed roles. But it is also relevant to consider the economic impact that digital government policy design and implementation have on other policy areas and on businesses.

Economic and social impacts of DT for many aspects have to be seen together as they influence each other. A multiplicity of factors, national and local contextual situations and diversity of inter-related areas, make the impact evaluation a complex and multi-metrics exercise with different time scales, involving simultaneously quantitative and qualitative dimensions.

A comprehensive overview of the social impact of DT should cover three distinct areas which may be part of the future research agenda:

— the impact of technology used in society on the processes of governing, for example social networks;
— the impact of technology on society that needs a policy intervention e.g. regulatory, information campaign;
— the impact on society of the use of digital technology within policy-making, politics and/or public adminis-tration.

Empirical observations, perceptions, philosophies or partial analysis cannot replace the coherent, multidimensional and rigorous scientific approach systematically planned and conducted by interdisciplinary teams.

Conclusions: The way forward for policy and research

It is clear from the analyses provided in this report that DT has a great disruptive potential that can bring many benefits. Nevertheless DT may also have negative effects, and many technological, social and legislative aspects need to be addressed through appropriate policies.

DT is therefore expected to be a strategic European policy area for a number of years to come. Clearly national policies will also be profoundly impacted. The challenge for regulators is to balance, on the one hand, technological progress and the many benefits DT can bring to the economy and society, and on the other one, addressing negative effects of DT and safeguarding fundamental rights of the citizens according to EU fundamental values.

As indicated in this report, the European Commission has already taken in recent years many concrete actions in order to ensure that European economy and society can benefit from the positive effects of DT, while mitigating the impact of negative ones. The new von der Leyen Commission will continue these efforts and intends to develop a digital policy agenda on 'a Europe fit for the digital age.'

Research, to observe and explore current and future DT developments and to analyse their impacts, is crucial in order to support evidence-based policy making. JRC will continue to contribute to this important domain.

1 INTRODUCTION, CONCEPTUAL FRAMEWORK AND HORIZONTAL POLICY ISSUES

① INTRODUCTION, CONCEPTUAL FRAMEWORK AND HORIZONTAL POLICY ISSUES

1.1 | Introduction

The main purpose of this report is to provide an analysis of digital transformation in a selection of sectors, of its socio-economic impacts, and when feasible, to include initial recommendations for more coherent policy development.

This report covers digital transformation in three key economic sectors – transport, construction, and energy – and in digital government and public administration.

In the context of this analysis, *digital transformation* refers to the profound changes that are taking place in the economy and society as a result of the uptake and integration of digital technologies in every aspect of human life.

1.1.1. The importance of digital transformation for Europe's future, and of understanding its implications

Digital technologies have become the foundation of all innovative modern economic and social systems. In the 2017 European Commission reflection paper on "Harnessing Globalisation", digitalisation is mentioned as one of the main issues influencing globalisation in 2025, affecting all sectors of the economy at the global level (European Commission, 2017a). This marks a significant difference from previous waves of technological innovation which tended to affect one specific sector at

a time, making it possible for displaced workers to find jobs in other sectors. However, this time the effects on both economy and society are likely to be deeper because of their global, cross-sector nature. Indeed, besides the direct transformation of economic sectors, digitalisation changes the society by impacting on the way of living, on communication, and on the social interaction of an increasing proportion of the population.

The consequences of digital transformation (DT) will therefore affect almost all European policies. DT is expected to be a strategic policy area for the next years. For example, its importance for Europe's future was recognised by the European Commission in its May 2018 multi-annual budget proposal for the European Union for 2021-2027 by including an almost 9 fold increase of investments in DT and networks to reach €12 billion.[1] A new Digital Europe Programme was announced that identifies Artificial Intelligence (AI), Cybersecurity, and High Performance Computing as key strategic areas for Europe.

The development of AI technologies in particular is recognised as one of the most important enablers,

increasingly transforming every aspect of society, and therefore deserving a specific focus within the broader scope of DT developments, as addressed in two communications on the European AI strategy published by the Commission in April and December 2018 (European Commission, 2018a and 2018b).

DT is already having a profound impact and is also occurring at increasing speed and there is an urgent need to identify and address the current and future challenges for the economy and society, evaluating the impact and identifying areas requiring policy intervention.

1.1.2. JRC report on digital transformation

The present report was produced in the context of the JRC Digital Transformation and Artificial Intelligence project (see Box 1.1). It covers DT in the following areas:

— Transport, a large economic sector with a wide spectrum of interconnected devices and systems that ensure the mobility of people and goods. Digital technologies and services are transforming traditional concepts of mobility (e.g. new and for sometimes disruptive on-line platforms). Vehicles and transport infrastructures are also being transformed by digital technologies.
— Construction, a sector in which there are significant opportunities for the whole value chain to benefit

from DT, despite the rather slow pace of adoption of digital technologies by this sector until now. While digital technologies applied to the construction sector can be disruptive, at the same time they can provides considerable advantages in terms of cost savings, safety, productivity, improved quality, and innovative services.
— Energy, a sector in which decentralization and decarbonisation of supply must be supported by a digitalisation process in order to keep the energy supply secure, affordable, stable, and sustainable. The "Clean Energy for all Europeans" package pushes innovation in the direction of energy efficiency, demand response, small-scale generation at consumer level,

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[1] See "EU budget for the future" at: https://ec.europa.eu/commission/priorities/democratic-change/future-europe/eu-budget-future_en

and aims to create markets for this increased flexibility. Digital technologies are also instrumental in creating new energy services and products.

— Government and public administration, a sector which is a major economic and societal actor delivering goods and services, regulating behaviour, collecting and redistributing funds and resources, and contributing to growth and inclusion. This crucial role of government and public administration regulates and affects the entire society and economy, and makes DT in the public sector particularly worthy of attention. DT changes the way data is generated and processed, offering new options to deliver public services, and changes interaction with citizens.

Box 1.1
The JRC digital transformation and artificial intelligence project

Because of the importance of DT for Europe's future, it is essential, relevant, and timely for the European Commission's Joint Research Centre (JRC) to observe current DT developments and to explore future developments and their impacts, in line with JRC's role as the European Commission's science and knowledge service. Observation, exploration, and analysis of impacts are the main objectives of the project "Digital Transformation and Artificial Intelligence" (DT&AI) launched by the JRC in 2018 with the aim of informing policy makers.

The present report was produced in the context of this project. In 2018, the project also produced a flagship publication providing a European perspective on Artificial Intelligence (Craglia et al., 2018). Activities of the DT&AI project are continuing and expanding in 2019. Notably, the JRC is setting up a knowledge service, AI Watch, which will monitor on-going and future development, uptake, and impact of AI in Europe.[2] Other important digital technologies, for example, blockchain, internet of things (IoT), application programming interfaces (APIs), are also being analysed by the JRC.

Because of the very wide range of interrelated domains to be considered when analysing DT, as shown in Figure 1.1, a multidisciplinary approach was adopted in the project. DT in the various policy areas is investigated by the relevant JRC experts on thematic policy areas and on horizontal cross-cutting issues, working in close collaboration. External experts also contribute.
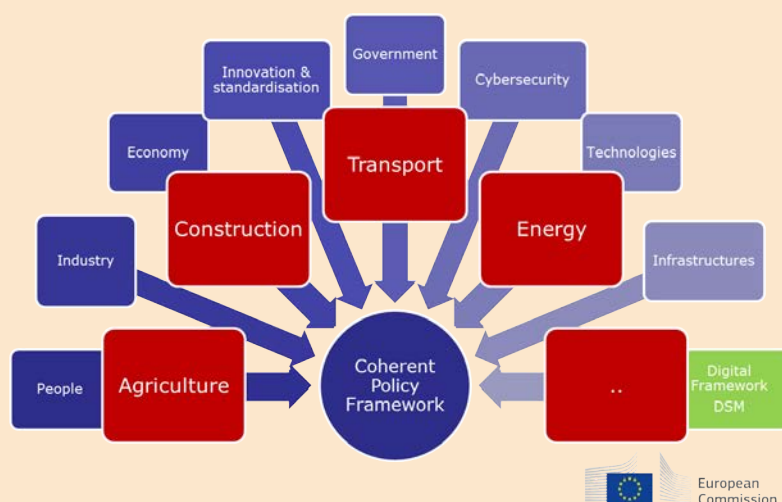
FIGURE 1.1: ANALYSING DIGITAL TRANSFORMATION: THE NEED FOR A MULTI-DISCIPLINARY APPROACH.
Source: JRC analysis.

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[2] https://ec.europa.eu/knowledge4policy/ai-watch_en

1.1.3. Structure of the report

This report includes the following five parts:

— The first part includes the present introduction, followed by a description of the conceptual framework proposed to analyse DT, and by a general overview of several horizontal policy issues linked to DT: legal issues on data ownership and access, digital platforms, cybersecurity, and territorial aspects linked to digital innovation.

— The other parts of the report cover DT development and impact in the four sectoral policy areas mentioned above: transport, construction, energy, and government and public administration. The four thematic parts follow the common structure shown in Figure 1.2, including a general overview of DT in the policy area, enablers of DT and barriers, and economic and social impacts of DT, finally concluding with the way forward for policy and future research. In the section on government and public administration, focus is given on governance models rather than business models.

The report ends with overall conclusions on the way forward for policy and research.

Chapter 1: Overview of DT in [Policy Area]
Chapter 2: DT Enablers and Barriers in [Policy Area]
2.1. Technology Infrastructure
2.2. Standardisation & Legal Framework
2.3. Innovation, Business models and Skills
Chapter 3: Impacts of DT in [Policy Area]
3.1. Economic impacts
3.2. Social impacts
Chapter 4: Conclusions: Way forward for Policy and Research

FIGURE 1.2: COMMON STRUCTURE OF THE SECTIONS REPORTING ON DIGITAL TRANSFORMATION IN A SPECIFIC SECTORAL POLICY AREA.

1.2 | A Conceptual Framework for Analysing Digital Transformation

A common conceptual framework to capture DT evolution, dynamics, trends, and impacts is required in order to address DT potential and challenges with a systematic approach.

DT is rapidly shaping the complex techno-socio-economic ecosystems at the basis of our society and economy (education, employment, markets, governance etc.). There is a need to study the dynamics, interactions, models, actors, and influencing factors in digitalisation, and its profound impact on our society and economy. An important goal of this exercise is to show to policy makers that all of these aspects need to be considered when designing and implementing new policy interventions.

The conceptual framework should therefore serve the following purpose:

1. *Provide a map of the landscape.* The framework should provide a holistic overview of the entire DT landscape in terms of actors, technologies, sectors, policies, and underlying values. It should show the interaction and dynamics between its various components and identify the influencing factors and sectors and actors impacted.

2. *Organise the multidisciplinary analysis of DT* on the basis of relevant topics, areas, and actors in a complementary fashion. The framework should help in organising a multidisciplinary analysis of DT and positioning the various contributions within the wider picture of DT.

3. *Communicate effectively.* The framework should show the need to study the interactions between
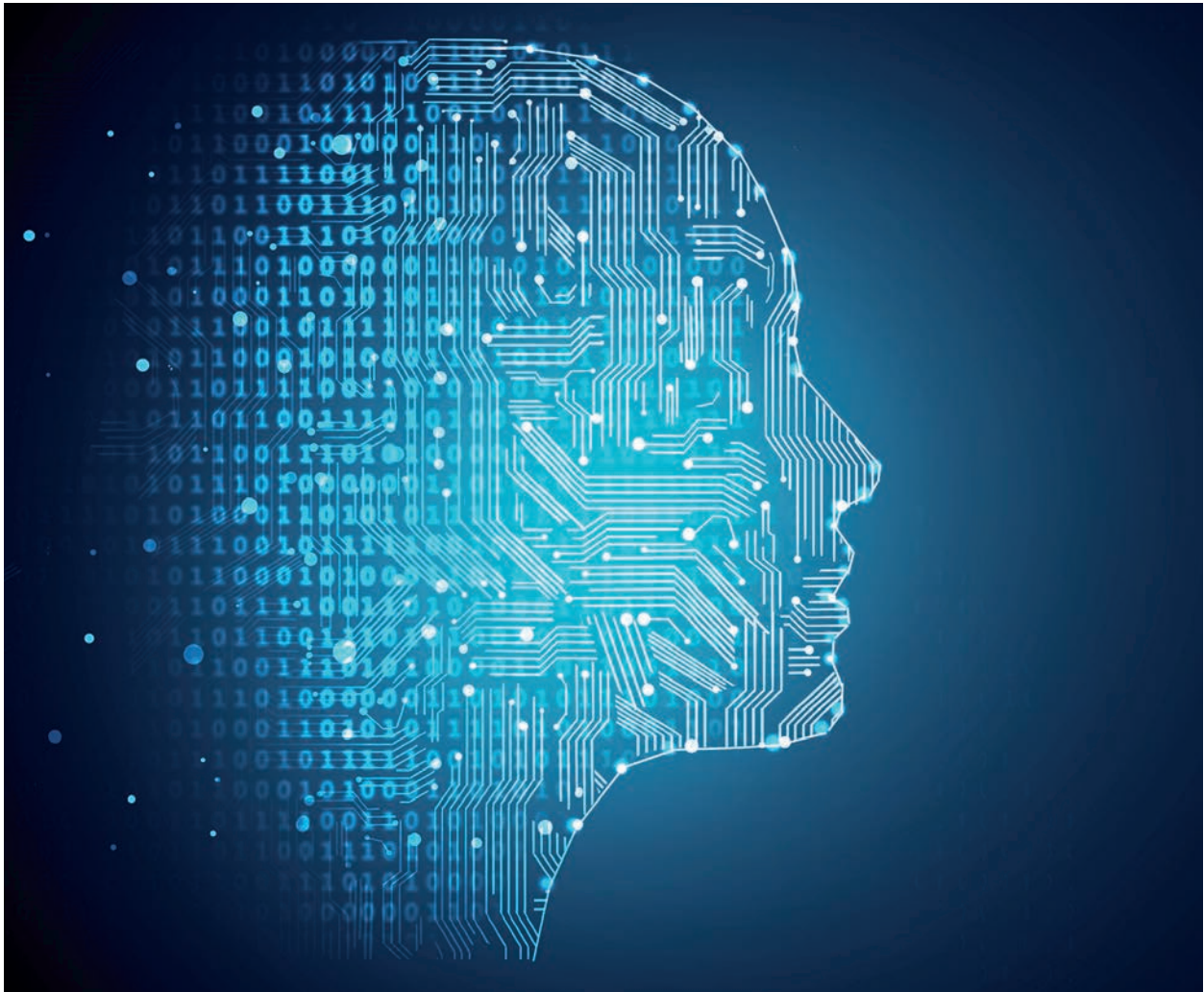
digitalisation and the impacts on society and economy that policy makers need to consider when new policy interventions are designed. It should also facilitate effective communication of the project to a wider public, both inside and outside the European Commission.

1.2.1. The proposed framework

A simple, yet comprehensive, conceptual framework to analyse DT is therefore proposed in Figure 1.3 below.

As shown in the figure, the proposed framework has four main sets of interdependent and interacting components:

— EU values & objectives
— Policies
— Digital technologies
— The different socio-economic players in our society, economy, government & public administration, and our environment.
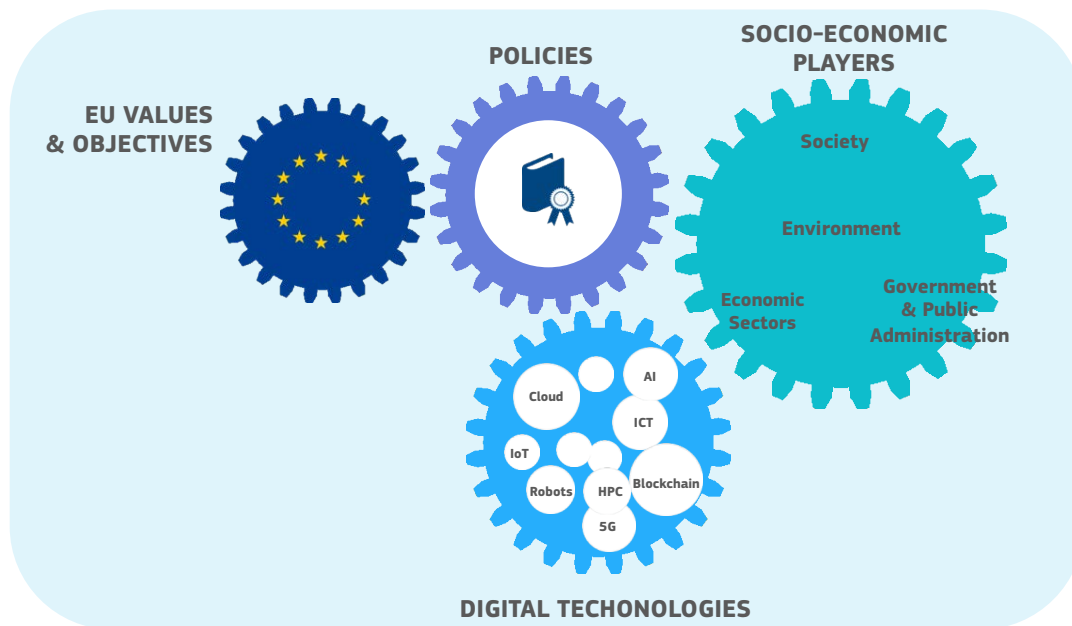
FIGURE 1.3: PROPOSED CONCEPTUAL FRAMEWORK TO ANALYSE DIGITAL TRANSFORMATION.
Source: JRC analysis.

1.2.2. Framework components

Framework components and their interactions are briefly described below.

— EU Values & Objectives form our starting point. We share the following fundamental values in the European Union: respect for human dignity and human rights, freedom, democracy, equality, and the rule of law.[3] These values officially unite all of the EU Member States. Countries outside of the EU may also share all or some of these values or have different ones. These fundamental values drive EU policies, and there are other important values and objectives that drive EU policies such as well-being, environment preservation, growth and jobs, fairness, privacy, etc. These values and objectives should be reference points when analysing DT.

— Two categories of policy areas should be considered when analysing DT:
  • Sectoral policy areas, for example, transport, energy, construction, digital government, health, agriculture, etc., which can also be identified as "vertical" policy areas.
  • "Horizontal" policies areas that impact on all vertical sectors and are closely linked to digital technologies

and DT. For example, cybersecurity, privacy, data, IPR, telecom infrastructure, standardisation & interoperability, R&D & innovation, labour, skills, etc.

— Digital infrastructure and digital technologies are the technical backbone and key enablers of DT. New digital technologies, networks, and services are constantly being developed, and this set of components is certainly the most dynamic of the whole framework.

— The fourth set of components considered in the framework encompasses the players in the overall socio-economic-environmental ecosystems who are both impacted by DT and impact DT, and who include:
  • the entire society where individual people and civil society organisations have different roles as, for example, citizens, producers, workers, volunteers, consumers, influencers, etc.
  • all economic sectors such as the three sectors analysed in this report, and also others such as health, agriculture, retail, finance, etc.
  • the various sectors of government and public administration,
  • our living environment (urban, rural, maritime, etc.).

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[3]   EU fundamental values: https://europa.eu/european-union/about-eu/eu-in-brief_en

1.2.3. Interactions between components in the conceptual framework

Interactions, movements, and forces between these components are conceptualised by the interconnected wheels shown in Figure 1.3. The following interactions provide some meaningful examples:

— EU values and objectives drive all EU policies and initiatives. Values are indeed important drivers of technological and socio-economic developments and have clear transformative effects. Values and societal objectives in the EU such as fairness, green economy, health and wellbeing, and security are important in guiding policies and the resulting transformation.
— By nature sectoral policies have a direct impact on society, economy, government, and the environment. They also have an impact on the development of the digital infrastructure and technologies, and vice-versa.
— Horizontal policies closely linked to DT have a direct impact on the development of the digital infrastructure and on digital technologies, and also impact on society, the economy, government, and the environment. Likewise, the potentialities, challenges, and changes in the various segments of what are nowadays complex ecosystems will have an impact in shaping new policies.
— EU and national policies in general have an impact as enablers or drivers, but also as obstacles or barriers. Examples of enabling policies include setting incentives, funding research and innovation, investing in infrastructure, governmental procurement strategy, regulation, etc.
— The digital infrastructure and digital technologies are the building blocks and key enablers of the DT in society, the economy, and governments. This does not exclude the role of non-digital technologies: digital technologies increasingly interact or are embedded in traditionally non-digital products or systems. Digital innovation involving the necessary organisational, social, and political changes in the players' ecosystems is a necessary link between digital technologies and the outcome of digital transformation which should create value.

It is easy to see from the considerations outlined above that these interactions also include feedback effects, for example:

— Actors in society, the economy, and government are impacted by DT, but at the same time, have an impact as enablers, co-designers, drivers, or obstacles on the development of digital infrastructure and technologies, for example, as users, developers, innovators, researchers, creators, funders, lobbyists, opinion groups, influencers, etc.

— Many policies are and will be impacted by the DT. Changes in society, economy and government caused by DT will result in the need to revise policies (vertical and horizontal), including specific policies to mitigate and compensate for the negative effects of the DT.

— Changes in EU society caused by the DT will also lead to an evolution of EU values and objectives, for example on privacy, etc.

1.2.4. The way forward

The above framework was developed in order to provide an overview of the linkages between values, policies, technologies, and the socio-economic-environmental ecosystem. Our aim was to deliberately keep the framework simple and understandable rather than to produce an ultimate and exhaustive model that would be too complex to serve its purpose. This explains why the diagram in Figure 1.3 does not explicitly show comprehensive and detailed lists of actors, economic and policy areas, or the interactions mentioned above.

Yet, this framework is meant to provide enough ground to make an analysis of the impact of the DT possible and to show the dynamics and interactions between the various components, which will need to be taken into account when designing, developing, and implementing EU Policies.

Because DT is a dynamic phenomenon, new components and interactions may clearly complement the proposed framework.

We realise that the conceptual framework presented here may be too high-level or too generic to be applied directly to particular sectors. To have a simple model does not eliminate the complexity of phenomena; further conceptual details may be necessary to catch the drivers, impacts, and trends. This framework can therefore also be used as a starting point that then enables analysts to "zoom in" on specific sets of components (policies, actors, sectors) and on the various interactions between them to provide a more detailed view when necessary. It can also lay the foundations for further research to identifying possible indicators and influencing factors in digital transformation.

1.3 | Horizontal policy issues in digital transformation

This section reviews several of the digital transformation policy issues that are not specific to a particular economic sector but are relevant to several sectors. The issues covered below relate to legal aspects of data ownership and access, digital platforms, cybersecurity, and territorial innovation support via digital innovation hubs. In addition to the general discussion below, aspects and examples specific to the sectors covered in the report can be found in the relevant sections of the report.

1.3.1. Legal issues with ownership of and access to data

Amongst the legal issues of relevance to the topic of this report, it was decided to concentrate on a somewhat horizontal issue, i.e. ownership of and access to data. Regardless of the sector concerned, digital transformation goes hand-in-hand with increased production of and reliance on data.

The issue of ownership and access to data has triggered legal debates and new questions about ownership of data, in particular of machine-generated data, and about access to such data by others [4] [5] – *"Data is funny stuff in legal terms"* [6].

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[4] This contribution is partly based on a text written by Maria Iglesias (Iglesias, 2018).
[5] For an overview of the academic discussion in a number of European countries (France, Germany, UK, Spain), see Osborne Clarke (2016).
[6] (Kemp, R., Hinton, P., Garland, P., 2011) p. 142.

Privacy and personal data protection are beyond the scope of this section, which focuses on intellectual property rights.

In addition to the text below on data ownership and access in general, some aspects specific to the sectors covered in the report can be found in the relevant sections of the report.

1.3.1.1. *The debate on ownership of data*

There is currently no legal or statutory title providing for ownership of data[7] as such (either from traditional property rights or as intellectual property since data *per se* is not copyrightable or patentable subject matter) even though under certain circumstances data is protected by the database's *sui generis*[8] right or by the trade secrets directive[9] provided certain conditions are met[10]. Copyright does not protect information as such, and only applies to a work that is original in the sense that it is an "author's own intellectual creation" (this would not be the case with a dataset of machine-generated data). The *sui generis* right of the producer of databases applies if the collection of the (*existing*) data required a substantial investment, but does not apply to the creation of *new* data and commentators do not agree on the important question of whether data collected by sensors are "collected" (in which case they could benefit from the *sui generis* right) or "created" (in which case they could not).[11]

In practice, negotiations and arrangements on data access, use and sharing, in a large number of cases, are regulated at the contractual level on the basis of a *de facto* (rather than legal) ownership. In general in this area, "*contract is king*"[12], and the Court of Justice of the European Union has confirmed the binding character and validity of contracts in such cases, while recalling that these issues were governed by Member States law[13].

The lack of a comprehensive legal framework for machine generated data was raised in the "Communication on building the data economy" where the Commission put forward a series of legislative and non-legislative options for discussion, including the creation of a new data producer's right[14].

This idea no longer appears in the follow up of the Communication "Towards a common European data space"[15]. The EC has instead focused on access to data and adopted various measures such as a proposal to review the PSI Directive,[16] an updated recommendation on access to and preservation of scientific information, and a guidance document on business-to-business and business- to-government exchanges.

However, at national level, for example, the German government still has this issue on the policy agenda. The Coalition agreement announced the willingness of the new government to clarify "*whether and how data ownership can be structured*"[17].

To what extent there is a need to create a new IP right to incentivise the production and collection of data and (more fundamentally) to encourage data commercialisation[18] or data access is a question that has been explored by scholars with opposing views.

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[7] For a review of the legal framework in the various Member States, see Osborne Clarke (2016). Also relevant, the state of play carried out by (Deloitte et al., 2017).

[8] Directive 96/9/EC of the European Parliament and of the Council of of 11 March 1996 on the legal protection of databases.

[9] Directive (EU) 2016/943 of the European Parliament and of the Council of 8 June 2016 on the protection of undisclosed know-how and business information (trade secrets) against their unlawful acquisition, use, and disclosure.

[10] (Hoeren, 2014) p. 751 et s.; (Mezzanotte, 2018) p.165.

[11] (JIIP, 2018) p. 111; (Mezzanotte, 2018) p.166.

[12] (Kemp, R., Hinton, P., Garland, P., 2011) p. 142; also (Osborne Clarke, 2016) p. 83.

[13] See Case C-30/14, Ryanair Ltd v PR Aviation BV.

[14] COM(2017) 9 final Brussels, 10.1.2017; see also Staff Working Document on the free flow of data and emerging issues of the European data economy.

[15] On the contrary, the Communication reads " *In general, stakeholders also do not favour a new 'data ownership' type of right, with a range of inputs indicating that the crucial question in business-to-business sharing is not so much about ownership, but about how access is organized*".

[16] Directive on the re-use of public sector information.

[17] Cited in (Hoeren, 2018) p. 47. Original Version of the Coalition agreement can be found at https://www.bundesregierung.de/Content/DE/_Anlagen/2018/03/2018-03-14-koalitionsvertrag.pdf. The author also recalls that "*In May 2017, the German Conference of Justice Ministers published a long report clearly showing that general data ownership de lege ferenda is neither meaningful nor economically desirable*" (our translation) and that the German government has recently published a study on mobility data that suggests a system of ownership for data. Study available on: https://www.bmvi.de/SharedDocs/DE/Publikationen/DG/eigentumsordnung-mobilitaetsdaten.pdf?_blob=publicationFile

[18] (Drexl, 2017a) p. 274-275.

Those who argue that such a new right is not needed point out[19], [20]:

— that there is no visible need for an incentive to produce more data (as enormous amounts is already produced despite the absence of such rights), nor is there a visible problem of illegal copying of data which would require new enforcement tools;

— that a data owner can already use technical means such as encryption and contracts to ensure "excludability" of its data vis-à-vis third parties;

— that the scope of such a right would be very complex to decide in regard of both specification (syntactic vs semantic data, individual data vs datasets) as well as regarding allocation of rights (individual vs joint ownership);

— the potential conflict with other existing intellectual property (IP) rights and with fundamental freedoms such as the freedom of expression and information, the freedom to conduct a business, and the freedom of services[21];

— the perils of creating a new layer of rights to be cleared (with the corresponding higher transaction costs) and of increased possible information lock-ins;

— the difficulty justifying the introduction of such a new right under the theories that have traditionally served to justify copyrights (i.e. personality, labour, or utilitarian theories).

On the contrary, those who are in favour of the creation of such a right argue the following[22]:

— it would allow a clear allocation of rights, would prevent the use of technical mechanism to ensure de facto ownership, and would also serve to promote a culture of greater transparency;

— it would stimulate a greater use of data and facilitate sharing arrangements.

No recent economic research makes a clear case for creating new IP rights for data [23], [24].

It is unlikely that such a new property right will be created in the immediate future, and many commentators agree that it would be, at best, premature in view of the numerous uncertainties about the consequences that such a new right could have[25]. As one study for the EC has concluded, "*it appears to be premature to attempt to identify aspects of the legal framework which could be supplemented by further legislation. (…) it is essential to assess the economic impact of a right in data in detail before considering further legislation*" [26]; as stated by an author, *"for the introduction of a new exclusive right on industrial data, the time is not right"* [27].

1.3.1.2. *The debate on access to data*

While discussions on ownership are still very much undecided, many commentators consider that some rules on access to data should be introduced. And indeed, "*the problem of rights of access to data might be a much more important future research topic than the question of exclusive ownership*"[28]. With an increasing share of

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[19] (B. Hugenhotz, 2017); (Strowel, 2018) p. 258.; (Wiebe, 2017) p. 67; against the idea of a new right, see also J. Drexl (2017b) p. 232; see also Position Statement of the Max Planck Institute for Innovation and Competition of 26 April 2017 on the European Commission's 'Public consultation on Building the European Data Economy', (Max Planck Institute for Innovation and Competition, 2017).

[20] Data Producer's Right: Power, Perils & Pitfalls. Paper presented at Better Regulation for Copyright, p. 51-58, Brussels, Belgium, 2017, available at https://juliareda.eu/wp-content/uploads/2017/09/2017-09-06_Better-Regulation-for-Copyright-Academics-meet-Policy-Makers_Proceedings.pdf

[21] (Hugenholtz, 2017) p. 95.

[22] (Van Asbroeck, et al., 2017).

[23] (Kerber, 2016b) pp 759–762.

[24] (Duch-Brown, B. Martens, F. Mueller-Langer, 2017).

[25] In a similar way, (IDC, 2015).

[26] (Osborne Clarke, 2016) p. 100.

[27] (Wiebe, 2017) p. 71.

[28] (Kerber, 2016a) p. 998.

data in the digital economy being held privately, *"the problem of access to data will be one of the pivotal future policy questions for the governance of the digital economy"*[29].

Discussions on a possible right of property on data are somewhat speculative or theoretical, but issues of access to (or refusals of access to) data are more concrete and can be the subject of more empirical analysis (as they can be observed in practice or by economic studies). Such rules on access are independent of any underlying regime of ownership: refusal of access will mostly rely on a *de facto* ownership of data (combined if necessary with technical protection measures) and the introduction of certain rights of access by legislation does not pre-suppose the existence of an underlying data producer right[30]. Even in the absence of a new ownership right, questions of access to data may arise: requests to access data can face *de facto* monopolies on data (sometimes combined with technical protection measures and confidentiality precautions)[31].

> *Rules on data access play a more important role than discussions on legal ownership*

[29] (Kerber, 2016a) p. 998.
[30] (Kerber, 2017) p. 129.
[31] See below for the relevance of EU competition law and for relevant case-law on e.g. (abusive) refusals to license.

Interestingly yet logically, it seems that market operators view issues of access to (and re-use of) data as more important and more impacting for them than (more theoretical) data ownership issues[32].

On the other hand, when discussing access to data, it is "data sharing" and "data re-use" that are foremost.

A recent survey showed that companies that have not yet engaged in B2B (business to business) data sharing mentioned three main factors which would facilitate it[33]: legal clarity about "data ownership rights" (62%), ability to track the usage of data (46%) and increased certainty about the nature of and procedures relating to licensing agreements (42%). The same survey showed that 66 % of companies reporting experienced obstacles to data re-use mentioned denial of access as the main one[34]. The other main obstacles mentioned included unfair (discriminating or costly) conditions of access, lack of interoperability and standardisation, and data localisation concerns[35].

Commentators generally agree that each "data market" presents very different and specific characteristics in terms of business models, actors, strategic importance of the data, etc. This leads to the rather widely shared recommendation that sector-specific regulations should be preferred to a general "*one size fits all*" regime of access to data, at least as a first step: "*Whereas access solutions in certain cases of public interest and for scientific research are comparably unproblematic, we should be very cautious about general mandatory access regulations to privately held data for other private parties, even if, on first sight, this might have positive effects on competition and innovation*"[36].

A combination of a general access regime (mainly defined as a function of objectives) with sectorial regulations (more readily defined in terms of beneficiaries) has also been advocated[37]. Some have insisted that if access rights are created, they should be "un-waivable"[38].

In France, a preparatory report for the "Loi Lemaire" (which provides for certain rights of access to data of public interest) also recommended a sectoral approach and expressed reservations vis-à-vis any transversal/horizontal regulation[39]. The Villani report on artificial intelligence in France also suggests increased rights of access to data ("*presently held by a handful of very big actors*") for the benefit of public administrations but also smaller economic players and for public research[40], including via a sector-by-sector approach.

Commentators generally favour a "*minimal regulatory approach to foster B2B data sharing*"[41]; in a recent report the JRC has stated that it "*offered no policy conclusions*" and that "*more research is required to bring economics up to speed with these questions*"[42].

While the possible introduction of new mandatory rights to access privately-held data is considered a delicate issue, a number of sectorial regulations already foresee some sorts of rights to require access, for specific purposes[43].

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[32]   (Deloitte et al., 2017) p. 16.
[33]   (Everis Benelux, 2018) p. 45 and p. 76.
[34]   (Everis Benelux, 2018) p. 79 and p. 95.
[35]   One could also add that, even where the data is made available under open data licenses, the issue of the legal compatibility of the many different "open licenses" can also be an obstacle to reuse and sharing; see e.g. (De Filippi, P. and Maurel, L., 2015) 1–22.
[36]   (Kerber, 2017) p. 133; (Kerber, 2016a) p. 998: *"(...) policy solutions in regard to access to privately held data, and particularly obligations to grant access, will need very careful consideration and justifications."* See also discussion on the different possible modalities of a non-consensual right of access (Mezzanotte, 2018) p. 181.
[37]   (Mezzanotte, 2018) p. 184.
[38]   (Drexl, 2017b) p. 238 et s.
[39]   (Conseil général de l'économie and Inspection Générale des Finances, 2015).
[40]   (Vilani, 2018) p. 14. See also p. 34: *«la plupart des acteurs auditionnés par la présente mission se montrent favorables à une ouverture progressive, au cas par cas et selon les secteurs, de certains jeux de données pour des motifs d'intérêt général. Cette ouverture pourrait prendre deux formes : un accès à ces données pour la seule puissance publique afin, par exemple, de nourrir une plateforme publique de données ; ou une ouverture plus large (open data), y compris pour les autres acteurs économiques. Le degré d'ouverture imposé à ces données doit prendre en compte un ensemble de facteurs, notamment l'impact économique, financier et concurrentiel sur les entreprises concernées».*
[41]   (Everis Benelux, 2018) p. xi; see also (Osborne Clarke, 2016) p. 99.
[42]   (Duch-Brown, N., B. Martens, F. Mueller-Langer, 2017) p. 47.
[43]   See the MIFID Directive for trading data, the PSD2 Directive for web banking login data, Regulation 715/2007 for car maintenance data, the Software directive for interoperability information, the REACH Regulation for chemical safety testing data, the regulation on medicines approval for pharmaceutical testing data, the Aarhus Convention and the INSPIRE Directive for environmental data; (Osborne Clarke 2016) Legal study on Ownership and Access to Data, a report for the European Commission.

At the sectoral level, the European Parliament has called on the Commission to publish a legislative proposal on access to in-vehicle data[44]. With the release of the third mobility package, the Commission has announced a recommendation that among other things will deal with "*a data governance framework that enables data sharing in line with the initiatives of the 2018 Data Package, and with data protection and privacy legislation.*"[45] Indeed, the issue will be very important for connected cars as the data "*might be interesting for many different kinds of economic, sociological, medical, and technical research as well as for public statistics offices which provide statistics about different aspects of traffic and transport*"[46].

The Commission has decided to publish a guidance document on data sharing in both B2B contexts and regarding sharing of data between the private and public sectors[47]. The Commission hopes that the principles of the guidance document will be respected in contractual agreements to ensure fair and competitive markets for the IoT objects and for products and services that rely on non-personal machine-generated data created by such subjects, but will continue to assess whether amended principles and possible codes of conduct are sufficient to maintain fair and open markets. If necessary, the Commission stated that it would take appropriate action.

> " *On access to data, a 'one size fits all' solution is unlikely to be appropriate* "

The approach to issuing such guidance is all the more interesting as at this early stage of development of Big Data and the IoT, it is not yet possible to decide what the standard and/or fair practices in the field are[48].

In the case in which a company refuses to share its own data, it may in certain cases be possible to rely on competition law, arguing that the refusal is abusive while originating from a company in a dominant position

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[44] Resolution of Tuesday, 13 March 2018 "A European strategy on Cooperative Intelligent Transport Systems. In this respect the EP recommends "*that this proposal should enable the entire automotive value chain and end users to benefit from digitalisation and guarantee a level playing field and maximum security with regard to storage of in-vehicle data and access thereto for all third-parties, which should be fair, timely and unrestricted in order to protect consumer rights, promote innovation and ensure fair, non-discriminatory competition on this market in line with the principle of technological neutrality*".

[45] Communication From The Commission To The European Parliament, The Council, The European Economic And Social Committee, The Committee Of The Regions, On the road to automated mobility: An EU strategy for mobility of the future, COM(2018) 283 final, Brussels, 17.5.2018.

[46] (Kerber and J.S. Frank, 2017).

[47] Staff Working Document - Guidance on sharing private sector data in the European data economy, https://ec.europa.eu/digital-single-market/en/news/staff-working-document-guidance-sharing-private-sector-data-european-data-economy

[48] (F. Graf von Westphalen, 2017) p. 245 et s.

in the sense of article 102 TFEU (or the corresponding provision under national law, where available). However, the thresholds for the application of competition law at both national level or at EU level are high and do not cover many potential situations. In addition, the courts have imposed a number of conditions to apply before finding that a refusal to licence can be seen as abusive[49].

Box 1.2
Review of the PSI Directive

As part of the "Data Package" and following an impact assessment and various public consultations, the European Commission has also published a draft directive reviewing the existing PSI Directive[50].

The main changes to the existing framework have been presented in the explanatory memorandum to the text as follows:

Dynamic data/APIs[51]: a 'soft' obligation for Member States to make dynamic data available in a timely manner and to introduce APIs. There will be a hard obligation to do this for a limited number of fundamental high-value datasets (to be adopted through a Delegated Act).

Charging: tighten the rules for Member States to invoke the exceptions to the general rule that public sector bodies cannot charge more than marginal costs for dissemination.

Create a list of fundamental high-value datasets that should be freely available in all Member States (the same datasets as above, to be adopted through a Delegated Act).

Data in the transport and utilities sector: only public undertakings will be covered, not private companies. A limited set of obligations will apply: public undertakings can charge above marginal costs for dissemination and are under no obligation to release data they do not want to release[52].

Research data: Member States will be obliged to develop policies for open access to research data resulting from publicly funded research while being flexibility in implementation. The PSI Directive will also cover research data that has already been made accessible as a result of open access mandates, focusing on re-usability aspects.

Non-exclusivity: transparency requirements for public-private agreements involving public sector information (ex-ante check, possibly by national competition authorities, and openness of the actual agreement).

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[49]   See the CJEU cases Magill (1995), Bronner (1998), IMS Health (2004), Microsoft (2007), and some national cases: Engie (France, 2017), UK CMA Energy Market Investigation (2016).
[50]   Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the re-use of public sector information (recast) Brussels, 25.4.2018, COM(2018) 234 final, 2018/0111(COD) https://ec.europa.eu/digital-single-market/en/proposal-revision-public-sector-information-psi-directive
[51]   API: application programming interface. In computer programming, an application programming interface is a set of subroutine definitions, communication protocols, and tools for building software.
[52]   It is worth mentioning that transportation, utility, and governmental services are also governed by the INSPIRE Directive, notably article 4, "*spatial data sets*" which are held by or on behalf of "*a public authority, having been produced or received by a public authority, or being managed or updated by that authority and falling within the scope of its public tasks*", or by or on behalf of "*a third party to whom the network has been made available in accordance with Article 12*" for which the sharing of data sets is mandatory (Art. 17).

1.3.1.3. *The link with copyright rules and a possible text-and-data mining exception*

In the discussions about access to data, the issue of text-and-data mining (TDM) is important. TDM is carried out by applying automated techniques to a set of selected digital materials; "automated" as opposed to "made by humans" and it is indeed this characteristic which makes TDM so powerful and which raises new IP (intellectual property) issues. TDM involves the processing of data, which may include the extraction, copying, comparison, classification, or some other statistical analysis, etc. of data, or a mix of data; it can be applied to all types of contents and in most cases, the process is concerned with including a large amount of different materials.

TDM unavoidably involves some copying of the materials. Often, TDM will require accessing and processing materials that are protected by copyright (e.g. when TDM is carried out in relation to written publications or original images) or by the database maker's sui generis right. In many cases, TDM will target publishers or data providers' databases, but in many other cases it may also concern the scraping of publicly available websites that, in spite of being freely accessible, may also be protected by copyright or the sui generis right.

In order to avoid the copyright becoming a factor hindering the development of TDM, several legislators have proposed the introduction of a TDM exception in copyright legislation, and some Member States (such as the UK and France) already have it in their legislation. The European Commission has also decided to propose an exception for TDM[53].

■ *TDM in the case of research organisations*

The text of the draft directive as adopted by the EC proposed a binding exception (not waivable by contract) applying in all MS and benefitting research organisations. Research organisation is defined as:

"a university, a research institute, or any other organisation the primary goal of which is to conduct scientific research or to conduct scientific research and provide educational services:

(a) on a not-for-profit basis or by reinvesting all of the profits in its scientific research;

or (b) pursuant to a public interest mission recognised by a Member State;

in such a way that access to the results generated by the scientific research cannot be enjoyed on a preferential basis by an undertaking exercising a decisive influence upon such an organisation".

The exception in the initial text of the draft directive makes no distinction between commercial and non-commercial research, and research organisations would also benefit from the exception when they engage in public-private partnerships.

A criticism expressed about the text is that it only benefits research organisations and not commercial companies. However, the text proposed by the European Parliament would allow (but not oblige) Member States to go further, as Member States would also be able to allow TDM by the private sector and for commercial purposes.

However, the exception would not apply when the use of the material has been "expressly reserved by their rightholders, including by machine readable means"[54]. It means, for instance, that the terms and conditions on a website could still validly prohibit TDM being made of the contents of the website.

It is worth noting that when a possible TDM exception at EU level was first discussed in 2014, it was not in the broader context of artificial intelligence and machine-learning, and those words do not appear in the two reports which were commissioned by the European Commission[55]

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[53] Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on copyright in the Digital Single Market, COM(2016) 593 final, 14.9.2016.

[54] The proposed amendment reads as follows: "*Without prejudice to Article 3 of this Directive, Member States may provide for an exception or a limitation to the rights provided for in Article 2 of Directive 2001/29/EC, Articles 5(a) and 7(1) of Directive 96/9/EC and Article 11(1) of this Directive for reproductions and extractions of lawfully accessible works and other subject-matter that form a part of the process of text and data mining, provided that the use of works and other subject matter referred to therein has not been expressly reserved by their rightholders, including by machine readable means.*"

[55] (Hargreaves et al. 2014); also (Triaille, J.P., J. de Meeus, A. de Francquen, 2014).

even though TDM was then already seen as a promising field which needed to be nurtured, and even though the growing importance of data to the economy was obviously the background to these studies. In addition, many discussions around TDM initially focused on the mining of scientific literature with less emphasis on the importance of the information generally available on the Web: with the increasing diversity of AI applications, it is the Web itself which has become the main source of data, and less so the journals published by scientific publishers.

However, the TDM exception, in whatever manner and whether or not it ends up being adopted, is still just an exception and does not create a right to access the information. On the contrary, it has always been drafted in such a manner that it was limited to contents to which the user had first obtained lawful access. Even in its most liberal interpretation by the proponents of the idea that "the right to read is the right to mine", the right to read would not in itself create a right to require access to data that is not made freely available.

1.3.1.4. *A specific case for access to data: for scientific research or statistical purposes*

Separately from the issue of access to data for competition purposes, many commentators favour a right of access for scientific research purposes to increase scientific progress and innovation.

For reasons that are somewhat similar to the existence of exceptions for the benefit of scientific research under copyright law[56], patent law, database protection law, and data protection law[57], many commentators argue that a right to access certain kinds of data should exist for the purpose of scientific research. Sometimes this is as an exception to a new property right, other times including in the absence of such a right[58].

This sometimes translates into a right to access private data "of public interest", or a right to access data "for statistical purposes" even if these objectives do not fully coincide[59].

The Commission has explicitly mentioned this issue in its Communication "Building a European data economy" in a reference to a right of access "in the general interest".

Many questions arise from this and will have to be examined further: who are the beneficiaries of such right of access, to which data, for which purposes, under which conditions (financial, confidentiality, storage, standard format or not, etc.)?[60] [61]

1.3.2. Digital platforms

Since the early nineties new economic organisations have been flourishing in many countries and many sectors of the economy thanks to the development and rapid diffusion of digital technologies. The main feature of these new businesses is to facilitate transactions between several types of users (producers, consumers, advertisers, software developers, etc.). It is not rare to find a few large online platforms that account for a

substantial share of the market, a phenomenon called "platformisation". Platforms bring many benefits to all the users that join. For instance, they reduce market entry costs, they make it easier to access a wider variety of goods and services, they give producers a wider consumer reach and facilitate matching users with each other, usually at lower costs than offline markets or traditional firms could do. Online platforms rely on

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[56]   See above on the TDM exception proposed for scientific research.
[57]   (Triaille, 2018) p. 269 et s.
[58]   In addition to some of the references mentioned above on access to data in general, see also A. Wiebe (2017), p. 69; (Deloitte et al., 2017) p. 53; (Kerber,2017) p. 133 (the author mentions this right of access as "comparably unproblematic" as opposed to rights of access in other circumstances); (Kerber and J.S. Frank, 2017); (Zech, 2016) p. 469.
[59]   On the different concepts, see F. Mezzanotte (2018) p. 167.
[60]   On this, see W. Kerber and J.S. Frank (2017); also F. Mezzanotte (2018) p. 177.
[61]   On the different concepts, see F. Mezzanotte (2018) p. 176.

digital data collection and algorithms to facilitate these transactions. At the same time, these platforms raise concerns and are increasingly subject to scrutiny by regulators. Dominant positions may enable platforms to impose unfair conditions on some market participants. Lack of transparency in the data collected and their use in search and recommendation algorithms or for advertising purposes also raises concerns.

A key driver of the success of platforms is their ability to use data and algorithms to match users on two or more sides of the market and lower transaction costs. While this seems to be obvious to most observers, there are as yet no economic models that explain the role of data in these platforms, how data analytics contributes to the platformisation of many industry sectors, and what this implies for the digital transformation of companies and markets (Duch-Brown et al., 2017). From this perspective, the role and value of data is growing fast. It is the essential factor that keeps multi-sided platforms operating. It is not only collecting data that is important, but even more so it is also extracting new insights and value from data, mainly through the use of machine learning algorithms and artificial intelligence. Access to data has become a key issue in promoting AI as a new phase in the digital transformation.

By using digital technology, platforms have appeared as a new and improved mechanism to address the fundamental problem of economic organisation: how to coordinate supply and demand to reach the highest possible efficiency when information is imperfect. Technology is therefore an important element in the emergence of digital platforms. However, in the context of sophisticated economies with increasingly varied types of goods and services on offer, and a wider dispersion of preferences from the consumption side, finding valuable

> *Platforms use technology to assign resources more efficiently*

matches becomes a complex task. An additional important enabler of the value of platforms comes from 'market design', the strand of economics devising algorithms for matching heterogeneous demand and supply in a context of incomplete information. In order to provide accurate matches, algorithms require large amounts of data, making data collection and access a key feature of the platform economy.

Despite the attention given to these new organisational forms in science, policy, and for media, it is surprisingly hard to find a satisfactory definition of platforms. This is mostly due to the fact that they have characteristics of firms and of markets, may be involved in both production and exchange; and they implement different co-ordination mechanisms (technical standards, matching algorithms, or social norms, among others). A frequently used typology attempts to classify platforms in terms of their market orientation, taking into consideration the type of users involved in the interaction, as defined in Table 1.1, which also shows some widely known examples.

	Production	Intermediation	Exchange
B2C	AWS, software OS, games consoles	Ad-funded media, phone networks, Zoopla, travel booking	Ebay, Amazon Marketplace
B2B	Internal platforms, Slack, AWS	Payment cards	Financial exchanges
P2P	Sharing economy work platforms (Thumbtack, Taskrabbit)	Social media, UberX	Sharing platforms e.g., UberPool, Airbnb, home swaps, Kidney exchanges

TABLE 1.1: TYPOLOGY OF PLATFORMS.
B2C: Business to Consumers; B2B: Business to Business; P2P: Peer to peer; AWS: Amazon Web Services.
Source: Coyle (2016).

1.3.2.1. *The forces at work*

The competitive landscape of multi-sided markets is determined by several factors (Duch-Brown, 2017). From the perspective of economics, a market is typically called two-sided (or multi-sided) if indirect network effects are of major importance. Indirect network effects can be distinguished from direct network effects, depending on the size of a network. 'Direct network effects' mean that the utility a user receives from a particular service directly increases as the number of other users increases (Katz and Shapiro, 1985). In contrast, indirect network effects only arise if the number of users on one side of the market attracts more users on the other side. For example, consider an e-commerce marketplace: more potential buyers attract more sellers to offer goods on the platform since the likelihood of selling their goods increases. On the other hand, competition between sellers of the goods becomes more intense – lowering prices – but at the same time an increased variety of goods is offered, making the trading platform more attractive to a larger number of potential buyers (Rochet and Tirole, 2003).

These network effects imply that the efficiency and user benefits of platforms increase with their size. In multi-sided markets, it is not sufficient for the platform operator to attract users from only one market side to join the platform because there is an interrelationship between the user groups on both market sides. Neither side of the market will be attracted to join the platform if the other side is not large enough. In order to solve this "chicken and egg" problem (Caillaud and Jullien, 2003), platforms have traditionally subsidised access – with zero price – for one type of user – normally the side that is more sensitive to price variations. They have financed this subsidy by charging the less price sensitive group of users on the other side. The magnitude of network effects varies widely across platforms and is an empirical question. Hence, high market concentration levels cannot simply be interpreted in the same way as in conventional markets without network effects (Wright, 2004).

Most online multi-sided markets are characterized by a cost structure which has a relatively high proportion of fixed costs – particularly for R&D activities – and relatively low variable costs (Jullien, 2006). For instance, the costs of developing, establishing, and maintaining the algorithms and databases needed to operate are to a certain extent independent of the volume of transactions. Therefore, economies of scale are rather typical of multi-sided markets. This cost structure implies that traditional marginal cost pricing can no longer be used and alternative pricing schemes are needed. Moreover, since there may also be economies of scale on the demand side (due to direct network effects), pricing decisions have to take into account both sides of the platform (Evans and Schmalensee, 2007). What matters in platforms is the price structure, i.e., the relationship between the prices charged on every side. Hence, different business models for attracting consumers and suppliers typically co-exist in the market (Rochet and Tirole, 2003). These models are mainly differentiated by which side of the market the platform charges the most. Whether users can capture value in the system or not depends on their bargaining position inside the platform (within-platform competition) and the strength of the competition with other platforms (between-platform competition).

> *The economic forces at work tend to favour greater concentration and hence, the appearance of large platforms*

While both (indirect) network effects and economies of scale lead to higher concentration levels, there are also other forces that work in the opposite direction (Evans and Schmalensee, 2007). One important countervailing force is capacity constraints. While in physical two-

sided markets space is physically limited (i.e. a shopping centre), this does not necessarily hold for online two-sided markets. However, advertising space is often restricted since users can perceive too much advertising to be a nuisance and therefore decreases the platform's value in the recipients' eyes (Becker and Murphy, 1993; Bagwell, 2007). Similarly screen size especially on mobile devices may reduce advertising space and the variety of products that can be meaningfully displayed. In some electronic two-sided markets, capacity limits can also emerge as a result of negative externalities caused by additional users. For instance, if additional users make the group more heterogeneous, users' search and transaction costs may increase. In contrast, the more homogeneous the users are, the higher a given platform's value for the demand side will be. For example, if only a certain user group visits a particular platform, it is much easier to target the advertising. This reduces the search costs for all visitors involved. Additional users would make the user group more heterogeneous and not necessarily add value as increased heterogeneity also increases the search cost for other users. However, the use of data to personalise offers and/or advertising in many instances can be used to overcome the effects of capacity constraints.

The degree of differentiation between platforms is also relevant. Consumer preferences are sufficiently heterogeneous in some cases to allow some product differentiation to emerge (as in dating sites, and magazines or newspapers). This differentiation can be vertical (e.g.,

the advertising industry may find high-income users more interesting than a low-income audience), and/or horizontal (e.g. people interested in sports newspapers versus people interested in financial newspapers). The higher the degree of heterogeneity among potential users, the easier it is for platforms to differentiate. In this scenario, diverse platforms would emerge targeting specific niches. Therefore, a unique leading platform is less likely to emerge within the ecosystem. Finally, the cost of expanding a digital offering to cater for a different audience may be lower than in conventional businesses.

In settings where a multiplicity of platforms co-exists, horizontal differentiation can result in customers choosing to join and use several platforms, a phenomenon called "multi-homing" (Rochet and Tirole, 2006). How easy it is for consumers to multi-home depends, among other things, on the nature of the alternative platforms (substitutes or complements), switching costs between platforms, and the pricing policy (usage-based tariffs or flat rates) of the platform. Many information products and technologies are associated with switching costs, i.e., buyers must bear these costs when they switch from one product to a functionally-identical product supplied by another firm. Switching costs arises when a consumer makes investments specific to buying from a particular firm, making it more valuable for the consumer to buy different goods, or goods at different dates, from that particular firm. Multi-homing can occur on both sides of the platform, or on just one side, or otherwise be impossible.

1.3.2.2. *Market development and the road ahead*

As a consequence of the relative strengths of these forces – and their interactions – online platform ecosystems are prone to the appearance of leading players. However, this is not necessarily the case for all activities involving platforms because the balance resulting from the interplay of all the forces involved will differ between activities. The presence of indirect network effects is by no means sufficient for a monopoly or even high levels of market concentration to emerge. On the other hand, it is not even clear whether competition between several platforms is necessarily welfare enhancing when compared to a monopolistic market structure: the existence of multiple platforms may not be efficient due to the presence of indirect network effects. A monopoly platform could be efficient because network effects are maximized when all agents manage to coordinate over a single platform.

Hence, strong network effects can easily lead to highly concentrated market structures but strong network effects also tend to make these highly concentrated market structures efficient.

The evidence available about the relative strength of these forces would suggest that, if left alone, they would promote the creation of closed ecosystems. The potential effects of such ecosystems on innovation are not well understood yet because they develop their own services and content and prevent competing services from accessing the platform(s), or reduce the quality or compatibility of the competing services. These closed platform ecosystems can be good for competition since they increase intersystem competition – leading to fierce competition 'for the market' – generating greater incentives to innovate and

entry due to future profit expectations. Alternatively, an open platform ecosystem may achieve the full benefits of network effects and economies of scale for component makers, increases intra-ecosystem competition, and stimulates market entry through component innovation. However, there is as yet no clear benchmark for efficient market structure in digital platform markets. Digital markets are characterized by fast innovation that can rebalance leadership and facilitate entry. Most big players cannot be complacent and have to constantly strive to preserve their positions by preventing other firms from innovating faster. In the case of platforms, incumbents have relied on their financial advantage to absorb small competing entrants or potential status-quo disruptors.

Just as digital technologies change rapidly, so do the markets where these platforms operate. We are already seeing that some platforms overlap (online advertising and social networks, for instance), and some platforms operate on top of other platforms (such as data platforms on top of commercial platforms or app stores on top of

operating systems platforms). In addition, constellations of platforms, where many platforms are connected to each other, are emerging (online advertising platforms and social networks or search engines appear to be naturally linked to each other).

The phenomenon of the platform and data economy is somewhat new and developing quickly. To date, most scientific contributions have been of a theoretical nature. Empirical research faces the problem of lack of appropriate data and evidence is still at best based on case studies which normally lack external validity. It took economists around 150 years to develop a reasonable theory of the firm (Coase, 1937). Hopefully, it will take less time to reasonably pin down the implications and ramifications online platforms are having – and will certainly have – in the digital transformation of the economy.

Some aspects and examples of digital platforms specific to the sectors covered in the report can be found in the relevant sections of the report.

1.3.3. Digital Transformation and Cybersecurity

The history of digital transformation and cybersecurity is a story of co-evolution. Cybersecurity was conceived as a result of the development of the first computer systems and digital communication networks years before the term "cybersecurity" itself was coined. It quickly moved from a mere concept studied by only a few to a new field of science and technology that emerged from the first wave of cybersecurity incidents in actual and deployed systems and networks.

Cybersecurity threats started becoming more relevant from the 1990s with the creation and subsequent popularisation of the Internet. While the Internet led to the development of a world-wide cyberspace populated by a rich and – at the time – revolutionary ecosystem of online services and products, it also exposed computers to a wider range of cybersecurity threats, which exploited the connectivity provided by Internet. Two decades later, the escalation in the number of cybersecurity incidents and their impact has seen cybersecurity go to the top of the priority list of both governments and businesses world-wide.

1.3.3.1. *A conceptual model of cybersecurity in the context of digital transformation*

The growing digitalization of governments, industry, and society and their increasing dependency on Information and Communication Technologies (ICT) has deeply transformed the cybersecurity landscape in the last

decade. This is primarily because digital transformation enhanced efficiency of implementation and provision of services but it also created digital assets, which are vulnerable and appealing to cyberattacks[62], increasing the

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[62] One example relates to the financial/banking sector. Before the digital revolution, consumer credit information was either not digitally stored or it was stored in secluded mainframe systems. The digital revolution enhanced the digital storage of consumer credit information in enterprises but the accessibility of this information also increased the potential for cybersecurity threats through the Internet. This was demonstrated in the recent case of the Equifax data breach where cybercriminals accessed the sensitive data of more than 145 million users.

motivation of and rewards for *attackers*, **enlarging the attack surface**[63]**, and creating higher potential** *impacts* from cybersecurity attacks.

Cybersecurity risk is specifically based on these three main dimensions: *threats* (i.e., attackers), *vulnerabilities* (i.e., weaknesses), and *impacts* (i.e., adverse effects of successful cyberattacks). Figure 1.4 depicts a conceptual model of cybersecurity in the context of digital transformation. The figure puts these three dimensions of cybersecurity into context, showing their interconnection and their role in the composition of the cybersecurity risk.
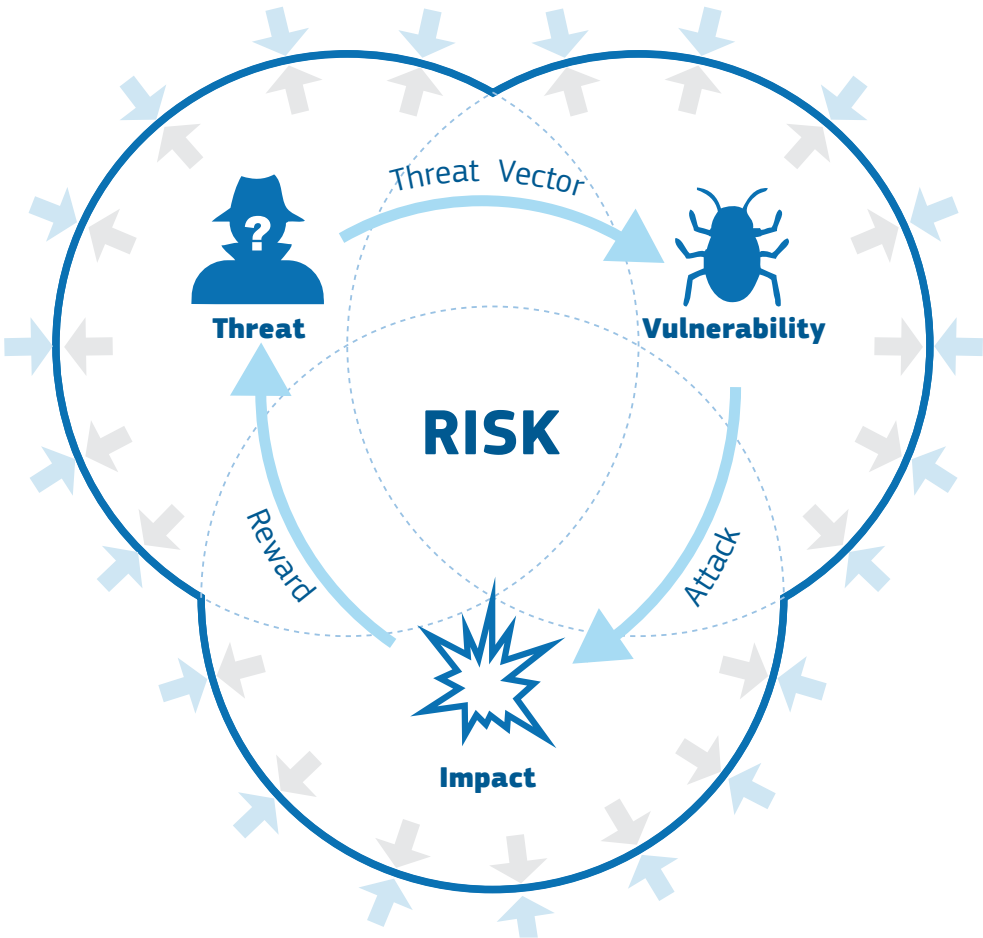
FIGURE 1.4: CONCEPTUAL MODEL DEPICTING THE LOGICAL LINKS BETWEEN THE VARIOUS COMPONENTS OF THE CYBERSECURITY RISK IN THE CONTEXT OF THE INFLUENCE OF DIGITAL TRANSFORMATION.
Source: JRC analysis.

Threat actors, or threat agents, are external actors motivated to carry out cyberattacks in order to obtain a reward (e.g. financial gain). To do so, they employ means (threat vectors) that exploit *vulnerabilities* present in the ICT deployed infrastructures, services and products to carry out an attack in order to achieve their goals. The *impact* of an attack is either directly linked to the reward sought by the perpetrator (e.g. money stolen by a "banking Trojan") or a side-effect of it (e.g. an attack of ransomware that results in the disruption of systems and communication networks).

The cybersecurity risk is a function of the likelihood that a cybersecurity incident will occur and the *impact* that it can generate. In turn, the likelihood of a security incident depends on the existence of *vulnerabilities* and *threat actors* motivated enough to develop and attack vectors that exploit them.

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[63] In cybersecurity, the term *attack surface* refers to the collection of all potential entry points that attackers could use to compromise services, systems, or information by using vulnerabilities.

The overall risk can be mitigated by employing strategies that act on the cyber threats (e.g. deterrent actions, such as prosecution of cybercrime), prevent the vulnerabilities (e.g. identification of the vulnerabilities, definition of mitigation techniques and implementation of software patching to correct them) and/or mitigate the impacts (i.e. increased resilience).

As depicted in Figure 1.4, digital transformation influences the forces that act over the threats, vulnerabilities, and impacts of our conceptual model, expanding them and leading to an overall increase in the cybersecurity risk. In Figure 1.4 this influence of digital transformation over the three main components of the cybersecurity risks is represented by the outward pointing arrows. They are referred to as the *expansion forces*. In the following subsections we show how these forces are stronger as a result of digital transformation.

Similarly, digital transformation also has the capacity to positively influence the forces that aim to mitigate the cybersecurity risk in the conceptual model presented here, supporting and enabling them to better counteract threats, vulnerabilities and impacts. These forces that mitigate the risk are represented by the inward pointing arrows in Figure 1.4. They are referred as the *compression forces* and in the following subsections some examples of how these forces can also be stronger as a result of digital transformation are presented.

1.3.3.2. *The challenge of cybersecurity in digital transformation*

■ *Threat actors and threat vectors*

Digital transformation has had a big influence on the cybercrime business. Cybercriminals can now expect more significant rewards due to the increased uptake of new technologies by governments, industry and citizens and the increasingly blurred line between the cyber/digital dimension and the physical world. Clear examples of this are ransomware and phishing campaigns targeting online banking users. In both cases, money is the big reward sought by the cybercriminals behind these attacks. In 2018, cybercriminals were estimated to be responsible for 80% of incidents (ENISA, 2019) with an estimated overall impact cost of 0.8% of the global gross domestic product.

The development of new technologies, such as the latest advances in artificial intelligence, provides attackers with newer and more effective means of conducting their crimes (*attack vector* in Figure 1.4). A similar influence occurs with other types of threat actors such as cyber-terrorisms or cyber espionage, which also exhibit the characteristic of co-evolving with its contextual environment (i.e., technology, society, politics and the economy). The effects of digital transformation in governments and society has also has an important influence in the sponsored threat actors and more recently on hybrid threats. It is worth highlighting that ENISA identified the former, together with cybercriminals, as one of the most important threat actor groups in 2018 (ENISA, 2019).

■ *Vulnerability landscape*

The cybersecurity attack surface has also greatly increased due to the effect of the digital transformation in society, governments and industry. A clear example of this is the expansion of connected devices. It is estimated that there will be 14 billion IoT connected devices in 2019 and that this figure could reach 25 billion by 2021[64].

The bigger the attack surface, the easier is for an attacker to find and exploit vulnerabilities. The number of digital interconnected devices and the role that they play in society and industry also affect the magnitude of the potential impact that they can have. For example, in 2016 the *Mirai* botnet, assembled using hundreds of thousands of small compromised IoT devices worldwide (such as domestic webcams and media players), caused significant impacts on online businesses and internet infrastructure (Antonakakis, et al., 2017).

"*A chain is as strong as its weakest link*" and digital transformation has led to large sets of complex and long interconnected chains. The introduction of new technologies and the digital transformation of domains

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[64] https://www.gartner.com/en/newsroom/press-releases/2018-11-07-gartner-identifies-top-10-strategic-iot-technologies-and-trends

such as health, transport, energy and construction will be accompanied with new cybersecurity challenges.

It is also worth noting the relevance of the economic component in the development and deployment of cybersecurity solutions, which costs manufacturers, system integrators and deployers time and money. These costs are justified if there is an economic return on the investment (e.g., to ensure that users pay the fees) or because a regulation demands it. Such costs are not always justified. The term "Economics of Cybersecurity" (Moore, 2010) is used to describe this phenomenon where a combination of factors can hamper the deployment of solutions to mitigate cybersecurity threats. One factor is that there is often a trade-off between efficiency (in cost and time) and the cybersecurity resilience in ICT systems. This is due to market forces, which makes the reconciliation of short-term incentives to reduce operating costs with the long-term interest in reducing vulnerabilities quite difficult. Another factor is the lack of transparency or perception in the added value of cybersecurity. For example, security vendors may assert that their software is secure, but buyers or users may refuse to pay a premium for such protection and so vendors become disinclined to invest in security measures (Anderson, 2001).

■ *Impacts*

The impacts of successful cyberattacks in the current era of digitalisation are magnified due to the reliance of governments, society and industry on digital technologies and their global interconnection. For example, in 2017 the *WannaCry* global ransomware outbreak resulted in serious disruptions in the UK's health system (NHS) as well as interruptions to manufacturing chains across Europe. The cyberattack's cost to the NHS alone was estimated at GBP 92 million (NHS, 2018) despite the fact that the cyberattack was not specifically targeted at the NHS and that no ransoms were paid.

The growth in the number of cyber-physical systems (i.e. those systems that have a strong digital component and are capable of interacting with the physical world) such as automated vehicles, medical devices, or critical infrastructures will also pose new cybersecurity challenges due to the potential safety impacts as cybersecurity threats could directly influence the physical world (e.g., the steering of an automated vehicle in a crowd).

1.3.3.3. *Opportunities for digital transformation to improve cybersecurity*

Fortunately, digital transformation also works as a catalyst to boost those *compression forces* that, in the conceptual model in Figure 1.4, aim to contain the growth of the cybersecurity risk. These *compression forces* are

composed of the measures that can be taken to mitigate the cybersecurity risk by counteracting the growth of the threats, vulnerabilities and impacts.

Law enforcement is also affected by digital transformation because there are new technologies that can enhance the capabilities of law enforcement bodies and assist them in the prosecution of crime more efficiently and effectively. New technologies such as artificial intelligence are already used today to develop smarter forensic techniques and newer methods to identify, locate and prosecute threat actors such as cybercriminals.

Similarly, digital transformation enables the development of a new generation of techniques, tools and security controls for the prevention, identification and mitigation of vulnerabilities. An example is the development of smarter intrusion detection systems, better malware detection systems and the development of faster detection of emerging cybersecurity threats. In order to solve the problems of growing cybersecurity vulnerabilities, regulators must coherently allocate responsibilities and liabilities so that the parties in a position to fix problems have an incentive to do so (Moore, 2010). In other words, the protection of users from the cybersecurity point of view must be anticipated by regulators in the formulation of policies with a clear definition of specific responsibilities and duties.

> *Digital transformation can increase cybersecurity risks but, at the same time, it can also help to mitigate them more effectively*

Finally, digital transformation also has the potential to enable new strategies to mitigate the impact of successful cyberattacks and increase the resilience of industry, governments and society against these events.

1.3.3.4. *The challenge of cybersecurity in Europe*

The challenges ahead specifically lie in the net effect resulting from the balance between *expansion* and *compression* forces, which are both driven by digital transformation. The ultimate goal for European policy should be to create a framework in which the effects of digital transformation are driven towards the creation of more compression forces and thereby decreasing the overall cybersecurity risk.

In their joint communication on Cybersecurity released in September 2017, the European Parliament and the Council presented a package of high level measures to address these challenges horizontally and build strong cybersecurity in the EU (European Parliament and Council, 2017). These measures are grouped in three main areas, namely:

- **Resilience:** to promote cybersecurity and enable effective responses to cyber-attacks in the EU by

building cyber-resilience and strategic autonomy. The new Directive on the Security of Network and Information Systems ("NIS Directive") (European Parliament and Council, 2016) (which focuses on the implementation of response measures against cybersecurity threats) and the Cybersecurity Act (European Parliament and Council, 2019) with the definition of an European Cybersecurity certification Framework (which focuses on the definition of cybersecurity certification processes and standards for ICT products) are examples of initiatives orientated in this direction. To complement these initiatives, it was also proposed the creation of a network of cybersecurity competence centres with a European Cybersecurity Research and Competence Centre at its heart. Its aim is to stimulate development and deployment of technologies in cybersecurity and complement the capacity building efforts for the previous identified initiatives at EU and national level.

> *The challenge is to ensure that positive effects of Digital Transformation in cybersecurity outweigh negative ones*

- **Defence:** strengthening international cooperation on cybersecurity, with the recently adopted framework for a joint EU diplomatic response to malicious cyber activities, also called the EU Cyber Diplomacy Toolbox (Moret and Pawlak, 2017), and the Blueprint for rapid emergency response (European Commission, 2071b). Another key aspect is the EU-NATO cooperation to foster cyber defence research and innovation cooperation.

The Cybersecurity Act puts forward a set of measures to improve the response to cyberattacks and strengthen cybersecurity in the EU. Amongst them, a framework for European Cybersecurity Certificates for products, processes and services will be created. This initiative aims to increase the cybersecurity of ICT products, ranging from IoT devices to critical infrastructures, by creating cybersecurity certification schemes that are recognised across the EU, promoting cybersecurity assessment before market deployment and enabling end-users to improve their understanding of the level of security they can expect in the products and services they use.

- **Deterrence:** with measures aimed at enabling more effective law enforcement responses to dissuade, detect, trace and prosecute perpetrators of cyber-attacks. The Directive on attacks against information systems (European Parliament and Council, 2013) already represented a step forward in this direction by requiring Member States to strengthen national cybercrime laws. Public-private cooperation against cybercrime is fundamental for public authorities to fight crime effectively. For example, 16 Member States have created Cybercrime Centres of Excellence to facilitate cooperation between law enforcement authorities, academia and private partners for the development and exchange of best practices, training and capacity building (European Parliament and Council, 2017).

The mutual influence between digital transformation and cybersecurity, and the related trends and challenges ahead, will be analysed in the forthcoming report on cybersecurity to be released by the JRC. Additional more concrete cybersecurity considerations are included in the following sections of the present report, where the impact of digital transformation in several domains is analysed.

1.3.4. Territorial aspects: contribution of Digital Innovation Hubs to digital transformation in EU member states and regions

In April 2016 the European Commission launched the Digitising European Industry initiative (DEI)[65], the first industry-related initiative of the Digital Single Market package. Building on and complementing the various national initiatives for digitising industry, this initiative aims to trigger further investments in the digitisation of industry and to support the creation of better framework conditions for the digital transformation of industry.

One of the key DEI priorities is to support a strong network of Digital Innovation Hubs (DIHs) to ensure that every company in Europe can take advantage of digital opportunities. The rationale behind this initiative is to help European companies, small or large, high-tech or not, to grasp the digital opportunities and fully benefit from digital innovations to upgrade its products, improve processes, and adapt its business models to the digital change.

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[65] The Commission sets out path to digitise European industry, https://ec.europa.eu/digital-single-market/en/news/commission-sets-out-path-digitise-european-industry

> *Digital Innovation Hubs (DIH) work in partnership with SMEs all over the EU to help them understand the potential, test and use digital technologies to make the most of all the opportunities they have to offer*

DIHs are not-for-profit one-stop-shops that support companies – notably SMEs, start-ups, and mid-caps – in order to improve their business, production processes, and products and services by using digital technology. At the core of a DIH there is usually a research & technology organisation (RTO) or a university lab offering, in collaboration with partners, services to SMEs including: testing and experimenting with new digital technologies,

digital skills and training, access to funding, access to an innovation ecosystem, networking opportunities, and more.

Within this context, the Commission launched the Catalogue of Digital Innovation Hubs (DIHs)[66] in November 2017. This catalogue has mapped non-profit organisations in EU Member States (and beyond) that act as ecosystems which support regional SMEs in the uptake of digital technologies. These national or regional DIH infrastructures are often linked to their region's Smart Specialisation Strategies. The Catalogue is currently hosted under the JRC Smart Specialisation Platform (S3P)[67] benefiting from and providing opportunities for synergies with S3P initiatives and for interaction with the interregional innovation eco-systems created under the S3P thematic Smart Specialisation platforms[68] on Agri-Food, Energy, and Industrial Modernisation to facilitate business investments.

> *During the next programming period 2021-2027 the European Commission and the Member States plan to support at least one DIH per region*

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[66] Catalogue of Digital Innovation Hubs, http://s3platform.jrc.ec.europa.eu/digital-innovation-hubs-tool
[67] Smart Specialisation platform, http://s3platform.jrc.ec.europa.eu/s3-platform
[68] S3 Thematic Platforms, http://s3platform.jrc.ec.europa.eu/s3-thematic-platforms

The DIH concept has evolved since its inception and the conditions under which a proposed DIH is now considered to be fully operational are defined as follows:

— be part of a regional, national, or European policy initiative to digitize the industry

— be a non-profit organization (or demonstrate to have a non-profit objective)

— have a physical presence in the region and present activities and services on an updated website

— demonstrate at least 3 examples of how the DIH has helped a company with their digital transformation. This information (client profile, client needs, and solution provided) must be publicly available.

As of March 2019 the DIH Catalogue online tool hosted 269 *Fully Operational* hubs and 220 other hubs *In Preparation*, distributed in the EU countries as shown in Figure 1.5.

An overview and examples of DIHs in the sectors covered in this report can be found in the relevant sections of the report.

FIGURE 1.5: GEOGRAPHICAL DISTRIBUTION OF DIGITAL INNOVATION HUBS (MARCH 2019).
Source: European Catalogue of Digital Innovation Hubs.

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List of abbreviations and definitions for Part 1 – Introduction, conceptual framework and horizontal policy issues

AI   Artificial intelligence
APIs   Application programming interfaces
AWS   Amazon Web Services
B2B   Business to business
B2C   Business to consumers
CJEU   Court of Justice of the European Union
DEI   Digitising European Industry
DIH   Digital Innovation Hub
DT   Digital transformation
DT&AI   JRC project on Digital Transformation and Artificial Intelligence
EC   European Commisison
ENISA   European Union Agency for Cybersecurity
EU   European Union
GPB   British Pound
ICT   Information and communication technologies
IoT   Internet of things
IP   Intellectual property
JRC   Joint Research Centre of the European Commisison
MS   Member state(s) of the European Union
NHS   United Kingdom's national health system
NIS   Network and information systems
P2P   Peer to peer
PSI   Public sector information
R&D   Research and development
RTO   Research & technology organisation
S3P   JRC Smart Specialisation Platform
TDM   Text and data mining
TFEU   Treaty on the Functioning of the European Union

2

DIGITAL TRANSFORMATION IN TRANSPORT

② DIGITAL TRANSFORMATION IN TRANSPORT

Summary

Digital technologies, together with connectivity and social media are currently transforming traditional concepts of mobility. In particular, new technologies and transport trends add new levels of interaction with the society and users, and may have considerable influence on people mobility and freight transport services. New business models are emerging and giving rise to innovative mobility services including new on-line platforms for freight operations, car-pooling, car or bicycle sharing services, or smartphone applications offering real-time analytics and data on traffic conditions. Vehicles themselves are also being transformed by digital technologies. They are becoming increasingly smart as new on-board connected and cooperative services and increased levels of automation become available, aided by Artificial Intelligence (AI) and the development of the Internet of Things (IoT). The advent of Connected and Automated Vehicles (CAVs) with advanced sensing and wireless communication abilities could represent the standard in private transportation by 2050. CAVs can contribute to increasing the efficiency and safety of the transport system. They can improve traffic flows, optimise infrastructure and public transport usage, and foster multi-modal transport solutions.

In the other transport modes (aviation, railway and maritime), connectivity and partial automation have been present in different forms, and have gained passengers' and stakeholders' trust. In aviation, automation has changed the roles of both pilots and air traffic controllers, now assuming the roles respectively of strategic managers and hands-off supervisors. Automatic train operation is well-established on metro systems in Europe and around the world, and a further expansion is expected in main railway lines. In addition, autonomous ships are under development.

Parallel to the development of these technologies, a paradigm shift in road mobility use is already on the way. Traditional ownership of petrol-powered cars is challenged by Mobility as a Service (MaaS), which represent a shift away from personally owned means of transport towards on-demand pay-per-use mobility solutions. The impact of MaaS is accelerated by societal, economic and technological drivers. The sharing economy, big data and urbanisation are additional MaaS enablers. The widespread of the ownership-based car mobility is motivated by the high value given by people to the perceived reliability and accessibility of the transport service, rather than just its cost-effectiveness.

Digital transformation (DT) may also help developing autonomous mobility on demand (AMOD) services that could supplement public transport networks where they are too expensive to operate (e.g., in sparse, peri-urban areas, but also at off-peak/night times). AMOD could have a synergistic impact on public transport, as it saves money and resources and can support the optimal operation of the system in other, core areas.

DT has enabled fundamental reinvention of the old production processes and service delivery. DT is already revolutionising manufacturing and the supply chain. New forms of more sustainable freight delivery (e.g. bicycle-based delivery services) appear as viable alternatives for (last-mile) delivery of goods. Sidewalk-based autonomous solutions are being developed and if scaled up to the city level could have a big impact. Delivery robots (ground drones) also seem to be making much progress at a city level. Air-drones are promoted and supported by a growing number of firms nowadays as a valid alternative for last mile delivery in rural and suburban areas, with much progress made at legislation level.

Transport electrification assisted by DT can contribute to breaking transport dependency on oil and decrease tailpipe emissions. Network and traffic management systems based on digital technologies are used for the optimisation and management of the transport networks' operation.

Predicting future transport developments, whether they are on new transport technologies, new mobility approaches, demand changes etc. is a constant challenge. Many of today's transport trends did not exist a few years ago. Ride-hailing service companies that use online platforms to connect between passengers and local drivers using

their personal vehicles, did not exist 10 years ago while nowadays serve tens of millions of trips every day.

It is clear from the above that the transition to a new era of transport systems assisted by DT in the sector has a great disruptive potential. Nevertheless, there are potential issues such as data collection, and related challenges such as privacy and cybersecurity that need to be addressed through an appropriate policy framework, integrated with R&I actions and the development of standards. Furthermore, the path to the digital transport era will not be quick and without pitfalls. Many technological, social and legislative barriers will need to be addressed. Standardisation issues for technologies that have not reached maturity (e.g. hyperloop technologies) and legal aspects for others (liability of automated vehicles, air-drones etc.) need to be addressed meticulously, in order to avoid future pitfalls, assist technology diffusion and achieve future safety and security goals. As in other domains, the challenge for regulators is to balance the need for technological progress and its many benefits with the safeguard of the fundamental rights and safety of the citizens.

To this aim, the European Commission (EC) is taking concrete steps. It launched the Cooperative Intelligent Transport Systems (C-ITS) initiative in 2016 to foster cooperative, connected and automated mobility, which lead to the adoption of five principles about granting access to in-vehicle data and resources. In May 2017, the second Mobility Package introduced the Strategic Transport Research and Innovation Agenda (STRIA), which has as an aim to determine the needs and set the objectives for what needs to be achieved in Europe's transport innovation system. The Transport Research and Innovation Monitoring and Information System (TRIMIS) is the analytical support tool for the establishment and implementation of STRIA. In May 2018, the EC presented the third Mobility Package with the objective to allow citizens to benefit from safer traffic, less polluting vehicles and more advanced technological solutions, while supporting the competitiveness of the EU industry. Particular focus is given in autonomous mobility that has the potential to make transport safer, more accessible, inclusive and sustainable. In March 2019, the EC adopted new rules stepping up the deployment of C-ITS in the form of a delegated act, which is based on the ITS Directive. The specifications establish the minimal legal requirements for interoperability between the different cooperative systems used. On 8th July 2019 the Council of the European Union however adopted a decision to object to the EC proposal for delegated regulation on C-ITS.

The design and implementation of governance, regulatory and public procurement strategies is required in order to support and strengthen the development of integrated planning tools and open, real-time data systems to allow for the validation and optimisation of integrated mobility eco-systems. The appropriate tools combined with the necessary data can indeed catalyse the transport system reform at all spatial levels.

2.1 | Overview of the Digital Transformation in Transport

Transport is one of the main pillars of development and is composed of a spectrum of individual systems and their interconnections whose purpose is to cover the mobility demand of people and goods. Transport systems include a series of physical and organisational elements and are characterised by overall intrinsic complexity. These elements may influence each other directly and/or indirectly, linearly or nonlinearly, and also have potential feedback cycles (Cascetta, 2001). In particular, new technologies and transport trends add new levels of interaction within the society and between society and users and may influence people mobility and freight transport services considerably.

Moreover, digital technologies and an enhanced level of connectivity are transforming traditional concepts of mobility. New business models are emerging and giving rise to innovative mobility services including new on-line platforms for freight operations, car-pooling, car or bicycle sharing services, or smartphone applications offering real-time analytics and data on traffic conditions. Vehicles themselves are also being transformed by digital

technologies. They are becoming increasingly smart as new on-board connected and cooperative services and increased levels of automation become available. The advent of Connected and Automated Transport (CAT) is likely to provide a turning point in mobility. Connected and automated vehicles (CAVs) with advanced sensing and wireless communication abilities could become the standard in private transportation by 2050 (Alonso Raposo et al. 2017).

Significant advances have already been made: from the emergence of the first affordable vehicles in the early 1900s to the development of passive and active safety technologies in the 1970s, and the advent of Intelligent Transport Systems (ITS) and driver assistance technologies since the 1980s, which together are supporting the optimisation of road transport. Advances in the field of Artificial Intelligence (AI), on which autonomous vehicles are heavily dependent, are developing steadily at present, and are likely to bring extensive changes to mobility and transport systems, revolutionising all aspects of society and life. The impacts of such a revolution on road transport
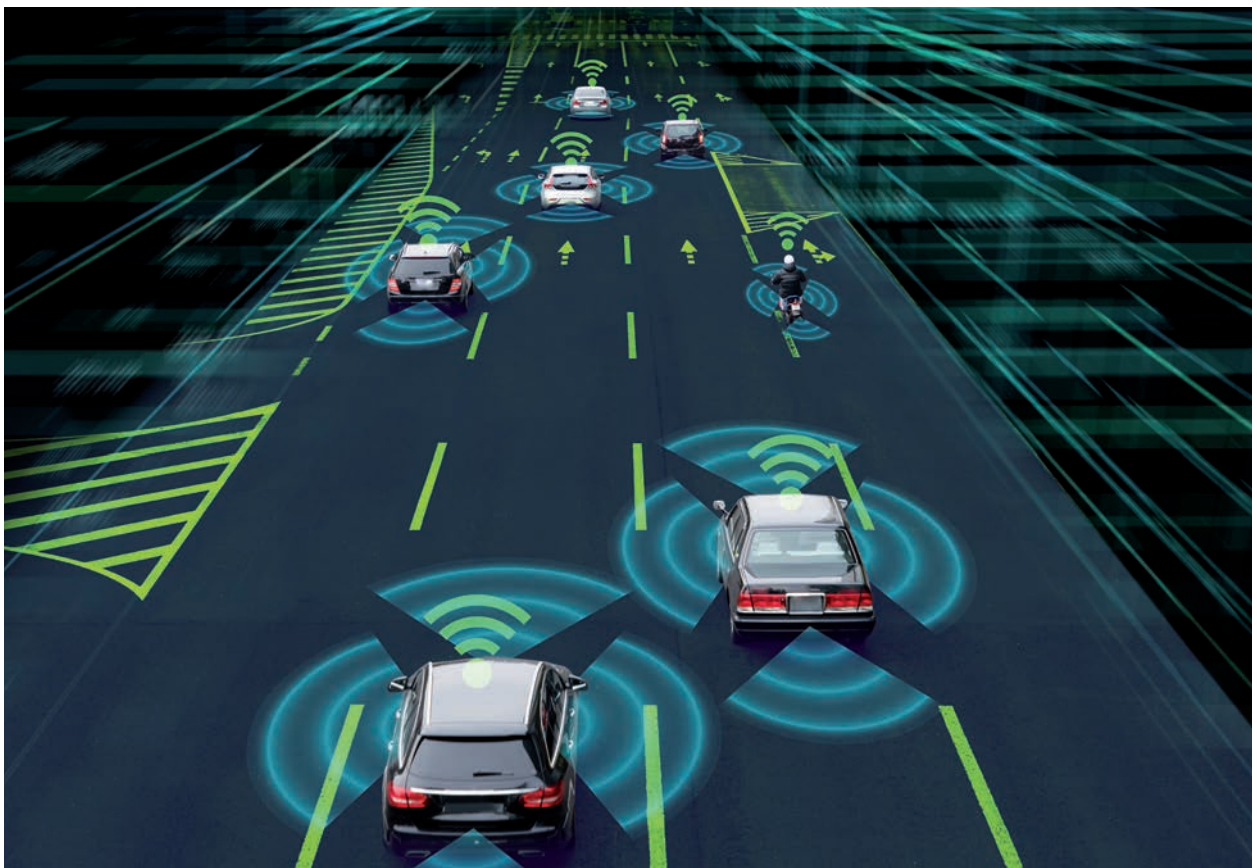
> *Advances in digital technologies and greater connectivity are causing a paradigm shift in the transport sector*

can be far reaching, from drastically reducing road accidents to allowing efficient traffic flows and decreasing road transport emissions. According to some authors, the forthcoming technologies and impacts of the AI revolution will probably be significantly greater than those of the digital and even industrial revolutions (Makridakis, 2017).

Parallel to the development of these technologies, a paradigm shift in mobility is already on the way. Traditional ownership of petrol-powered cars is challenged by Mobility as a Service (MaaS) or Transport as a Service (TaaS), which represent a shift away from personally owned modes of transport towards on demand pay-per-use mobility solutions. It seamlessly combines transport options from different providers, handling everything from travel planning to payments[69]. Societal, economic, and technological drivers are accelerating the disruptive impact of MaaS. Urbanisation, climate change, the sharing economy, big data, or the need to match demand and supply better are some examples of MaaS enablers (Holmberg et al. 2016). However, it is only with fully connected and automated (and possibly also electric) vehicles that MaaS will be able to express all of its potential by being able to contribute disrupting mobility (Arbib and Seba, 2017). The widespread nature of ownership-based car

mobility - the European Union (EU) counts 511 cars per 1,000 inhabitants[70] - is motivated by the high value people give to the perceived reliability and accessibility of the transport service rather than just its cost-effectiveness. The certainty of an available vehicle coming to pick one up when requested is crucial if any substantial change in the mobility patterns is going to happen for people who already rely on private cars for their daily transportation. Moreover, it is easy to argue that the demand for personal mobility (although consumed as a service) will be even greater in the future, especially when aspects such as the accessibility for elderly or disabled people are considered[71]. Consequently, it is important to understand how future road transport system(s) will accommodate this increase.

Digital technologies have also enabled fundamental reinvention of old production processes and service delivery. New forms of more sustainable freight delivery (e.g. bicycle-based delivery services) appear to be viable alternatives for (last-mile) delivery of goods. Sidewalk-based autonomous solutions are being developed and if scaled up to the city level might have a positive impact

> *A shift away from personally owned means of transport towards on-demand pay-per-use mobility solutions has already begun*

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[69] What is Mobility as a Service? http://maas.global/what-is-mobility-as-a-service-maas
[70] https://www.acea.be/uploads/statistic_documents/ACEA_Report_Vehicles_in_use-Europe_2018.pdf
[71] http://europa.eu/rapid/press-release_IP-15-6147_en.htm

> *Digital technologies have also reinvented service delivery and affected logistic chains, including more sustainable freight last-mile delivery (e.g. bicycle-based delivery services, drone delivery, etc.)*

in terms of convenience and cost, but also a negative impact (i.e. crowding of the limited urban space which is now reserved for pedestrians). Delivery robots (ground drones) seem to be making a great deal of progress with several pilot schemes taking place worldwide at the time of writing, including one operating at scale in George Mason University[72] in Virginia, United States of America). Air-drones are also proposed as a valid alternative. Home delivery by air-drones is being promoted and supported by a growing number of firms, especially in rural environments[73], while studies highlight that there is a potential market and

economic viability of using air-drones for parcel delivery in Europe (Aurambout et al. 2019).

Furthermore, urban air mobility (UAM) is being explored as a valid option by various companies and in research activities in Europe and worldwide. The European Commission (EC) aims to contribute to the creation of a market for urban air mobility that brings together cities and regions[74].

In order to address current socio-economic challenges within this ever-changing complex and competitive environment, the transport sector requires new technological developments. In 2017, the EC adopted the Strategic Transport Research and Innovation Agenda (STRIA) as part of the "Europe on the move" package (European Commission, 2017a), which highlights main transport Research and Innovation (R&I) areas and priorities for clean, connected, and competitive mobility to complement the 2015 Strategic Energy Technology Plan (European Commission, 2015a).

With this goal in mind, the STRIA focuses on the development and deployment of low-carbon transport technology solutions while encompassing digitalisation, safety, security, and other relevant aspects. It has identified priority areas with specific actions for future R&I, outlined in seven roadmaps, as seen in Figure 2.1.

The implementation of STRIA is supported by an effective monitoring and information mechanism that will assist the development and updating of STRIA and support transport R&I. The Transport Research and Innovation Monitoring and Information System (TRIMIS) has been developed at the EC Joint Research Centre (JRC) to provide a holistic assessment of technology trends, transport R&I capacities, to publish information and data, and to develop analytical tools for the European transport system (Tsakalidis et al. 2018).

The rest of this section closely follows the seven STRIA Roadmaps in identifying challenges and opportunities in digital transformation, with focus on road transport and the cooperative, connected, and automated transport roadmap, areas that has received great interest in recent

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[72] https://www.engadget.com/2019/01/22/starship-robot-deliveries-george-mason-university/
[73] https://uavcoach.com/drone-deliveries-2018/
[74] https://ec.europa.eu/transport/media/news/news/2018-05-30-commission-welcomes-european-cities-joining-urban-air-mobility-initiative_en

FIGURE 2.1: THE STRATEGIC TRANSPORT R&I AGENDA (STRIA): ROADMAPS.
Source: European Commission, 2017a.

years. In fact, it is expected that EU transport activity will continue to grow in the coming decades, with road transport preserving the dominant role among all transport modes (Alonso Raposo et al. 2019).

2.1.1. Connected and Automated Transport

CAT technologies can contribute to increasing the efficiency and safety of the transport system. They can improve traffic flows, optimise infrastructure and public transport usage, and foster multi-modal transport solutions.

In the road sector, massive hype has surrounded CAT, with autonomous vehicles being at the peak of inflated expectations in the 2015 Gartner Hype Curve[75]. A number of pilot demonstrations of CAT technologies are taking place in Europe, but there is still a need for large-scale testing to determine the technological readiness, reliability, and safety of automated transport functions

in complex situations. Digital Connectivity plays a vital role in addressing key issues such as the performance of innovative automated transport technologies, the regulatory framework that supports deployment of CAT solutions and technologies, acceptable levels of cybersecurity, as well as new business models.

In future scenarios (especially in the event of substantial increases in travel demand due to greater accessibility, e.g., for people with reduced mobility, younger and older age groups currently not permitted to drive), traffic management would need to play a decisive role in

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[75]   Gartner's 2015 Hype Cycle for Emerging Technologies Identifies the Computing Innovations That Organizations Should Monitor https://www.gartner.com/en/newsroom/press-releases/2015-08-18-gartners-2015-hype-cycle-for-emerging-technologies-identifies-the-computing-innovations-that-organizations-should-monitor

enabling safe and efficient mobility, that is, a Connected, Coordinated and Automated Road Transport (C2ART) system (Alonso Raposo et al. 2017). This "connected" and "coordinated" aspect adds increased control possibilities towards an optimisation of transport flows.

A number of issues remain unresolved. First, given the intrinsic complexity of the road transport system, the uncertainty in predicting the impacts of CAT remains high. In fact, even after several years of testing, it remains unclear how CAVs, mixed with conventional legacy vehicles, will behave in real traffic. Their promising impacts in energy/fuel efficiency could be partially outweighed by higher travelling speeds (Makridis et al. 2018a), or these technologies may stimulate more travel as a result of safer, cheaper, more accessible, and more comfortable and productive driving conditions (Fagnant and Kockelman, 2015). Besides, many of the expected benefits associated with CAVs would most probably not materialise until they constitute a significant part of the road transport market, which will require time and is difficult to predict.

> *Connected and automated transport will likely reduce road accidents, improve traffic flows and decrease road-transport emissions*
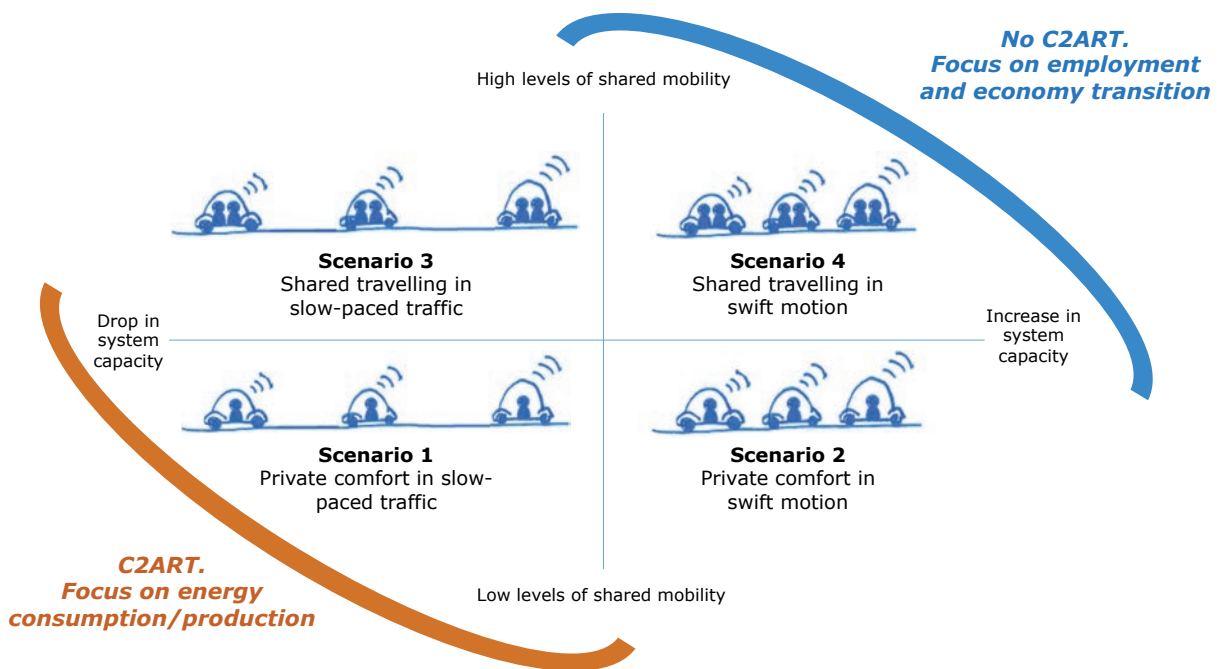
FIGURE 2.2: FOUR FUTURE MOBILITY SCENARIOS.
Source: JRC analysis, adapted from Alonso Raposo et al. 2018a.

■ *Scenario 1: Private comfort in slow-paced traffic*

The deployment of CAVs does not change users' mobility paradigms and car ownership at a personal level remains strong. Road traffic demand may

significantly increase as a result of the enhanced travel conditions. Risk averse design of autonomous vehicles may force a drop in the system's capacity. Higher levels of coordination become necessary to avoid the collapse of the transport system. A

Coordinated Automated Road Transport (C-ART) system is needed to ensure the sustainability of road transport.

- ■ *Scenario 2: Private comfort in swift motion*

The deployment of CAVs does not change users' mobility paradigms and car ownership at a personal level remains strong. Road traffic demand may significantly increase. However, CAVs facilitate increased roadway capacity. This circumstance may mean that major coordination efforts are unnecessary. Nevertheless, the capacity of the road infrastructure is always limited and coordination of CAVs could still be crucial in managing potential congestion peaks. Consequently, a C-ART system may be required.

- ■ *Scenario 3: Shared travelling in slow-paced traffic*

The deployment of CAVs is disruptive and quickly allows the transition to shared on-demand mobility at large scale. As a result, road traffic demand does not increase although risk-averse design of autonomous vehicles may make the capacity of the system drop. While travel demand does not increase in this scenario, CAV coordination may be necessary to solve the roadway capacity reductions at certain points. A C-ART system may therefore be necessary.

- ■ *Scenario 4: Shared travelling in swift motion*

The deployment of CAVs is disruptive and soon allows transition to a shared on demand mobility at large scale. The number of vehicles is significantly reduced and congestion phenomena rarely arise. Major coordination efforts for the system are not necessary. The automated road transport system means users enjoy a safe and efficient mobility.

Focusing on Scenario 4, where technology alone will be able to increase the capacity of the road transport system and vehicles will mainly be used as a shared means of transport, any increase in traffic demand will be absorbed by the system. Traffic prediction or car/ride sharing can optimise the use of parking space and may in turn make road transport more efficient. Coordination will probably not be required unless demand peaks occur. The focus should shift to the societal implications of the transformation and on how to deal with the possible changes in the skills and employment structures.

Digitalisation could also help develop autonomous mobility on demand (AMOD) services that could supplement public transport networks where they are too expensive to operate (sparse, peri-urban areas, but also off-peak/night times). This could have a synergistic impact on public transport as it saves money and resources and supports the optimal operation of the system in other core areas. On the other hand, the offering of AMOD in denser, more central areas could compete with public transport, drawing ridership from it.

In order to understand the implications of new technologies on different aspects of our society, the JRC has recently decided to establish at its Ispra site a Living Lab[76] for Future Urban Ecosystems where new smart city technologies and solutions are introduced and tested in their interactions with citizens, or in this case with JRC staff and visitors. Among others, automated shuttle, robotaxi services, and ride-sharing applications will be tested.

Connectivity and (partial) automation in the other transport modes (aviation, railway, and maritime) are present in various forms. Automation in aviation has changed the roles of both the pilot and the air traffic controller, who are now strategic managers and hands-off supervisors, only intervening when necessary[77]. Autonomous airplanes under development are not foreseen in the next decade, while an intermediate step would be a single-pilot operation. On the other hand, both developments require the trust of both passengers and stakeholders. Automatic train operation is well-established on metro systems in Europe and around the world, and further expansion is expected to main line railways. Autonomous ships are under development, but the economic advantages of full automation are not clear, and several steps need to be made from navigation automation to fully autonomous navigation (Lloyds Register, 2016). A notable example is an urban-oriented autonomous boat fleet which is under development, with fully functioning prototypes expected in 2020[78].

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76   https://ec.europa.eu/jrc/en/research-facility/living-labs-at-the-jrc
77   https://www.acare4europe.org/sites/acare4europe.org/files/document/Flightpath2050_Final.pdf
78   Transforming Amsterdam's canals with a fleet of autonomous boats. http://roboat.org

2.1.2. Transport Electrification

Transport electrification contributes to breaking transport's dependency on oil and to decreasing tailpipe emissions. The increasingly decarbonised electricity generation will provide cleaner electricity to propel EVs. The development of energy storage technologies and devices remains the cornerstone of a fully electrified transport system integrated in a clean energy network. Decreasing battery costs while increasing their energy density and lifetime will speed up electrification of road transport. The deployment of a network of recharging points covering the whole EU road network is another key enabling condition for transport electrification.

Even though the Electric Vehicle (EV) market share and available recharging infrastructures have increased significantly since 2010, further research and development efforts are needed. Road EVs have already found their way onto the market, especially for personal transport, with increasing confidence from users (Gomez Vilchez et al. 2017). This is a disruption considering the past 100 years of combustion engine dominance in the sector. For this purpose, the European political trajectory should be adjusted according to the needs introduced by current technological trends, towards a sustainable and economically viable future. EV registrations have been increasing in the EU during recent years providing

> *Transport electrification in combination with digital transformation can contribute to decrease both dependency on oil and tailpipe emissions*

a starting point for technological and market penetration evaluation as well as analysis of the status and future trends of road transport electrification (Tsakalidis and Thiel, 2018). Figure 2.3 presents an overview of selected projections on the future of EV sales share for the EU until 2050.
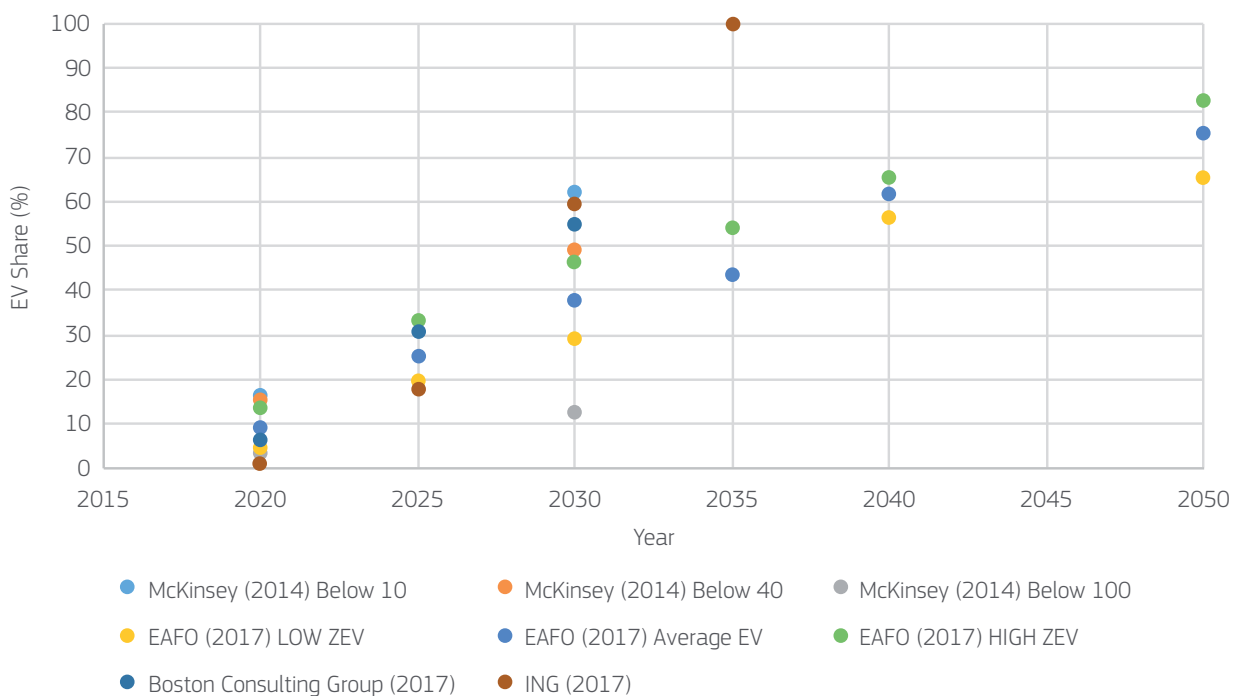
FIGURE 2.3: RANGE OF SALES PROJECTIONS FOR BEV/PHEV IN EUROPE UNTIL 2050.
Source: Tsakalidis and Thiel, 2018.

Railway electrification is now the standard, while several pilot projects in the maritime and the aviation sector complete the picture on electrification. Two examples are the EU-funded Horizon 2020 projects E-ferry[79] which is building a new 100% electric ferry, and MAHEPA[80] which is developing prototype planes using electric motors and modular power-generation systems.

2.1.3. Vehicle Design and Manufacturing

Transport vehicle design and manufacturing (VDM) is a collaborative, integrated, and complex set of processes and tools that consider the whole vehicle life cycle and is a key element in the competitiveness of the European transport industry. For example, the design of future cars will probably be very different. Depending on the automation level, several features of the car will need to be changed, e.g. size, seat configuration, weight, infotainment layout, comfort features, personal storage solutions, and presence of a steering wheel. Continuous R&I is necessary for the seamless integration of digital and physical vehicle design and manufacturing processes, tools, and infrastructure. Electrification, digitalisation, and automation now drive the disruption of the evolutionary path of car design and manufacturing. Advances in Digital Transformation help optimise both production and supply chain operations. Modularity and modular architectures are expected to advance further and shift from recycling to remanufacturing. With this aim in mind, SMART (*Sustainable use of Materials through Automotive Remanufacturing to boost resource efficiency in the road Transport system*), a 2-year Exploratory Research project by the JRC concluding in 2019 focuses on remanufacturing of car vehicles and vehicle components, thereby supporting the efficient and circular use of materials. Exploratory Research as a direct action is included in the Horizon 2020 Framework Programme (H2020) for the JRC to pursue excellence[81].

> *Electrification, digitalisation and automation are heavily impacting vehicle design and manufacturing*

2.1.4. Low-Emission Alternative Energy for Transport

Electric battery and hydrogen fuel cell powertrains are now seen as a viable option for many road vehicles. However, aviation, waterborne transport, and certain heavy-duty road vehicles are likely to rely on combustion engines and liquid fuels for the time being.

In order to decarbonise the transport sector in the short- and medium-term, it is therefore essential to increase the use of renewable energy sources and improve the overall energy efficiency of the transport system. This will not only reduce greenhouse gases but also pollutants that are responsible for poor urban air quality. Nevertheless, increasing the share of alternative low-emission energy in the transport sector poses a number of technical and environmental challenges.

For energy production, R&I efforts will need to focus on novel low-emission alternative energies based on

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[79] Prototype and full-scale demonstration of next generation 100% electrically powered ferry for passengers and vehicles (E-ferry) http://e-ferryproject.eu

[80] Modular Approach to Hybrid Electric Propulsion Architecture (MAHEPA) https://mahepa.eu

[81] https://cordis.europa.eu/programme/rcn/664511/en

renewable and sustainable sources. The development of a new generation of powertrains will require R&I efforts to focus on a change in technology that allows greater and more efficient use of alternative energies to reduce greenhouse gases.

The use of big data in the road sector, in the form of datasets of real world driving and mobility patterns collected from navigation systems, will be important in supporting low-emission alternative energy road transport policies in Europe. The JRC transport technology and mobility assessment platform (TEMA) was conceived as a flexible and modular data mining platform, natively interfaced with GNSS-based digital mapping systems, developed and designed for harnessing the potential of big data in the field of transportation policies (De Gennaro et al. 2016). Among other things, the innovativeness of TEMA consists of its ability to process large databases to derive Geographic Information System (GIS) based on spatial distributions of energy demand and offer other analyses in the fields of real-world driving and non-driving emissions, hybrid and electric vehicle deployment, and transport and energy networks interface.

2.1.5. Network and Traffic Management Systems

Network and Traffic Management (NTM) systems are used for the optimisation and management of transport network operations. Bottlenecks across air, rail, road, and water can result in system-wide capacity constraints, traffic jams, increased pollutant emissions, and environmental impacts.

The transition towards an advanced multi-modal transport system requires better coordinated and organised traffic flows to optimise the entire transport network. This involves devices to detect real traffic conditions, traffic information sharing, optimisation processes, and the distribution of control actions via end-user devices.

Digital technologies and the emergence of the connected traveller may influence real-time demand by encouraging off-peak travel and use of alternative routes through intelligent applications and user information services. Integrated urban traffic management and mobility information systems can therefore contribute to optimising transport flows in both cities and rural regions. Consequently, the concept of traffic management system should evolve towards a mobility management system in which all means of transport are integrated in a seamless way in order to provide the user with the best option to satisfy their mobility needs (Alonso Raposo et al. 2018b).

> *Digital technologies and the emergence of the connected traveller can influence real-time transport demand by optimising off-peak travel and use of alternative routes through intelligent applications and user information services*

2.1.6. Smart Mobility and Services

Smart mobility systems and services can contribute to the decarbonisation of the European transport sector. Changes in transport behaviour and lifestyle such as the use of smartphones, mobile web applications, and social media together with the trend to use rather than own a particular means of transport has opened up new pathways to sustainable mobility.

A critical link exists between new technologies, services, and transport decarbonisation. However, policy and innovation efforts have overwhelmingly focused on small changes to improve vehicle technology rather than on integrated transport and mobility strategies. Breaking this path-dependency remains a key innovative challenge.

Future transport and mobility services will need to be part of smart and sustainable city strategies to improve urban resource efficiency, decarbonisation, and ensure an integrated transport system. Smart cities also rely on smarter urban transport networks[82]. The European Institute of Innovation and Technology's (EIT) Urban Mobility initiative addresses solutions that improve the collective use of urban spaces in the digital age[83].

Car pooling services have exploded in recent years and co-exist with public transport. In Germany, Isar Tiger (operated as a pilot by the Munich Transport Corporation – MVG – in Munich) or BerlKönig[84] (operated in Berlin) complement public transport, offering the comfort of shared mobility at an extra cost. Uber and Lyft believe they can provide their shared services (e.g. UberPool) at prices below that of public transport in many cases, essentially competing directly with it.

2.1.7. Infrastructure

Transport infrastructure includes physical networks, terminals, and intermodal nodes, information systems, and refuelling and electrical supply networks that are necessary for the safe, secure operation of road, rail, civil aviation, inland waterways, and shipping. EU transport infrastructure faces key challenges with regard to governance; pricing, taxation and finance; intermodality (that is, the sequential use of different transport modes), synchromodality (that is, the simultaneous usage of multiple transport modes), interoperability, and integration of transport systems; life cycle optimisation; and infrastructure operation. Infrastructure development for the electric, autonomous, and connected environment will dominate in the next few years, starting from the development of smart recharge infrastructures, and the design of a customer-driven smart recharge infrastructure and tailored Vehicle-to-Grid (V2G) application in public areas (Paffumi et al., 2016). Moreover, the application of digital technologies can improve the process of monitoring and maintenance of transport infrastructure. They can contribute towards enhanced safety of ageing existing infrastructures through innovative monitoring technologies currently being researched, e.g., air-drones, satellites, and crowdsourcing (Gkoumas et al. 2019).

2.2 | Digital Transformation Enablers and Barriers in Transport

2.2.1. Technologies and Infrastructure

This section focuses on significant technological changes and challenges in infrastructures (both physical and IT) arising out of the Digital Transformation in the transport sector. The issues identified are arranged according to the previously mentioned seven STRIA Roadmaps.

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[82] https://ec.europa.eu/info/eu-regional-and-urban-development/topics/cities-and-urban-development/city-initiatives/smart-cities_en
[83] https://eit.europa.eu/eit-community/eit-urban-mobility
[84] https://www.berlkoenig.de

In the cooperative, connected, and automated transport roadmap, principal challenges (↗) and enablers (↕) are the following (JRC analysis based on European Commission (2017a)):

↗ AI is a pillar of the decision-making process in a connected and automated environment, and includes all processes related to learning, reasoning, and behaving. Artificial Intelligence will become increasingly important in semi-autonomous and autonomous mobility as well as in on-demand mobility dispatching and point-to-point multimodal navigation.

↗ *Telecommunications and connectivity*. Personal road vehicles and self-driving trucks in platooning mode (ACEA, 2017a) – that is, trucks using connectivity and automation to follow each other at a very short distance to save fuel and reduce CO_2 emissions – will need to exchange information between themselves on a frequent basis (Vehicle-to-Vehicle, V2V) as well as with the communications infrastructure (Vehicle-to-Infrastructure, V2I). To this extent, V2V and V2I communications will become key enablers for the successful deployment of CAT. At the time of writing, two communications standards have been proposed for short-range V2V services, namely ITS G5 (based on enhancements to current Wi-Fi standards) and LTE-V2X (based on enhancements to cellular communications standards). Further information on the ITS G5 and LTE-V2X standards can be found in Appendix below.

↗ *Sensor technology*. Sensors for autonomous vehicles will become smaller, cheaper, and more integrated. Modularity and sampling rate will be crucial for successful deployment. During the last decade, there has been a growing dependency of vehicles on sensors and computing platforms able to process the sensor data in an increasingly sophisticated way to implement advanced driver-assistance systems such as electronic stability control, anti-lock brakes, lane departure warning, adaptive cruise control, and traction control (Fleming, 2013).

↕ *Cybersecurity*. The proliferation of connected and autonomous means of transport will raise cybersecurity risks due to the increased amount of interconnected digital components in vehicles, their

external connectivity (i.e., the connected part), and the increasing reliance on Artificial Intelligence algorithms and sophisticated sensors (e.g., the autonomous part). These issues are likely to become even more important with semi-autonomous or autonomous vehicles and it is important to define a strategy and related policies to foster the design and implementation of security solutions in vehicles and road infrastructure in general (European Commission, 2016).

↕ *Data harmonisation*. Data exchange will be crucial for the future development and success of CAT. Data will need to have a standard format that will allow the seamless exchange between vehicles and infrastructure and will form the basis of interoperability at European level and also between the main elements of the road transportation infrastructure.

↕ *Privacy*. CAT will both generate and use significant amount of data. The data generated and processed often contains personal data (e.g. geolocation data), which means that the collection and processing needs to be compliant with the EU data protection regulatory framework and all privacy issues need to be addressed. Various issues have been identified in the work by the Cooperative Intelligent Transport Systems (C-ITS) platform coordinated by the Directorate-General for Mobility and Transport (DG MOVE) and described in the final technical reports on cooperative, connected, and automated mobility (CCAM)[85].

The principal issues and challenges in transport electrification are:

↗ *Consumption optimisation*. Digital technologies will allow further optimisation of consumption in electric vehicles, including consumption monitoring.

↗ *Distributed technologies*, such as vehicle stabilisation functions and distributed regenerative braking will benefit from digital technologies in size and performance.

↗ *Real time analytics* include predictive maintenance, demand response, and outage detection, and will benefit from digital technologies in reliability and real-time information.

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[85] Cooperative, connected and automated mobility (CCAM) https://ec.europa.eu/transport/themes/its/c-its_en

- $\updownarrow$ *Interoperability* is one of the principal challenges for the successful deployment of EVs. Digital technologies may help towards integration and interoperability of chargers and EVs.

The principal issues and challenges in vehicle design and manufacturing are:

- $\nearrow$ *Modular design.* This will be achieved by optimising processes, with digitalisation along the value chain, enabling modular vehicle architecture and a closed loop approach. There is need for research on innovative repair and end-of-life recovery options, which allow a move from traditional recycling to more energy efficient remanufacturing.

- $\nearrow$ *Remanufacturing* will come as a consequence of modularity and modular architectures.

- $\nearrow$ *Made to order manufacturing*, fulfilling the requirements laid out by customers will become particularly important in the future. Digitalisation will help towards a transparent and optimised process.

- $\nearrow$ *Supply chain.* Internet of Things (IoT), location tracking, sensors, and other digital technologies will transform the entire supply chain.

- $\nearrow$ *Removal chain:* smart tags and digital markers will progressively make the tracking of components and materials after their disposal possible so that assessment of the life-cycle sustainability improves.

- $\updownarrow$ *Data compatibility*, together with standardisation, interchangeability, and security is a key issue in facilitating the ever-increasingly modular approach in the future. Digital technologies will help, in particular in aspects regarding digital footprints.

Enablers in alternative low-emission energy for transport include:

- $\nearrow$ *Supply chain integration*, including sustainable feedstock supply chains, will benefit from tracking procedures made possible by digital technologies.

The principal issues and challenges in network and traffic management systems are:

- $\nearrow$ *Network-level flow management*, including use of virtualised environments, is important in balancing demand and capacity in networks across modes.

- $\nearrow$ *Synchromodality* promotes *the* use of all transport modes in parallel and is equally important for freight and personal transport. It can benefit from digital technologies at all levels (e.g. planning, booking, and management).

The principal issues and challenges in smart mobility and services are:

- $\nearrow$ *Digital ticketing* and transport paying environment is about the freedom to travel from door to door across any mode through the convergence of ticketing and payment. Digital technologies are the key to ordering and dispatching services, including in-carriage retailing.

- $\nearrow$ *Co-use of infrastructure, using residual capacity of (also shared) vehicles, tendentially combined with transshipment boxes and also potentially crowd shipping (like amazon flex[86] or similar UPS services operating in several cities).*

- $\updownarrow$ *Shared mobility* and MaaS enables users to gain short-term access to transportation modes on an "as-needed" basis. Connectivity and integration with digital technologies is crucial for the successful deployment of shared mobility.

- $\updownarrow$ *Integration with smart cities.* Smart mobility services and systems will need to interface with multi-sectoral and citywide strategies through a technological interface in order to optimise the use of energy, and spatial, economic, and material resources, mainly through crowdsensed data.

The principal issues and challenges in infrastructure are:

- $\updownarrow$ *Real time information.* The growth of digital systems and mobile information means that transport users, and increasingly transport operators, demand more timely and accurate provision of information, and this information provision spans across modes.

- $\updownarrow$ *Freight automation.* Freight transport bears all of the challenges of poor system performance and first/last mile problems. The nature of freight flows from producer to consumer means there are imbalance problems in container systems for intermodal

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86   https://flex.amazon.com

transport, resulting in large-scale empty container movements that can benefit from digital technologies on different fronts (tracking, supply chain control, cloud based information).

⇕ *Automated management, operations, and maintenance* through the interconnectedness of mobile sensors, mobile applications, and in general the opportunities offered by the IoT. This part includes transversal issues such as connected roads, energy harvesting, and structural health monitoring.

↗ *Resilience*, including urban, operating, and service resilience. Digital technologies help reduce unforeseen incidents, including those due to human errors, and allow the recovery to full service after such incidents to be speeded up.

Figure 2.4 summarises the above. It should be noted that some elements do not only fall under one category but have a transversal nature and can impact all areas i.e. cybersecurity, privacy, or artificial intelligence.

Connected and automated transport
• Artificial Intelligence
• Telecommunication and connectivity
• Sensor technology
• Cybersecurity
• Data harmonisation
• Privacy

Electrification
• Consumption optimisation
• Distributed technologies
• Real time analytics
• Interoperability

Vehicle design and manufacturing
• Modular design
• Remanufacturing
• Made to order manufacturing
• Supply chain integration
• Removal chain integration
• Data compatibility

Low-emission alternative energy for transport
• Supply chain integration

Network and traffic management systems
• Network level flow management
• Synchromodality

Smart mobility and services
• Digital ticketing
• Co-use of infrastructure
• Shared mobility
• Integration with smart cities

Transport infrastructures
• Resilience
• Real time information
• Freight automation
• Automated management, operations and maintenance

Digital Transformation in Transport

FIGURE 2.4: DIGITAL TRANSFORMATION ISSUES AND CHALLENGES IN THE TRANSPORT SECTOR.
Source: JRC analysis based on European Commission (2017a).

2.2.2. Cybersecurity and Privacy Aspects

2.2.2.1. *Cybersecurity*

The proliferation of connected and autonomous means of transport will raise cybersecurity risks, due to the increased amount of interconnected digital components in vehicles, their external connectivity (i.e., the connected part) and increasing reliance on AI algorithms and sophisticated sensors (i.e., the autonomous part). Various studies have already investigated these aspects (ACEA, 2017b; ENISA, 2017; Petit et al. 2015; Parkinson et al. 2017; Keen Security Lab, 2018; Computest, 2018) and they have identified various critical cybersecurity vulnerabilities that not only pose a threat to privacy, but also to the safety of roads and vehicles. Example of such vulnerabilities are those found by the white hackers who, in 2015, demonstrated how it was possible to remotely control an Internet enabled vehicle shutting it down and controlling the steering wheel while it was running on the highway (Parkinson et al. 2017). More recently other research teams found similar type of vulnerabilities in other vehicles (Keen Security Lab, 2018; Computest, 2018).

> *The proliferation of connected and autonomous means of transport will raise cybersecurity risks, due to the increased amount of interconnected digital components in vehicles*

The communication between vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) should also be protected and a number of actions are already ongoing at European level to set up a security framework based on a Public Key Infrastructure (PKI). One of the aims is the integrity of the messages exchanged on V2V and V2I communications. More details are discussed later in this section.

The vulnerabilities identified by many studies occur for several reasons, both technical and historical. The multimedia capabilities of vehicles have exploded in recent years, where the infotainment system has evolved to become a truly smart device with connectivity to external devices (e.g. mobile phones) and the Internet over wireless networks and the possibility of installing applications. The infotainment system has become an information hub, often able to interact with the other digital components of the vehicle.

Indeed, vehicles until recently were mostly non-connected mechanical systems with limited capabilities from an Information and Communications Technology (ICT) point of view. In the last five to ten years, there has been a growing dependency of vehicles on sensors and computing platforms able to process the sensor data in an increasingly sophisticated way to implement advanced driver-assistance systems such as electronic stability control, anti-lock brakes, lane departure warning, adaptive cruise control, and traction control. These systems are built using in-vehicle networks, which are mostly (if not all at the moment of writing this report) insecure: a malicious attacker, who is able to connect to the vehicle, can gain access and control the system and can potentially create serious safety hazards (Eiza and Ni, 2017). These new complex connected systems have not been designed with security in mind because there were either no economic drivers to implement security measures or because of the limitations of existing in-vehicle network protocols (Controller Area Network – CAN - bus), which did not allow easily implementation of security solutions.

These issues will become even more important with semi-autonomous or autonomous vehicles and it is important to define a strategy and related policies to foster the design and implementation of security solutions in vehicles and road infrastructure in general (European Commission, 2016). In addition, autonomous vehicles will depend on data from

sensors in order to make decisions. The cognitive processes of the autonomous vehicle will require highly accurate high quality data. Various studies have shown that sensors data of low quality can produce false results even when sophisticated autonomous cognitive systems are being used. In other words, the quality and accuracy of the data is quite important. Tampering with sensors or sensor data can also provoke significant security threats. The authentication of the sensors or the integrity of the data are two security functions which need to be implemented in future generations of both personal and commercial vehicles. Regulatory frameworks can also support and overcome the economics of cybersecurity in this area by requesting specific regulation or baseline requirements for the compliance assessment of vehicles. At the same time, the emergence of cooperative ITS (V2V and V2I) not only provides significant benefits for the road transportation community but also potential security challenges: messages exchanged between vehicles and infrastructure can be tampered with or modified consequently creating safety hazards.

Therefore, it is important to set up a security framework to guarantee the integrity of the messages exchanged. In other words, the messages exchanged between vehicles and the roadside equipment, both called ITS-stations in European

Telecommunications Standards Institute (ETSI) terminology, must be protected for integrity and authentication, otherwise the messages could be modified or tampered with at the risk of serious safety hazards occurring.

As a result, the EC set up a C-ITS platform for the definition of a trust model for cooperative vehicles in Europe based on Public Key Infrastructure (PKI). In this context, the JRC will play a central role because it will design and manage the pilot project for the implementation of the central elements of the PKI, which is essential in providing the interoperability of the cooperative vehicles across Europe and across different manufacturers.

The JRC has coordinated the drafting of the certificate policy and the security policy of the trust model, which are the main documents. They define and describe the rules and policies for the European trust model of cooperative vehicles. The drafting of these documents was an intensive process carried out by many different stakeholders (manufacturers, member states, security experts). The certificate policy was officially published on the DG MOVE web site in July 2017 (European Commission, 2017b).

2.2.2.2. *Privacy*

The main issues identified for privacy are:

- Possible insufficient control of data subjects over the processing of their personal data. Users may not

have the capability of controlling the information flow originating from the vehicle either because the interpretation of the data is difficult, but also because appropriate user-machine interfaces are currently

missing. For example, it may be difficult to acquire consent in an ITS environment (Neisse et al., 2016). In addition, the vehicles driven by users will contain mobile C-ITS stations, which will exchange information with the surrounding environment. This may result in exchange of data out from the vehicle over which the individual driving the vehicle may have only a limited amount of control in terms of both the transfer of information and the purpose of processing.

■ The data emitted by the C-ITS stations may be collected by other C-ITS stations and further processed for the purposes of incompatibility. For example, commercial parties can implement re-purposing of data where the initial data used to support C-ITS applications (e.g., safety application) can be used for other purposes. For example, the position broadcast by the vehicle, which is used for safety purposes, can be used to track the driver to target advertisements from commercial companies.

■ The information generated by the vehicles may be cross-correlated with other information leading to a possible re-identification of a user even in cases where the data set would be considered anonymous or anonymised by the data controller (Kondor et al. 2018a). To the extent that it is possible to aggregate batches of the data originating from various parts of the C-ITS systems, it is possible to use the data to build behavioural patterns and driving profiles. For example, pseudonyms are proposed in the ETSI standards for C-ITS to anonymise the messages but if they are not frequently changed, there is the possibility that vehicle behaviour can be inferred from specific patterns in the anonymous (thanks to the use of pseudonyms) C-ITS messages broadcast by the vehicle (Petit and Shladover, 2015). Consequently, the C-ITS certificate policy (European Commission, 2017b) has defined a pseudonyms change strategy for the deployment of C-ITS.

2.2.3. Standardisation and Legal Framework

With the availability of Big Data, accessibility and standardisation will be vital for the successful employment of digital technologies in the transport sector, especially in the connected environment. A clear legal framework is necessary to support any future changes.

The development of C-ITS in Europe is based on various standards defined in European Standardization Organizations (ESO) or International ones (e.g., ISO, IEEE). Standards are needed to ensure interoperability at European and International level and to define harmonised processes (e.g., testing, operations) which support economies of scale in the market. It is important that the standardisation process in Europe for C-ITS is both: a) innovative so that it takes new technological developments into consideration, and b) closely integrated into the regulatory frameworks.

In this context from the legislative point of view, in March 2019 the Commission has adopted new rules stepping up the deployment of C-ITS on Europe's roads. The new technology will allow vehicles to 'talk' to each other, to the

road infrastructure, and to other road users – for instance about dangerous situations, road works, and the timing of traffic lights, making road transport safer, cleaner, and more efficient. The specifications establish the minimal legal requirements for interoperability between the different cooperative systems used. The Commission decision takes the form of a delegated act and is based on the ITS Directive; the publication of the delegated act is followed by a two-month period during which both the European Parliament and the Council may oppose it coming into force. Unfortunately on 8th July 2019 the Council of the European Union adopted a decision to object to the EC proposal for delegated regulation on C-ITS.

The digital transformation of information exchange also has the potential to significantly improve the efficiency of freight transport and therefore to contribute to the smooth functioning of the digital single market. Currently, the European Commission has published a proposal[87] which aims to foster the use of digital documentation in freight transport, ensuring interoperability and providing solutions for the electronic exchange of freight transport information.

A lot of attention has been paid to the issue of ownership and/or access to data produced by connected cars. In 2016 The Commission started the C-ITS initiative to foster cooperative, connected, and automated mobility, which lead to the adoption of five principles about granting access to in-vehicle data and resources[88]. Future governance mechanisms will need to respect both the rules on the protection of personal data and the necessity to protect some data as trade secrets of manufacturers or service providers.

Various possible governance models have already been described in the literature, with the data transferred to a central server under the de facto control of several stakeholders, or with the data remaining with the car owners, or even with some data (i.e. not personal data and not confidential data) being made available as open data (Kerber and Frank, 2017).

The use of privately-held data in the transport sector is already mandated in different instruments, such as the ITS Directive, the delegated regulation on EU-wide multimodal travel information services, the delegated regulation on reading safety data, and the legislation on railway transport services for passengers and freight. When it comes to multimodal travel information services, dynamic data, such as real-time fare data, seems to be more difficult to access than static data; for the moment whether the exchange of dynamic data will be mandated has been left up to the Member States (MS) to decide[89].

In its Communication "Building a European Data Economy", the Commission mentions "optimisation of traffic management systems on the basis of real-time data from private vehicles" as an example where access in the public interest would improve the functioning of the public sector[90].

Furthermore, in its Communication "On the road to automated mobility: An EU strategy for mobility in the future" of May 2018[91], the Commission announced that it intends "to improve access and reuse mobility and vehicle data for commercial and non-commercial purposes as

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[88]   C-ITS Platform, final report, p. 11.

[89]   DG CONNECT draft report: 26 June 2017 workshop on access to privately-held data for public bodies: http://ec.europa.eu/information_society/newsroom/image/document/2017-28/final_-_report_from_reverse_psi_workshop_B7FA94EE-FA15-1929-8BBA2754D0D2FBE9_45916.pdf; see also Osborne Clarke (2016) Legal study on Ownership and Access to Data, a report for the European Commission, p. 18 and p. 28.

[90]   COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE, AND THE COMMITTEE OF THE REGIONS "BUILDING A EUROPEAN DATA ECONOMY", SWD(2017) 2 final}, p. 12.

[91]   COMMUNICATION FROM THE COMMISSION, "On the road to automated mobility: An EU strategy for mobility of the future, 17.5.2018, COM(2018) 283 final.

part of a forthcoming Recommendation", and that it will "continue monitoring the situation on access to in-vehicle data and resources and will consider further options for an enabling framework for vehicle data sharing to enable fair competition in the provision of services in the digital single market, while ensuring compliance with the legislation on the protection of personal data".

The Commission will also "consider the need to extend the right of public authorities to have access to more data". "In particular, it will consider specifications under the Intelligent Transport Systems Directive regarding access to data generated by vehicles to be shared with a public authority for improved traffic management. It will also

> "
> *Connected and automated transport will both generate and use significant amount of data, requiring compliance with the EU General Data Protection Regulation (GDPR)*
> "

consider requirements to collect large-scale real-world fuel/energy consumption information in an anonymised form within the framework of carbon dioxide emission standards for light-duty vehicles (cars and vans)[92]".

Among innovation in the automotive sector, Truck Platooning will benefit from the standardisation of data of vehicle communication protocols across different brands[93]. The three-year Enabling Safe Multi-Brand Platooning for Europe (ENSEMBLE) project, which received EU funding of 20 million Euros, started in summer 2018 and will support the standardisation of communication protocols for multi-brand platooning. As far as Vehicle-to-Anything (V2X) communications is concerned, the European Commission advocates a hybrid and technology-neutral approach (European Commission, 2008).

Another aspect of interest for future mobility is the regulation of unmanned aircraft systems (UAS) or air-drones. Legislation is under development following an agreement, endorsed by the EU, reached with the European Parliament on Dec. 22, 2017 (EASA, 2018). This would allow a great degree of flexibility from Member States (MS) so they can define areas in their territory where either UAS operations are prohibited or restricted (for example to protect sensitive areas), or where certain requirements are alleviated. More recently, supported by the European Union Aviation Safety Agency, the European Commission adopted common EU-wide rules for the technical requirements for UAS[94]. The implementation of common rules across the EU will set the limits for safety while at the same time it will provide a framework fostering investment and innovation, seamlessly allowing drone business development and drone operation.

Finally, discussions on liability and intellectual property rights are taking place at various policy levels to meet the challenges that the nascent autonomous vehicle industry faces (Holder et al. 2019).

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[92]   COMMUNICATION FROM THE COMMISSION, "On the road to automated mobility: An EU strategy for mobility in the future, 17.5.2018, COM(2018) 283 final, p. 13.
[93]   On the road to automated mobility: An EU strategy for mobility of the future. Brussels, 17.5.2018 COM(2018) 283 final https://ec.europa.eu/transport/sites/transport/files/3rd-mobility-pack/com20180283_en.pdf
[94]   COMMISSION DELEGATED REGULATION (EU) on unmanned aircraft systems and on third-country operators of unmanned aircraft systems. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=PI_COM:C(2019)1821

2.2.4. Innovation, Business Models, and Skills

As in many other sectors, new business models in the transport sector stem from the increased interactions facilitated by the digital and IT environment. Car-pooling, car and bicycle sharing services, on-line platforms for freight operations, smartphone applications, real time geolocation, and traffic conditions services are just some of the innovative mobility services facilitated by the digital transformation. Furthermore, service-based business models will become common as soon as the new mobility schemes materialise. Specific business cases in the transport sector have been widely publicised and been successful. For instance, facilitated by a user-friendly app and connectivity in the personal transportation sector, Uber Technologies Inc. has been prominent in the sharing economy in recent years.

Alternative fuel technologies, electrification, connected and automated vehicles have also impact manufacturing and require new skills, especially since processes demand increasingly sophisticated IT skills. Reskilling will become important considering the potential impact of automated driving on the workforce, especially lorry drivers. Automation has the potential make a larger contribution to connectivity-related business models, given the fact that it enables the possibility of doing non-driving tasks while travelling.

> *New business models are emerging that give rise to innovative mobility services, such as online platforms for freight operations, car-pooling, car and bicycle sharing services, and smartphone applications*

2.2.4.1. *Digital Transport Start-Ups*

The most essential elements of a modern economy are to create, exploit, and commercialise new technologies. Digital entrepreneurs and start-ups are one of the main vehicles by which digital potential is converted into economic benefits. Rather than existing businesses, digital start-ups are more likely to pursue opportunities associated with radical innovations that may have transformative consequences for the society and economy. Indeed, the last two decades of the digital transformation have shown that such newcomers as Skype, Uber, or Airbnb soon disrupted traditional industries. The transport sector has already attracted many digital entrepreneurs

and large Venture Capital investments. It includes such companies as Uber, Tesla, and BlaBlaCar that have become prime examples of digital transformation. Despite these continuous activities and investments, the benefits of digitalisation of the transport sector do not seem to be exhausted yet and large gains are still expected. Uber exemplifies this. Although the firm is continuously losing money, with a valuation of $72Bln it is the most highly valued digital start-up in the transport sector.[95]

Considering their key role in the digital transformation, this section looks at the number of Venture Capital (VC)

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[95]   See: https://app.dealroom.co/companies/uber

investments in digital transport start-ups over the period between 2000 and 2017. It uses Venture Source by Dow Jones as a source of data of global VC activity and VC-backed start-ups. In order to identify digital transport start-ups, two sets of companies were considered:

- **Digital start-ups in the transport sector**: this set includes start-ups in the transport sector whose description of activity includes any digital-related keyword.

- **ICT start-ups providing applications to the transport sector**: this set includes start-ups in the ICT sector whose description of activity includes any Transport-related keyword.

Figure 2.5a presents the total number of Transport start-ups and the percentage of digital start-ups in the

transport sector that received VC funding between 2000 and 2017. Out of 2007 Transport start-ups, 990 or nearly 50% can be considered to be digital start-ups. The figure shows that despite the latest economic crisis, both the number of VC-backed Transport start-ups and the share of digital start-ups in this sector increased. In 2017, nearly 70% of Transport start-ups were digital start-ups. The most common activities of these companies include Transportation Services (25%), Logistics/Delivery Services (25%), and Vehicle Parts Retail (6%) (see Figure 2.5b).

Figure 2.5c shows the total number of ICT start-ups and the percentage of ICT start-ups that provide applications to the transport sector that received VC funding between 2000 and 2017. Out of 22548 ICT start-ups, 1421 developed ICT applications targeting the transport sector. Over time, the number and share of ICT start-ups supplying applications to the transport sector have shown an

a: Total number of Transport start-ups & % of digital start-ups in the transport sector

b: Total number of digital start-ups & % of digital start-ups providing applications to the transport sector

c: Area of activity of digital start-ups in the transport sector

d: Type of applications provided by digital start-ups to the transport sector
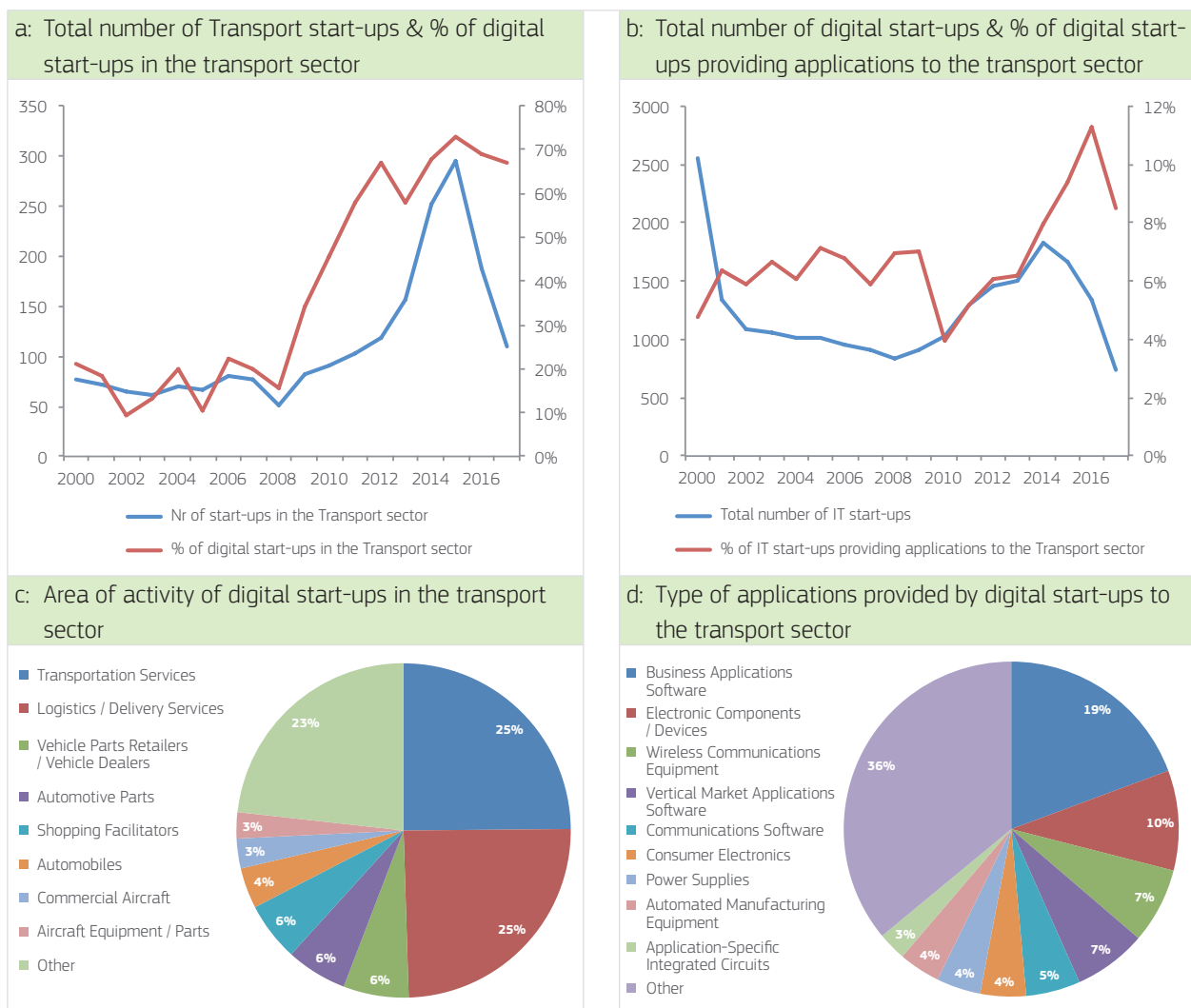
FIGURE 2.5: DIGITAL TRANSPORT START-UPS AND THEIR ACTIVITY, 2000–2017.
Source: JRC analysis based on Venture Source, Dow Jones data.

upward trend. Starting from 5% in 2000, the share of ICT start-ups supplying the transport sector nearly doubled and reached 9% in 2017. The most common applications provided by ICT start-ups to the transport sector include "business application software", "electronic component/devices" and "wireless communication equipment" (see Figure 2. 5d).

Figure 2.6 displays the total amounts of VC investments in digital transport start-ups by world regions between 2000 and 2017. The picture reveals that the Chinese start-ups received the highest amount of VC investments, i.e., nearly €37Bln or 46% of the total investments in this type of start-up. Second in the ranking is the USA. VC funds invested over €30Bln in US digital transport start-ups. This represents 38% of global VC investments in this domain. European digital transport start-ups received nearly €3.4Bln or 4% of the global VC investments in digital transport start-ups.

The above analysis of digital transport start-ups concludes the following:

■ The total number of VC-backed start-ups in the transport sector has been constantly increasing. So has the share of ICT start-ups providing applications for this sector.

■ The most common activities of digital start-ups in the transport sector include Transportation Services, Logistics/Delivery Services, and Vehicle Parts Retail. Digital applications addressing the needs of the transport sector include "business application software", "electronic component / devices", and "wireless communication equipment".

■ The US and China together attract nearly 85% of global VC investments in digital transport start-ups. European start-ups received only 4% of the global VC investments in start-up activity related to digitalisation of the transport sector.

FIGURE 2.6: VC INVESTMENTS IN DIGITAL TRANSPORT START-UPS BY REGION, 2000-2017, M€.
Source: JRC analysis based on Venture Source, Dow Jones data.

2.2.4.2. *Innovative Small Medium Enterprises in the EU Framework Programmes*

Small and Medium Enterprises (SMEs) are also a cornerstone in the EU workforce and innovation. The European Union SME Instrument[96] under H2020 supports investment and entrepreneurship by addressing small and medium-sized enterprises (SMEs) with a radically new idea underpinned by a business plan for rolling out marketable innovation solutions and with ambitions to scale up. The programme

commenced in 2014 and is currently running until 2020. According to the analyses based on the TRIMIS database[97] 266 SME Phase 1 and 86 SME Phase 2 proposals in the transport sector were financed in the period 2014-2017 (Figure 2.7.). Among these, 48 and 16 were respectively directly linked to digitalisation in transport.

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[96] https://ec.europa.eu/programmes/horizon2020/en/h2020-section/sme-instrument
[97] https://trimis.ec.europa.eu
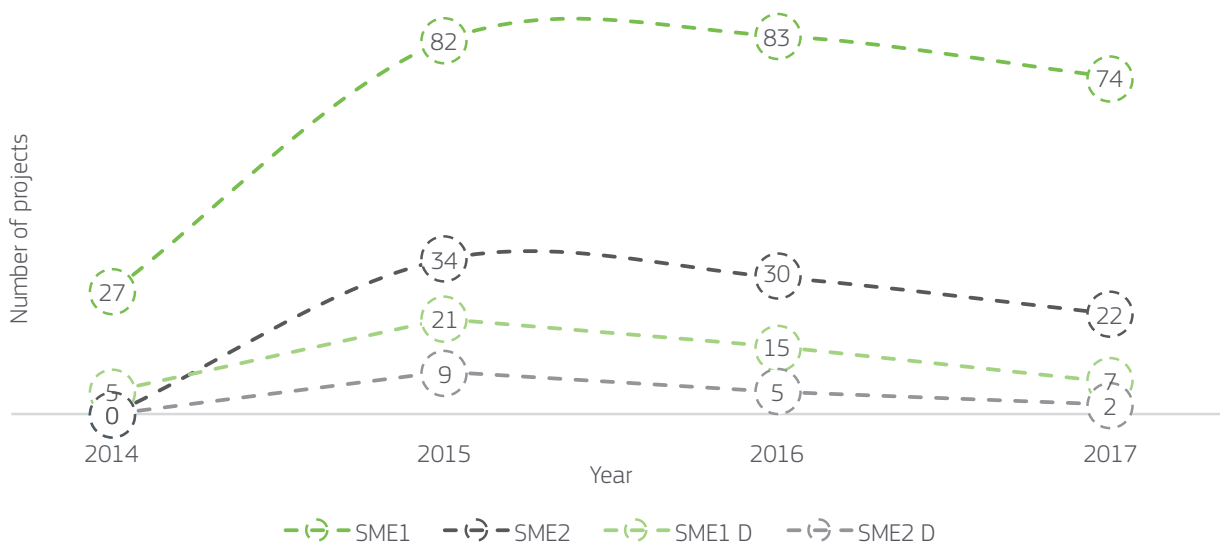
FIGURE 2.7: EU SME INSTRUMENT PROJECTS UNDER H2020 IN THE TRANSPORT SECTOR.
Source: (JRC-TRIMIS elaboration).

2.2.4.3. Territorial Aspects: Contribution of Digital Innovation Hubs to Digital Transformation in the Transport Sector

Digital Innovation Hubs (DIHs) in MS and regions are contributing to the digital transformation of enterprises in many sectors. When it comes to transport (and selecting "Transport, Storage & Communication" in the online DIH catalogue of the S3P[98]), 122 fully operational DIHs in the EU28 countries offer digitisation services to companies and contribute to the digital transformation process in this sector[99]. Their geographical distribution can be seen on the online Catalogue's map.

In addition to DIHs, the EIT Urban Mobility initiative[100] is worth mentioning. It is dedicated to accelerating solutions that improve the collective use of urban spaces, integrating all urban mobility players – including cities and citizens –

and increasing social inclusion and equality, while ensuring accessible, convenient, safe, efficient, sustainable, and affordable multimodal mobility. EIT Urban Mobility has formed five Innovation Hubs (co-location centres) across Europe and brings together 48 leading partners from business, education, research as well as cities and regions.

Distribution of Fully Operational Transport DIHs by Country

The distribution by country of the above mentioned 122 DIHs that provide digitalisation services in the transport sector is shown in Figure 2. 8.

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98   http://s3platform.jrc.ec.europa.eu/digital-innovation-hubs-tool
99   **Disclaimer**: The DIH Catalogue website is a "yellow pages" of Digital Innovation Hubs. The information provided about each entry is based on self-declaration. The European Commission cannot take any responsibility for the information provided. All of the entries in the catalogue are currently being verified (based on the information provided) as to whether or not they comply with the following four criteria:
1. Are part of a regional, national, or European policy initiative to digitise the industry;
2. Are a non-profit organisation;
3. Have a physical for the digital transformation of SMEs/Midcaps or industrial sectors currently lagging behind in taking up digital technologies.
4. Have at least three examples of how the DIH has helped companies with their digital transformation, referring to publicly available information, identifying the following for each one:
    • Client profile
    • Client need
    • Solution provided to meet their needs
The purpose of the catalogue is to support networking of Digital Innovation Hubs and to provide an overview of the landscape of Digital Innovation Hubs in Europe, supported by regional, national, and European initiatives for the digitalisation of industry. There is no relationship between being present in the catalogue and being able to receive funding from the European Commission.
100   https://eit.europa.eu/eit-community/eit-urban-mobility
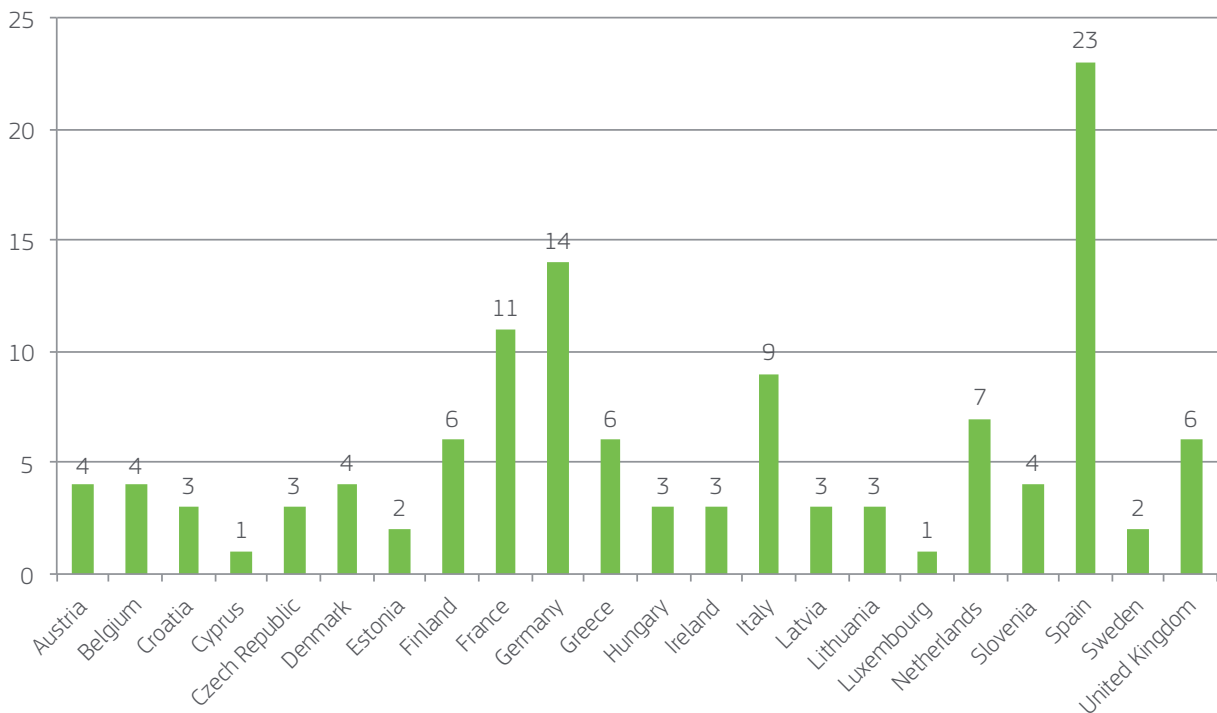
FIGURE 2.8: NUMBER OF DIHS SPECIALISING IN THE TRANSPORT SECTOR IN EU COUNTRIES.
Source: JRC analysis.

The DIHs identified possess a number of technical competences and offer a range of services to businesses in the transport sector. Information on the frequency of technical competences and the range of services provided is now given.

Frequency of technical competences of Fully Operational DIHs in transport ("Transport, Storage & Communication")

The technical competences most frequently declared by DIHs in the transport sector are the following:

- Internet of Things (e.g. connected devices, sensors, and actuators networks)

- Artificial Intelligence and cognitive systems

- Data mining, big data, database management

- Robotics and autonomous systems

- Augmented and virtual reality, visualization

The chart in Figure 2.9 provides the full list of the frequency of technical competences.

The most frequent services offered by Fully Operational DIHs in transport ("Transport, Storage & Communication")

There is a broad range of services provided by DIHs depending on their capacities and also on the level of maturity of SMEs in their process of digital transformation.

The types of services most commonly mentioned by DIHs that provide support to the transport sector SMEs are the following:

- Collaborative Research

- Ecosystem building, scouting, brokerage, networking

- Concept validation and prototyping

- Awareness creation

- Education and skills development

The chart in Figure 2.10 provides a full list of the frequency of services provided.

Frequency of technical competencies

Competency	Value
Internet of Things (e.g. connected devices, sensors and actuators networks)	112
Artificial Intelligence and cognitive systems	101
Data mining, big data, database management	93
Robotics and autonomous systems	90
Augmented and virtual reality, visualization	84
Cyber physical systems (e.g. embedded systems)	83
Simulation and modelling	82
Interaction technologies (e.g. human-machine Interaction, motion recognition and language technologies)	77
Cloud computing	75
Sensors, actuators, MEMS, NEMS, RF	73
Software as a service and service architectures	72
ICT management, logistics and business systems	70
Location based technologies (e.g. GPS, GIS, in-house localization)	68
Cyber security (including biometrics)	65
Advanced or High performance computing	64
Broadband and other communication networks (e.g. 5G)	58
Additive manufacturing (3D printing)	58
Micro and nano electronics, smart system integration	53
Internet services (e.g. web development, web production, design, networking, and e-commerce)	44
Photonics, electronic and optical functional materials	41
Gamification	40
New Media technologies	40
Laser based manufacturing	29
Screens and display technologies	26
Other	23
Organic and Large Area Electronics (OLAE)	19

FIGURE 2.9: FREQUENCY OF TECHNICAL COMPETENCIES OF DIHS SPECIALISING IN THE TRANSPORT SECTOR.
Source: JRC analysis.

Examples of digitalisation services in Transport:

DIHs are already contributing to the digital transformation of businesses in the transport sector in Europe and their future role will be increasingly important. The following are some examples of different digitisation services provided by DIHs to beneficiaries in the Transport, Storage & Communication sector in different countries:

I) IT4Innovations National Supercomputing Centre, Czech Republic

(http://s3platform.jrc.ec.europa.eu/digital-innovation-hubs-tool/-/dih/1436/view)

Service example:

Virtual Prototyping

Borcad (http://www.borcad.cz) is a company designing and manufacturing passenger seats for railway trains. To penetrate the British market, their products has to fulfil very rigid safety criteria including obtaining a safety certificate which can only be obtained after the seat passes physical crash tests. These crash tests are not only expensive but also time consuming because a prototype has to be built and tested. This makes the traditional approach of trial and error very ineffective. Numerical modelling and simulation of these crash tests is one of the most practical and widely used solutions. During this collaboration, a

Frequency of services provided

Service	Frequency
Collaborative Researchs	116
Ecosystem building, scouting, brokerage, networking	115
Concept validation and prototyping	111
Awareness creation	106
Education and skills development	106
Testing and validation	104
Incubator/accelerator support	91
Visioning and Strategy Development for Businesses	72
Mentoring	66
Digital Maturity Assessment	57
Access to Funding and Investor Readiness Services	55
Market intelligence	55
Voice of the customer, product consortia	41
Pre-competitive series production	38
Commercial infrastructure	34
Other	26

FIGURE 2.10: FREQUENCY OF SERVICES PROVIDED BY DIHS SPECIALISING IN THE TRANSPORT SECTOR.
Source: JRC analysis.

team of researchers and engineers from BORCAD and IT4Innovations was created. The existing design cycle was modified in such a way that all of the design and changes to it are virtually tested first and only when it passes the virtual test dies it undergo the physical crash test at a certification laboratory. This collaboration was recognized by HiPEAC as an example of technology transfer and as such was awarded the HiPEAC Tech Transfer Award in 2016 (https://www.hipeac.net/press/6801/hipeac-tech-transfer-awards-announced/ "Improved passive safety and comfort of passengers in railway traffic").

II) Centre for Applied Data Analytics and Machine Intelligence, CeADAR, Ireland

(http://s3platform.jrc.ec.europa.eu/digital-innovation-hubs-tool/-/dih/1109/view)

Service example:

AURORA: Advanced User-centric efficiency metRics for air traffic performance Analytics

Client profile: A collaboration between Boeing Research & Technology Europe SLU headquartered in Spain;

CeADAR, in Ireland; CRIDA (CENTRO DE REFERENCIA INVESTIGACION DESARROLLO E INNOVACION ATM, A.I.E.) in Spain, and Flightradar24 AB.

Client needs: Assessed the operational efficiency of the Air Traffic Management (ATM) system. The new metrics were developed with the aim of encapsulating the airspace users' operational objectives, considering fuel consumption, schedule adherence, and cost efficiency of the flights. A new stream-based data model was created and tested for ATM decision-making based on real-time performance monitoring of user-centric efficiency indicators in which the airspace users could take an active role.

Solution provided to meet their needs: This project created advanced metrics to assess the operational efficiency of the ATM system. These new metrics were developed with the aim of encapsulating the airspace users' operational objectives, considering fuel consumption, schedule adherence, and cost efficiency of the flights. User-preferred trajectories were defined as references for performance analysis purposes. AURORA also proposed metrics to measure how fairly the inefficiencies in the system are distributed among the various airspace users.

The other main research area consisted of exploring and testing techniques for the collection and aggregation of data borrowed from data science and information management fields. These techniques allowed AURORA to propose a new framework for ATM decision-making based on real-time performance monitoring of user-centric efficiency indicators in which airspace users could take an active role.

AURORA validated all these advanced user-centric efficiency metrics (and the methods to obtain them) at European and local level by comparing them with the current Flight Efficiency indicator used by the Performance Review Commission. AURORA also assessed the benefits for the performance-oriented operational concepts (e.g., SESAR[101]) of using the real-time ATM performance monitoring framework to identify opportunities to improve system efficiency and cater for the users' operational needs better.

The innovative method of assessing the metrics was based on defining a generic advanced trajectory-based airline cost model that, to the extent required for air traffic efficiency assessment, captured the impact of different aspects of the trajectory on the airlines' operational costs (e.g., fuel burn or departure and arrival times). The model was characterized by not requiring sensitive information from the airspace users and by the fact that it was applicable to both recorded and streaming data.

For more details please see: https://cordis.europa.eu/project/rcn/200861_en.html

III) DIH: Virtual Vehicle Research Centre, Graz, Austria

(http://s3platform.jrc.ec.europa.eu/digital-innovation-hubs-tool/-/dih/1346/view)

Service example:

Automated Driving and Assistance Systems

Client profile: Vehicle manufacturer and supplier, Software and Hardware vendor, Government, Infrastructure provider, SMEs

Client needs: Both industry and consumers expect numerous benefits from new automated driving technologies including improved vehicle and road safety, reduced congestion, lower stress for car occupants, social inclusion, lower emissions, and better road utilization due to optimal integration of private and public transport with and without automated functions. This creates fundamental challenges for R&D engineers.

Solution provided by the hub to meet the clients' needs: VIRTUAL VEHICLE covers the development, validation, test, operation, and continuous self-diagnosis of fail-operational automated driving architectures and ensures the coexistence of these highly automated vehicles with conventional vehicles on the road.

Expected benefits:

- Move automated driving to higher readiness by developing and implementing advanced methods, tools, and validation processes;

- Remain flexible by selecting different combinations of re-useable, calibrated, and scalable models together with proven hardware and software architectures;

- Reduce time-to-market with the open vehicle platform, proven hardware in the loop (HIL) testing and the use of in-house test beds and tools;

Access to future-proof technologies because VIRTUAL VEHICLE is a partner in the leading worldwide development partnership AUTOSAR, and is a member of the International Standardization Organization (ISO PAS 21448).

More details: https://www.v2c2.at/expertise/adas/

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[101]   https://www.sesarju.eu/

2.3 | Impacts of Digital Transformation in Transport

## 2.3.1. Innovation Spending with a Potential Impact

This section focuses on the state of R&I in Digitalisation in Europe[102] based on the EC's TRIMIS database[103], which covers over 7000 transport research projects and programmes classified according to the STRIA Roadmaps.

Based on the information available in the TRIMIS, a list of relevant financial and socio-economic indicators was determined that cover several dimensions, including financial, technological, organisational, legal, and socio-economic elements.

According to the analyses based on the TRIMIS database[104], under H2020, a total of 300 million Euros has been invested in Digitalisation research. These funds include 38 million Euros of own contributions by beneficiary organisations. Figure 2.11 shows the average daily H2020 related spending for each mode of transport. The investments peaked at approximately 300,000 Euro of daily research spending in late 2017. At the same time, the graph identifies drops in research spending at the beginning and end of each Framework Programme (FP), including the current (H2020).

It is noticeable that the multimodal category is relatively large compared to the other categories. The reason is in part methodological as projects that relate to road and urban transport were categorised as multimodal projects. An additional finding is the limited Digitalisation research uniquely dedicated to waterborne transport. Although not all projects have yet been assigned to a transport mode, it seems likely that there is comparatively smaller interest in connected and automated waterborne transport.
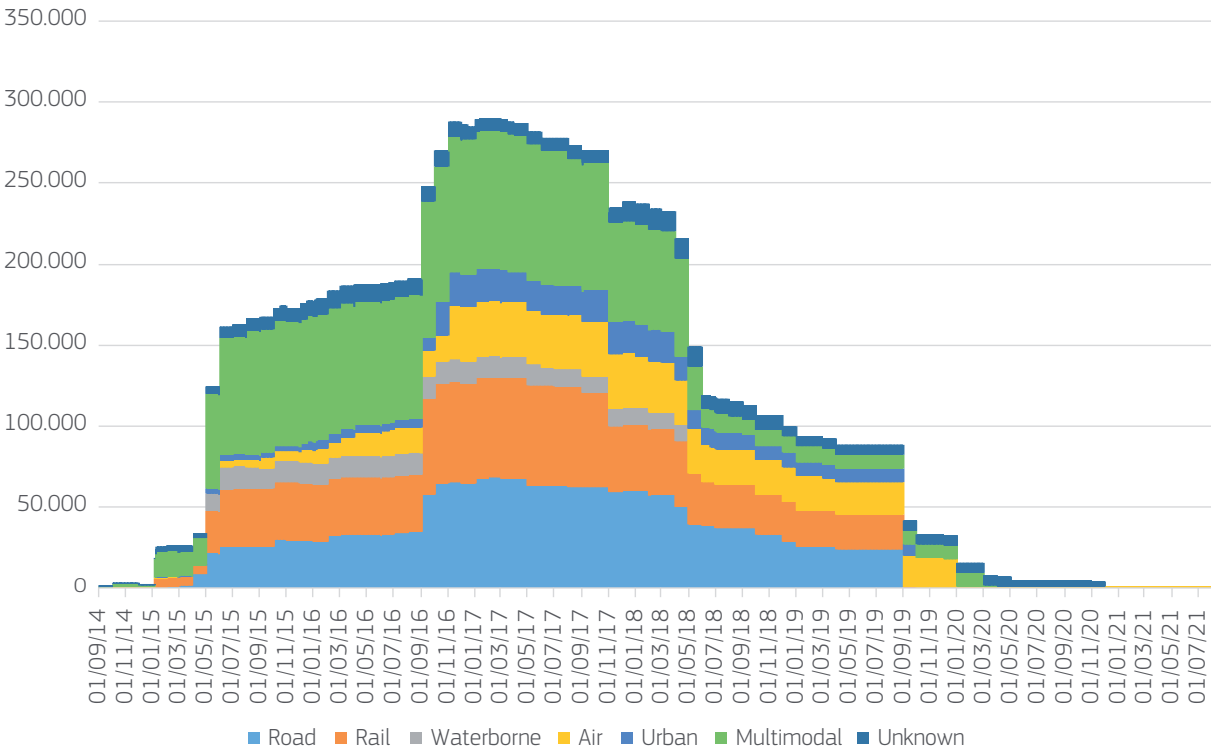
FIGURE 2.11: DAILY H2020 DIGITALISATION R&I SPENDING PER TRANSPORT MODE (EUROS).
Source: JRC-TRIMIS elaboration.

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[102]   A Digital Single Market Strategy for Europe - Analysis and Evidence SWD/2015/100 final. Brussels. https://ec.europa.eu/digital-single-market/en/news/digital-single-market-strategy-europe-analysis-and-evidence-swd2015-100-final
[103]   Transport Research and Innovation Monitoring and Information System (TRIMIS) programmes and projects database, JRC109363, Ispra http://publications.jrc.ec.europa.eu/repository/handle/JRC109363
[104]   https://trimis.ec.europa.eu

2.3.2. Social Impacts: Employment

In 2016, the transportation and storage sector employed over 11.3 million Europeans and generated more than 500 billion Euros of value added[105], while the land, air and water transport sectors alone employed over 6.5 million people. Digital technologies have already had a significant effect on the nature of work in the transport sector, with additional communication, geo-positioning, and advanced driving assistance tools.

As the digital infrastructure gains importance and we move towards a CCAM, we are likely to witness significant changes to our economy and society. It is expected that CCAM will have significant impacts in the labour market, progressively making some occupations and skills less relevant, while at the same time opening up new opportunities for different businesses and requiring new and more advanced skills (Alonso Raposo et al. 2018c). In addition to this, an intermediate shift before full automatisation will probably be a change in type of employment following new paradigms of technology-enabled mobility services (e.g., taxi to ride service hailing companies, vehicle-based to bicycle-based home delivery services etc.). This mobility change requires regulation in order to avoid social problems.

Nevertheless, compared to other sectors such as manufacturing, the impact of automation in road transport has been relatively low so far. The reason is that driving (the main occupation within the transport sector, as we shall see later) requires capabilities such as fast processing of unstructured data about the environment, fast decision-making, and hand-eye coordination that have until recently been beyond the possibilities of even the smarter machines. However, thanks to recent technological developments, highly automated vehicles are already being tested and piloted. According to a recent briefing published by the European Parliament, driverless vehicles will be on the EU market from 2020.[106] Indeed, technologies such as digital sensors, machine learning, and algorithmic control, together with geo-positioning and internet connectivity have made the partial or total automation of driving increasingly feasible even though it may still not be socially acceptable because of safety and other considerations. Therefore, in the medium-term it seems likely that occupations in the transport sector such as car, bus, or truck driver may also be affected by automation.

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[105]   Eurostat - Annual enterprise statistics for special aggregates of activities (NACE Rev. 2).
[106]   http://www.europarl.europa.eu/news/en/headlines/economy/20190110STO23102/self-driving-cars-in-the-eu-from-science-fiction-to-reality.

According to a recent study conducted by Eurofound (Fernández-Macías, 2018), the digital revolution can transform work and employment through three vectors of change, often acting simultaneously: automation of work, digitalisation of processes, and coordination by platforms.

- Automation of work consists of the replacement of (human) labour input by (digitally-enabled) machine input for some types of tasks within production and distribution processes;

- The digitalisation of processes consists of the use of sensors and rendering devices to translate (parts of) the physical production process into digital information (and vice versa), and involves changes in tasks and occupations;

- Coordination by platforms consists of the use of digital networks to coordinate economic transactions through "algorithmic management", according to which a task not only specifies what is to be done but how it is to be done and the exact time allocated to it.

All three vectors of change can affect the structure of employment by occupation and sector as well as working conditions, industrial relations, and the social organisation of production (Fernández-Macías, 2018).

To investigate the extent to which the digital transformation may have affected the transport sector, we carried out an empirical analysis drawing on data from Eurofound's European Jobs Monitor (1995-2014). In particular, we show:

> *Automation of work, digitalisation of processes and the use of digital networks to coordinate economic transactions can affect the structure of employment*

I. how employment in transport has evolved during the last 20 years;

II. how occupations in transport have changed during the same period;

III. which task content, methods, and tools are used in the three main occupations in the sector.

2.3.2.1. *Evolution of Employment in the Transport Sector through Time*

To illustrate the evolution of employment in the transport sector over time, we identified the relevant areas using the Statistical Classification of Economic Activities in the European Community (NACE). Before 2008 the relevant transport areas corresponded to NACE code 60 (Land transport; transport via pipelines), NACE code 61 (Water transport), and NACE code 62 (Air transport). However, after 2008 the relevant transport areas correspond to NACE code 49 (Land transport; transport via pipelines), NACE code 50 (Water transport), and NACE code 51 (Air transport)

In order to compare levels of employment in transport with employment in all other sectors, we built two indices with base 1995=100 and calculated the cumulative growth (Figure 2.12).

Figure 2.12 compares the evolution of employment in transport with the rest of the economy across 28 European MS between 1995 and 2014. It also includes a chart for the 15 countries which have been part of the EU since 1995.

The evolution of employment in the transport sector (blue line) compared to all the other sectors in the economy (dashed line) shows a substantial heterogeneity across countries. In some cases (Austria, the Czech Republic, Germany, Denmark, Estonia, Hungary) employment in transport has consistently declined relative to other sectors. In Ireland, employment in transport grew significantly faster than overall employment until the onset of the latest Great Recession after which it started declining. However, in the majority of countries, and for the EU15 as a whole, employment in transport has followed roughly the same trend as employment in all other sectors in the economy.

FIGURE 2.12: EVOLUTION OF EMPLOYMENT IN THE TRANSPORT SECTOR VS. THE REST OF THE ECONOMY (1995-2014).
Source: JRC analyses using European Job Monitor data – EU15 includes: Belgium (BE), Denmark (DK), France (FR), Germany (DE), Greece (GR), Ireland (IE), Italy (IT), Luxembourg (LU), Netherlands (NL), Portugal (PT), Spain (ES), the United Kingdom (UK), Austria (AT), Finland (FI), and Sweden (SE).

2.3.2.2. What are the Main Occupations in Transport?

To investigate whether occupational shifts have occurred in the transport sector, we looked at the top 15 occupations (ISCO 2 digits) in 1995, 2010, 2011, and 2014. The change is calculated for two separate periods to account for the revision in ISCO classifications.

Table 2.1 summarises the relative weight of the top 15 occupations in transport and shows whether an occupation has increased, decreased, or been stable over time (fourth and eighth column).

The highlighted cells indicate the main occupation in the sector – "drivers and mobile plant operators" – which account for more than 50% of the total occupations in the first period and approximately 60% in the second. It is worth noting that in the first period this main occupation

within the transport sector increased its employment share rather significantly (53% to 59%) whereas it remained stable (with a minor decline) in the second. Although there have been some ups and downs in the various occupational groups, the transport sector seems to be relatively stable in its occupational structure compared to other types of economic activity (Eurofound, 2016). Compared to other sectors, employment in transport is very concentrated in a single occupational group that requires a medium skilled level (drivers), and which has remained rather resilient in Europe in the last 20 years. As mentioned in the introduction to this section, this may change in the future with the arrival of automated driving. Nevertheless, the figures suggest automation has had a very limited effect in this particular sector so far.

	1995	2010	Change		2011	2014	Change
Corporate managers	4%	3%	⬇	Administrative and commercial managers	1%	1%	—
Managers of small enterprises	1%	2%	⬆	Production and specialised services mana	3%	3%	—
Physical, mathematical and engineering s	1%	1%	—	Science and engineering professionals	1%	1%	—
Other professionals	1%	1%	—	Business and admin. professionals	1%	2%	⬆
Physical and engineering science associates	4%	5%	⬆	Science and engineering associate professions	4%	4%	—
Other associate professionals	4%	4%	—	Business and administration associate professions	4%	3%	⬇
Office clerks	10%	8%	⬇	General and keyboard clerks	2%	2%	—
Customer services clerks	2%	2%	—	Customer services clerks	1%	1%	—
Personal and protective services workers	5%	4%	⬇	Numerical and material recording clerks	5%	6%	⬆
Extraction and building trades workers	1%	1%	—	Personal service workers	4%	4%	—
Metal, machinery and related trades work	7%	4%	⬇	Sales workers	1%	1%	—
Machine operators and assemblers	0%	0%	—	Metal, machinery and related trades work	3%	3%	—
Drivers and mobile plant operators	53%	59%	⬆	Electrical and electronic trades workers	1%	1%	—
Sales and services elementary occupation	2%	1%	⬇	Drivers and mobile plant operators	60%	59%	⬇
Labourers in mining, construction, manufacturing	3%	3%	—	Labourers in mining, construction, manufacturing	3%	2%	⬇

TABLE 2.1: OCCUPATIONAL CHANGE WITHIN LAND, WATER, AND AIR TRANSPORT.
Source: JRC analysis based on European Job Monitor data, 1995-2014.

2.3.2.3. *A Task-Based Analysis of Occupations in the Transport Sector*

The idea of jobs as bundles of tasks is central to understanding the impact of the digital transformation. David Autor defines a task as "a unit of work activity that produces output". In the task-based approach technological and economic forces determine the division of labour between labour and capital (Acemoglu and Autor, 2011; Autor, 2013): capital typically takes over tasks previously performed by (human) labour once the tasks become routine or standard. However, even when a task becomes fully codified, it is only automated if it makes economic sense, i.e., if capital inputs are cheaper than labour inputs.

Jobs that mainly consist of routine tasks are more susceptible to be partly or fully automated; by illustrating the task content, methods, and tools in the three main occupations of the transport sector, it is possible to speculate about what impact the digital transformation is likely to have in the future.

The indicators summarised in Figure 2.13 are based on work by Fernández-Macías, Hurley, and Bisello (Eurofound, 2016). In this framework, tasks are classified according to content (i.e. physical, intellectual, and social tasks),

methods, and tools. The contents axis refers to the object of work activity, understanding work as a transformative process, which is applied to things, ideas, or social relations. The methods axis refers to the ways in which work is organised and to the physical objects used in the production process. Each line in Figure 2.13 represents an occupation and the markers represent the task content.

The three occupations analysed are: first, "drivers and mobile plant operators", that as previously mentioned involves mid-level skills and occupies the bulk of workers in the sector; secondly, "numerical and material recording clerks", a mid-level skill white-collar occupation; and thirdly, "Business and administration associate professionals", a high-level skill professional group. The category of "drivers and mobile plant operators" has an interesting task profile because it does not seem to stand out for anything in particular: it involves degree certain number of physical tasks (especially dexterity), a relatively low level of intellectual literacy and numeracy tasks (except for some

degree of technical literacy), some problem-solving, limited social tasks, very little teamwork, with some repetitiveness but little standardisation, and machinery but no ICT use. The limited amount of routine and standardised tasks suggests a limited risk of automation while the relatively high level of physical tasks compared to intellectual and social tasks may suggest the opposite. As previously mentioned, the job of driving does not involve high-level skill, but it has been very difficult to automate because it involves the processing of unstructured information about the environment, requiring fast and precise reaction and problem-solving, tasks which have not been automatable until now but may be in the near future. With respect to the other two task profiles of the sector, they are typical of mid-level skill automatable work (numerical and material recording clerks) and high-level skill not (immediately) automatable work (business and administration associate professionals) so according to the literature a relative decline of the former and expansion of the latter is to be expected (Fernández-Macías, 2018).
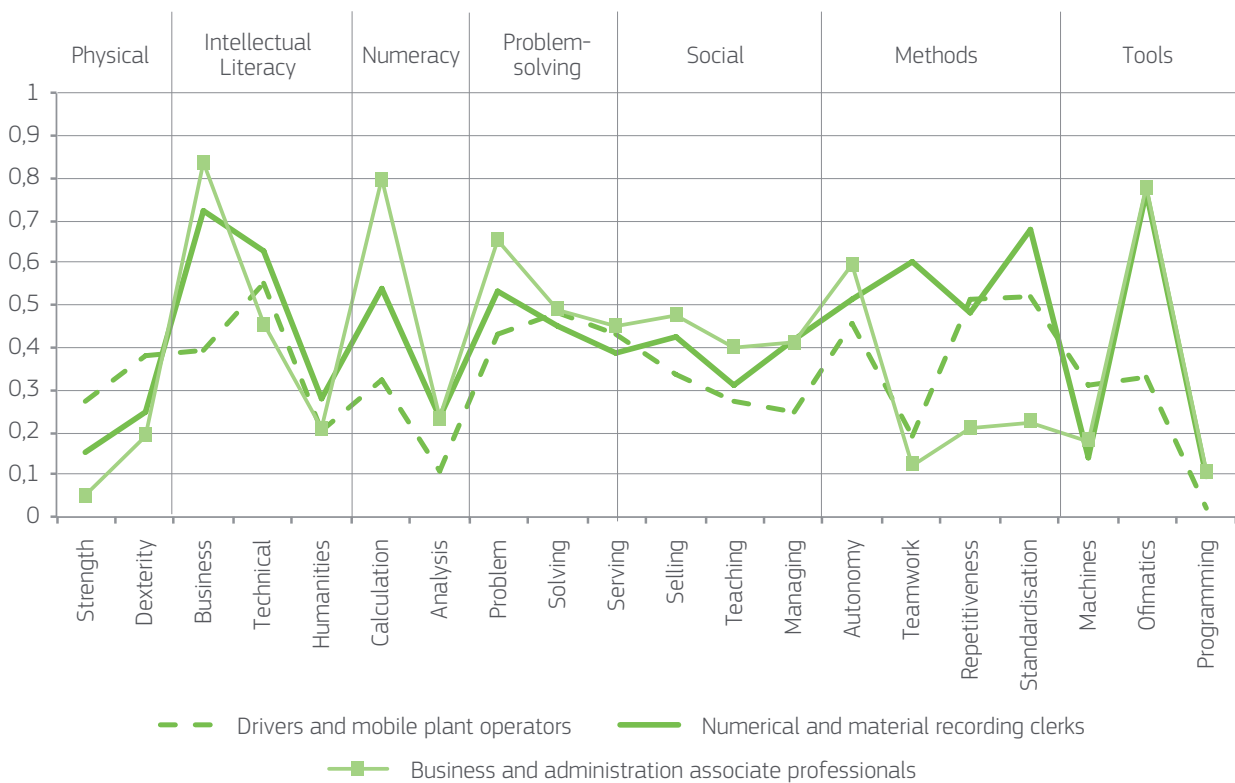
FIGURE 2.13: TASK BASED ANALYSIS OF THE THREE MAIN OCCUPATIONS IN TRANSPORT.
Source: JRC analysis based on European Job Monitor data, 2014.

2.3.3. Other Social Impacts

To eliminate deaths and serious injuries on European roads, the EU has adopted the Vision Zero and Safe System

approach. Furthermore, focusing on future benefits from CCAM adoption, according to the European Road Transport

Research Advisory Council (ERTRAC), automated driving can support several of the EU's objectives and societal challenges such as road safety, congestion, decarbonisation, and social inclusiveness in the following ways (ERTRAC, 2017):

- Safety: Reduce accidents caused by human error.

- Efficiency and environmental objectives: Increase transport system efficiency and reduce time in congested traffic by applying new urban mobility solutions. In addition, smoother traffic will help to decrease vehicle energy consumption and emissions.

- Comfort: Enable user's freedom for other activities when automated systems are active.

- Social inclusion: Ensure mobility for all, including elderly and impaired users.

- Accessibility: Facilitate access to city centres.

An additional aspect is the urban quality: the smaller number of parking lots required or their displaced location from the city centre to multi-storey parking outside the centre will free valuable space in the urban environment. However, the main challenge here could be the extra traffic generated from AVs travelling without a passenger that may increase congestion if not supported by more users switching to sharing/mass transit (Kondor et al. 2018b).

Digital transformation of transport will have a huge impact on the resilience of the transportation system, which means the ability to resist and recover the loss of traffic-serving capability. In fact, connectivity, facilitated by digital technologies, is a prerequisite for facing capacity challenges in transportation networks, including as a consequence of exceptional circumstances or events. Vehicles able to communicate in a seamless and secure way can theoretically see an effective reduction in time headways and reaction time with a consequent positive effect on network capacity and therefore road congestion until traffic demand stays constant (Makridis et al. 2018b). Consequently, connectivity has the potential to help avoid capacity overflow, and can complement existing adaptive traffic control strategies. V2I connectivity will further increase resilience at an urban or city level, enhancing recovery after major disruption.

The different digital transformations within transport have already impacted many aspects of society. These regard:

a. Improved safety using automated speed limit control system: the case of Italian "Tutor" system on highways[107].

Persons killed in road accidents by type or road (2006=100%)
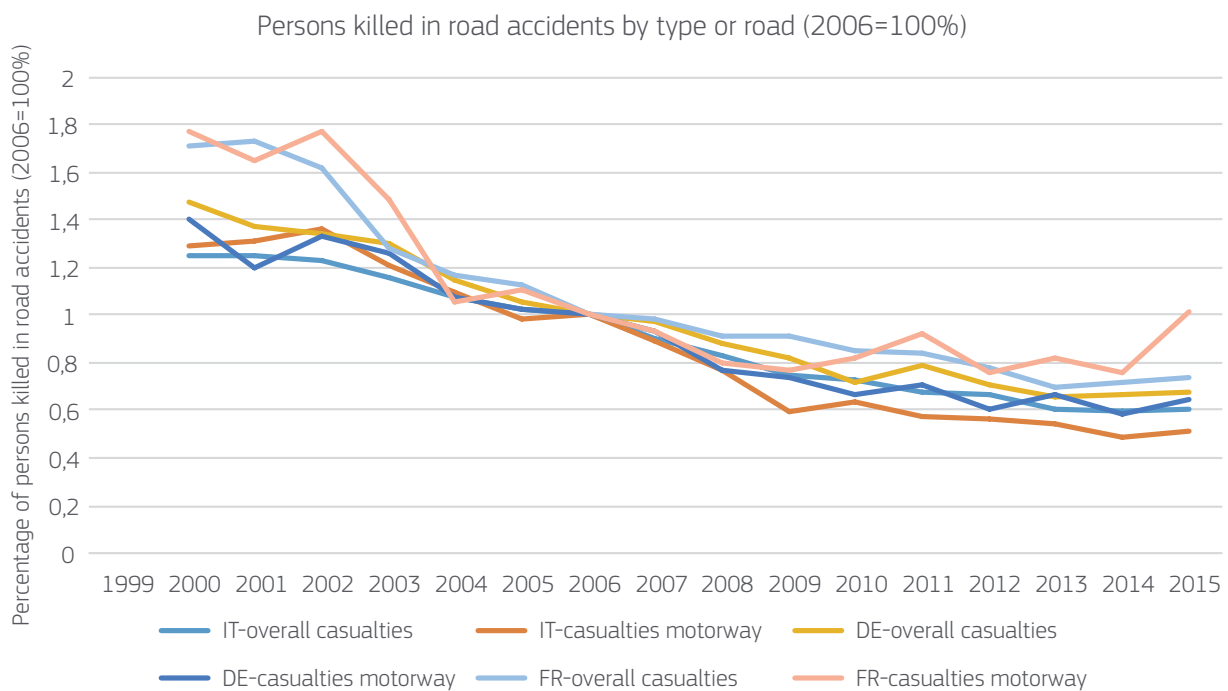
FIGURE 2.14: PEOPLE KILLED IN ROAD ACCIDENTS BY TYPE OR ROAD (2006=100%).
Source: EUROSTAT: Persons killed in road accidents by type of road (CARE data), http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=tran_sf_roadro&lang=en

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[107] Tutor System http://www.autostradetech.it/en/solutions/security-access-control/tutor-system.html

The first "Tutor", an average speed measuring speed camera system, was introduced in December 2005, so the number of persons killed on the road is compared to the reference year 2006. Comparing the situation of Italy against Germany and France. The data presented in Figure 2.14 indicates that the reduction of causalities on the Italian motorways decreased more compared to all Italian roads and compared to fatal motorway accidents in other European countries without a tutor system like Germany and France.

Even though at this stage a sound statistically significant analysis is not possible, the data are an indication that smart speed limit control systems improve safety on the road and new technologies such as Intelligent Speed Assistance (ISA) have the potential to improve safety further.

b. Air quality improvement due to the introduction of urban road tolls: the case of London, Milan, and Stockholm[108] (DG Environment, 2009). Data shows that the congestion taxes in the different cities not only reduced the incoming traffic but also directly

improved the air quality as emissions reduced considerably.

Researchers have shown that the rate of asthma attacks among local children in Stockholm decreased as a result of the congestion tax (Simeonova et al. 2018). At the same time business and the economy did not suffer any negative effects.

	Milan	London	Stockholm
Incoming traffic	30%	18%	18%
CO_2	22%	19%	14%-18%
NOx	8.5%	12%	10%
PM_{10}	18%	12%	13%

TABLE 2.2: REDUCTION OF TRAFFIC AND EMISSIONS DUE TO CONGESTION TAX. *Source*: DG Environment.

It is expected that new digital technologies will lead to more efficient speed violation and urban access monitoring and control (European Commission, 2015b). The recent applications of urban tolls in London and Milan have in general had positive outcomes thanks to the available digital technology, and expansion to other areas in the city are planned[109] or already in action[110].

2.4 | Conclusions: The Way Forward for Policy and Research

The transition to a new era of transport systems assisted by the digital transformation in the sector has the potential to be disruptive. Nevertheless, there are issues such as data collection and related challenges such as privacy and cybersecurity that need to be addressed by an appropriate policy framework, integrated with R&I actions, and by the development of standards. Consequently, the European Commission has taken concrete action.

In 2016, it started the C-ITS initiative to foster cooperative, connected, and automated mobility, which lead to the adoption of five principles for granting access to in-vehicle data and resources.

In May 2017 the Second Mobility Package introduced the Strategic Transport Research and Innovation Agenda (STRIA), which aims to determine the needs of and set the objectives for a system of transport innovation in Europe. The Transport Research and Innovation Monitoring and Information System (TRIMIS)

is the analytical support tool for the establishment and implementation of STRIA.

In May 2018, the European Commission presented the Third Mobility Package with the objective of citizens benefitting from safer traffic, less polluting vehicles, and more advanced technological solutions while supporting the competitiveness of EU industry. Particular focus is given to autonomous mobility that has the potential to make transport safer, more accessible, inclusive, and sustainable. The Commission's proposal encompasses a strategy aiming to make Europe a world leader in fully automated and connected mobility systems. The successful implementation of such ambition is strongly dependent on the accompanying legal framework, which includes data accessibility and protection, and on technological barriers and enablers.

In March 2019, the European Commission adopted new rules stepping up the deployment of C-ITS in the form of

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108   Impacts of urban road tolls https://urbanaccessregulations.eu/urban-road-charging-schemes/impacts-of-urban-road-charging
109   https://www.theguardian.com/politics/2019/jan/05/london-ultra-low-emission-zone
110   http://www.ansa.it/english/news/general_news/2019/02/25/milan-beefs-up-fight-on-smog_d345a417-1a43-4a82-9f35-e25ce6a38387.html

a delegated act, which is based on the ITS Directive. The specifications establish the minimal legal requirements for interoperability between the various cooperative systems used. On 8th July 2019 the Council of the European Union however adopted a decision to object to the EC proposal for delegated regulation on C-ITS.

Nevertheless, there are issues and activities that go beyond policy or where it is difficult to formulate appropriate policies. Technology acceptance is conditioned by human and economic factors, and is linked to current social issues (e.g. safety, security, sustainability, climate change), and society is often reluctant to accept new technologies, especially during a period of rapid technological advance or there is a risk of creating a digital divide between different categories of citizens. This deceleration phenomenon could be further intensified due to possible bottlenecks in the design and implementation phase of new technologies and services, also being directly and indirectly affected by multiple individual system factors (e.g., supply chain problems, policy decisions, maturity of regulations, and standards). The fragmentation of different technologies and standards in the transport domain (especially when they are used for the same applications) can also be an obstacle to efficient digital transformation of transport because it results in a lack of interoperability and may increase deployment costs.

Predicting future transport developments, whether they are on new transport technologies, new mobility approaches, demand changes etc., is a constant challenge. Many of today's transport trends did not exist a few years ago. Ride-hailing service companies, which nowadays serve tens of millions of trips every day, did not exist ten years ago. Dockless scooter-sharing systems now trending in major cities did not exist two years ago. On the other hand, other past revolutionising transport technologies and products, simply did not meet hype and expectations, due to the lack of technological advances. One year ago there were tens of thousands of shared bicycles in many European cities, and now they are mostly gone (replaced by more robust bicycle-sharing systems). In addition, technologies not traditionally present in the transport sector can introduce new deployment models and applications which are difficult to anticipate or regulate in advance. For example, mobile applications, which are increasingly proposed in the transport sector, are disrupting existing business models and processes. As in other domains, the challenge for regulators is to balance the need for technological

> *Governance, regulatory frameworks, and public procurement all need to accommodate new digital developments in the transport sector*

progress, and its many benefits, with safeguarding the fundamental rights and safety of citizens.

Focusing on social aspects, employment in road transport is very concentrated in a single occupational group that requires a medium skilled level (drivers), and which has remained rather resilient in Europe in the last 20 years. This may change in the future with the arrival of automated driving, even though automation has had a very limited effect in this particular sector so far.

The path to the digital transport era will not be fast and without pitfalls. Many technological, social, and legislative barriers will need to be addressed. Standardisation issues for technologies that have not reached full maturity (e.g. hyperloop technologies) and legal aspects for others (liability of automated vehicles, air-drones etc.) need to be addressed meticulously in order to avoid future pitfalls, assist technology diffusion, and achieve future safety and security goals.

Governance, regulatory, and public procurement strategies, designed and implemented, to catalyse and strengthen the development of integrated planning tools, are fundamental, together with open, real-time data systems to validate and optimise integrated mobility eco-systems so that they meet overall targets. The appropriate tools combined with the necessary data can indeed catalyse transport system reform at all spatial levels.

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List of abbreviations and definitions for Part 2 – Digital Transformation in Transport

AMOD   Autonomous mobility on demand

C2ART   Connected, Coordinated and Automated Road Transport

C-ART   Coordinated Automated Road Transport

C-ITS   Cooperative Intelligent Transport Systems

CAN   Controller Area Network

CAT   Connected & Automated Transport

CAV   Connected & Automated Vehicles

CCAM   Cooperative connected and automated mobility

CO_2 Carbon dioxide

DG MOVE   Directorate-General for Mobility and Transport

DIH   Digital Innovation Hub

DSRC   Dedicated short-range communication

EC   European Commission

EIT   European Institute of Innovation and Technology

ERTRAC   European Road Transport Research Advisory Council

ESO   European Standardization Organizations

ETSI   European Telecommunications Standards Institute

EU   European Union

EV   Electric Vehicle

FP   Framework Programme

GIS   Geographic Information System

H2020   Horizon 2020 Framework Programme

ICT   Information and Communication Technologies

IoT   Internet of Thing

ITS   Intelligent Transport Systems

MaaS   Mobility as a Service

MS   Member State(s) of the European Union

NTM   Network and Traffic Management

PKI   Public Key Infrastructure

R&I   Research and innovation

SESAR   Single European Sky ATM Research

SME   Small & Medium Enterprise

STRIA   Strategic Transport Research and Innovation Agenda

TaaS   Transport as a Service

TRIMIS   Transport Research and Innovation Monitoring and Information System

UAM   Urban air mobility

UAS   Unmanned aircraft systems

V2G   Vehicle-to-Grid

V2I   Vehicle-to-infrastructure

V2V   Vehicle-to-vehicle

V2X   Vehicle-to-anything

VC   Venture Capital

VDM   Vehicle Design and Manufacturing

Appendix – An Overview of the State of the Art in Communications Technologies for Connected Vehicles

As described above, future V2X communication deployments might leverage a combination of WiFi-based and cellular-based standards in a similar way to the deployment of wireless and cellular technologies in commercial smartphones and tablets. This Appendix provides an overview of the state of the art for the WiFi-based (i.e., IEEE) and cellular-based (3GPP) families of V2X communications standards.

IEEE 802.11p / ETSI ITS-G5

The IEEE 802.11p specification, adopted as the basis of the ETSI ITS-G5 standard, defines a set of enhancements to IEEE 802.11 physical and medium access control (MAC) layers aimed at enabling Dedicated Short-Range Communication services (DSRC) between vehicles. It is based on a combination of the Orthogonal Frequency Division Multiplexing (OFDM) based physical layer from IEEE 802.11a and the Enhanced Distributed Channel Access (EDCA) based MAC layer from IEEE 802.11e. The EDCA mechanism enables data traffic prioritisation using four different access categories.

IEEE 802.11p has some desirable features for V2V communications such as direct communication between nodes (i.e., no need for network infrastructure) and a fully distributed architecture. Consequently, 802.11p-enabled clients no longer need to join a so-called Basic Service Set, unlike laptops or mobile phones when they connect to a wireless access point. Instead, 802.11p endpoints can start transmitting data without prior exchange of control information.

However, one of the main drawbacks of 802.11p is the impact of network congestion on data throughput and end-to-end latency caused by the contention-based medium access mechanism. Therefore, the greater the number of 802.11p clients contending for the shared channel, the greater the number of collisions and the lower the quality of experience perceived by end users. This effect can be partially mitigated by enabling 802.11e access categories (a feature that allows users to reduce the safety time interval that must be observed before initiating a data transmission). Nevertheless, the overall quality of experience of 802.11p in dense scenarios still lags behind that of cellular standards.

Another well-known issue in WiFi-based systems is the hidden node problem. In this scenario, an endpoint A might start sending information to an endpoint B after confirming that the channel is available for transmission. However, a third endpoint C (unaware of A's intentions) might also sense that the channel is available for transmission, thus sending a packet and causing a collision at B. This situation can be mitigated by enabling the Request-to-Send/Clear-to-Send (RTS/CTS) mechanism in the 802.11 standard whereby clients notify neighbouring nodes about their intention to transmit a packet, consequently deferring potential transmissions until a CTS response has been received. This mechanism alleviates channel congestion at the expense of reducing throughput and increasing end-to-end delay, which can in turn pose additional challenges for the deployment of critical low-latency V2X services.

802.11p has been designed with short range use case scenarios in mind. However, short range communications will not necessarily address all connected vehicle use cases. For example, broadcast updates from the network/road infrastructure operator (e.g., accident and congestion warnings, traffic routing updates, rich multimedia data, etc.) as well as communication services with distant vehicles (e.g., coordination of emergency and security vehicles on patrol) will require long-range communication services via the network infrastructure. Although roadside units installed along main motorways can help roll out these services, deploying such a pervasive network infrastructure might have significant CAPEX and OPEX implications for the communications and road operators.

Current 3GPP Standards: LTE/LTE-Advanced

Vehicles and pedestrians in most situations might find themselves under cellular coverage provided by a Mobile Network Operator (MNO). MNOs currently offer communication services based on 3GPP standards such as GSM, UMTS, and LTE. This affords the opportunity to leverage the existing network infrastructure to provide V2X services to connected vehicles. This communications paradigm is commonly referred to in the telecommunications industry as C-V2X (Cellular Vehicle-to-Everything).

3GPP standards feature centralised scheduling mechanisms in which the network infrastructure allocates dedicated time and frequency resources to end users depending on their communication needs. Coordinated scheduling techniques significantly improve spectrum usage, throughput, and delay, as mobile terminals no longer experience collisions, particularly during peak hours. In addition, centralised scheduling mechanisms enable quality of service enforcement as the network infrastructure has full control over the radio and network resources allocated to each user.

3GPP standards were originally designed for human-centric communication services such as voice, messaging, and Internet access. These applications require involvement from the communications infrastructure, either to schedule radio and core network resources or to route voice and data traffic between terminals. Further modifications to the standards are required for C-V2X services that do not require network involvement (e.g., direct communication between vehicles). In the context of 3GPP, these modifications are proposed, discussed, finalised, and published in periodic releases of the 3GPP Technical Specifications (3GPP TS). One of the key enhancements to 3GPP standards for C-V2X communications is the LTE-V2X Technical Specification (Long-Term Evolution, Vehicle-to-Anything), published in March 2017. This collection of features allows terminals to communicate with each other without network infrastructure involvement, but it must be further investigated with test trials and studies on the performance and feasibility of LTE-V2X in realistic V2V and V2I scenarios.

Future 3GPP Standards: the Role of 5G in Connected and Collaborative Vehicles

The advent of 5G communications technologies will bring new opportunities and capabilities for connected and collaborative vehicles. Contrarily to current cellular technologies, where proximity services have been enabled a-posteriori by progressive amendments to the standards, 5G will natively incorporate connected cars as one of its main use cases for the ultra-reliable low-latency communications.

5G's new air interface (commonly referred to as 'New Radio' or NR for short) will lay down the key technology foundations to build upon and enhance C-V2X communications. Some of these features comprise extreme throughput (in the order of 10Gbps/cell), high-density networks (~100K simultaneous connections per cell), sub-millisecond end-to-end latency, and native support for multi-hop and sidelink communications. As far as next-generation network infrastructure features are concerned, network slicing and virtualisation will provide the flexibility and adaptability needed to dynamically deploy functional entities specifically targeted at C-V2X scenarios over commercial off-the-shelf networking and server infrastructure, consequently reducing capital expenditure for network operators. Network slices can be created, managed, and torn down by Mobile Network or Roadside Infrastructure Operators according to the mobility state and specific needs of each vehicle (e.g., network functions in the form of virtual machines will be able to follow a vehicle's route throughout the radio access network in order to meet the latency requirements of critical safety services).

3

DIGITAL TRANSFORMATION IN CONSTRUCTION

③ DIGITAL TRANSFORMATION IN CONSTRUCTION

Summary

The Architecture, Engineering, and Construction (AEC) sector is a key industry in the EU accounting for up to 9% of EU gross domestic product and providing 18 million direct jobs, i.e., more than 6% of European employment. However, this strategic sector for the world economy is lagging behind in terms of adoption of ICT and digital innovation compared to other sectors such as telecommunication or manufacturing industries. Whereas the design of buildings and infrastructures already relies on digital tools (e.g. computer-aided design (CAD) and structural analysis programs as well as budget and resource management software), the construction phase in particular lacks many of the potential benefits of more recent digital technology. The same adoption lag applies across the whole value chain in the AEC Sector (e.g. starting from Strategy and all the way up to Operation, Maintenance, and Repair - OM&R phases).

This section of the report on *Digital Transformation in Construction* considers how new digital technologies can improve and change the AEC sector and the limitations that affect widespread adoption of innovative systems and methodologies.

Despite the seemingly low adoption rates, the potential of digital transformation in the AEC Sector is significant for the whole value chain. New technologies can disrupt the future of construction both due to the advent of Smart Buildings and Infrastructures as well as novel construction processes and business models. This will lead to significant improvements in terms of efficiency, competitiveness, and optimal use of resources. Digital transformation in the AEC sector is not only related to smoothing production processes by providing more efficient data handling, but also encompasses novel production technologies (e.g. additive manufacturing) that would not exist without the advent of ICT technologies.

The *disruptive technologies* for the AEC sector can be identified as follows:
— Sensors
— Internet of Things (IoT)
— Mobile Internet
— Additive manufacturing
— Automation
— 3D scanning
— Drones
— Building Information Modelling (BIM)
— Virtual and Augmented reality Artificial intelligence

These technologies can be disruptive in the way they introduce new business models while providing considerable advantages in terms of cost savings, productivity, improved quality and innovative services. The modern construction sector is already changing with companies shifting their core business from the physical construction process to reconfiguring their structure as service providers.

Adoption of alternative technologies, which include new materials (composites, hybrids and engineered materials), new construction technologies (such as 3D printing and robotized assemblies), and distributed sensor networks will shape the drive for more sustainable, inter-connected buildings and infrastructures. In tandem with these, artificial intelligence (AI) will deal with the massive amounts of data generated for more effective management of resources.

The real flow of disruptive digital technologies in the AEC Sector can therefore be represented as: data acquisition, digital information and analysis, and automation of processes. The availability of unprecedented amounts of data from sensors and connected devices (IoT) in the construction sector along with georeferenced data (i.e. implementation using GIS) will allow an ever increasing number of analysis services to improve productivity in the construction process as well as in real estate, commerce, urban dynamics and services.

Data Science (or Data Analytics) is therefore crucial to linking all of the innovative technologies in this sector and so the availability of data during construction or operation of the infrastructure will be crucial and will lead to significant improvements and transformations in the way work is done. The added value of knowing exactly what is happening in a site through data collation and matching it to complementary databases and data sources will be very valuable.

Automation of the construction process by adopting robotics, additive manufacturing, 3D measuring systems, and drones are key technologies for the sector.

The installation of sensor networks for monitoring buildings and infrastructures and the adoption of Internet of Things (IoT) devices, mobile Internet, and drones with integration into AI based management systems are essential for the paradigm shift of construction into services offering novel opportunities for the efficient management of buildings and lower energy consumption.

The digitisation of the physical dimensions of real world structures (3D scanning) contributes to the digitalisation of the whole process when associated to Building Information Modelling (BIM). BIM is fundamental for the digital transformation of AEC: from the initial investment and call for tenders, to the design phase and planning, the construction phase (procurement and supply chain, construction site management) and, after completion, the OM&R phase (asset, property, and facility management).

Despite its importance, the AEC sector is facing challenges in innovation, increasing productivity, and attracting new skilled workforce. This sector has been a slow adopter of new technologies, in particular, ICT and innovation has suffered from past economic crises, and the fragmentation of the market, with a small number of large enterprises investing in R&D and a large group of SMEs with too small profit margins to invest in modernization, represents a major obstacle. Moreover, the sector is facing low attractiveness to younger professionals (more technology oriented) and ageing skilled workers, both inducing problems of workforce recruitment and availability to meet current and future demand.

Education is one of the key factors for the European AEC sector to prevent skill shortage. Scarcity of training and higher education profiles really knowing the technology in the construction sector is high. University programs must be modified to include these specialities in Digital Technologies. These needs are currently covered by industrial or telecommunications engineers but ICT and novel hub technology skills must be learnt by civil engineers and architects in the AEC Sector.

The expected increase in the construction market in the next few years calls for increased productivity that can only be achieved through a paradigm shift away from the traditional approach to a fully exploited digital transformation of the sector throughout the whole value chain. The European AEC sector is already adopting digital innovation, but the EU construction industry is calling directly for policy makers to support and lead the digital transformation of the European AEC sector, develop a specific regulatory framework on data policy, and support in the development of digital skills, research, and IT infrastructure.

However, the implementation of ICT and new technologies in general requires initial investment in IT infrastructure whereas the fragmentation of the European AEC market (consisting of a multitude of SMEs and a handful of very large big players) creates another barrier to broadening and homogenising digitalisation of the sector. New technologies are being supported at national and EU level—the Digital Single Market among others—but the high initial investments tends to reflect the sector fragmentation leaving the major companies as the only innovators. Programmes to support SMEs in the adoption of ICT technologies will be strategic in homogenising the level of digitalisation in the AEC.

Furthermore, the legal aspects of shared use of BIM must be clearly addressed to ensure data ownership and avoid disputes. Legal barriers for the full adoption of BIM must be addressed by specific legislation and solutions harmonized across Member States. Moreover, the need to ensure data privacy and confidentiality would suggest that the implementation of EU Cloud systems for both sensors and BIM projects would be highly beneficial.

The adoption of new technologies in itself cannot provide the AEC sector with improved productivity and efficiency: the business model must also change and be innovative. The construction industry business model has primarily been based on industrial logistics but is progressively transforming into a service model. A clear example of the digitally driven change in the sector is represented by the advent of digital platforms and a radical change in the business model.

Finally, and importantly, innovation methods and new technologies for workers must be assessed in terms of safety and security by developing new procedures, legislation, certification, and testing to address their uniqueness. Moreover, the development of new construction techniques (e.g. 3D printing) and automatization should be anticipated by appropriate testing, dedicated standards, and building codes. The JRC is active in supporting policies in the construction sector with ongoing scientific research in the field (smart buildings, wireless sensor networks, safety, and security of buildings) supported by unique testing facilities, and it can contribute to smoother introduction of innovative technologies in AEC.

Considering the rapid evolution of new technologies and the critical need to adopt them in the construction sector, Governments should ensure constant and effective communication with companies and innovators and facilitate the elimination of barriers to innovation.

Introduction

The Architecture, Engineering, and Construction (AEC) sector is a key industry in the EU. It accounts for up to 9% of the EU's gross domestic product and provides 18 million direct jobs, i.e. more than 6% of European employment (see Figure 3.1). However, this strategic sector for the world economy is lagging behind in adoption of ICT and digital innovation compared to others such as telecommunications or manufacturing industries. Whereas the design of buildings and infrastructures already relies on digital tools (e.g., CAD and structural analysis programs as well as budget and resource management software), the construction phase, in particular, lacks many of the advantages of more recent digital technology. The same limitations apply across the whole value chain of the AEC Sector (e.g. starting from Strategy all the way up to Operation, Maintenance, and Repair (OM&R) phases).

One of the reasons for the slow adoption of digital technologies in the sector lies with the business model: just a few large companies deal with major projects which, typically, subcontract parts of their activities to Small and Medium Enterprises (SMEs) that do not have the economic margins for initial investment in new technologies (see Figure 3.2). At the same time, the lifetime of the built environment evolves on a completely different time scale to that of digital technologies. Therefore, newly installed ICT becomes obsolete very early in the lifetime of a building.

Another aspect is that the products of the AEC sector are usually bespoke prototyping products the vast majority of which are unique. This is in marked contrast to the manufacturing sector (serial product). This implies that customization of products is often required and the adoption of technology, in particular on existing structures, may be hindered by specific local constraints.

Despite the seemingly low adoption rates, the potential of ICT in the AEC Sector is significant and new technologies can disrupt the future of construction due to both the advent of Smart Buildings and Infrastructures as well as novel construction processes and business models.

Employment by A*10 industry breakdown [%]
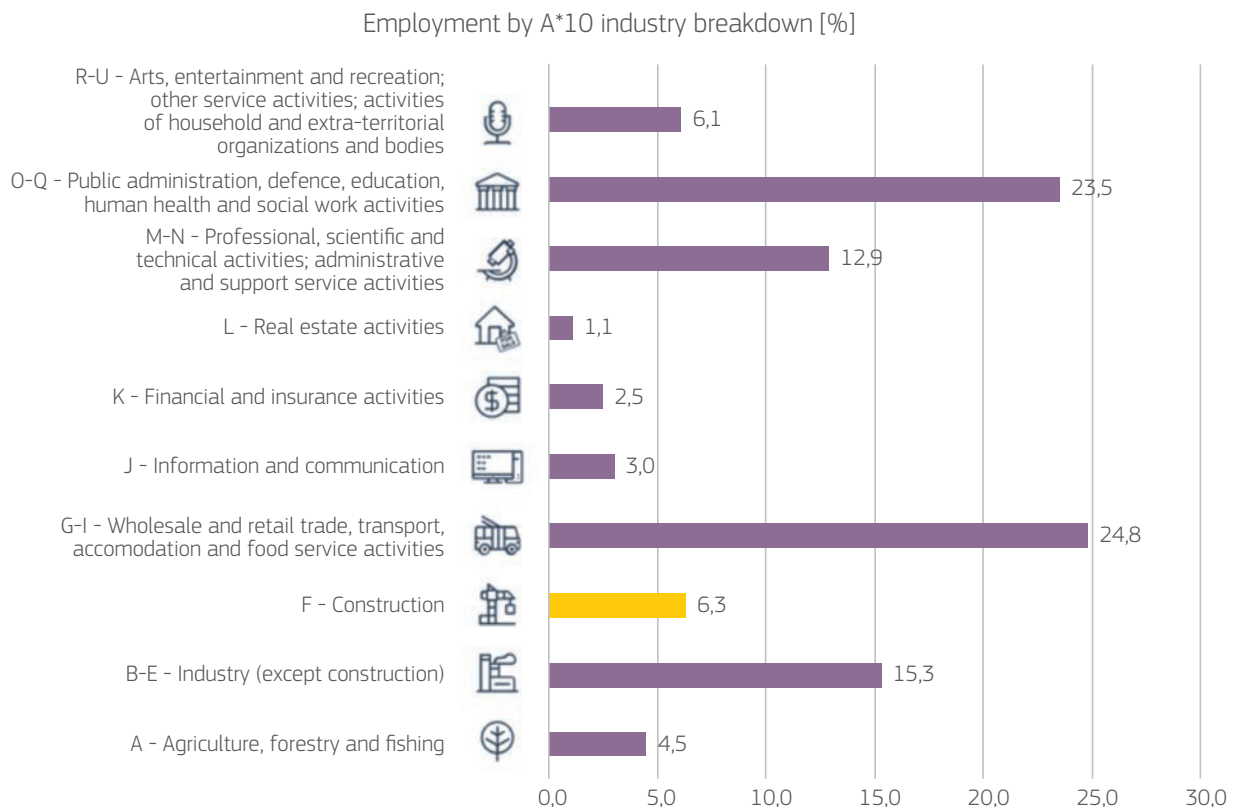
FIGURE 3.1: EUROPEAN EMPLOYMENT BY SECTOR IN 2017.
Source: Eurostat.

This section of the report considers how new digital technologies can improve and change the construction sector and the limitations that affect widespread adoption of innovative systems and methodologies (Bono, et al., 2017) (Strozzi, et al., 2014) (Bono, et al., 2015)).

Digitalisation in the AEC sector is not only related to smoothing production processes by providing more efficient data handling, but also encompasses novel work technologies (e.g., additive manufacturing) that would not exist without the advent of ICT technologies.

Two *megatrends*, namely, climate change and increased urbanization, require significant direct improvement in the Construction Sector, as identified in (World Economic Forum, 2016).

The goals of energy performance and reduction of energy consumption are at the base of green buildings and energy efficiency: novel materials, building codes and new design approaches all play a fundamental role in achieving the performance required to meet the emission goals.

In addition to the aforementioned components for building energy efficiency, a significant contribution to emissions reduction may be provided by the adoption of technology, artificial intelligence (AI), and data analysis for more efficient building management (by the adoption of Building Management System – BMS - tools): HVAC systems (heating, ventilation, and air conditioning) can

> *Management of cities facing accelerated population growth will be a major challenge: modern technology will play a key role in enabling resilient infrastructures for more efficient services and contribute to combating climate change*

EU 28 Construction Enterprises by employment size class in 2016

3.3 Millions *(94%)*
■ From 0 to 9 persons

■ From 20 to 49
■ From 20 to 49
■ From 50 to 249
■ More than 250

0.2 Millions *(6%)*

(NACE Rev. 2, F)
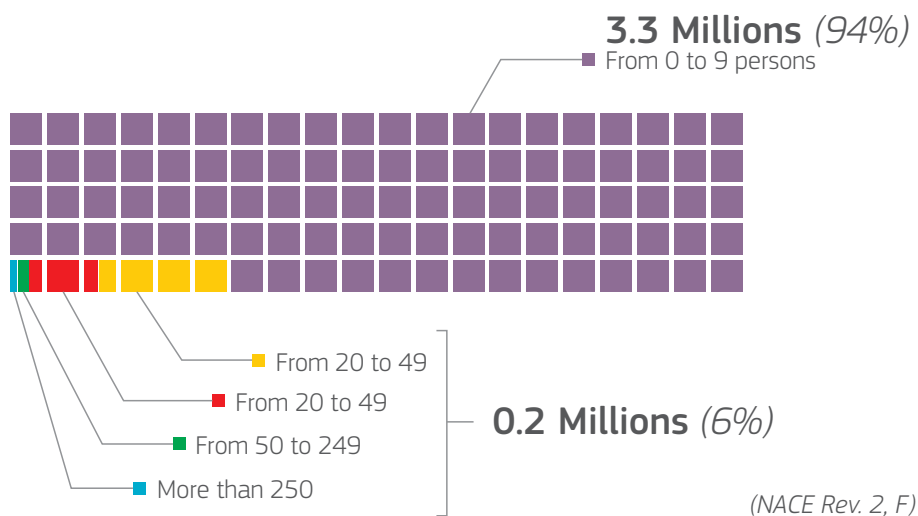
FIGURE 3.2: EU 28 CONSTRUCTION ENTERPRISES IN 2016 BY EMPLOYMENT SIZE CLASS (NUMBER OF PERSONS EMPLOYED).
Source: Eurostat sbs_sc_con_r2 data.

> *Smart buildings and smart infrastructures will be key interacting elements within smart cities*

be integrated into SMART Buildings by using sensors and monitoring systems to create adaptive control systems that sense the environment and respond accordingly to handle energy in an optimal way.

The second megatrend is the significant increase in urbanization and unavoidably stresses the existing urban environment. Consequently, the AEC industry will play a key role by increasing efficiency and applying novel solutions through the adoption of new technologies all the way along the production chain.

According to the UN, 54 per cent of the world's population today lives in urban areas, a proportion that is expected to increase to 66 per cent by 2050. The management of urban areas will be a major challenge and modern technology will play a key role in supporting a secure, sustainable, and liveable modern built environment. Moreover, the need for higher density spaces will challenge the available urban space if quality of life and energy efficiency are going to be ensured.

Digital transformation and the *Internet of Things* (IoT) will play a key role in enabling innovative and more efficient services and use of resources, while radical hi-tech green buildings and infrastructures will reshape the urban environment. For example, the drive towards high-rise buildings needed to accommodate an increased population density, advocate for sustainable architectural and housing solutions with careful attention to public spaces and human needs at individual and societal levels.

The availability of an unprecedented amount of data from sensors and connected devices (IoT) in the

construction sector along with geolocalisation of data (i.e. implementation using GIS) will not only allow an increasing number of analysis services to improve productivity in the construction process but also in other fields such as real estate, commerce, urban dynamics, and services. Although the impact of DT in these sectors is undoubtedly revolutionary and has a significant impact, the main focus of the present section is on the construction industry, particularly the production phase. This section does not go into the details on how digital technology will impact other Sectors while strictly related to the built environment.

Finally, the advent of so-called smart buildings and infrastructures will not limit the benefits of interconnectivity to single structures, but these will be able to contribute and interact in the context of much-touted smart cities and other connected systems (e.g. V2I vehicles to infrastructures integration).

There are a number of initiatives at European level promoting the digital transformation of the AEC sector in Europe. The Commission Communication to the European Parliament and the Council Strategy for the sustainable competitiveness of the construction sector and its companies in 2012 (COM(2012) 433 final) (European Commission, 2012) started to address the challenges of the EU construction sector with a number of initiatives to stimulate investment and improve sector performance and resource efficiency as well as skills and jobs. However, the fast pace of digital technology development requires additional effort to reduce the gap in the construction sector.

The climate change challenge also puts additional pressure on achieving greater efficiency in buildings, and the Commission Directive 2018/844 (European Parliament and Council, 2018) calls for a contribution from digital solutions in smart homes and connected communities to improve energy efficiency, with these solutions including building automation and electronic monitoring of technical building systems.

DG GROW (the European Commission Directorate-General for Internal Market, Industry, Entrepreneurship, and SMEs) promotes a number of initiatives for the shared introduction of BIM in the European AEC sector (EU DT-ICT-13-2019 call: Digital Construction Platform), notably by supporting the *EUBIM Taskgroup* (EU BIM Taskgroup, July 2017). Several national initiatives have been also activated by Member States in support of BIM adoption in both the public and private sectors.

Member States have also started initiatives to support the construction industry and the need for a new workforce with new skills to support the digital transformation.

Innovation is nevertheless evolving rapidly and the significant market growth expected drives the need for rapid adoption of new technologies in the AEC sector and the removal of existing barriers so that not only big companies but also SMEs can get involved.
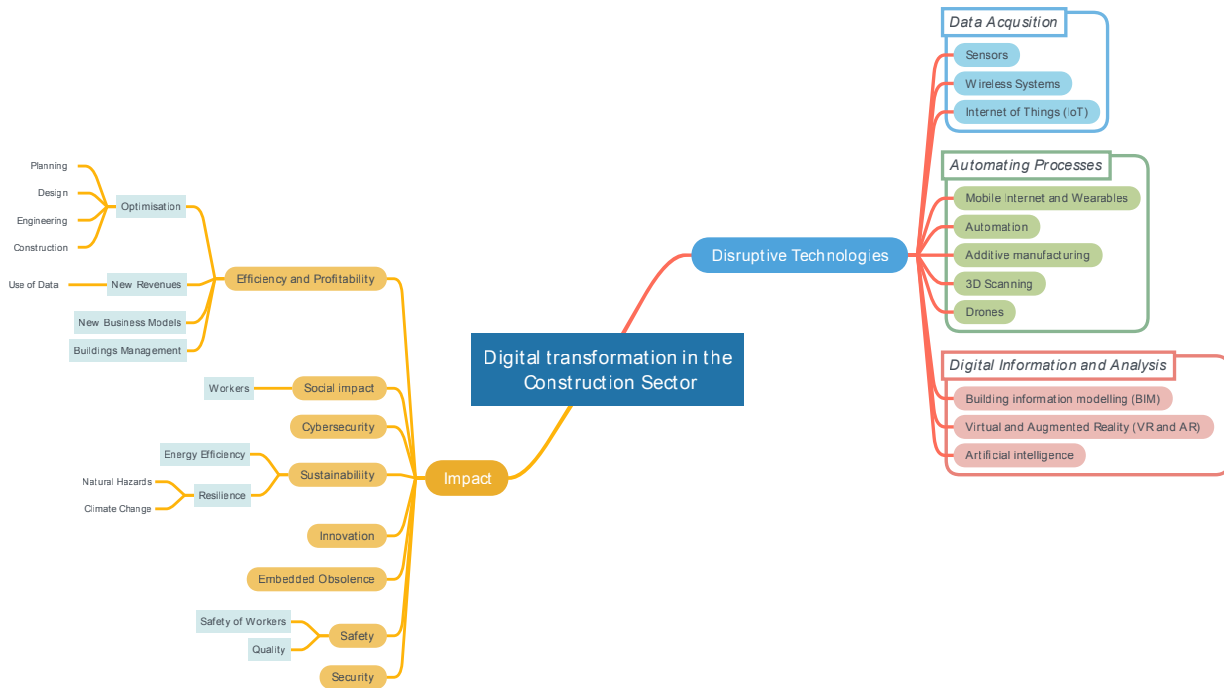
FIGURE 3.3: DIGITAL TRANSFORMATION IN THE CONSTRUCTION SECTOR IDENTIFIED IN THIS WORK.
Source: JRC analysis.

The enabling of alternative technologies, which includes the adoption of new materials (composites, hybrids, and engineered materials), new construction technologies (such as 3D printing and robotized assemblies), and distributed sensor networks will shape the drive for more sustainable, inter-connected buildings and infrastructures. In tandem with these, artificial intelligence (AI) will deal with the massive new amounts of data generated for more effective management of resources.

The present analysis identifies disruptive technologies in the AEC Sector and the impact expected; the topics for discussion in this section are organised as shown in Figure 3.3.

Innovative technologies are clustered into three distinct groups by main function:

- Data Acquisition

- Automating Processes

- Digital Information and Analysis

It must be noted that the technologies analysed do not exclusively belong to one group, but rather exploit innovation from advances in parallel groups. However, a distinct character can be identified and as such they can be sorted into functionality groups. For example, although *3D Printing* mainly addresses automation issues, it uses software, data, and analytical tools and methods that are not strictly related to the same group.

The real flow of disruptive digital technologies in the AEC Sector is therefore encapsulated in data acquisition, digital Information and analysis, and automating processes (Figure 3.4).

Data Science (or Data Analytics) is therefore crucial to linking all of the innovative technologies in this sector and availability of data during construction or operation of the infrastructure is crucial and will facilitate significant improvement and transformations in the way work is carried out. The very real value of knowing exactly what is happening in a site is obtained by collecting data and matching it with different databases and data sources.
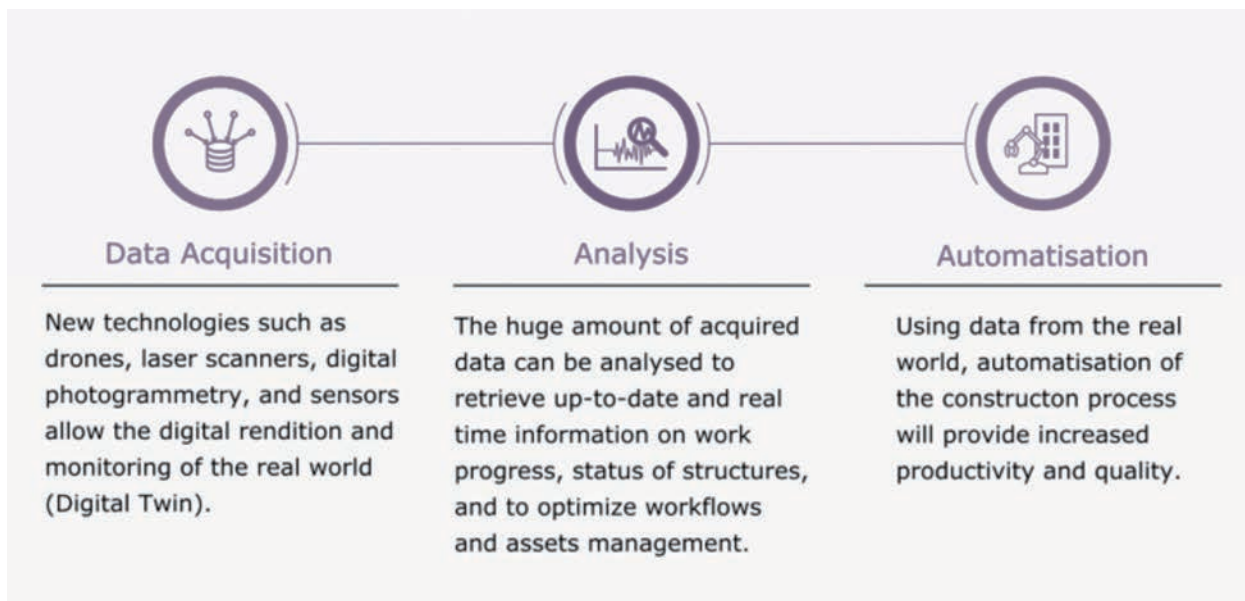
FIGURE 3.4: THE REAL FLOW OF DISRUPTIVE DIGITAL TECHNOLOGIES IN THE AEC SECTOR.
Source: JRC analysis.

Digital Innovation in the AEC Sector unavoidably leads to changes (positive or negative) in the way business and procedures are run, in particular:

- Efficiency and Profitability

- Social Impact

- Cybersecurity

- Sustainability

- Innovation

- Embedded Obsolescence

- Safety and Security

Easy access to digital technology and democratisation of technology are the foundations of digital transformation in the AEC sector, with more and more start-ups each month that are developing businesses based on digital technology is something that is only possible because technology is now easily accessible to the wider public.

3.1 | Overview of Digital Transformation in the Construction Sector

Despite the slow pace of adoption of digital technologies by the construction sector, there are significant opportunities for the whole value chain to benefit from the implementation of digitalisation (Berger, 2016). These technologies can be disruptive due to the way they introduce new business models but at the same time they provide considerable advantages in terms of cost savings, productivity, improved quality, and novel services. The modern construction sector is already changing with companies shifting their business core from the physical construction process to reconfiguring their structure as service providers.

The digitalisation of the whole process is central for the future of Construction: from the initial investment and call for tenders to the design and planning phase, the construction phase (procurement and supply chain, construction site management) and, after completion, the OM&R phase (asset, property, and facility management) (Figure 3.5). The installation of *sensor networks* to monitor buildings and infrastructures with integration in AI-based management systems is essential in fostering the paradigm shift of constructions as services (and to improving the quality of assets – building and infrastructure – and component products for all users).
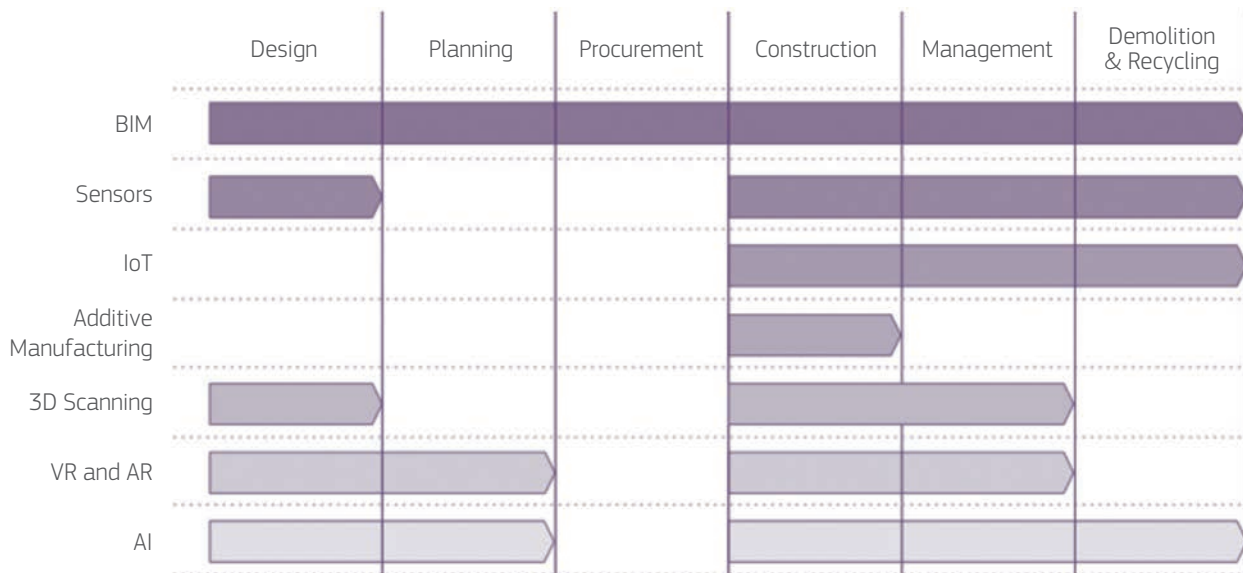
FIGURE 3.5: THE CONSTRUCTION PROCESS AND INNOVATIVE TECHNOLOGIES APPLICATION.
Source: JRC analysis.

Automation of the construction process with the adoption of robotics, additive manufacturing, 3D measuring systems, and drones are key technologies in the sector.

The *disruptive technologies* for the AEC sector are the following:

- Sensors
- Internet of Things (IoT)
- Mobile Internet
- Additive manufacturing
- Automation
- 3D scanning
- Drones
- Building Information Modelling (BIM)
- Virtual and Augmented reality (VR and AR)
- Artificial intelligence

Sensors, IoT, mobile Internet, and drones are already affected by current cybercrime attack capabilities. However, the limited number of attacks is expected to change once the growth of the market reaches a level of maturity which is profitable for criminal attacks (see *1.3.3.1 A conceptual model of cybersecurity in the context of digital transformation* in Part 1 of this report). The entire construction domain may potentially be exposed to cybersecurity threats. A transversal set of processes, technologies, and organisational structures (e.g., intrusion detection, Public Key Infrastructures, Access Control, ISO27001 certification) should be put in place to minimise the exposure to attacks, reduce vulnerabilities, and to prevent cyber-criminal activities. This is especially important in this domain where safety and security aspects are interrelated (e.g., security attacks can generate safety hazards).

3.2 | Digital Transformation Enablers and Barriers in Construction

3.2.1. Technologies and Infrastructure

3.2.1.1. *SMART Buildings and Infrastructures: sensors and IoT for intelligent construction*

Structural monitoring is not a new idea (many critical infrastructures in the world are already equipped with wired sensors and signal recording systems). The element of novelty lies in the opportunities offered by recent developments in electronics and communication.

Monitoring a building or infrastructure used to require expensive installations, limited energy autonomy, had minimal connectivity, and often relied on proprietary control systems. Conversely, the Internet of Things (IoT) foresees the adoption of low cost and low energy consumption devices, capable of sensing the environment through sensors and of transmitting information through wireless internet connections or through sensor mesh networks.

Embedded sensors and wireless systems, along with energy harvesting approaches (e.g. solar power, vibration, or thermal based) contribute to the advent of Smart Buildings and infrastructures.

Optimized HVAC Systems rely on data from IoT devices to regulate the environmental parameters in buildings for managed energy savings in real time, and *predictive maintenance* approaches can be applied to support leaner and more efficient facility management. Moreover, IoT sensors provide unique capability for building security and structural monitoring (Lilis, et al., 2017).

The concept of Smart or intelligent buildings is distinct from standard building automation (Batov, 2015) and most of the commercial products usually allow remote management and monitoring of a built environment (e.g. domotic systems) but mostly rely on actions initiated by users. However, no *intelligence* is associated with those systems. On the contrary, the ability to sense the environment and take decisions, with adapted responses based on information collected (e.g. sensor measurements) along with the possibility of anticipating future performance and functionality, differs substantially from traditional automation systems (Buckman, et al., 2014).

Sensors and AI-based monitoring will provide unique opportunities for *Assisted Living* strategies in supporting the ageing European population allowing the elderly to enjoy an autonomous life in their own homes[111].

These intelligent systems (see Figure 3.6) are based on layers of components:

- Sensors to collect information and monitoring,
- Actuators to take actions and respond
- Communication networks: wireless and wired systems to transmit information
- Artificial Intelligence to process data and take decisions.

FIGURE 3.6: SMART BUILDING COMPONENT LEVELS.
Source: JRC.

[111]   Ongoing collaboration between *JRC E.4 Unit* and *LIUC Università Cattaneo* on the emergence of technologies for Assisted Living, project *Systematic approach for Horizon Scanning using bibliometric tools: the digital transformation in the construction sector*.

Smart Buildings and Infrastructures along with distributed environmental sensors are essential elements of the larger system of monitoring devices relevant to the so-called *smart cities initiatives* promoted by many European municipalities. Networks of heterogeneous sensors, data integration, and *big data* processing lead to unprecedented analysis capability, providing the opportunity to develop knowledge-building strategies by collecting of disaggregated information. This is valid at different scales, that is, from the monitoring of one single building or bridge to whole cities and urban spaces.

In addition, the construction process can benefit from the advent of autonomous sensors and novel data processing techniques. RFID tags have been in use in many sectors for a long time and can provide advantages in resource management and material tracking on construction sites. These tags can be embedded in construction components and structural elements cast *in situ* to improve logistics and accounting.

Critical infrastructure (CI) protection is one of the most important applications of smart infrastructures; the possibility of implementing self-monitoring structures with communication and self-regulation capabilities is the next goal in protection against natural hazards and prevention of failures by implementing maintenance schedules. Moreover, the deployment of low cost self-powered wireless devices and sensor nodes relying on energy harvesting strategies offer unprecedented opportunities for the monitoring of ageing European infrastructures such as the transport network. The possibility of monitoring critical structures and collecting information to feed predictive maintenance algorithms could become a widespread low cost approach to maximising the limited resources for retrofitting and maintenance given the enormous number of existing structures like bridges and viaducts in the EU.

Digital transformation-associated risks in the AEC sector

The advent of complex sensor networks in smart buildings and infrastructures with ever-increasing digital complexity and connectivity raises serious concerns about their hacking security. Recorded cyber-attacks on critical infrastructures in recent years (Ball, 2018) clearly highlight how the
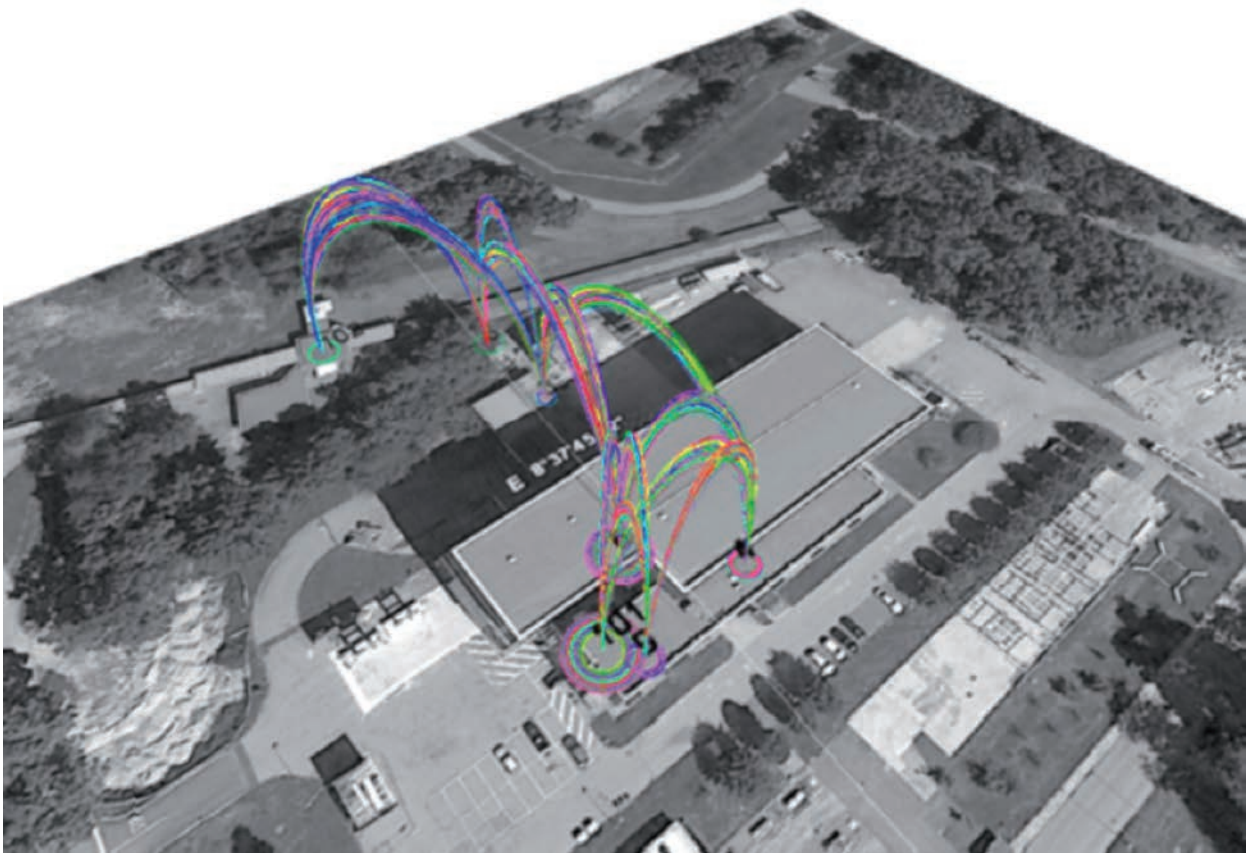
FIGURE 3.7: JRC STUDY ON LATENCY IN WIRELESS MESH NETWORKS FOR SMART BUILDINGS APPLICATION: MULTI-HOP COMMUNICATION OF PERCOLATION NETWORK DEPLOYED AT THE JRC UNIT E.4 FOR THE JRC SMARTBUILD PROJECT.
Source: JRC.

remote control of systems inherently implies the presence of weaknesses in systems security. Apart from the rising number of warnings related to attempts of intrusion into CI systems, striking examples exist of successful cyber-attacks on the Ukrainian supervisory electricity network control and data acquisition (SCADA) and nuclear power plants.

Unless a control system is segregated from other networks (i.e. the Internet), which drastically hinders the advantages of connected infrastructures, the opportunity for unauthorized digital access is always possible and must be mitigated by implementing security procedures, system management, and constant updates. The main limit of the ever-increasing number of IoT devices lies in the necessity for remote management to apply firmware updates and security patches (patching strategies).

Moreover, the increasing complexity of digital systems in smart buildings and infrastructures requires specialized teams with strong expertise in digital threats and security (Mansfield-Devine, 2015). Examples of hacking of so-called Smart buildings have already started to appear and although the damage inflicted has so far been limited by the strategic functional value of the system (for example, HVAC control systems for energy efficiency), as the complexity and control tasks increase (e.g. security systems), the associated risk of major disruption scales dramatically.

Therefore, beyond the possibility of stealing critical data from monitoring systems and databases, cyber-attacks on vital systems (e.g. buildings security or plant control systems) are already concrete, exposing vital systems to the risk of direct damage or ransomware.

Alongside attacks aiming at inducing direct damage (e.g. impairing network availability and service availability by denial-of-service (DoS), attacks or signal interference in wireless networks, or taking control of systems and forcing them act against their purpose), more subtle threats include compromising data integrity. This can be achieved by injecting false information into systems (Ijaz, et al., 2016) leading to wrong decisions and management (e.g. in Smart Cities) or wrong reactions in plants and infrastructure. One example of massive infection of IoT devices is the *Mirai* botnet that exploited known vulnerabilities in hundreds of thousands of less powerful devices to carry out a distributed DoS (DDoS) attack (Antonakakis, et al., 2017). This example clearly shows how the security of

minor devices has not been carefully considered yet (e.g. many consumer devices were distributed with default passwords) exposing systems to major threats.

The systems architecture is also crucial for robustness and resilience of communication and reliability of data and must be carefully selected to account for uptime connections and response time. For example, the increasing dependence of systems on the cloud (i.e. the Internet based services and data repositories) constrains their reliability to the physical connection availability. Consequently, when the cloud is not a viable or sufficiently reliable solution, local processing of information or edge computing, consisting of the computing infrastructure close to the devices collecting data, is a preferable alternative (as is becoming increasingly common in industrial automation solutions).

Many communication protocols have been developed and exist for the communication stack of IoT devices (*LTE*, *ZigBee*, *6LowPAN*, *SigFox*, and *LoRaWAN* to name but a few) each one with specific advantages and characteristics. However, the advent of 5G, the 5th generation mobile network, promises to radically change the way IoT devices are connected by providing M2M communication, increased bandwidth, and low consumption to cope with the billions of devices expected to be connected by 2020 and the need to transmit more information consequently enabling novel data intensive applications (e.g. augmented reality, real time monitoring). In general, all of the above affects the CS by definition because of the intrinsic exposure of connected devices.

Privacy issues arise from the diffusion of internet-connected devices, monitoring solutions, and IoT systems capable of tracking and recording the behaviour of people. Data Protection strategies must be implemented by *Design*, ensuring that installed devices have a built-in security strategy, and by *Management* ensuring patching procedures and addressing comprehensive security and identity control especially in relation to remote access to devices and connection to services.

On the other hand, the design and deployment of solutions to mitigate cybersecurity risks and threats for the present field of application should be requested by the regulatory frameworks in the AEC sector itself. The challenge for regulators is to balance the security requirements with market aspects to avoid distorting competitiveness in the construction market: smaller builder companies could be

placed in a disadvantageous position compared to larger companies because it would be too expensive for them to build and maintain the cybersecurity competence.

With the progress of connectivity and adoption of new technologies, construction will potentially be among the sectors attracting most interest for cyber terrorism (CT). Although Internet security is a major issue, it is not perceived as such as the impact on people is still not problematic enough to make it an issue. However, as recently stated by B. Schneier (Schneier, 2019), this situation can *"change in a world of physically capable computers. Automation, autonomy, and physical agency will make computer security a matter of life and death, and not just a matter of data"*.

With the increasing adoption of ICT Technologies in buildings and infrastructures, the provision and strategies of new cybersecurity protection in smart buildings must be supported by appropriate regulations.

Embedded Obsolescence

One aspect that needs to be considered in the implementation of digital technology in smart buildings and infrastructures is the expected service lifetime: structures and buildings are designed to last for decades (25, 50, 100 years or more) whereas digital technologies typically evolve in months. The major risk is that legacy systems will leave smart buildings and infrastructures exposed to cyber-attacks. This conflict must be addressed carefully by using a completely novel approach that plans for constant updates of those systems. Moreover, in the case of smart buildings the risk is that the main focus is devoted to the application (e.g. controlling an HVAC system) with digital security aspects being given minor consideration. A new reliable approach should have those systems implemented by joint teams with distinct expertise in plant, automation, and cyber security.

> *Embedded technologies in buildings and infrastructures face obsolescence challenges due to the incommensurate lifetime of ICT technologies and constructions (months vs decades)*

Finally, the majority of the buildings in the world were built before the advent of home automation, the Internet, the web or ICT recent developments in general and in Europe before HVAC systems and similar advanced technological systems. This adds even more complexity and constraints because the introduction of these new technologies into existing (usually inhabited or in-use) buildings and infrastructures is not as easy as a simple product upgrade, which is the case in other manufacturing sectors.

3.2.1.2. Mobile Internet and wearables

The adoption of tablets and mobiles as standard tools in the construction industry is paving the way for a more connected working environment. Many of the tasks of a construction project are already being facilitated by able to exchange up-to-date information rapidly.

Tablets: The seamless integration of these tools in the BIM-integrated data pipeline of construction processes

will allow smooth communications and real time updates. The possibility of visualising all of the information required on portable devices (or with more sophisticated virtual reality devices), georeferenced in a 3D graphical simulation model, will ensure constant updates of plans and drawings as well as technical, financial, and legal information. This eases change requests and the rapidly fulfilment of additional details. The adoption of tablets

provides advantages in always ensuring up-to-date and real time information to workers and can lead to significant savings and improved quality and efficiency. Tablets can efficiently substitute paper work and allow the visualization of 3D virtualisation. An example from a real-world implementation in a medium-sized American construction company[112] claims estimated savings of up to $1.8 million USD a year.

The constantly decreasing cost of sensors, beacons, etc., along with their portability and power efficiency, and the support of more efficient communication protocols and devices, finds direct application in wearables. These devices are already in use in a number of fields such as healthcare for the monitoring of patients conditions, sport, and first aid (firemen, policemen, etc.). Construction safety will gain significantly from adopting these systems in environments like construction sites where the risk of serious injury is one of the highest of all production sectors.
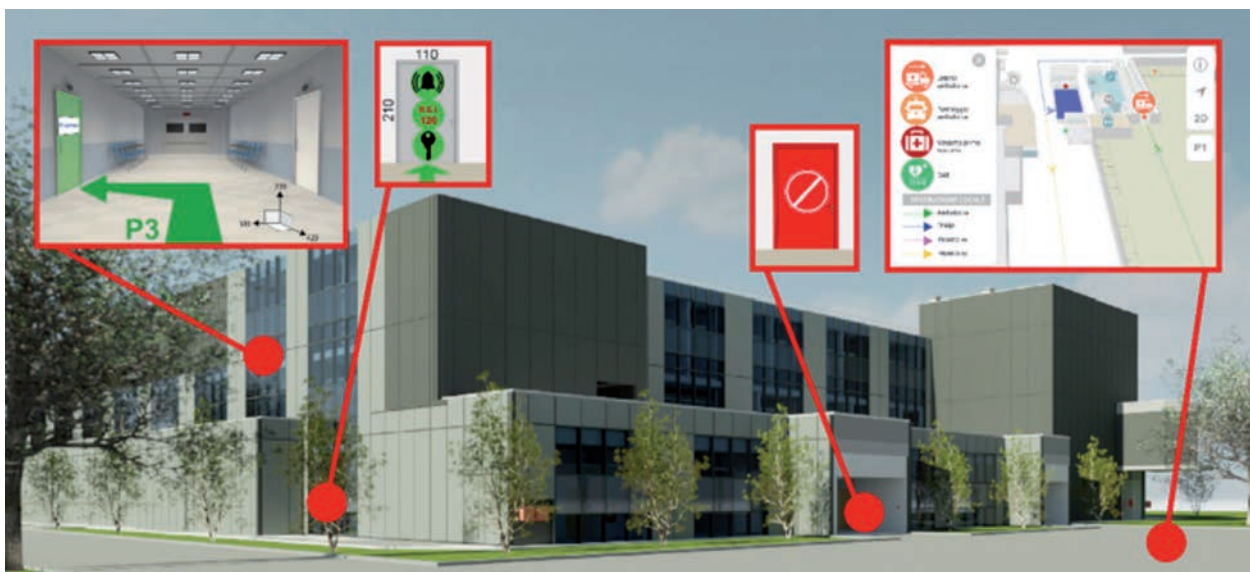
FIGURE 3.8: 3DBIM – SAFETY PLATFORM: RED CROSS, FIRE SERVICE, POLICE – POLITECNICO DI MILANO D. ABC, NOOVLE, FASTERNET – SMART LIVING PROJECT – REGION OF LOMBARDY – ITALY: BIM SAFETY MODEL OF POLIAMBULANZA HOSPITAL (BS).
Source: image provided with the permission of Politecnico di Milano.

Wearables: The adoption of wearables in construction can also be useful for data collection and statistics so that better strategies for safety at work can be defined (Awolusi, et al., 2018). Already advanced in sectors like e-Health for monitoring patients' conditions, the application of remote wireless sensors for monitoring workers in the construction sector is still in its infancy and the environmental conditions are challenging due to the ever-changing nature of construction sites. Some implementations include real-time proximity detection and warning systems, location tracking, and fall detection systems which rely on accelerometers in smartphones. The possibility of wirelessly connecting these devices allows constant update of multiple systems improving safety (Awolusi, et al., 2018). Moreover, commercial use of these technologies helps planners and developers to analyse the real use and exploitation of both buildings volumes and space in cities by collecting users' data (resident and consumer habit).

Robotics: The robotics production market is expected to scale significantly in the next few years and in common with the industry, the technology expected to have the fastest increase is the development of exoskeletons in support of workers dealing with repetitive tasks involving heavy manual material handling (Linner, et al., 2018). Exoskeletons will improve productivity on construction sites and will contribute to minimising injuries and improving wellbeing and safety of workers.

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[112]   https://consultantsinsider.com/articles/How-a-Dallas-construction-company-saves-nearly-2-million-a-year-by-using-hundreds-of-Apples-iPads--5af4ca1bb809f650e3d30eef

3.2.1.3. Building information modelling (BIM)

The adoption of digital tools such as CAD/CAE or planning and management software have already been adopted by clients, designers, architects, engineers, and builders for some time. This has allowed a significant improvement to the design phase. Graphical changes and modifications can be applied easily and constantly updated 2D or 3D drawings rapidly plotted. The digitisation of civil structures and MEP[113] systems in the design phase also allowed smoother collaboration of large teams in which sharing drawings and collaborating on shared elements is easier.

Building information modelling (BIM; EN-ISO 19650-1-2:2019) is considered to be the next step of computer aided design (CAD). A BIM model goes beyond the 3D CAD drawing by adding additional information layers in the entire process and supply chain (phases and actors). BIM relies on object oriented programming with classes specifically defined for the AEC sector (standardized in the IFC – Industry Foundation Classes open language - EN ISO 16739:2017 - and in the ifcOWL ontology), a machine's accessible data stored in a database for the construction process. Consequently, different dimensions of BIM are considered depending on the information stored: from the initial BIM 3D, containing the virtual 3D model, to BIM 4D, which includes the time variable and provides support in scheduling and planning the construction phase, all the way up to the BIM 7D regarding sustainability (across 5D, cost, and 6D, operation and maintenance; UNI 11337-1:2017).

Despite the importance of BIM across all of the seven defined dimensions, OM&R activities are expected to benefit significantly from the use of BIM 7D for Facility Management work based on BIM. Presumably this will be the most profitable use of BIM technology.

Future BIM developments will include the real-time integration of sensor data in smart buildings to create a fully functioning virtual living model of the construction, including information on the status of possible damage and malfunctioning (*digital twin*).

BIM is already being adopted by major clients and developers, construction companies, and design firms due to it having the advantage of allowing interdisciplinary collaboration and smooth sharing of data, but there is still the need to complete standardization (which is waiting for the CEN 442 work to be completed) and full adoption throughout the construction life cycle.

Despite the many advantages promised by the adoption of BIM, a number of factors have limited its diffusion so far. One of the major obstacles is the high implementation cost due to the requirement for powerful new hardware, new sophisticated software, and professional skills (BIM manager, coordinator, specialist, CDE manager; UNI 11337-7:2018). Moreover, the adoption of BIM only in small parts of the construction process limits the advantages for the investment needed. In this context, European regulations and requirements (against the use of various proprietary guidelines) can lead to wider adoption of this tool and could help SMEs to face costs and initial investments that are not always sustainable today. The development of a future (BIM) European digital platform for the AEC sector could promote the innovation of these processes (EU DT-ICT-13-2019 call: Digital Construction Platform).

The European Parliament's Directive 2014/24/EU on public procurement repealing Directive 2004/18/EC promotes the use of electronic tools in public call for tenders and Art. 22 c.4 states that "*For public works contracts and design contests, Member States may require the use of specific electronic tools, such as of building information electronic modelling tools or similar*". This is a significant action to promote the adoption of BIM. Indeed, some EU Countries already require BIM projects in public work with some Member States already making the use of BIM compulsory in the near future (e.g. in Italy Legislative Decree 50/2016 – D24/14 EU adoption - and Ministerial Decree 560/2019 guideline to introducing BIM in public works, services, and supplies with mandatory schedule: complex work costing over €100 million from 2019, every work costing under €1 million/ to 2025) following the "European Union Public Procurement Directive" 2014/24 that promotes the adoption of BIM in public calls for tenders and adoption by Member States.

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[113]   Mechanical, Electrical, and Plumbing

3.2.1.4. *Automation of the Construction phase*

The construction phase has not seen significant improvements in productivity in recent years, which contrasts with the rapid advances in other manufacturing sectors (Changali, et al., June 2015). The use of machines (e.g. cranes or concrete pouring pumps) on construction sites already provides support but a great deal of manual labour is still undoubtedly indispensable for most construction site activity. Compared with the increase in productivity in the Manufacturing Sector in the last twenty years shown in OECD data[114], it is clear that the technological advances in general have not benefited overall efficiency of the Construction Sector (see Figure 3.9).

Additive manufacturing (AM) is a technique to generate 3D elements by the incremental superposition of layers of material. Strictly speaking, additive manufacturing is an ancient method because brick-laying (be it with adobe or simple clay bricks) or more recently concrete pouring, are methods that rely on the addition (as opposed to the subtraction) of material to construct a form for a building. However, the modern form of this technique, initially conceived in the manufacturing industry with the aid of

> " *The construction sector has not seen significant productivity improvements in recent years. This contrasts with rapid advances in manufacturing sectors* "

FIGURE 3.9: EU28 PRODUCTIVITY IMPROVEMENT OVER TIME (MANUFACTURING VS CONSTRUCTION).
Source: JRC analysis based on OECD data..

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[114] OECD Productivity and Unit Labour Cost (ULC) by main economic activity (ISIC Rev.4) https://stats.oecd.org/Index.aspx?DataSetCode=PDBI_I4

computer-controlled machinery, has recently become better known as 3D Printing. More recently it has been widely adopted for rapid prototyping, manufacturing of complex elements (e.g. in the aviation industry) that would otherwise not have been possible using traditional techniques. Additive manufacturing (AM) for construction is in its infancy with R&D units and start-ups working on the development of systems (machines, materials, and algorithms) for the 3D printing of entire buildings or cement-based elements (Figure 3.11 is an example of 3D printed building by CyBe, based in the Netherlands).

This approach allows greater flexibility in the form, design, and speed of completion with real examples having already been constructed to demonstrate the feasibility of this method (up to now limited to individual components and low-rise buildings only). A notable example is the first 3D printed pedestrian bridge installed in Alcobendas (Madrid, Spain) in 2016, structurally designed and manufactured by Acciona (Figure 3.10). The 3D printed bridge is a real world AM application which is considered (Julia, 2016) as the first milestone achieved in 3D printing of bridges anywhere in the world.

The challenge to increase the size of printed models is being taken in the adoption of crane printing process.

FIGURE 3.10: 3D PRINTED 12 M LONG PEDESTRIAN BRIDGE IN MADRID.
Source: image provided with the permission of Acciona.

Other approaches consider the adaptation of welding robots, frequently used in the automotive industry, to operate as metal additive systems exploiting the 3D movements of robotic arms in space (Figure 3.12 shows a 3D printed metallic bridge produced by a robotic arm for metallic additive manufacturing of the Amsterdam company MX3D).

However, the adoption of AM for the construction of large buildings or infrastructures still needs the development of more complex production and materials systems. Some consider that in the short term it is more realistic to implement AM for the manufacturing of building components such as concrete slabs and panels in a similar way to prefabrication processes but with the advantage of greater design flexibility and portability of the machinery to the construction site, consequently avoiding the transport costs of detached production plants.

One potential commercial application of AM in the Construction sector deals with 3D printing of individual components that could have a major market niche in reproduction of "unique" special parts of heritage buildings consequently reducing the cost of renovation works and speeding up the making of unique and complex artistic elements.

FIGURE 3.11: CYBE 3D PRINTED CONCRETE DRONE LABORATORY.
Source: image provided with the permission of CyBe.

If the 3D printing approach aims to substitute traditional cast-in-place concrete structures, *robotized assembly* is being developed to automate the building process of steel structures (or precast concrete) and minimizes the risks during on-site erection or installation work. Brick masonry buildings can be assembled by rapidly improving bricklaying robots that are improving in precision and flexibility with fast execution times.

It is important to stress that the systems described above strongly depend on digital models of the final structural design, integrated sensors, and measuring systems.

Autonomous vehicles also have a direct involvement on construction phase in transport of construction materials from manufacturers to construction sites, earthmoving works, or inspection and surveillance. Autonomous vehicles will have a role in the integrated and automated construction phase. Tele operated machinery will ensure remote control in hazardous environments and constant monitoring. However, design and use of robotized machines must carefully consider the human-machine interaction because the coexistence of people and robots on construction sites leads to more dangerous and critical interactions. This hazard is usually avoided in manufacturing industry as robotized processes are segregated from areas accessible to humans whereas on construction sites, the ever-changing spatial configuration associated with low modularity prevents standardized movements and operations. Moreover, considering the built environment, future buildings and infrastructures will interact with transport systems by exchanging data in vehicle to infrastructure (V2I) communication improving efficiency and optimising traffic flows.

Collaborative Robots or Cobots will allow human-machine interaction in a complex environment such as a construction site or prefab elements factory. *Cobots* have been defined

FIGURE 3.12: MX3D 3D PRINTED METALLIC BRIDGE.
Source: image provided with the permission of MX3D.

(Institut für Arbeitsschutz der DGUV (IFA), 2018) (Danish Standards Foundation, 2016) as follows: *"Collaborative industrial robots are complex machines which work hand in hand with human beings. In a shared work process, they support and relieve the human operator".* Once AI implementation allows sufficient autonomy and flexibility for the adoption of *cobots* in the construction process, this will offer novel opportunities to increase quality and productivity and avoid human exposure to risk areas. However, it is reasonable to expect *cobots* will be initially adopted for limited tasks only, and the requirement that *cobots* and human workers share the same environment will require dedicated legislation and standards.

3.2.1.5. *3D Scanning and Drones*

Design and construction of civil engineering structures is based on spatial measurement. From the very initial phase of a construction project, the design of a building requires precise assessment of the site where the construction will be created. Measuring the real position of elements on construction sites is crucial and the project is frequently adapted by a recursive two-way exchange between the real and the designed model.

3D scanning technologies are becoming more frequently used in AEC which is increasing precision and productivity. The acquisition of precise point clouds of existing structures and convert them into 3D models is crucial in the digitisation of AEC. A BIM system based from the outset on the 3D model of the structure is sufficient.

The advent of drones has spread rapidly to many sectors, but it is achieving real advantages in AEC in the digitisation of construction sites and large infrastructures. The ability to scan large areas and inaccessible parts of structures dramatically speeds up the production of accurate surveys and job inspections. The opportunity to have constant updates of evolving jobs is also contributing to improving the safety of workers.

In addition to 3D scanning and drones for the AEC sector, a survey of system utilities is necessary (installed underground, under roads, or inside walls, etc.). The detection of individual details of a system component (e.g. identification of services within concrete walls) remains a great issue – time, cost, and precision of survey – with

> *The advent of drones in the AEC sector can provide real advantages in the digitisation and monitoring of construction sites and of large infrastructures*

However, non-invasive technologies are needed to investigate inner volumes of structures particularly as the European building stock is composed of existing buildings of which there is little or no knowledge of their internal technical details[115].

Whereas drones and laser scanning are automated processes, they are key technologies in the field of data acquisition as they are really sensors that generate large amounts of data (point clouds) that once processed, provide lot of information for monitoring construction work progress, site surveillance or infrastructure inspections.

Reality Capture is another important technology that will be essential in expanding the use of BIM. There is a significant amount of existing building stock without information to support Facility Management based on BIM because BIM models were not made during the construction phase. This is why IR scanners, drones, Laser Scanners, and Mobile Mapping (see as an example the JRC generated 3D point cloud from a low cost personal device in Figure 3.13) are going to enable rapid Digitisation of existing infrastructures. Creating a geometrical digital replica of buildings and infrastructures is therefore possible using Reality Capture technology which will help in the creation of a Digital Twin model. Automatisation from point clouds to BIM is already a

existing technologies (thermographs, tomography, radars, etc.). An example of new technologies in this field is multi-sensor robotic inspection systems which are used to perform ducts, tunnels, or pipeline networks surveys.
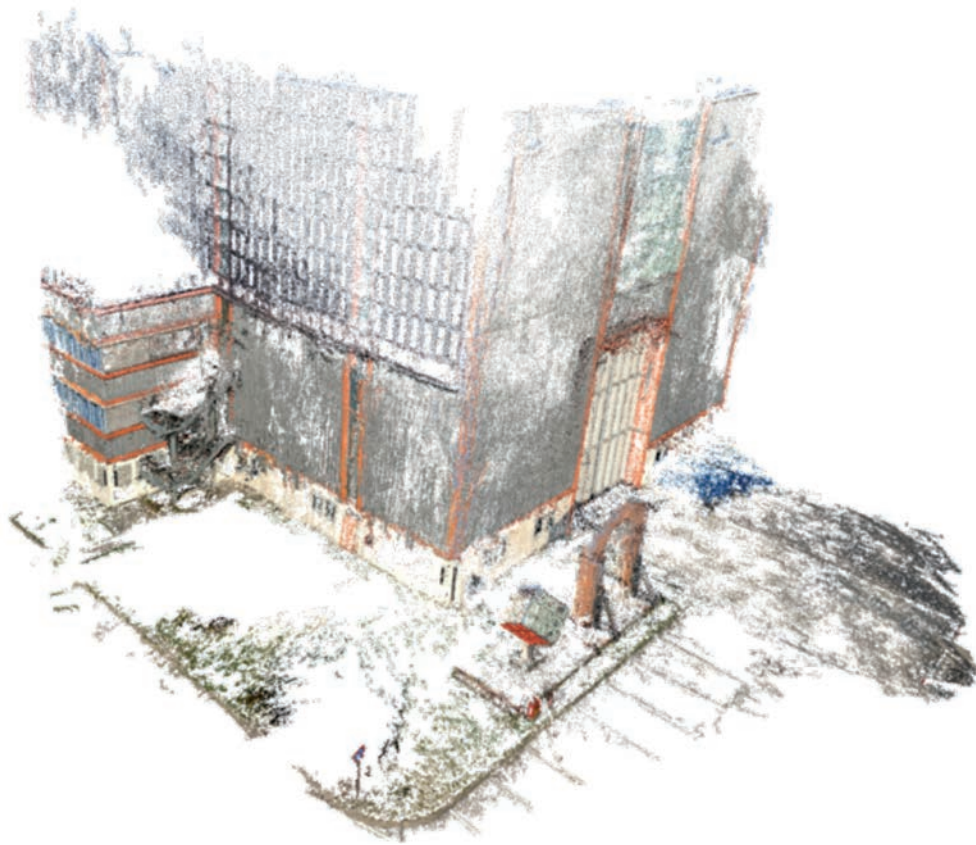
FIGURE 3.13: 3D POINT CLOUD OF THE JRC ELSA FACILITY CAPTURED USING LOW COST PERSONAL DEVICES.
Source: JRC SMARTBUILD Project.
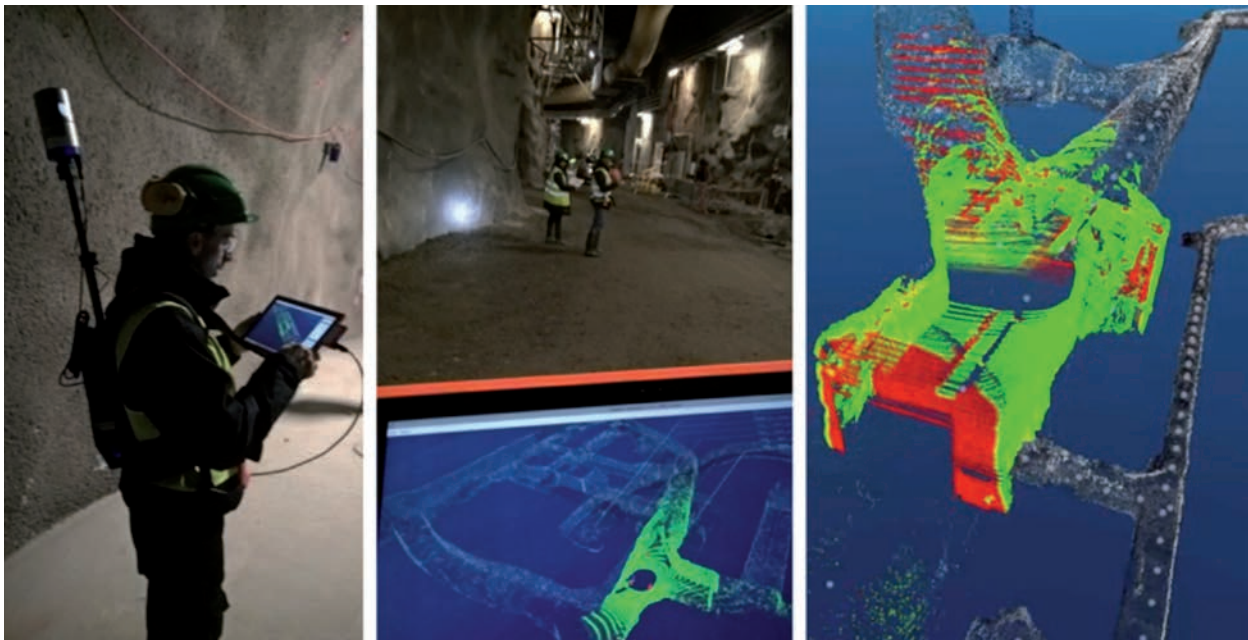
FIGURE 3.14: JRC MOBILE LASER SCANNING FOR SAFEGUARDING FINAL SPENT FUEL DISPOSAL FACILITIES. REAL-TIME VERIFICATION OF THE ABSENCE OF UNDECLARED CHANGES USING THE MOBILE LASER SCANNING PLATFORM.
Source: JRC.

challenge that needs to be accomplished as it will speed up engineering work time. For example, the JRC's Mobile Laser Scanning Platform (MLSP) unit uses a real-time 3D laser scanner mounted on a backpack for the real-time verification of the absence of undeclared changes in nuclear facilities (Figure 3.14) by scanning the environment and processing the point cloud as a 3D model (Sanchez Belenguer, et al., 2018) (Sánchez, et al., 2016).

3.2.1.6. *Virtual and Augmented Reality (VR and AR)*

Virtual reality has already been adopted by larger companies in the AEC sector in order to visualise complex projects, and to provide a simulated environment in which engineers and clients can experience and navigate around the digitally constructed virtual model. Project ideas can therefore be visualized in an immersive 3D environment long before the real structure takes shape. This has clear advantages in detecting possible design issues and enhances communication between designers, architects, engineers, clients, and stakeholders in the initial phase of building design. This solution usually requires dedicated indoor space equipped with electronic devices to retrieve information on the user position in 3D space and for the digital virtual environment to be visualised.

The advances in visualization and rendering, along with the recent development in portable hardware that allow the projection of digital information or models on transparent glasses, offer the construction industry unprecedented opportunities. Commercial applications are already available particularly in the manufacturing industry to assist technicians and engineers working on complex systems. One example is the visualization of instructions during repair and maintenance operations thus providing direct support with spatially relevant data.

The same approach is being studied for the construction sector with applications on construction sites, e.g. to provide information on work progress or to support quality inspections. The integration of these systems with the data pipeline requires access to BIM data in order to access all of the information related to the project (e.g. 3D model or materials).

Because virtual reality is an effective tool for visualising complex models, it could also prove to be a strategic tool for business development as it will help clients to visualise a structure at the project proposal stage.

Augmented Reality (AR) is going to play a significant role in DT of the AEC sector. It is really a key enabler as it allows the digital and physical worlds to be combined. Workers using AR can directly visualise on-site BIM models in the exact place where they are going to be built. This can provide significant advantages on construction sites to reduce dependency on surveying as workers will be able to determine what they are going to build based on visualising the BIM model directly on site. Other interesting applications in AEC are in real estate as clients are going to be able to see in situ buildings and infrastructures in the environmental context they are going to be built in.

3.2.1.7. *Blockchain*

Blockchain technology is being increasingly implemented often when a distributed approach is preferable to a centralised encryption system (Nascimento, S., et al., 2019). The potential of this technology for the AEC Sector is strategic in enabling wider adoption of digital processes in the construction process thereby solving one of the major obstacles to the adoption of BIM: traceability and consistency of exchanged information.

As increasingly reported in several conferences (Turk & Klinc, 2017), the information exchanged by BIM systems has strong legal implications. Due to its nature, construction is a highly collaborative process[116] and what was once exchanged and signed on paper documents and drawings is nowadays transmitted electronically between a notable number of actors in the construction process

which leads to increasing fragmentation. If, on the one hand, the digitisation of information improves quality, safety, and productivity, on the other there is the need to ensure that none of this information suffers unauthorized changes by one of the actors involved; and copyright and ownership must be preserved.

Although the architecture of BIM is centralised (within a specific contract) and *blockchain* is conceptually the opposite, as it relies on a distributed ledger, this technology is being explored for a range of different applications such as smart contracts, B2B transactions such as payments and insurance, and data from sensors in smart buildings. Therefore, one of the interesting aspects of blockchain for the AEC sector (private and public) in the future will be to ensure both the integrity of data and its availability as

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[116]   Digitalization could improve the collaborative aspect, or nature, of construction process.

well as access to it (e.g., data unavailability may result as a consequence of holding company bankruptcy) and data re-usability (design copyright, data format, etc.) in the long term (50, 100 years or more, over the original author and the temporary owner or manager, etc.).

The major difference between the adoption of *blockchain* for cryptocurrencies and for BIM lies in the number and size of transactions: the former sees billions of small size transactions between millions of users whereas the latter consists of hundreds of transaction with sizes in the order of Gigabytes. Consequently, the adoption of *blockchain* within a BIM system, involves the availability of sufficient resources in terms of storage space and computational power, and more testing and analysis of business cases must also be performed. A solution to those criticalities in the AEC domain could be the adoption of EU-wide digital sector platforms which are in the process of being developed (EU DT-ICT-13-2019 call: Digital Construction Platform) similar to other production sectors (i.e. manufacture, agriculture, healthcare, etc.).

Blockchain is really going to change public governance. Transparency and immutability are key advantages

that this technology is going to bring to all processes. The administrative burden is also going to be reduced by smart contracts. One of the main advantages in the adoption of this technology is the transparency in all administrative processes, e.g., calls for tenders. The EU is currently investigating the potential for adopting an enabling framework or infrastructure for blockchain-based services. (European Commission, 2018). A notable example of this is a pioneering project by the government of the autonomous community of Aragon in Spain adopting blockchain technology for procedures controlling and transparency of call for tenders for public works (Beltramino, 2019).

The project has two main phases: the first deals with the registration of offers in a decentralized way, allowing public verification of the exact moment when a company's bid is submitted; the second phase is related to the development of intelligent contracts that facilitate the automated evaluation of the bids without human intervention. It is expected that this process will ensure full transparency in managing prices during the tender process (*eTendering*).

3.2.1.8. *Artificial Intelligence*

Artificial intelligence (AI) is a disruptive technology that has recently acquired unprecedented capability thanks to increases in computational power. In order to be effective, AI requires the processing of large amounts of information to train the neural networks on which its functioning is based.

The complexity of this subject requires dedicated analysis and discussion that goes beyond the scope of the present report, but a parallel JRC report on Artificial Intelligence specifically addressing the impact and innovation of this technology was published in 2018 (Craglia, et al. 2018). Therefore, only an outline of the AI-based technologies relevant for AEC is provided here.

Some areas in the AEC sector that will be impacted by AI are the following:

- Structural and Building Design, and Monitoring
- Planning and Construction Works Management
- Autonomous Equipment
- Monitoring and Maintenance (Machine Vision and Signal Processing)

AI is going to change (and in some cases is already changing) the way we interact with our buildings and homes. Natural language is directly linked to domotics and to automatisation of buildings. This means that new approaches must be considered for the new built environment: building design needs to consider our homes as living spaces where people live and interact with them by voice control. This will radically change the way buildings are conceived and the type of installations and technology that is going to be included in new build homes.

Structural and Building Design, and Monitoring

Within the construction sector, the adoption of AI is also starting to show its capabilities in structural analysis, design, and optimisation. In particular, the implementation of Artificial Neural Networks (ANN) for structural damage assessment (e.g., detecting structural damage from the earthquake acceleration responses of a building (Huang, et al., 2003)) or structural health monitoring (e.g., identification of damage and nonlinearities in wind turbine blades based on a pattern recognition technique from the

measurements of different sensors (Sierra-Pérez, et al., 2016) or exploitation of vision-based systems for crack detection (Cha & Choi, 2017)). Such ANN-based methods are becoming more and more popular particularly for their capability in pattern recognition and classification problems. The widespread deployment of structural monitoring systems (IoT, WSNs) will also provide the essential big data to train Machine Learning algorithms and to develop AI-based Structural Health Monitoring (SHM) systems.

Design, Planning, and Construction Work Management

Conversely, Machine Learning techniques can be used to differentiate or extract items hidden in large data sets. These techniques provide support in more efficient construction work management, adapting to the continuous changes made to the initial plan.

AI methods are supporting generative design approaches in both architecture and structural design. AI integrated with BIM software is able to explore all the possible permutations of a design, given the constraints and boundary conditions from which designers and engineers can choose from (*Design Optioneering*).

Furthermore, in BIM reviewing procedures integrated with AI (clash detection and code checking BIM review) it is possible to perform massive automatic checking of the conformity of all kinds of computable rules and interferences without direct human control. Such an automated approach could be of great interest and impact for the public administrations in the process of construction authorisation, and in automatic control of compliance not only to the project's building codes but also of the built structures through 3D scanning and AI.

Automation in the Construction Sector

The meeting of AI, parametric design, and robotics is already resulting in novel production approaches that in spite of being limited to relatively small scales look rather promising for the achievement of radical construction approaches. AI is fostering the development of *autonomous equipment and machines* and *industrial robots* that will possibly be adopted in the future in the construction sector.

The introduction of automation based on AI will also contribute to improving safety in a sector that has the highest rate of fatal injuries of any industry.

Predictive Maintenance and Optimised Energy Management

The advent of AI is already pervading many sectors of the industry such as in the case of predictive maintenance, but it is also providing novel opportunities for the rapid development of autonomous and robotic solutions.

Predictive maintenance can also be successfully applied to facility management as well as the *optimal energy management* of smart buildings: sensors allow the constant monitoring of environmental parameters and detect the presence of people in the buildings managed. AI-based tools then adjust the heating and electricity consumption not only on the basis of real time data but also learn from the building's usage statistics to adapt and anticipate needs.

Finally, machine vision makes use of AI for identifying objects and persons in video footage for applications in construction work monitoring or security surveillance systems.

3.2.2. Standardisation and Legal Framework

Standardisation is crucial to promoting wider adoption of digital technologies in the construction sector. The adoption of proprietary systems (sensors, data monitoring systems, protocols, software) or proprietary methods or guidelines (also in BIM methodology) creates de facto barriers that hinder interoperability of systems and innovation, and limits a fair and competitive market: "…*Without a standard data and process definition the*

supply chain and client will be re-creating a diverse range of proprietary approaches [proprietary BIM guidelines] *which will potentially add a cost burden for each project…*" (EUBIM Taskgroup, par. 3.1.3, pag. 48). (EU BIM Taskgroup, July 2017)

Open data standards are essential in ensuring future developments and digital technology diffusion in this

> **"** *The adoption of BIM is slowed down by legal aspects. The sharing and exchange of information across multiple actors is often a cause for concern* **"**

keep track of changes, ensure consistency, and facilitate collaboration. However, the practical implementation of such systems implies that one of the actors of the construction process administers and controls the BIM system, granting access to all the stakeholders. This model is controversial in the industry due to issues concerning data ownership and legal disputes. Consequently, the adoption of BIM by the AEC sector is slowed down by legal aspects (Arensman & Ozbek, 2012) (Fan, et al., 2018) that must be carefully addressed[117]. Legal issues, as identified in (Fan, et al., 2018), can be divided into the following four main groups:

1. Incompatibility of procurement systems with BIM
2. Liabilities for errors (design, transition) and for data loss or misuse
3. Model ownership and Intellectual Property Rights (IPR)
4. Unclear rights and responsibilities.

Consequently, all of the major world-wide standards organizations are working to complete the existing rules of BIM and write new ones. At the international level there is the ISO/TC 59/SC13/WG13 table; at EU level there are the CEN 442/WG 01 to 07 tables; and below those two there are a lot of national tables e.g. UNI (ITA), BSI (UK), DIN (D), and AFNOR (FR) to name but a few. The main BIM standards can be summarised as follows:

- EN-ISO 19650:2019 (parts 1 and 2, with all national appendices; now BSI 1192 for UK and UNI 11337 for ITA);
- EN-ISO 16739: 2017 (IFC);
- EN-ISO 12006:2016 (parts 2 and 3);
- EN-ISO 29481:2017 (IDM, parts 1 and 2).

sector which, more than others, needs to overcome the slow adoption of new technology and procedures.

The advent of novel construction methods using new and innovative materials must also consider the existing construction standards such as the EUROCODES, and the introduction of specifically tailored guidelines and parameters along with precise testing and certification procedures.

The adoption of BIM beyond single corporate use raises concerns about the exchange of information across multiple actors of the construction process. Ideally, BIM is designed to facilitate the exchange data and virtual models,

3.2.2.1. *Privacy and Data Ownership*

A vast amount of information has already being collected during manufacturing processes and the installation of sensors and IoT devices in buildings and infrastructures contribute to constant data collection. In the case of business related data, the dissemination of information can lead to issues with data sharing across the construction pipeline and among the different actors involved, whereas the IoT can have a direct impact on citizen's privacy and as such is regulated and must be carefully managed.

As mentioned in the general section on data legal issues, data ownership in a large number of cases is regulated at contractual level. However, the availability of data to public administrations in the case of managed facilities and infrastructures is critical, which is particularly so considering the revenue potential of data.

Access rights to privately held data might play an important role in many *IoT* (Internet of Things)

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[117] See the Introduction part of this report for the legal aspects and ownership of and access to data.

applications, for example, *"in smart homes or smart energy applications, several stakeholders as the tenants, the facility management, the producer of the devices as well as energy companies and others might have legitimate interests in the same data and might have contributed in producing them"* (Kerber & Frank, 2017).

Privacy is becoming a major concern in relation to the presence of sensors in public and private spaces, particularly concerning the European General Data Protection Regulation (GDPR), and there is the need to balance privacy rights of individuals and the needs of innovation. The advantage of *IoT* systems lies in the potential to collect information that, if limited and severely constrained, could prevent its full exploitation.

% of EU28 Enterprises (10 persons employed or more) buying Cloud Services used over the Internet
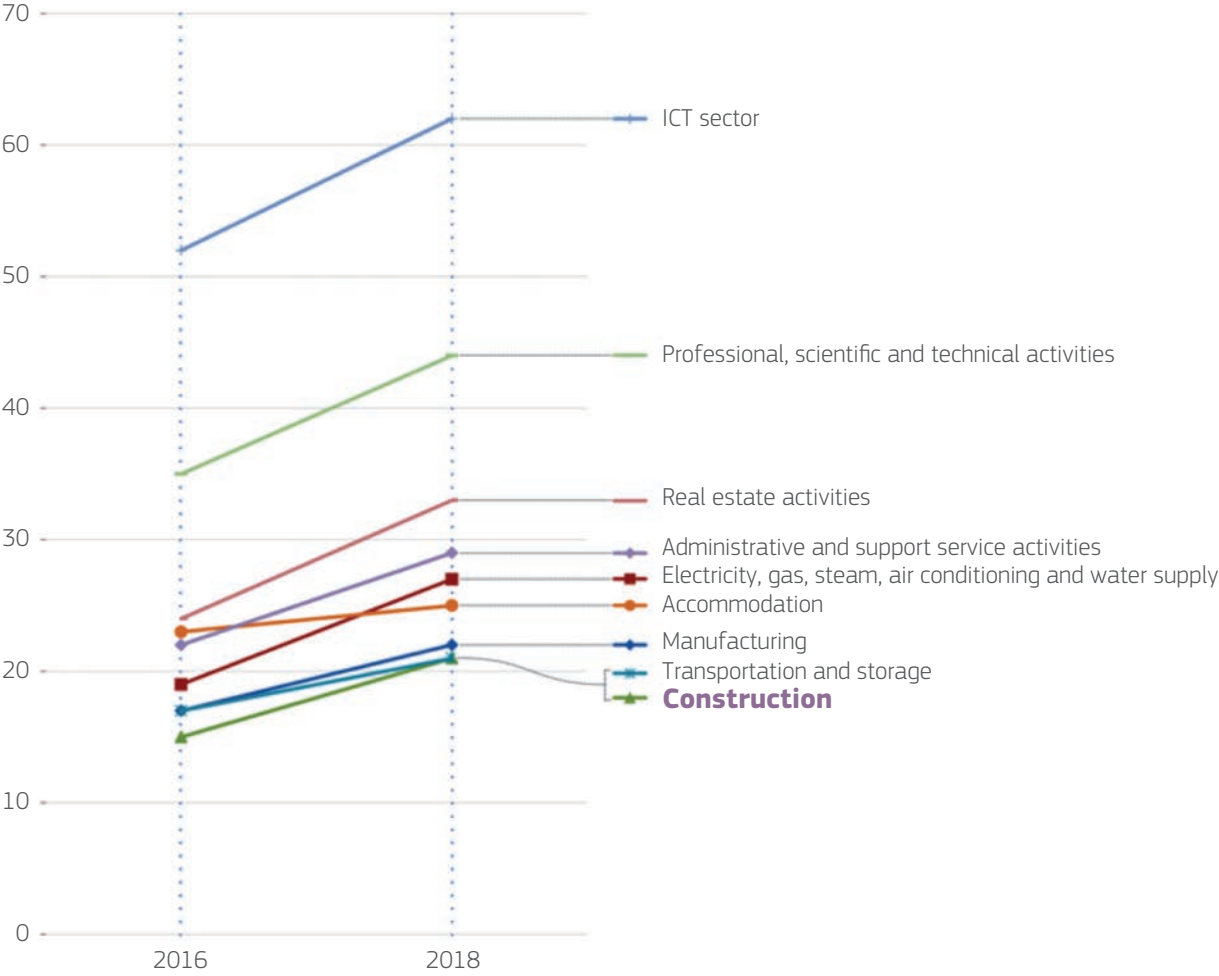
FIGURE 3.15: PERCENTAGE OF EU28 ENTERPRISES BUYING CLOUD SERVICES USED OVER THE INTERNET, BY SECTOR FOR THE YEARS 2016 AND 2018.
Source: JRC analysis based on Eurostat data.

Concerning the adoption of smart devices, the Commission has pushed the agenda to fostering the sharing and re-use of data by companies operating in the field of smart living environments (European Commission and EVERIS Benelux, 2018). In cooperation with the industry and the European Telecommunications Standards Institute (ETSI), in 2015 the Commission developed a European standard for smart appliances, the *Smart Appliances REFerence* ontology (SAREF) (European Commission, 2015), which

enables home devices to communicate in a standardised language, thereby making data exchange by companies more feasible.

The advent of cloud-based solutions, where data are transferred and stored on remote servers often located outside the EU and controlled by non EU entities, has raised concerns over the legitimacy and opportunity of these IT architectures, particularly considering the

increasing adoption of such IT systems (see Figure 3.15). For example, in considering BIM solutions, the architectural and technological details of projects for critical buildings and infrastructures (e.g. needing confidentiality) could be stored on remote server where the access control cannot be ensured by the data owner consequently increasing the risk of information disclosure.

3.2.3. Innovation, Business models, and Skills

Due to the complexity of the Construction Sector—which involves a significant number of stakeholders, contractors, and suppliers—the improvement based on the digital transformation of the processes can only be fully achieved if new technologies and data standardization are widely adopted.

As reported in the European Construction Monitor report (Deloitte, 2017), despite construction companies having an overall understanding that the adoption of digital technologies is crucial for the future of the business, only a few companies have really integrated digital construction approaches into their business.

Advances made by other industries already testify to the benefit of digitalisation in productivity with significant improvements in manufacturing. Conversely, productivity in the construction sector has been flat for a long time and is also more recently associated with scarcity of workers due to the diminishing appeal of a sector that was significantly affected by the last economic crisis.
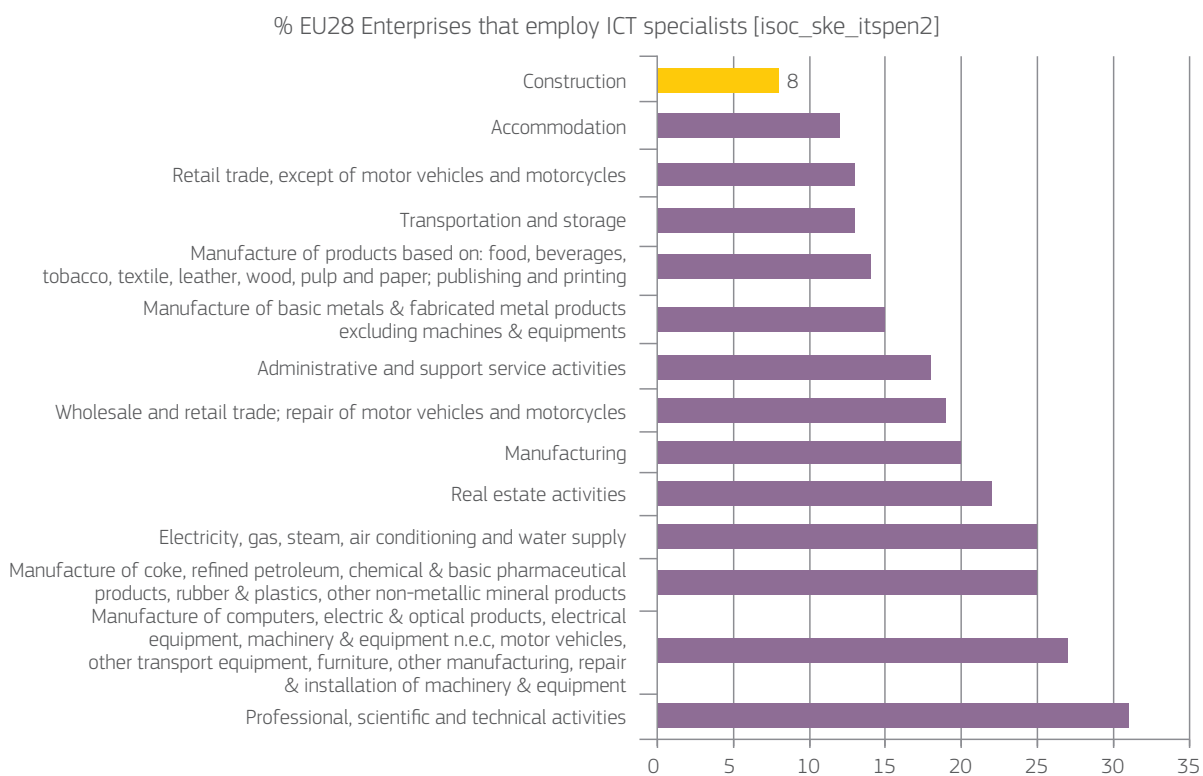
FIGURE 3.16: % OF EU28 ENTERPRISES THAT EMPLOY ICT SPECIALISTS (SOURCE EUROSTAT).
Source: Eurostat[118].

Large Companies are already benefitting from the implementation of ICT based tools and procedures, designs, and planning, but the advantage is limited by the lack of integration between all of the processes.

The number of IT employees in the AEC Sector is one of the lowest among European industries (Figure 3.16), and the recruiting of ICT specialists is also increasing slightly (Figure 3.17), consequently preventing rapid transformation and

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[118] http://appsso.eurostat.ec.europa.eu/nui/show.do?query=BOOKMARK_DS-284229_QID_-3110BAA5_UID_-3F171EB0&layout=TIME,C,X,0;SIZ EN_R2,L,Y,0;UNIT,L,Z,0;GEO,L,Z,1;INDICATORS,C,Z,2;&zSelection=DS-284229GEO,EU28;DS-284229INDICATORS,OBS_FLAG;DS-284229UNIT,PC_ ENT;&rankNa

adoption of IT tools. Although this trend is changing in the major construction corporates, AEC is composed of many SMEs and smaller contractors with low margins who cannot invest in new specialized personnel dedicated to IT innovation. Therefore, the business organisation is not structured towards homogeneous adoption of digital technologies.

If we consider the advantage of data availability across the whole construction process, many of the potential improvements are compromised by unavailable or not synchronised information. Data integration between designers, suppliers, and construction companies is lacking and leads to inefficiency and low productivity.

> " *The number of IT employees in the AEC Sector is one of the lowest among European industries* "

Enterprises that recruited or tried to recruit ICT specialists (10 persons employed or more)

% of Enterprises

Professional, scientific and technical activities

Manufacture of computers, electric & optical products

Electricity, gas, steam, air conditioning and water supply

Real estate
Administrative and support service activities

Wholesale and retrail trade (motor vehicles)
Manufacturing

Retail trade, except for motor vehicles and motorcycles

Transportation and storage

Accommodation

Construction

FIGURE 3.17: EU28 ENTERPRISES THAT RECRUITED OR TRIED TO RECRUIT PERSONNEL FOR JOBS REQUIRING ICT SPECIALIST SKILLS (ICT SECTOR NOT CONSIDERED).
Source: Eurostat data.

Training plays a fundamental role and the change in the AEC must be supported by universities in developing a new generation of architects, engineers, and construction professionals with a background in the new technologies to fulfil the increasing demand from the AEC sector.

If the building information modelling (BIM) is widely considered to be a tool to revolutionize and integrate the AEC sector, the unavailability of BIM professionals is preventing its widespread embracing.

A drive for the adoption of BIM in the European Construction Sector has been made by the EU Commission with several initiatives in the Digital Single Market Strategy to foster the adoption of digital technologies to improve key industries. The *EU BIM Taskgroup*[119] was organized to provide a common European network to promote and harmonize the adoption and use of Building Information Modelling in public works. However, common digital platforms[120] and

standardization as well as updated requirements in call for tenders still need to be developed.

The digital transformation of the AEC sector is also key to the successful adoption of new construction technologies such as automation and the introduction of robots and drones. 3D printing is a rapidly evolving technology that is very reliant on digital models and IT but these technologies should also be integrated in the data pipeline.

Attempts in the past to invest in the digital transformation and automation of the construction sector have led to many failures and financial losses. One of the reasons lies in the incompatible customised processes that make repeated and standardized production in the construction sector impossible in contrast to those from other industries like the automotive sector where automation is already well established.

3.3 | Impacts of Digital Transformation on Construction

3.3.1. Economic impacts

Improving the limited productivity in the AEC (Figure 3.9) is crucial for the future of companies operating in the construction sector, and better performance and increased economic margins will be achieved by the integrated adoption and implementation of digital technologies in every step of the construction value chain.

Increased productivity can promote the sector's competitiveness with positive consequences on price reduction and investment in research and development, promoting a cycle of positive feedback to better construction. At the same time, the adoption of new technologies can become an element of attracting a new labour force.

Digital technologies are already seen as a strategic means for new business opportunity by so-called 'constructech' companies capable of exploiting their IT knowledge to

challenge the market share of traditional AEC companies. New solutions can be imported into the more traditional AEC from different sectors. This is a threat to the traditional business model that is being profoundly transformed by new players entering the market. The economic downturn affected investment in adoption of new technologies by construction companies (Deloitte, 2017) leaving the sector exposed to the growing interest of external IT-oriented companies who are looking at this sector as an interesting novel business opportunity.

The AEC is a key sector that accounts for nearly 10% of the 9% of the EU's gross domestic product and a considerable number of companies. Even small improvements in efficiency and productivity will lead to significant savings and have an impact. According to the 2016 BCG Report (Gerbert, et al., March 2016) full-scale digitalisation in the AEC sector within ten years will lead to annual global

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Full Digitalisation of non residential construction sector: Expected annual savings

€ 0.44 T

10 to 17%

Operation Phase

€ 1.06 T

13 to 21%

Construction Phase

total spending
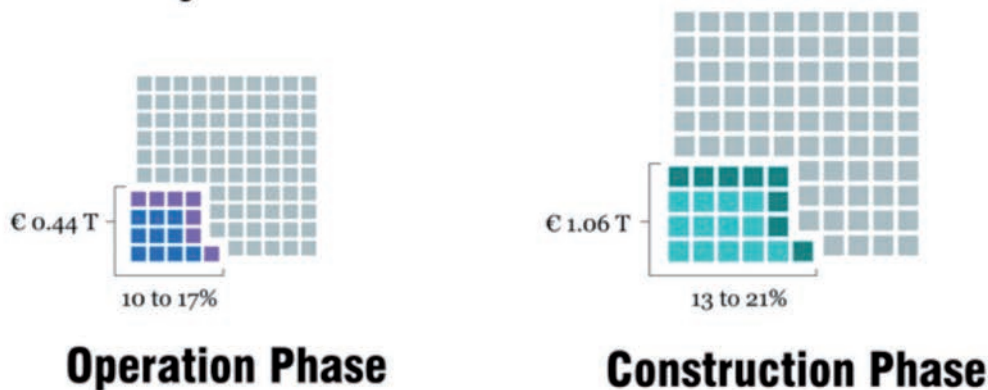
savings

Source data: BCG Group

FIGURE 3.18: ESTIMATED WORLD ANNUAL SAVINGS IN THE NON-RESIDENTIAL CONSTRUCTION SECTOR FROM FULL DIGITALISATION.
Source: BCG.

savings[121] (see Figure 3.18) in the various phases of non-residential construction up to:

- **Engineering and Construction**: €0.62 T to €1.06 T (13% to 21%)
- **Operations:** €0.26 T to €0.44 T (10% to 17%)

In 2016 Oxford Economics[122] ran a survey on the economic impact of digital transformation in the UK industrial sector, including the construction sector, from which summary results are shown in Figure 3.19).

Digitalisation of the industrial sector is therefore beneficial, and by way of example these figures could have an even bigger impact in the construction sector which has a much lower digitalisation index as a starting point.

Among new digital transformations that might disrupt the construction sector, new means of funding such as the *Initial Coin Offering (ICO)* might play a central role. ICOs are similar to start-ups IPOs but traders buy tradable tokens instead of company shares. This is a novel way for companies to raise capital through the sale of

Industries	Industries that have been subject to significant disruption from digital technologies in the past three years.	20%
Revenues	Revenue growth related to digital capacity in the last year (£m).	15.631 (highest increase 6%)
Jobs	Digital's impact on jobs in the UK by industry	▲ new 70k ▽ lost 24k (4% increase)
Increment	Potential increase in revenue (£m) by industry, after reaching full digital capabilities.	3.2%

FIGURE 3.19: ECONOMIC IMPACT OF DIGITAL TRANSFORMATION IN THE UK INDUSTRIAL SECTOR.
Source: Oxford Economics.

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121 Global savings converted from US dollars to Euros.
122 https://www.oxfordeconomics.com/recent-releases/the-UKs-digital-opportunity

cryptocurrency. The introduction of *BUILDCoin*, the world's first digital currency built specifically for the construction industry, is considered by Entrepreneur Europe[123] to be among the *top 14 Blockchain Companies to Watch in 2018*. It will hit a sector of approximately 100 million workers and worth $8 trillion USD. The impact (and the increase) of ICOs 2016-2107 is shown in the graph in Figure 3.20 below.

A notable example of the adoption of ICO in the public sector is from the state of Sao Paulo in Brazil. The administration funded feasibility studies for municipal lighting and public security projects using cryptocurrency through the aforementioned *BuildCoin* foundation (BuildCoin Foundation, 2018). The *Llumina SP* project is the first cryptocurrency-funded feasibility study that takes a series of advantages from the novel funding approach such as being able to access a world network of experts, motivating participation with novel ideas, and reducing project risks and costs. This novel approach, together with the digitalisation of the design process supported by BIM, opens the way to a more dynamic and competitive market for consultancy and design firms and professionals on a global scale.
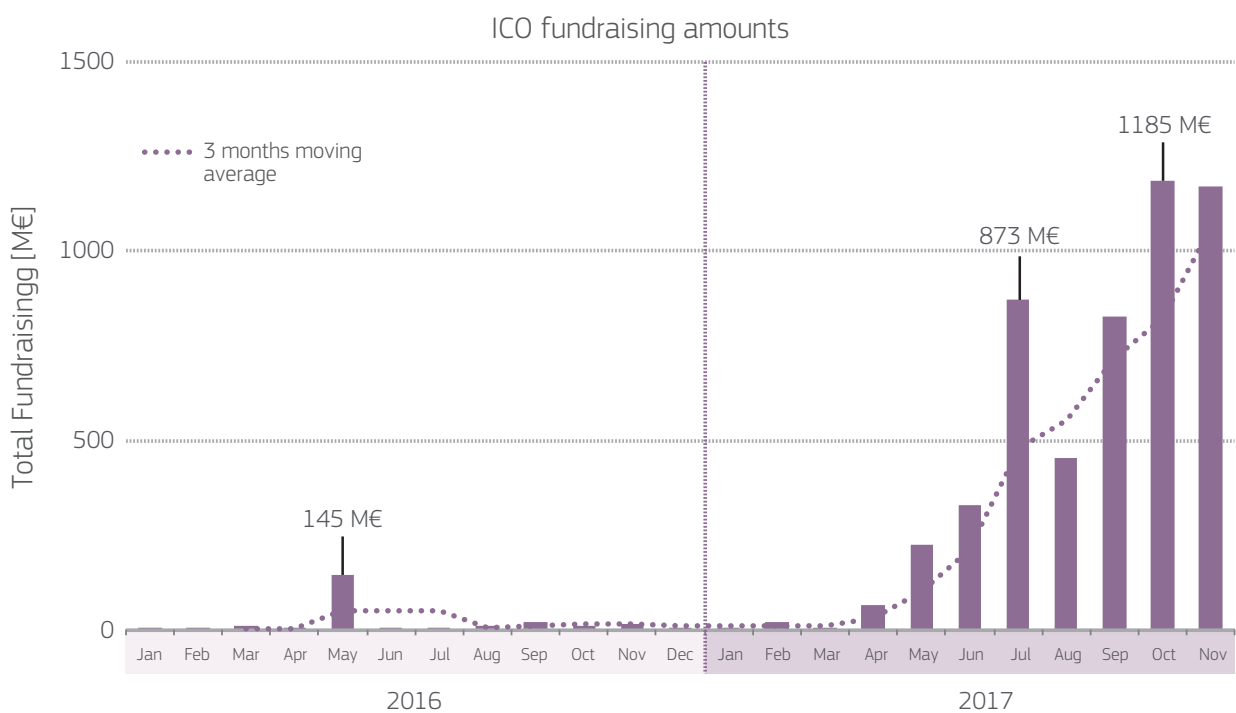
FIGURE 3.20: ICO FUNDRAISING AMOUNTS 2016-2017 BY MONTH.
Source: data from https://elementus.io/blog/token-sales-visualization/

Another threat (or opportunity) to the traditional pipeline business model of the Construction Sector is posed by the Digital Platform business. These platforms are already disrupting many other economic sectors such as energy, mobility (*Uber, BlaBlaCar*), logistics (online booking platforms for shipping containers), agriculture, and consumer goods (*Amazon*). Digital Platforms minimize the transaction costs, offer algorithms and data analysis to set economic and organizational strategies, and have nearly no scaling cost and are able to aggregate non-organized markets.

The following factors contribute to the exposure and vulnerability of the construction sector to the advent of new business models based on digital transformations:

- high rate of outsourcing
- economical volatility
- fragmented supply chain
- business relying on lowest offers in financial bids
- advantages of digital platforms in exploiting the network effect of a multi-sided market

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[123] https://www.entrepreneur.com/article/308558

Moreover, the advent of BIM further increases the role of digitalisation of the construction sector but the business model is still conventional and relies on traditional companies (main contractors) outsourcing activities beyond the scope of their main business to sub-contractors and materials suppliers. Considering that in the past 25 years only a few changes have been observed in the project management approach of construction projects, the opportunity for the development of novel business models is high (Alhava, et al., 2017).

3.3.2. Digital start-ups in the Engineering and Construction sector

The most essential elements of a modern economy are to create, exploit, and market new technologies. Digital entrepreneurs and start-ups are one of the main vehicles by which digital affordances are converted into economic benefits. Digital start-ups are more likely than existing businesses to pursue opportunities associated with radical innovations that may have transformative consequences for society and the economy. Indeed, the last two decades of the digital transformation has shown that such newcomers as *Skype, Uber,* or *Airbnb* quickly disrupted traditional industries. Until now, the AEC sector has neither attracted many digital entrepreneurs nor large Venture Capital investments. This situation is changing. For example, among one of the new unicorns[124] last year was *Procore Technologies*, a provider of cloud-based construction management software.[125] Founded in 2003, the firm is currently valued at $3 Bln USD and employs approximately 1,400 people.

Considering their key role in the digital transformation, this section looks at the global activities of digital start-ups in the AEC sector in the period between 2000 and 2017. It uses Venture Source by Dow Jones as a source of data for global venture capital (VC) activity and VC-backed start-ups. In order to identify digital start-ups targeting the AEC sector, two sets of companies were identified based on the description of their activity:

- **Digital start-ups in the AEC sector**: this set includes start-ups in the AEC sector whose description of activity includes any digital-related keyword.[126]

- **Digital start-ups providing applications to the AEC sector**: this set includes start-ups in the digital sector whose description of activity includes any AEC-related keyword.[127]

Figure 3.21a presents the total number of AEC start-ups and the percentage of digital start-ups in the AEC sector that received VC funding between 2000 and 2017. Out of 1210 AEC start-ups, 166 or nearly 14% can be considered to be digital start-ups. The figure shows that following the last economic crisis the number of VC-backed AEC start-ups decreased considerably. However, at the same time the share of digital AEC start-ups increased. In 2017, 60% of AEC start-ups were digital start-ups.

The most common activities of digital AEC start-ups include Environmental Engineering/Services (32%), Specialty Trade Contractors (11%), and activities related to Building Materials and Construction Machinery (7%) (Figure 3.22).

Figure 3.21b shows the total number of digital start-ups and the percentage of digital start-ups that provide applications to the AEC sector which received VC funding between 2000 and 2017. Out of 22548 digital start-ups, 302 developed and provided ICT applications targeting the AEC sector. The number and share of digital start-ups supplying applications to the AEC sector has trended upwards. In 2017, approximately 2% of all digital start-ups developed and supplied digital applications to the AEC sector.

The most common applications provided by digital start-ups to the AEC sector include "business application software", "consumer electronics", and "vertical market application software" (see Figure 3.23).
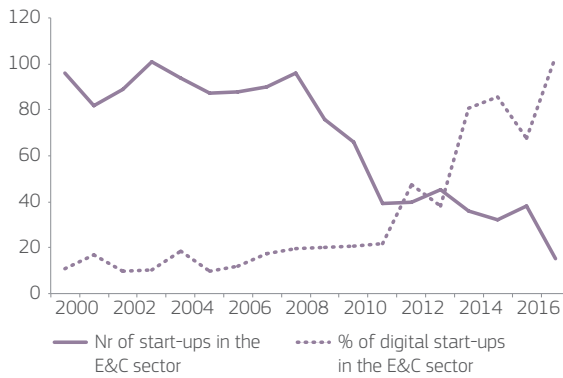
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[124]   A tech startup company that reaches a $1 billion dollar market.
[125]   See: https://www.businessinsider.com/tech-startups-unicorns-2018-full-list-2018-11?r=US&IR=T#8-plaid-40
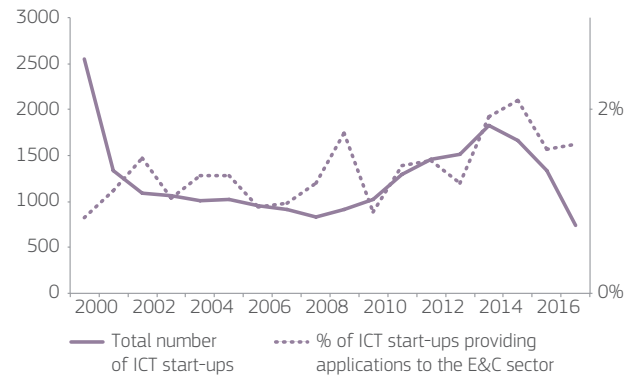[126]   For the full list of keywords, see Appendix A.
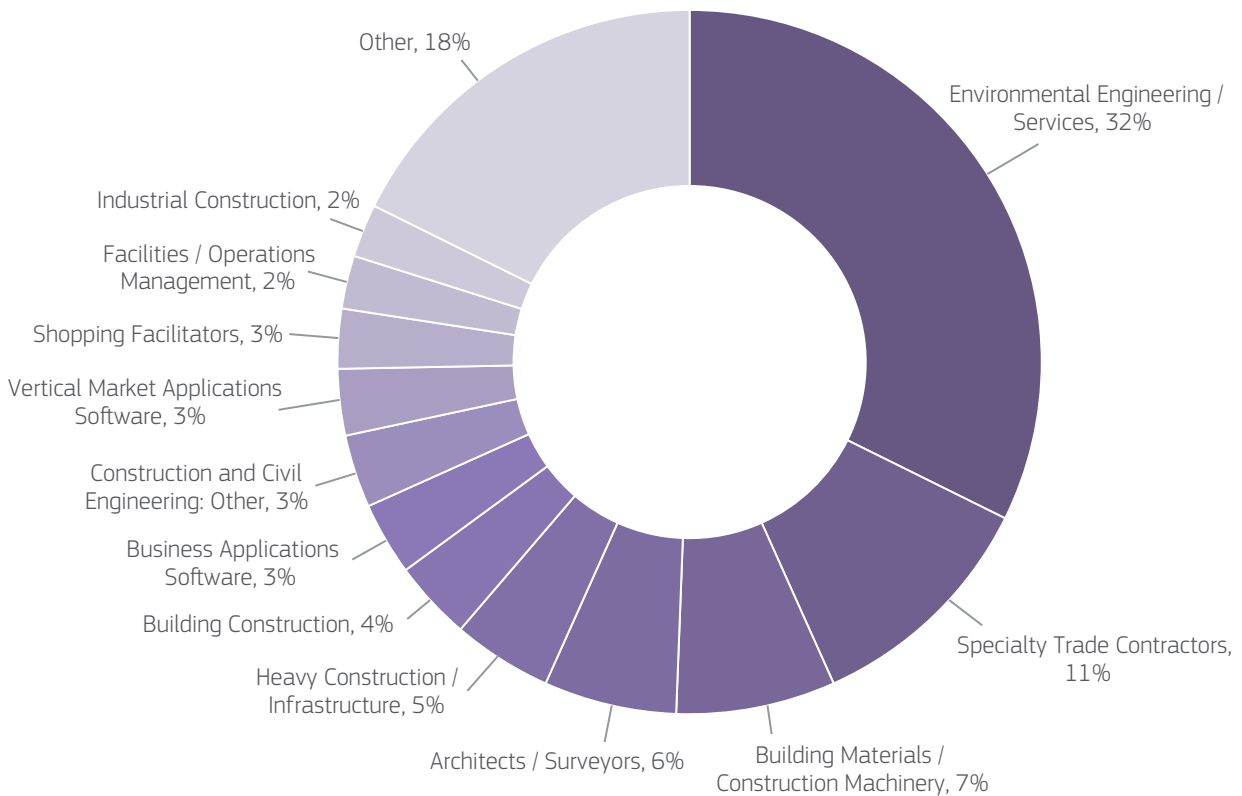[127]   For the full list of keywords, see Appendix B.

A) Total number of AEC start-ups and % of digital start-ups in the AEC sector

B) Total number of digital start-ups and percentage of digital start-ups providing applications to the AEC sector
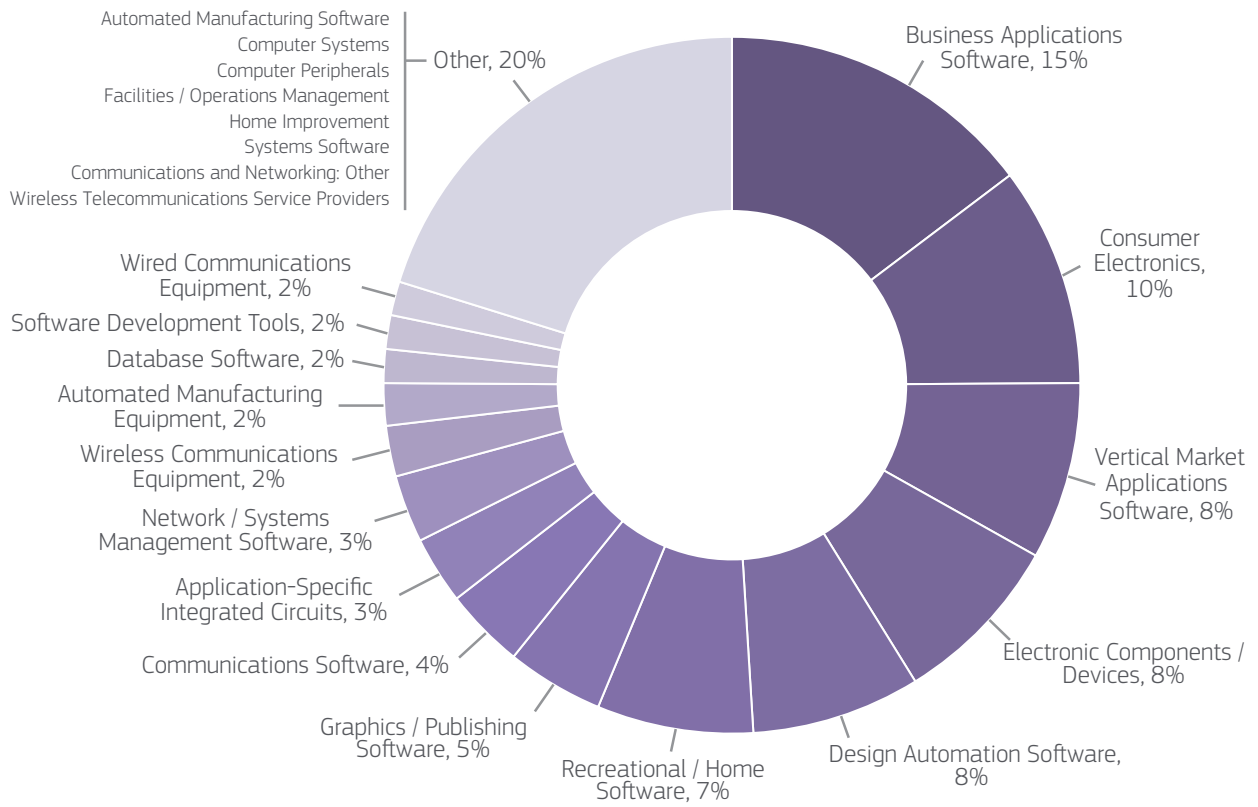

— Nr of start-ups in the E&C sector ···· % of digital start-ups in the E&C sector

— Total number of ICT start-ups ···· % of ICT start-ups providing applications to the E&C sector

FIGURE 3.21: GLOBAL OVERVIEW OF DIGITAL START-UPS IN THE AEC SECTOR AND THEIR ACTIVITY 2000-2017.
Source: JRC analysis based on Venture Source, Dow Jones data.

Other, 18%
Industrial Construction, 2%
Facilities / Operations Management, 2%
Shopping Facilitators, 3%
Vertical Market Applications Software, 3%
Construction and Civil Engineering: Other, 3%
Business Applications Software, 3%
Building Construction, 4%
Heavy Construction / Infrastructure, 5%
Architects / Surveyors, 6%
Building Materials / Construction Machinery, 7%
Specialty Trade Contractors, 11%
Environmental Engineering / Services, 32%

FIGURE 3.22: GLOBAL OVERVIEW OF DIGITAL START-UPS IN THE AEC SECTOR AND THEIR ACTIVITY 2000-2017: AREA OF ACTIVITY OF DIGITAL START-UPS IN THE AEC SECTOR.
Source: JRC analysis based on Venture Source, Dow Jones data.

Figure 3.24 displays the amounts of VC investment in digital start-ups in the AEC sector by world regions between 2007 and 2017. The picture reveals that US start-ups received the highest amount of VC investments, i.e., over €1.1 Bln. Second in the ranking is China. VC funds invested in Chinese digital start-ups in the AEC sector totalled nearly €0.7 Bln. This represents 36% of global VC investments in this domain. Through the last decade, European digital start-ups received nearly €71 Mln or 4% of global VC investment in digital start-ups in the AEC sector. These investments in Europe are mainly concentrated in France, the United Kingdom, Germany, and Sweden.

FIGURE 3.23: GLOBAL OVERVIEW OF DIGITAL START-UPS IN THE AEC SECTOR AND THEIR ACTIVITY 2000-2017: TYPE OF APPLICATIONS PROVIDED BY DIGITAL START-UPS TO THE AEC SECTOR.

Source: JRC analysis based on Venture Source, Dow Jones data.
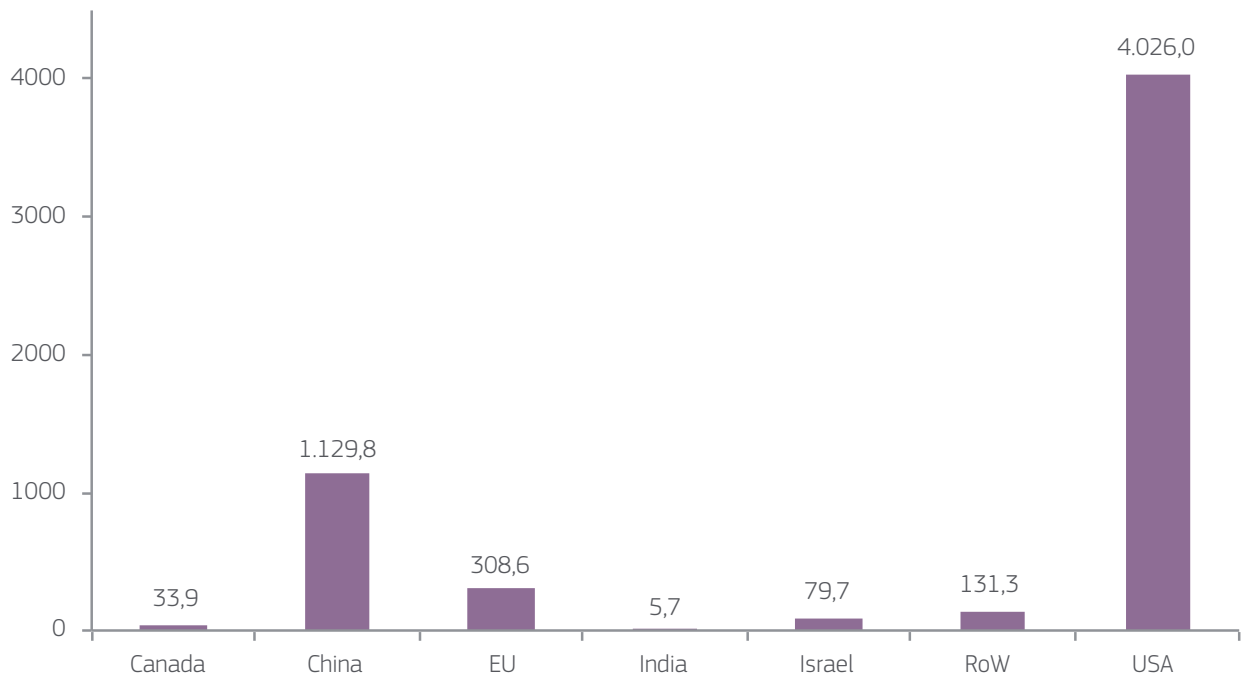
FIGURE 3.24: VC INVESTMENTS IN DIGITAL AEC START-UPS BY REGION 2000-2017 IN M€.

Source: JRC analysis based on Venture Source, Dow Jones data.

In conclusion, the following conclusions can be drawn from the analysis of digital start-ups in the AEC sector:

- While the total number of VC-backed start-ups in the AEC sector has been constantly decreasing since 2000, the share of digital start-ups has increased. This indicates that Digital Transformation is increasingly visible in this sector.

- The most common activities of digital start-ups in the AEC sector include Environmental Engineering/ Services, Specialty Trade Contractors, and Building

Materials and Construction Machinery. Digital applications addressing the needs of the AEC sector include business application software, consumer electronics, and vertical market application software.

- The US and China together attract nearly 95% of global VC investments in digital start-ups in the AEC sector. In the last ten years, start-ups based in Europe received only 4% of the global VC investments in start-up activity related to the digitalisation of the AEC sector.

3.3.3. Platform Business Models

One potential game-changer to the traditional business model in the construction sector are the opportunities provided by internet-based applications (similarly to those disruptions in the retail sector caused by well-known online technology companies), inducing the movement of traditional business in other sectors from physical stores to the web.

A *platform business model* is an intermediation service that uses technology, algorithms, and data to improve the matching service between different users. For instance, in the case of construction, one group of users could be construction materials firms and the other could be sub-contractors. Platforms work as marketplaces where users can find good matches (clients or providers, depending on the case) for their products/services.

For example, *Equipmentshare*[128] adopts a sharing economy approach analogous to *AirBnB* which provides a marketplace for affordable construction equipment rentals i.e., offer (owners) and demand (renters) meet online. Other European examples from major platform-based companies for the AEC sector include on line applications for the management of construction processes, apps to share information within the construction value chain, and marketing solution for real estate programs to ease the client customization process. Figure 3.25 reports some of the major European companies with the corresponding value of VC.
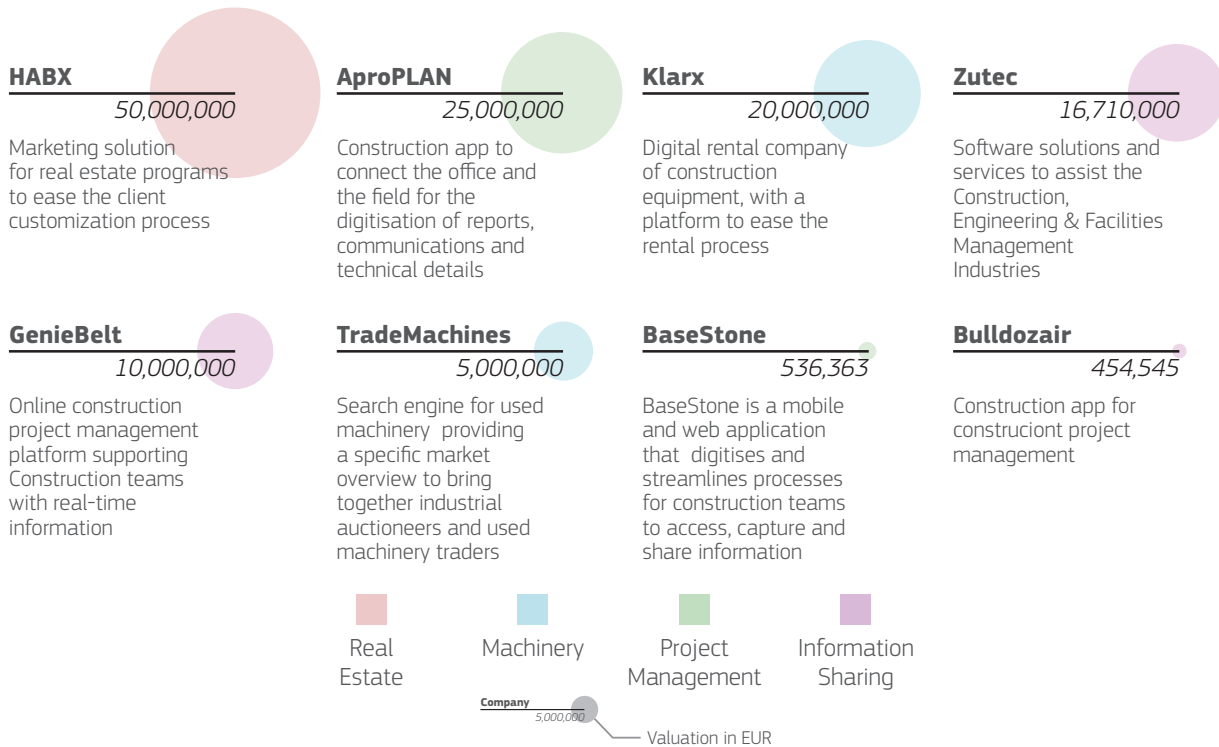
In order to identify potentially disruptive internet-based business models in the construction sector, data from the *Dealroom* database of companies has been analysed

> *Internet-based applications and digital platform business models are potential game-changers in the construction sector*

resulting in the identification of 108 firms operating in the construction sector (excluding Real Estate activities – another 523) that have adopted a *platform business model*.

This number represents a share of 0.4% of the total number of platforms included in the database studied. As panel *A* in Figure 3.26 shows, the majority of platforms in this sector started to appear around 2010, which were in effect delayed with respect to early-adopters in retail and media that started to appear in the early nineties. The increasing trend is clearly defined, indicating that albeit with significant delay and resistance, changes are also beginning to affect this sector. The majority of platforms headquarters are located in the USA and Canada, and 21 of them – representing some 20% – are located in Europe (Panel *B*).

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[128]   www.equipmentshare.com

HABX
50,000,000

Marketing solution for real estate programs to ease the client customization process

AproPLAN
25,000,000

Construction app to connect the office and the field for the digitisation of reports, communications and technical details

Klarx
20,000,000

Digital rental company of construction equipment, with a platform to ease the rental process

Zutec
16,710,000

Software solutions and services to assist the Construction, Engineering & Facilities Management Industries

GenieBelt
10,000,000

Online construction project management platform supporting Construction teams with real-time information

TradeMachines
5,000,000

Search engine for used machinery providing a specific market overview to bring together industrial auctioneers and used machinery traders

BaseStone
536,363

BaseStone is a mobile and web application that digitises and streamlines processes for construction teams to access, capture and share information

Bulldozair
454,545

Construction app for construciont project management

Real Estate   Machinery   Project Management   Information Sharing

Company — 5,000,000 — Valuation in EUR

FIGURE 3.25: MAJOR EUROPEAN PLATFORMS WITH VALUATION IN EUROS.
Source: JRC analysis, based on Dealroom data.
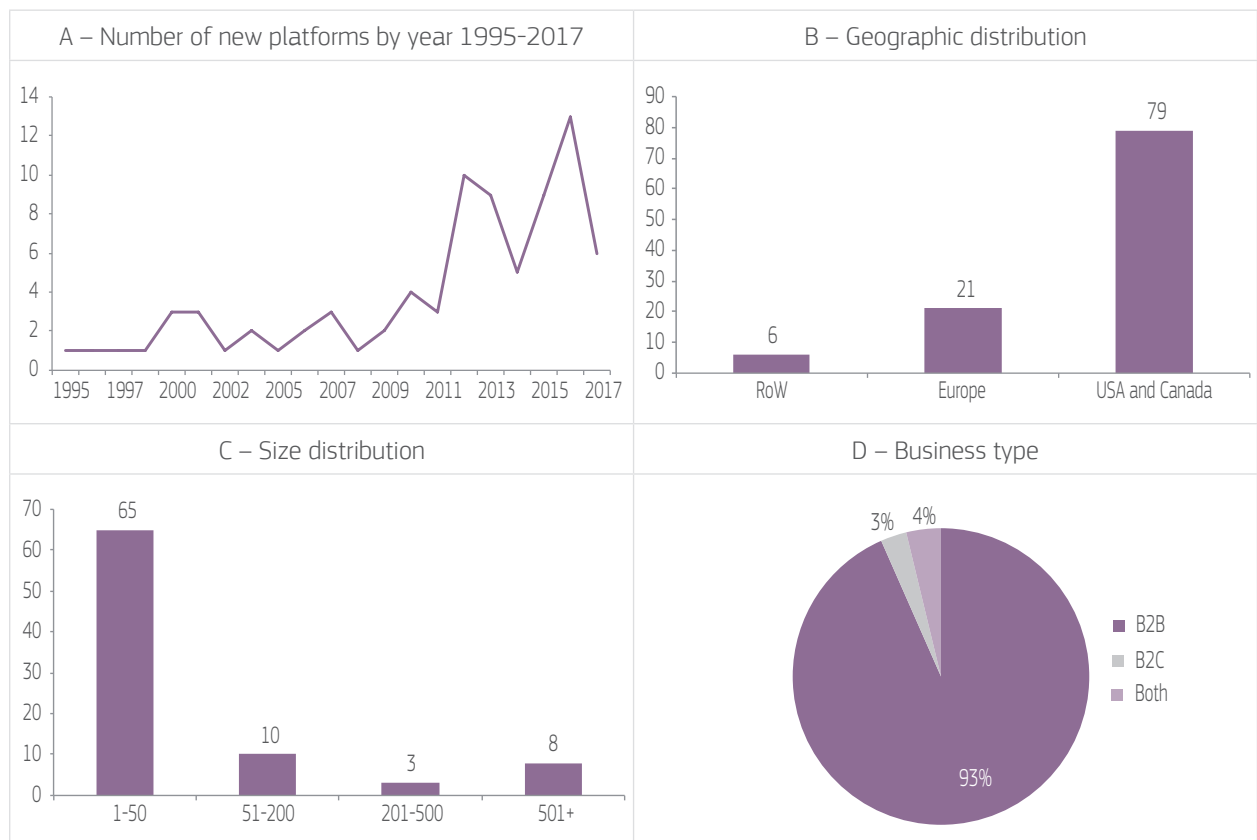
FIGURE 3.26: NUMBER AND CHARACTERISTICS OF PLATFORMS IN THE CONSTRUCTION INDUSTRY.
Note: the number of platforms shown does not always sum to 108 due to some companies not reporting information.
Source: JRC analysis based on data from *Dealroom.co.*

The great majority of *platforms* in the construction industry are still in early phases of growth and this is also reflected by their size. Consequently, most of them have between 1 and 50 employees, although some of them seem to have already reached some degree of maturity and are employing more than 500 employees. Finally, the vast majority of construction platforms operate in the B2B dimension – Panel D – meaning that they mainly focus on favouring the exchange of products, services, or information between businesses.

3.3.4. Innovation, Business Models, and Skills

3.3.4.1. Territorial aspects: Contribution of Digital Innovation Hubs to Digital Transformation in the Construction Sector

Digital Innovation Hubs (DIH) in MS and their regions are contributing to the digital transformation of enterprises in many sectors. When it comes to the construction sector (and selecting "Construction" in the online DIH catalogue of the S3P[129]), 89 fully operational DIHs in EU28 countries state that they offer digitisation services to companies and contribute to the digital transformation process in the construction sector[130]. Their geographical distribution can be visualised on the online Catalogue's map.

Country distribution of Fully Operational DIHs in Construction

The country distribution of the above-mentioned 89 DIHs that provide digitalisation services in the construction sector are distributed by EU country as shown in the following Figure 3.27:
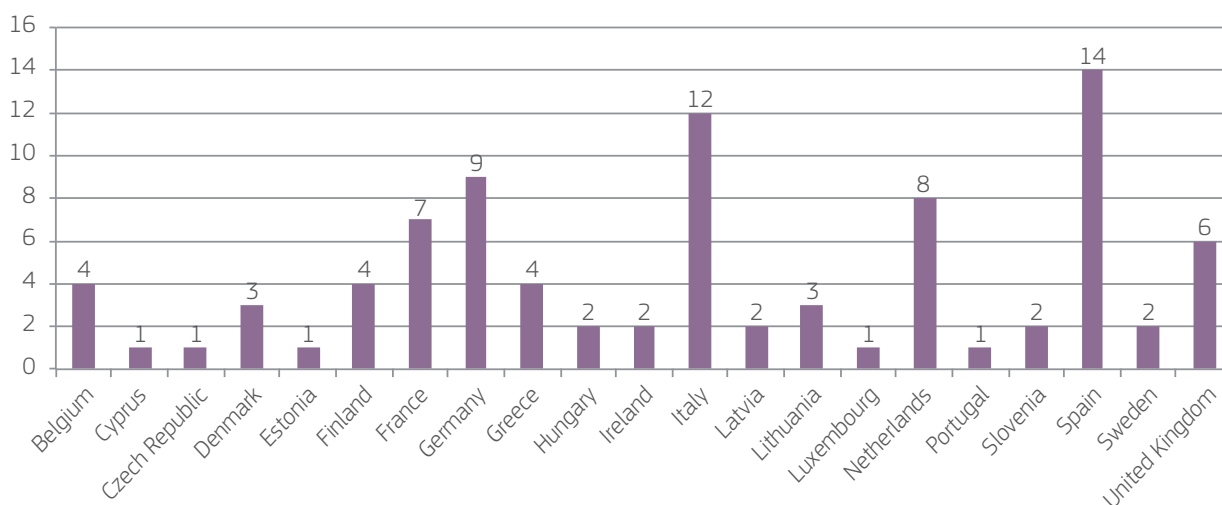
FIGURE 3.27: NUMBER OF DIHS SPECIALISING IN THE CONSTRUCTION SECTOR BY EU COUNTRY.
Source: JRC analysis.

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[129] http://s3platform.jrc.ec.europa.eu/digital-innovation-hubs-tool
[130] **Disclaimer**: The DIH Catalogue website is a "yellow pages" of Digital Innovation Hubs. The information provided about each entry is based on self-declaration. The European Commission cannot take any responsibility for the provided information. Currently all the entries in the catalogue are being verified (based on the provided information) if they comply with the following four criteria:
1. Be part of a regional, national, or European policy initiative to digitise the industry;
2. Be a non-profit organisation;
3. Have a physical presence in the region and present an updated website clearly explaining the DIHs' activities and services provided for the digital transformation of SMEs/Midcaps or industrial sectors currently lagging behind in taking up digital technologies;
4. Have at least 3 examples of how the DIH has helped a company with their digital transformation, referring to publicly available information, for each company identifying: Client profile; Client need; Solution provided to meet the needs.
The purpose of the catalogue is to support the networking of Digital Innovation Hubs and to provide an overview of the landscape of Digital Innovation Hubs in Europe supported by regional, national, and European initiatives for the digitisation of industry. There is no relationship between being present in the catalogue and being able to receive funding from the European Commission.

The DIHs identified possess a number of technical competences and offer a range of services to businesses in the construction sector. The following paragraphs provide information on the frequency of technical competences and the range of services provided.
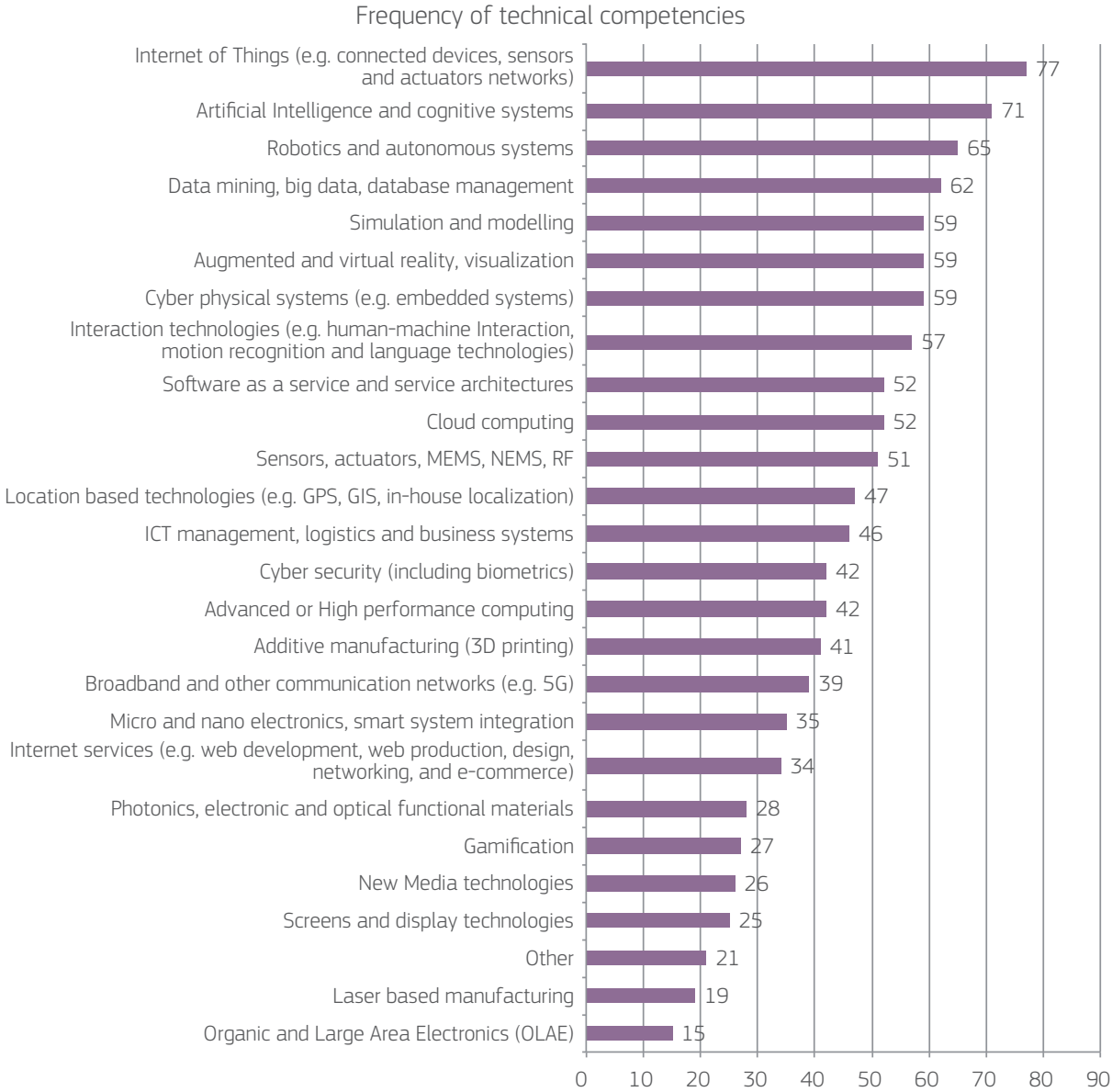
- Internet of Things (e.g. connected devices, sensors, and actuator networks)
- Artificial Intelligence and cognitive systems
- Robotics and autonomous systems
- Data mining, big data, database management
- Simulation and modelling

Frequency of technical competences of Fully Operational DIHs in Construction ("Construction")

The most frequent technical competences declared by DIHs in the construction sector are the following:

The services most frequently offered in Construction by Fully Operational DIHs

There is a broad range of services provided by DIHs depending on their capacities and also on the level of maturity of SMEs in their process of digital transformation.

Frequency of technical competencies

Technical competency	Frequency
Internet of Things (e.g. connected devices, sensors and actuators networks)	77
Artificial Intelligence and cognitive systems	71
Robotics and autonomous systems	65
Data mining, big data, database management	62
Simulation and modelling	59
Augmented and virtual reality, visualization	59
Cyber physical systems (e.g. embedded systems)	59
Interaction technologies (e.g. human-machine Interaction, motion recognition and language technologies)	57
Software as a service and service architectures	52
Cloud computing	52
Sensors, actuators, MEMS, NEMS, RF	51
Location based technologies (e.g. GPS, GIS, in-house localization)	47
ICT management, logistics and business systems	46
Cyber security (including biometrics)	42
Advanced or High performance computing	42
Additive manufacturing (3D printing)	41
Broadband and other communication networks (e.g. 5G)	39
Micro and nano electronics, smart system integration	35
Internet services (e.g. web development, web production, design, networking, and e-commerce)	34
Photonics, electronic and optical functional materials	28
Gamification	27
New Media technologies	26
Screens and display technologies	25
Other	21
Laser based manufacturing	19
Organic and Large Area Electronics (OLAE)	15

FIGURE 3.28: FREQUENCY OF TECHNICAL COMPETENCIES PROVIDED BY DIHS SPECIALISING IN THE CONSTRUCTION SECTOR.
Source: JRC analysis.

The types of services most frequently mentioned by DIHs that provide support to the Construction sector SMEs are the following:

- Ecosystem building, scouting, brokerage, networking
- Collaborative Research
- Concept validation and prototyping
- Awareness creation
- Education and skills development

Frequency of services provided

Service	Value
Ecosystem building, scouting, brokerage, networking	87
Collaborative Researchs	79
Concept validation and prototyping	78
Awareness creation	75
Education and skills development	74
Testing and validation	73
Incubator/accelerator support	65
Visioning and Strategy Development for Businesses	56
Mentoring	50
Access to Funding and Investor Readiness Services	44
Digital Maturity Assessment	42
Market intelligence	39
Voice of the customer, product consortia	32
Pre-competitive series production	31
Commercial infrastructure	29
Other	19

FIGURE 3.29: FREQUENCY OF SERVICES PROVIDED BY DIHS SPECIALISING IN THE CONSTRUCTION SECTOR.
Source: JRC analysis.

Examples of digitalisation services in construction:

DIHs are already contributing in the digital transformation of businesses in the construction sector in Europe and their role will be increasingly important in the future. The following, extracts taken from the EC SMART Specialisation Platform – DIHs are reported as examples of different digitisation services provided by DIHs in different countries to beneficiaries in the construction sector.

I) Embedded System Design & Application Laboratory (Greece)

Source: https://s3platform.jrc.ec.europa.eu/digital-innovation-hubs-tool/-/dih/12382/view

Service example: **Smart Service/System for Predictive Maintenance**

The infrastructure is TOBEA's (https://tobea.gr) SEATRAC, the award winning device that allows disabled persons to have access to the beach and the sea. The service/system developed allows **real time 24/7 monitoring and malfunction prediction** of SEATRAC devices worldwide.

The service and the Decision Support System (DSS) have been based on ATLAS IoT infrastructure (http://atlas.esda-lab.cied.teiwest.gr), which has been developed by Embedded System Design and Application Laboratory (http://esda-lab.cied.teiwest.gr).

Client profile: TOBEA is an SME located in Patra, Greece and its main goal is to develop products to support people with disabilities. More specifically TOBEA has developed SEATRAC, a device that allows people with disabilities to have access to the beaches and the sea. In addition, TOBEA is offering/developing SEATRAC based services for the persons with disabilities e.g. weather and sea conditions, water quality etc.

The client needs: TOBEA has an extended network of SEATRACs across Southern Europe. Given the harsh environment in which SECTRAC operates (near the sea, in sandy & windy beaches), malfunctions and failures on the technical equipment are quite often. Given the extended network of SDEATRACs, identifying correcting failures was a big problem for TOBEA! Failures were mainly identified by the end users (which are disabled people going at the sea), which had the following negative results for TOBEA: (1) they had unsatisfied customers and (2) similar failure happened ad hoc in different geographical places, resulting in increased maintenance cost.

The solution: In collaboration with TOBEA, ESDA Lab has developed a novel system that allows **monitoring in real time and predictive maintenance** of SETRACs worldwide. SEATRACs have been equipped with **sensors** and have been connected using ESDA Lab's ATLAS infrastructure (http://esda-lab.cied.teiwest.gr/index.php/en/research-developement-en/research-platforms) of ESDA Lab that allows TOBEA to have a clear view day by day of the conditions of all SEATRAC installations. In addition, **AI based algorithms** have been developed in order to allow TOBEA to predict failures and malfunctions before they actually happen. The system is fully operational for almost a year and, according to TOBEA, it has allowed the non-stop operation of SEATRACs with a 60% reduction of maintenance costs.

The service/system is privately funded and it has been developed for the SME TOBEA Ltd (https://tobea.gr).

More details: https://tobea.gr

Source: http://s3platform.jrc.ec.europa.eu/digital-innovation-hubs-tool/-/dih/1555/view

Service example: **Robotics for Maintenance and Inspection of Civil Infrastructures**

- **Service(s) provided:** Conceptual design and testing of robotic solutions for maintenance and inspection tasks in highways, tunnels, buildings, shafts, service galleries, etc. Improvement of the robotic cycle time and quality of the products. Technological consultation on how to introduce *collaborative robots* and *artificial vision* in the industry.

- The relation with digitization Digital infrastructures' services.

Name customer, contact details: BOSCH.

Other collaborations such as Egnatia Odos highway (Greece), London tube (UK) and HUNOSA (Spain).

More details:
http://www.badger-robotics.eu/,
http://www.robo-spect.eu/,
http://indires.eu/,
https://stams-rfcs.eu/

Source: http://s3platform.jrc.ec.europa.eu/digital-innovation-hubs-tool/-/dih/1876/view

Service example: **Ecosystem Development**

Service provided: DIGIHALL offers ecosystem development services for companies of all sizes that wish to engage with the Digital Innovation Hub. The DIH includes several **open innovation platforms that can be used by SMEs to share infrastructures and pool resources**, but also to engage with customers and suppliers around innovation projects. Examples of these platforms are:

— FactoryLab
— Additive Factory Hub
— FFLOR

An example of a company that has benefitted from this service is RB3D, a French robotics SME. By joining FactoryLab, RB3D has opened up new applications and market sectors for its innovative solutions by engaging with major industry partners in the aeronautics, naval, automotive, and oil and gas sectors, developing new products and increasing turnover.

In addition to several not-for-profit DIHs in various parts of Europe, industry is also investing in commercial oriented DIHs to speed up innovation in this sector.

3.3.5. Social impacts

The DT of the construction sector is an urgent and long awaited change, as highlighted in (European Commission, 2012), primarily to improve and provide advantages like those already seen in other sectors such as manufacturing.

3.3.5.1. *Employment and digital transformation in the construction sector*

In 2015, the construction sector provided jobs for nearly 12.3 million Europeans and generated more than €500 Bln of value added[131]. The progressive adoption of digital technologies across the sector can have wide-ranging consequences, changing the nature of some jobs, perhaps destroying some jobs while creating others. Whether the overall balance is going to be positive or negative depends on both the characteristics of the jobs themselves and on the response that institutions are able to provide.

According to a recent study conducted by *Eurofound*, the digital revolution can transform work and employment through three vectors of change, which often act simultaneously: automation of work, digitisation of processes, and coordination using platforms.

Automation of work consists of the replacement of (human) labour input by (digitally-enabled) machine input for certain types of tasks in production and distribution processes;

The digitalisation of processes consists of using sensors and rendering devices to translate (parts of) the physical production process into digital information (and vice versa), and involves changes in tasks and occupations;

Coordination by platforms consists of using digital networks to coordinate economic transactions by "algorithmic management", according to which a task not only specifies what is to be done but also how it is to be done and the exact time allocated to it.

All three vectors of change can affect the structure of employment by occupation and sector as well as working conditions, industrial relations, and the social organisation of production (Fernández-Macías, 2018).

To investigate the extent to which the digital transformation may have affected the construction sector, an empirical analysis was performed drawing on data from *Eurofound*'s European Jobs Monitor (1995-2014). In particular, the analysis indicates:

i. how employment in construction has evolved during the past 20 years;

ii. how occupations in construction have shifted during the same period;

iii. which task content, methods, and tools are used in the three main occupations in the sector.

Evolution of employment in construction over time

To illustrate the evolution of employment in construction over time, the relevant NACE codes (statistical classification code for economic activities introduced in EUROSTAT) were initially identified; before 2008 the construction sector corresponded to one *NACE* code 45, which encompassed all construction processes; from 2008 onwards, the sector corresponded to three NACE codes: *41* (Construction of buildings), *42* (Civil engineering), and *43* (Specialised construction activities).

In order to compare levels of employment in construction with employment in all other sectors, two indices were defined with base 2000=100 and the cumulative growth was calculated.

Figure 3.30 compares the evolution of employment in construction with the rest of the economy in 28 European Member States between 2000 and 2017 (with the year 2000 normalised to 100%).

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[131] Eurostat - Annual enterprise statistics for special aggregates of activities (NACE Rev. 2: F-Construction; indicator: persons employed).

EU Employment in Constructions and other Sectors

FIGURE 3.30: EVOLUTION OF EMPLOYMENT IN THE EUROPEAN CONSTRUCTION SECTOR COMPARED TO THE REST OF THE EUROPEAN ECONOMY (2000-2017).
Source: JRC analysis based on Eurostat data.

Despite the substantial heterogeneity across countries, it is possible to identify some common trends: for a significant number of years up to the Big Recession, employment in the construction sector (continuous line) appears to have grown more rapidly than employment in all other sectors (dashed line) in most European countries. However, in the countries where construction expanded most (particularly Southern and Eastern Europe) there was a dramatic subsequent drop after 2008, in most cases entirely reverting back to the previous growth. The short- to medium-term evolution of employment in construction is mostly driven by large cyclical fluctuations, which have little to do with technical change or other structural trends.

What are the main occupations in construction?

To investigate whether occupational shifts have occurred in the construction sector, the top 15 occupations (ISCO 2 digits) in 1995, 2010, 2011, and 2014 are considered. The change is calculated for two separate periods to account for the revision in ISCO classifications.

Table 3.1 summarises the relative weight of the top 15 occupations in construction and shows whether an occupation has increased, decreased, or remained stable over time (fourth and eighth columns).

The cells highlighted indicate the main occupation in the sector - Extraction and building trades workers in 1995-2010 and Building and related trades workers in 2011-2014 – which account for more than 50% of the total occupations in the first period and approximately 45% in the second. It is worth noting that the main occupation in both periods decreased its weight compared to other occupations, albeit slightly.

Conversely, more skilled occupations – managers, engineers, or science professionals – appear to have increased their weight compared to the other groups. However, the occupational structure remained rather stable over the 20 year period analysed, more than in other sectors (*Eurofound* 2016). This would suggest that the construction sector has been subject to less skill-biased technical change than other types of economic activity.

	1995	2010	Change		2011	2014	Change
Corporate managers	3%	4%	⬆	Chief executives, senior officials, and legislators	1%	1%	—
Managers of small enterprises	2%	3%	⬆	Administrative and commercial managers	1%	1%	—
Physical, mathematical, and engineering science professionals	4%	4%	—	Production and specialised services managers	4%	5%	⬆
Physical and engineering science associate professionals	3%	4%	⬆	Science and engineering professionals	4%	4%	—
Other associate professionals	2%	3%	⬆	Business and administration professional	1%	1%	—
Office clerks	6%	5%	⬇	Science and engineering associate professionals	8%	8%	—
Models, salespersons, and demonstrators	0%	0%	—	Business and administration associates	3%	3%	—
Extraction and building trades workers	**57%**	**54%**	⬇	General and keyboard clerks	3%	3%	—
Metal, machinery and related trades workers	6%	6%	—	Numerical and material recording clerks	1%	2%	↑
Other craft and related trades workers	1%	1%	—	**Building and related trades workers**	**44%**	**43%**	⬇
Stationary-plant and related operators	0%	1%	⬆	Metal, machinery, and related trades work	3%	4%	⬆
Machine operators and assemblers	1%	1%	—	Electrical and electronic trades workers	7%	8%	⬆
Drivers and mobile plant operators	6%	5%	⬇	Food processing, wood, garments	1%	2%	⬆
Sales and services elementary occupations	1%	1%	—	Drivers and mobile plant operators	5%	5%	—
Labourers in mining, construction, manufacturing, and transport	8%	7%	⬇	Labourers in mining, construction, and manufacturing	8%	6%	⬇

TABLE 3.1: OCCUPATIONAL CHANGE WITHIN CONSTRUCTION.
Source: JRC analysis, based on European Job Monitor data 1995-2014.

3.3.5.2. *Potential implications of Digital Transformation on construction workers in the EU: a general overview.*

The adoption of new technologies in the industry is often a cause for concern as it is considered to be a potential risk for workers replaced by machines. However, the construction sector is facing scarcity of work force due to it not being particularly attractive to younger workers, security concerns, and economic problems. Automation can make a significant contribution to reducing this issue. In the light of these considerations, the following paragraphs will provide insights into the extent and mechanism through which DT could impact the construction labour market.

In the literature on labour economics, the *Routine Biased Technological Change (RBTC)* hypothesis is one of the main models used to explain the effects of digitalisation on the labour market. RBTC is based on the assumption that digitalisation leads to a decline in jobs that are mainly composed of *routine tasks* (manual or cognitive routine) and an increase in the number of jobs that have a lot of *cognitive non-routine tasks*. In this task-based approach,

> *" Automation and Digital Transformation will make the AEC sector more attractive to professional highly qualified workforce, especially from the ICT sector "*

it is technological and economic forces that determine the division of labour between labour (tasks) and capital (tasks) (Acemoglu & Autor, 2011) (Autor, 2013): capital typically takes over tasks previously performed by (human) labour once the tasks become routine. However, even when a task becomes fully codified, it is only automated if capital inputs are cheaper than labour inputs. The *routine intensity* – used as a proxy of automation potential – of occupations can be measured by the so called *RTI* index. The *RTI* index increases the greater is the routine task content and decreases when abstract and manual tasks are more relevant[132].

Some broad assumptions on the potential impact of automation on the construction sector can be made when looking at the level of automation potential of each occupation (Figure 3.31) and at the share of workers that is respectively employed (Figure 3.32).

At EU-28 level, the construction sector employs more than 50% of its labour force as "crafts and trade workers" and this share reached almost 70% in the case of migrant workers[133] in 2016. Unravelling this category at Isco-08[134] 3-digit level reveals that these workers are mainly "building frame workers" and "building finishers". The main characteristic of this occupation category is a relatively high RTI index, potentially making it at a higher risk of being automated. However, it is "elementary occupations", which represent 8% of the total construction workforce, that report the highest automation potential. These are prevalently (EU and non-EU) migrant workers employed as "construction labourers".

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[132]   Indices for *Abstract, Routine, and Manual task aggregates* were computed using the OECD *Programme for the International Assessment of Adult Competencies (PIAAC)*. *Abstract* tasks are derived from the following items: "read diagrams", "write reports", "prepare charts, graphs, or tables", "use simple algebra or formulas", "face complex problems", "persuading and influencing people", and "negotiating with people". *Manual* tasks are computed using responses on "skill or accuracy in using hands/fingers" and "physical work". Finally, for the routine tasks, four items are selected regarding the frequency and repetitiveness of the job (change the sequence of tasks, change how you work, change the speed of work, and change the working hours) and three items regarding the lack of adaptation (learn work-related things from co-workers, learning by doing, and keeping up to date with new products/services).

[133]   Data provided is aggregated at EU-28 level for 2016. Nevertheless, it should be noted that there are differences between MS. For example, in Italy the share of employed as "crafts and trade workers" was 68% for nationals and 87% for migrants where as in Germany these shares are at 49% and 59% respectively.

[134]   "The International Standard Classification of Occupations (ISCO-08) is an international classification managed by the International Labour Organisation (ILO). [...] ISCO-08 is a tool for organizing jobs into a clearly defined set of groups according to the tasks and duties undertaken in the job." (as defined by EUROSTAT).

The second occupation absorbing the largest share of workers (12.4%) is the category "Technicians and associate professions". These are mainly "construction supervisors" and "physical and engineering science technicians" as data at Isco 3-digit level show. This occupation category has a very low level of automation potential and thus so the lowest risk of being replaced by machines.

In the light of these considerations, it can be assumed that DT in the construction sector could impact a relevant number of workers employed as "crafts and trade workers" and in "elementary occupations".

Construction Sector RTI Index per Occupation
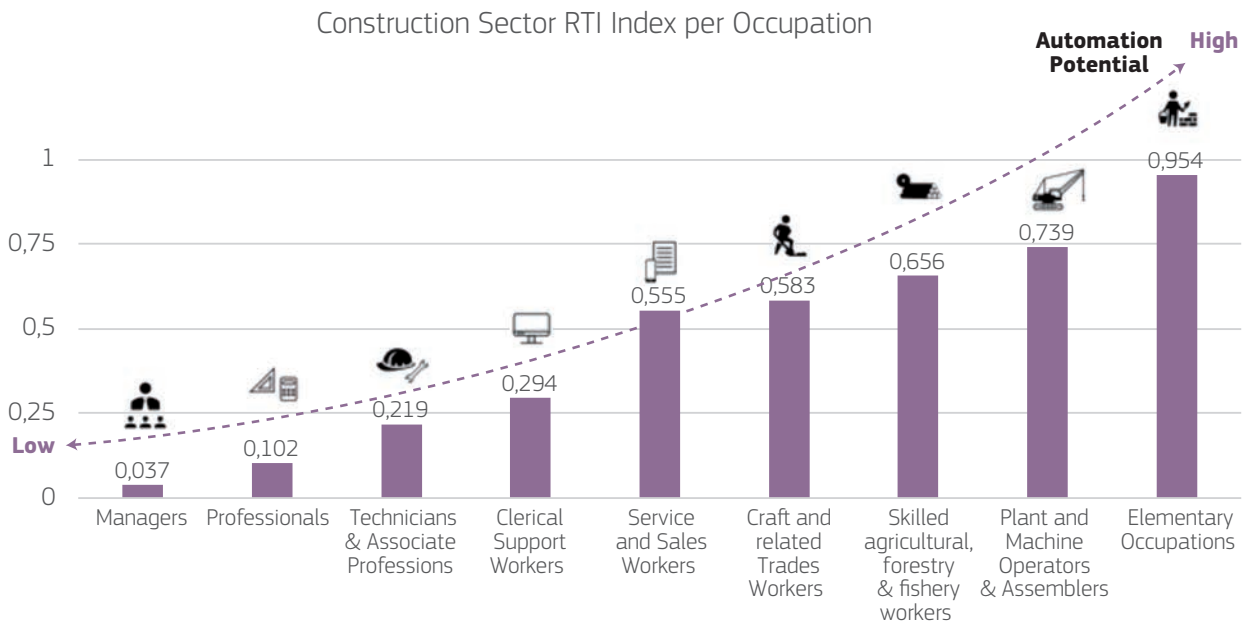
FIGURE 3.31: CONSTRUCTION SECTOR: LEVEL OF AUTOMATION POTENTIAL (RTI) OF OCCUPATIONS AT ISCO-08 1-DIGIT LEVEL.
Source: JRC analysis based on OECD PIAAC 2012 and EU LFS 2016 data.
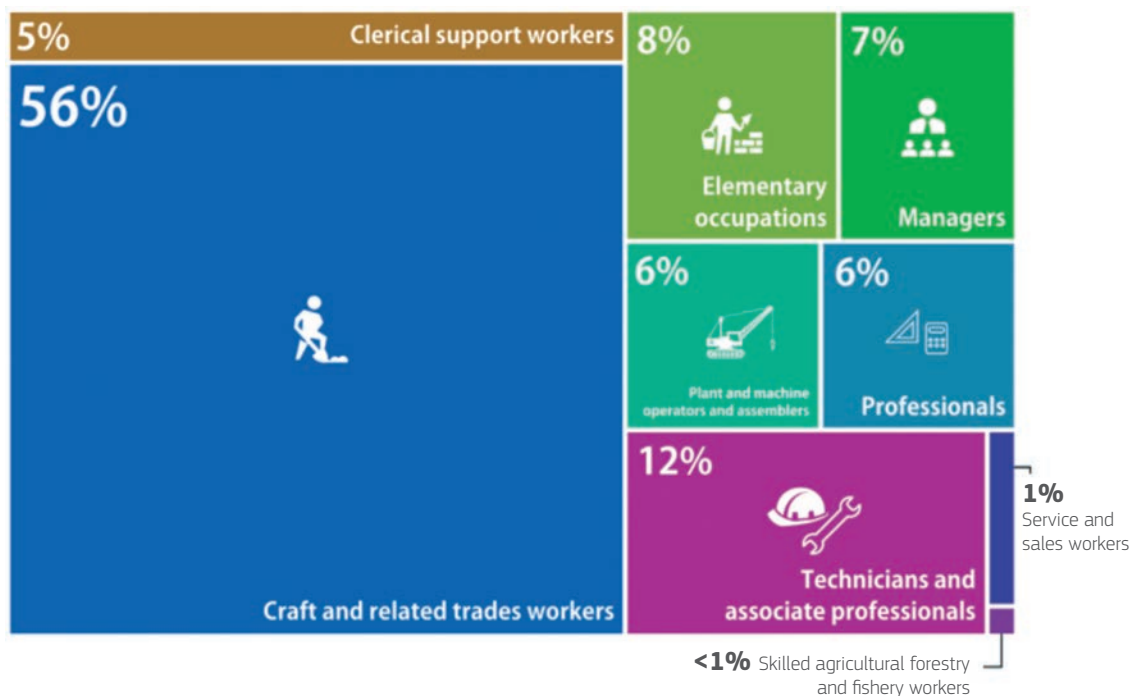
FIGURE 3.32: CONSTRUCTION SECTOR: SUBDIVISION OF WORKFORCE BY TASKS (ISCO-08, 1 DIGIT) IN PERCENTAGE OF WORKERS IN THE CONSTRUCTION SECTOR (NACE REV. 2 - 1 DIGIT).
Source: JRC analysis based on EU Labour Force Survey (EU-LFS), 2016.

Potential implications of DT on specific occupations

The following paragraph provides detailed task description of three occupations:

I) "science and engineering professionals" as representative of the technician category;
II) "building and related trades workers" as an example of craft occupation;
III) "labourers in mining, construction, manufacturing" as an example of elementary occupations.

The indicators summarised in Figure 3.33 are based on the work in (Fernández-Macías, 2018). Among these, one occupation has remained stable – Science and engineering professionals – possibly because it scores very high on problem-solving and intellectual literacy even though it also has a high score on standardisation. The other two occupations score relatively highly on standardisation and repetitiveness, and rather low on intellectual or social task content. This type of task profile in the literature is associated with a relatively high risk of automation due to the diffusion of advanced robotics and AI-enabled machinery (Fernández-Macías, 2018).
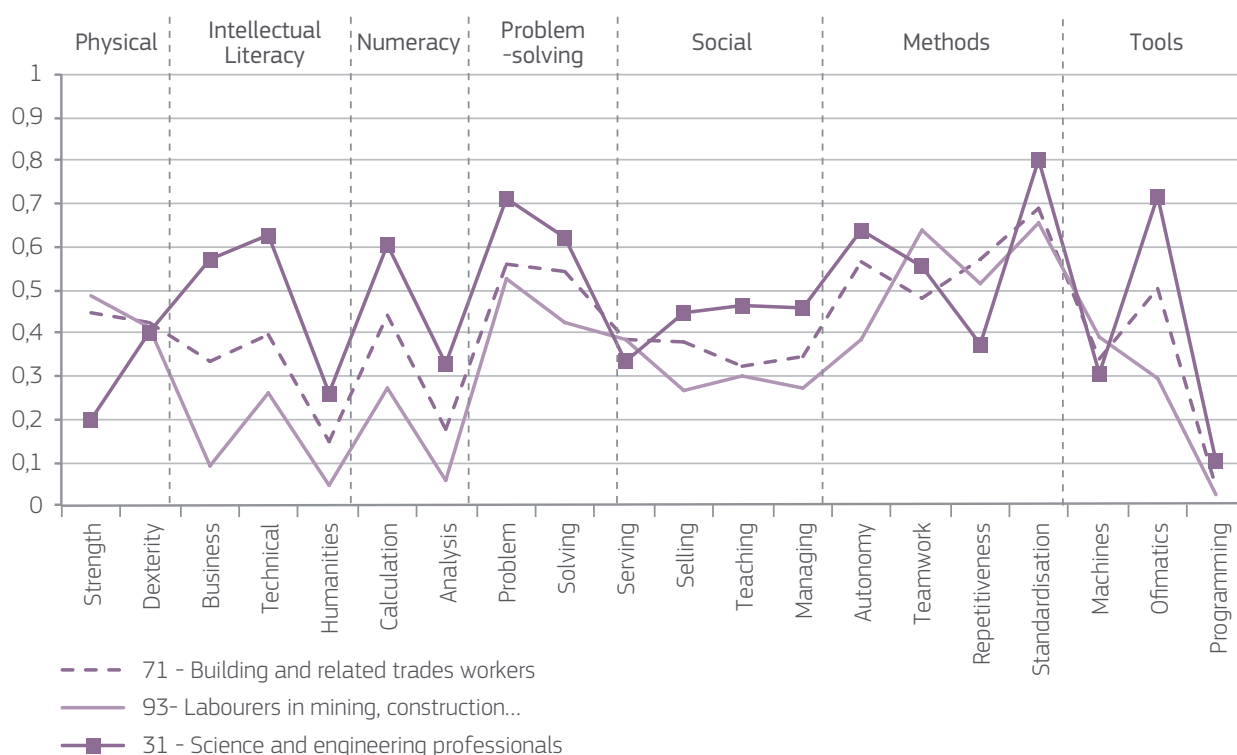
FIGURE 3.33: TASK-BASED ANALYSIS OF THE THREE MAIN OCCUPATIONS IN CONSTRUCTION.
Source: JRC analysis based on European Job Monitor data, 2014.

Potential impact of DT on migrant workers

In its efforts to manage the social impacts of DT efficiently, the EU has focused its actions on mitigating the negative effects of DT on the labour market. However, this task can prove to be more challenging for those groups on the labour market that are already vulnerable such as the migrant population. In 2016, the EU construction sector gave work to 1.5 million migrants out of which 898,000 migrants had EU nationality and 650,000 were non-EU nationals.

The overall results show that migrants working in the construction sector are potentially more vulnerable to the effects of job automation than non-migrants. More specifically, results from the analysis in (Biagi, et al., 2018) adapted to the construction sector[135] show that:

- **Migrants in the construction sector** have a greater probability of working in a job with high automation potential and hence at risk of disappearance compared to non-migrant workers. Moreover, non-EU

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migrants working in the construction sectors are 3.5 times more likely to be employed in jobs that have high automation potential compared to non-migrant workers. This likelihood is 2.6 times for EU migrants.

- **For workers employed in jobs with a great degree of automation potential**, both EU and non-EU workers have a lower probability of receiving professional training and a greater likelihood of being employed on a fixed-term contract than nationals. This lower investment in human capital can hamper migrants' opportunities to transition into better and more secure jobs should they lose their job in the construction sector. Furthermore, the chances of fixed-term contracts not being renewed increase during economic and technological shocks.

3.3.5.3. *Safety*

The construction sector is the activity with the largest number of accidents and fatalities (see the Eurostat statistics in Figure 3.34) and new technologies can assist in significantly reducing these numbers.
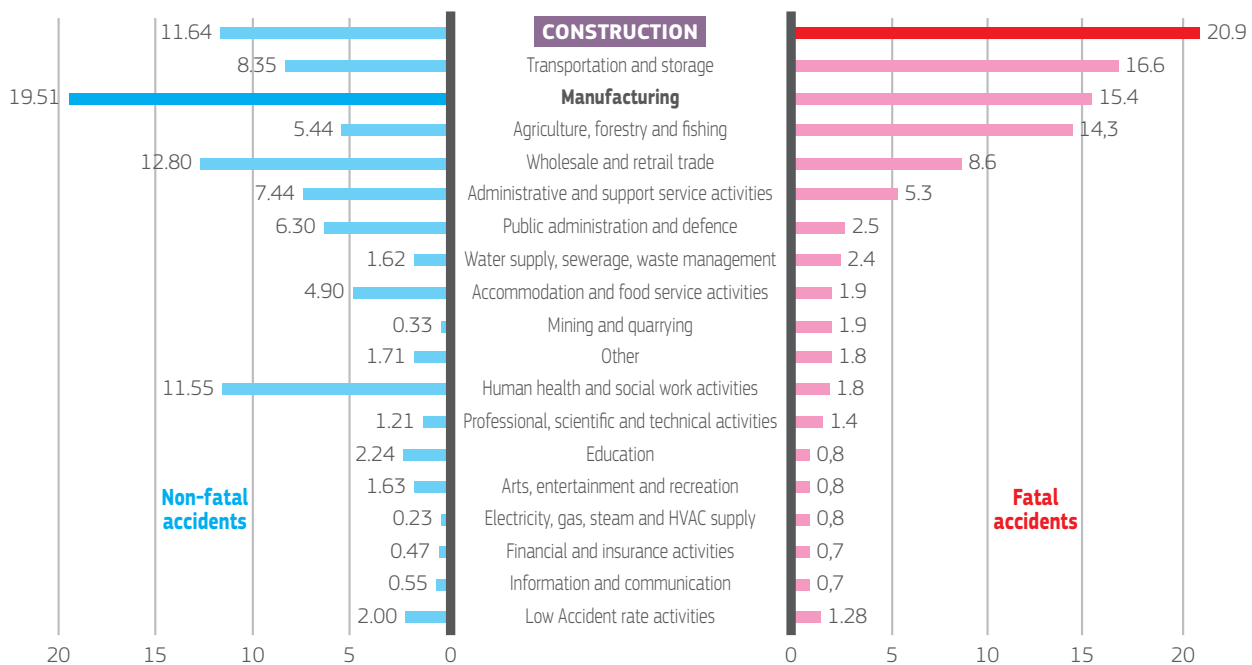
FIGURE 3.34: EU28 ACCIDENTS AT WORK EXPRESSED AS PERCENTAGE OF OVER THE TOTAL ACCIDENTS BY SECTOR IN 2016, ORDERED BY NUMBER OF FATALITIES FIRST.
Source: Eurostat[136].

Safety of workers in the Construction Sector can be purposely improved by exploiting new technologies (e.g. implementing VR-based training) or by implementing new processes (e.g. automation of processes).

If digitalisation of processes is crucial for a modern and competitive construction sector, the advent of smart buildings and infrastructures can provide improved security and resilience against natural hazards; sensors and communication modules can provide data for prevention, planning, and management of emergencies. The *Smart City* paradigm is rapidly spreading throughout Europe in cities where new technologies improve the quality of life of citizens and support public administrations in improving management and use of resources. However, just like in the construction process itself, only systems integration and widespread implementation of digital technologies make exploitation of the whole potential feasible.

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[136] http://ec.europa.eu/eurostat/statistics-explained/index.php/Accidents_at_work_statistics

Safety training in the construction industry

Many researchers have used empirical methods to evaluate the effectiveness of training in improving safety. Results include identifying safety training as one of the four most effective components in a safety program (Tam & Fung, 1998), making unsafe conditions better using *safety inductions* (i.e. the employer provides information on procedures, instruction, and training to new employees) (Aksorn & Hadikusumo, 2008), and identifying lack of training as one of eight root causes of construction accidents (O'Toole, 2002). It is also a fact that standards for construction safety training are low. Digital transformation in general and, in particular, the use of *Virtual Environment* (VE), can enhance safety training. VE is a technology that uses computers, software, and peripheral hardware to generate a simulated environment for its user.

Research has shown that: *(a)* there is a link between the rehearsed activities and performance within the VE and the actual performance and learning outcomes [(Bachvarova, et al., 2012); (Li, et al., 2008); (Li, et al., 2012)]; *(b)* training in VE reduces cost and time compared to the learning and training process in the real world [(Bachvarova, et al., 2012); (Li, et al., 2008); (Li, et al., 2012)], and *(c)* VE provides the possibility of conducting training on high risk activities that cannot be implemented in field-based training (Addison, et al., 30-31 October 2013). Results from (Dawood, et al., 2014) indicate that as construction sites become more complex through time – as construction work progresses – the ability of learners to identify hazards decreases. They developed a full-scale virtual construction site to test the ability of learners to identify hazards in a virtual environment at different construction phases represented in the form of a serious game. The virtual environment included a combination of hazards with varying levels of difficulty of identification. Within this stream of research, Sack et al (Sacks, et al., 2013) assess the impact of VE training in the construction sector. The following are noted among the main findings:

a. Overall both traditional and VE training showed their effectiveness in improving safety knowledge

> *"New digital technologies such as wearables, automation and AI, can assist in significantly reducing the high number of incidents and fatalities in the construction sector"*

b. trainees perceive the virtual construction site environment to be a sufficiently authentic simulation to facilitate learning;
c. VE is suitable for presenting trainees with hazards directly and realistically without compromising their safety
d. VR training holds the attention of trainees better than conventional classroom training.

More in detail, they highlight the following:

1. Virtual reality training was more effective in maintaining a high level of alertness than traditional training
2. Virtual reality training was significantly more effective in risk prevention and risk identification

All benefits resulting from VE training will be even stronger when the use of this tool matures. Similarly, it is also expected that the present cost of developing training materials and virtual construction sites will become less significant in the near future.

3.4 | Conclusions: Way Forward for Policy and Research

The European Construction sector provides 18 million direct jobs and contributes to 9% of the EU's GDP. In the next few years, significant growth of the global volume of construction output is predicted by several analyses (Global Construction Perspectives and Oxford Economics, 2015), providing new stimuli to the AEC

sector after the limited investment and the recession of the recent years. However, the European AEC sector is facing challenges to innovate, increase productivity, and attract a new skilled workforce. Competitiveness of the European Construction Industry's global players is crucial to competing in developing foreign markets, while the expected more limited internal growth requires more efficient processes.

The AEC sector has been a slow adopter of new technologies, in particular ICT. Innovation in the sector has suffered from past economic crises worsened by the **fragmentation of the sector** (McKinsey Global Institute, February 2017), with a small number of big enterprises investing in R&D and a large group of SMEs (with small margins to spend on modernisation), represents a major obstacle. Moreover, **the sector is facing low attractiveness** to (more technology oriented) youngsters and aging skilled workers, both inducing problems with workers being available to meet current and future demand.

Education is one of the key factors in the European AEC sector preventing skill shortages and avoiding restrictions in following the positive outlook. Scarcity of in the construction sector profiles who really know the technology is high. So University programs must be modified to include these Digital Technology specialities. Currently these needs are covered by Industrial or Telco engineers but ICT and novel hub technology skills for the construction sector must be learnt by civil engineers and architects.

The expected increase of the construction market in the years to come calls for increased productivity of the AEC sector that can only be achieved through a **paradigm shift to move away from the traditional approach** and fully exploit the digital transformation of the sector throughout the whole value chain from additive manufacturing (3D printing) and automation in the construction phase to the efficient collaboration and management of information, documents, and projects with the support of BIM. The digitalization of the real world (3D scanning) is making the management of all the information in digital form possible and AI is offering novel possibilities for the efficient management of buildings and lower energy consumption.

Considering the slow adoption of new technologies in the past, **the AEC sector has significant opportunities to exploit digital innovation** (some early adopters and innovation leaders are already demonstrating how substantial the improvement can be) provided that

> *University degree programmes should cover digital technologies in the AEC sector, increasing attractiveness and reskilling the future workforce*

obstacles are removed and full integration and adoption of systems is accomplished.

In May 2018 FIEC, the European Construction Industry Federation, joined by other major European construction industry associations, published the *Construction Industry Manifesto on Digitalisation* in recognition of the need for "*strong political leadership from the EU, an appropriate regulatory framework on data policy and budgetary focus on digital skills, R&D and IT infrastructure*" (FIEC, 2018). The manifesto recognises the crucial role of digitisation in the European Construction Industry achieving increased productivity, better quality, making workers safe, and in meeting future EU challenges (e.g. jobs, sustainability, and increased urbanization among others). The European AEC sector is already adopting digital innovation but the EU construction industry directly calls for policy makers to support and lead the digitalisation of the European construction sector, to develop a specific regulatory framework on data policy, and to support the development of digital skills, research, and IT infrastructure.

However, the implementation of ICT and new technologies in general requires initial investments in IT infrastructures whereas the fragmentation of the European AEC market (consisting of a multitude of SMEs and a handful of very large big players) creates another barrier to broadening and homogenising digitalisation of the sector. New

technologies are being supported at national and EU level, the Digital Single Market among others, but the **need for high initial investments** tends to reflect the sector fragmentation leaving the major companies as the only innovators. **Programmes to support SMEs in the adoption of ICT technologies** would be strategic in homogenising the level of digitalisation in the AEC.

Not only the adoption of new technologies can improve productivity and efficiency in the AEC sector but also the business model must change and innovate. The construction industry business model has primarily been based on industrial logistics but is progressively transforming into a service model (Kähkönen, et al., 2016). A clear example of the digitally driven change to the sector is represented by the advent of platforms and a radical change in the business model.

Innovation introducing novel construction methods such as additive manufacturing, robotics, along with the use of novel materials, intelligent control systems (for smart buildings and infrastructures), and new technologies for workers **must be assessed in terms of safety and security by the development of new procedures, legislation, certification, and testing** to address their uniqueness. Moreover, the development of new construction techniques (3D printing) and automatization should be anticipated by **appropriate testing and dedicated standards and building codes**. The JRC is active in supporting policies in the construction sector with ongoing scientific research in the field (smart buildings, wireless sensor networks, and safety and security of buildings) with the support of unique testing facilities and so contributes to a smoother introduction of innovative technologies in AEC.

Considering the rapid evolution of new technologies and critical adoption by the construction sector, governments should ensure constant and effective communication with companies and innovators and facilitate the elimination of barriers to innovation.

Moreover, the **legal aspects of shared use of BIM** must be clearly addressed to ensure data ownership and avoid disputes. Legal barriers for the full adoption of BIM must be addressed by specific legislation and solutions harmonized across Member States. Moreover, the need to ensure data privacy and confidentiality suggests EU Cloud systems for both sensors and BIM projects should be implemented, possibly within the EC Connecting Europe Facility funding program and as part of the European Digital Building blocks[137].

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[137] https://ec.europa.eu/cefdigital/wiki/display/CEFDIGITAL/Building+Blocks

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List of abbreviations and definitions for Part 3 – Digital Transformation in Construction

AEC	Architecture, Engineering & Construction
AI	Artificial Intelligence
AM	Additive manufacturing
ANN	Artificial Neural Network
BMS	Building Management System
BMS	Building Management System
CC	Cyber Crime
CI	Critical infrastructures
CT	Cyber Terrorism
DDoS	Distributed Denial of Service
DIH	Digital Innovation Hubs
DoS	denial-of-service
E&C	Engineering and Construction Sector
EC	European Commission
GIS	Geographic information system
GPU	Graphics processing unit
HSIC	High-Speed Inter-Chip
HVAC	heating, ventilation and air conditioning
ICO	Initial Coin Offering
ICT	Information and Communication Technology
IFC	Industry Foundation Classes
IoT	the Internet of Things
IPO	Initial Public Offering
IPR	intellectual property rights
M2M	Machine to machine
MS	Member States
OM&R	Operation, Maintenance and Repair
OWL	Web Ontology Language
R&D	Research and Development
RFID	Radio-frequency identification
SB&I	Smart Buildings and Infrastructures
SCADA	Supervisory Control And Data Acquisition
SHM	Structural Health Monitoring
SME	Small and Medium Enterprises
UN	United Nations
VC	Venture Capital
VE	Virtual Environment
VR	Virtual Reality
WSN	Wireless Sensor Networks

4 DIGITAL TRANSFORMATION IN ENERGY

④ DIGITAL TRANSFORMATION IN ENERGY

Summary

The European Union is moving towards the creation of a fully-integrated internal energy market to ensure a safe, viable, accessible to all and climate neutral energy supply.

The EU's Energy Union strategy is made of five dimensions:

— Security, solidarity and trust
— A fully-integrated internal energy market
— Energy efficiency
— Climate action and decarbonising the economy
— Research, innovation and competitiveness.

The Energy Union aims at diversifying Europe's energy sources as a way to enhance energy security, and at eliminating regulatory and technical barriers that prevent frictionless flow of energy in within Union.

To achieve the Energy Union, a transformation of the energy system is necessary. Decarbonisation and climate action require a gradual phase-out of fossil energy sources and the integration of renewable energy sources in the energy mix. This will also reduce EU dependency on energy imports and create a market for research and innovation to boost growth and competiveness.

The transformation of the energy system will affect the way in which energy is produced, transmitted, distributed and consumed. The system must become more "intelligent" and flexible in order to integrate energy sources that have different behaviours and technical characteristics compared to traditional ones.

New functions such as time-decoupling of production and consumption though storage, demand side management, flexibility, efficiency, exploitation of distributed resources, and market clearing at prosumers' level are necessary. These new functions, in turn, require the use of new technologies and infrastructures. Smart meters, power electronics, smart grids at the distribution and transmission level are only some of the pre-requisites for the implementation of the functionalities needed for the energy transition. The new infrastructure must cater to the communication needs of prosumers, Distribution System Operators, Transmission System Operators, aggregators and of the devices that participate in the system.

The combination and interconnection of these new technologies, paradigms, services and devices require an energy distribution infrastructure and data exchange channels and platforms. Not only energy, but also data must flow freely in the system. All players and devices in the new energy system need to be able to communicate bi-directionally.

To support this, a new consistent European framework must be developed. It must consider the technological aspects but also matters of social acceptance and business models. The framework will allow the management of interactions with all energy commodities and non-energy sectors like water, finance and transport. New technologies such as Advanced Metering Infrastructure, electronic ledgers, the Internet of Things, Artificial Intelligence must be integrated in the new framework.

In this context the digitalization of energy, in terms of technologies, infrastructures and services is emerging as the crucial enabler of the energy transition.

4.1 | Overview of Digital Transformation in Energy

4.1.1. Introduction

The European Union is working towards the creation of a fully-integrated internal European energy market to ensure an energy supply that is safe, viable, accessible to all, and climate neutral. This is called the Energy Union[138], and it is one of the Juncker Commission's ten priorities. It works hand in hand with other flagship initiatives such as the Digital Single Market[139], the Capital Markets Union[140], and the Investment Plan for Europe[141] in order to deliver on jobs, growth, and investments in Europe.

The EU's energy union strategy is composed of five dimensions:

- *Security, solidarity, and trust*: working closely with Member States to diversify Europe's sources of energy and ensure energy security.

- *A fully-integrated internal energy market*: energy should flow freely across the EU – without technical or regulatory barriers. This will enable energy providers to compete freely and promote renewable energy while providing the best energy prices.
- *Energy efficiency*: improving energy efficiency to reduce the EU's dependence on energy imports, cut emissions, and drive jobs and growth.
- *Climate action and decarbonising the economy*: putting policies and legislation in place to cut emissions, moving towards a low-carbon economy and fulfilling the EU's commitments to the Paris Agreement on climate change.
- *Research, innovation, and competitiveness*: supporting research and innovation in low-carbon and clean energy technologies which are able to boost the EU's competitiveness.

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138 https://ec.europa.eu/commission/priorities/energy-union-and-climate_en
139 https://ec.europa.eu/digital-single-market/
140 https://ec.europa.eu/info/business-economy-euro/growth-and-investment/capital-markets-union_en
141 https://ec.europa.eu/commission/priorities/jobs-growth-and-investment/investment-plan-europe-juncker-plan_en

Key EU targets for 2020

- Cut greenhouse gas emissions by 20% compared to 1990

- 20% of total energy consumption from renewable energy

- 20% increase in energy efficiency

Key EU targets for 2030

- Greenhouse gas emissions cut by at least 40% compared to 1990

- At least 27% of total energy consumption from renewable energy

- At least a 27% increase in energy efficiency

Long-term goal

- By 2050, the EU aims to cut its emissions substantially – by 80-95% compared to 1990 levels as part of the efforts required by developed countries as a group.

On the 30th of November 2016, the European Commission presented a new package of measures for the purpose of providing a stable legislative framework for the transition to clean energy – taking a significant step towards the

> *The Energy Union is working towards achieving a sustainable, affordable, and secure energy future without compromising any fundamental resource for the quality of life of today's European citizens*

> *The Clean Energy for all Europeans package supports the shift from fossil fuels to renewable energy sources*

creation of the Energy Union. This is known as the Clean Energy for all Europeans package[142].

The Clean Energy for all Europeans package pushes innovation in the direction of energy efficiency, demand response, small-scale generation at consumer level, and it promotes the shift from fossil fuels to renewable sources. These innovations bring added flexibility in terms of the capability of energy systems to respond to changes in demand and generation, on various scales including transmission, distribution, and final uses promptly and in such a way as to ensure a good supply/demand balance. The Clean Energy package aims at creating a market for this added flexibility.

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[142] https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/clean-energy-all-europeans

The Energy Union is working towards a sustainable energy future while still meeting present energy needs. The aim is to achieve this without compromising any fundamental resources for the quality of life of European citizens.

Digital technologies are not only instrumental in managing a grid with an ever increasing share of renewables, distributed generation, and loads with new behaviours such as electric vehicles, but they are also instrumental in creating new services and products.

Digitalization enables bidirectional communication between all the players in the energy field: prosumer to prosumer, prosumer to distribution system operator (DSO), DSO to transmission system operator (TSO), prosumer to retailer, retailer to DSO, etc.

The distribution sector is particularly affected by these changes. The increasing penetration of local Renewable Energy Sources (RES), and the emergence of demand response enabling solutions are placing new requirements on the distribution networks, challenging the reliability and efficiency of system operation. However, these new applications can also concurrently create opportunities to manage the distribution grids in a more flexible and efficient manner, paving the way for new services to end-consumers (Prettico G., et al. 2016).

4.2 | Digital Transformation Enablers and Barriers in Energy

The goals of the energy transition are sustainability, affordability, and security of the energy supply. To achieve all of these, a huge transformation in the way in which energy is produced, transmitted, distributed, and consumed is necessary. This transformation requires new functions such as time-decoupling of production and consumption though storage, demand side management, flexibility, efficiency, exploitation of distributed resources, and market clearing at prosumer level. In turn, these new functions require the use of new technologies and infrastructures. Smart meters, power electronics, smart grids at the distribution and transmission level are all pre-requisites for the implementation of the functionalities needed for this energy transition.

All players and devices in the new energy system need to be able to communicate bi-directionally. The new infrastructure must cater for the communication needs of prosumers, DSOs, TSOs, aggregators, and the devices that participate in the system. New technologies such as Advanced Metering Infrastructure (AMI), electronic ledgers, the Internet of Things (IOT), and Artificial Intelligence (AI) must be integrated in the new framework. In this context the digitalization of energy in terms of technologies, infrastructures, and services is emerging as the crucial enabler of the energy transition.

All those aspects must be coordinated. A consistent European framework in terms of social acceptance, technology standards, and business models must be developed. The framework will facilitate the management of interactions with all energy commodities (Gas, H2, etc.) and non-energy sectors like water, finance, and transport.

This framework is now described in the following without claiming to be exhaustive.

> *A consistent European framework for the energy sector needs to be developed, to address issues such as consumer acceptance, technology standards, and novel business models*

4.2.1. Functions

4.2.1.1. *Control of Active Distribution Grid with Distributed Energy Resources (DER)*

The emerging context of distribution grids is populated by distributed small scale generators that make them active in terms of being able to inject power into transmission grids through high voltage distribution.

The possibility of controlling the distribution grid by taking advantage of distributed generation, demand side management, and concentrated and distributed storage provides new opportunities to control power flows between transmission and distribution. The active controlled distribution system is able to provide ancillary services to the transmission systems in terms of congestion management, frequency control, voltage profile regulation, and black start capabilities.

Various studies confirm the economic benefits of active network management versus grid expansion, and a very recent study[143] reports a 40% cost reduction for active RES integration compared to grid expansion.

In transmission systems, despite the permissible curtailment of 3% of each renewable generator's annual production, most local flexibility is not available to the DSO or TSO for congestion management. In addition, there is no

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[143]   Federal Ministry of Economics and Innovation (BMWi) by E-Bridge, OFFIS and RWTH.

information about the impact of distributed generators on the network or any strong incentive to cooperate.

One real-life example of TSO-DSO collaboration is between the Italian TSO Terna and the local DSO Edyna, aiming to transform the challenge of managing these reverse flows into an opportunity by enhancing observability and control of the RES units located at the distribution level.

This is a real-time monitoring process mainly based on digital sensors, devices, and fast communication. Terna will be able to receive aggregated information for this purpose at the TSO-DSO interconnection point. This information is the total power installed for each RES type (hydro, PV), the total load, the gross load compensated by RES, and real-time information about both active and reactive power production per power source.

4.2.1.2. Demand side management

Ancillary grid services are those services that facilitate, support, and enable the flow of power from producers to consumers ensuring that supply meets demand at all times. They are referred to as ancillary as they complement normal generation and transmission services.

Traditionally, ancillary services have been procured from assets connected to the transmission network and mainly from the generation side. Active distribution systems can play a crucial role in providing ancillary services to the transmission side through high voltage distribution systems. In addition to the exploitation of DER discussed above in previous sections, demand side management, with concentrated and distributed storage, is also able to play a crucial role. Demand side management provides responsiveness from the load side enabling demand-response in the operation of grids.

In Europe, the availability of aggregated demand-response for provision of grid services is rather limited. In countries where this takes place, the service is mainly provided by industrial loads, aggregated using digital platforms, and mainly offered to the TSOs by a service provider known as a load aggregator.

France and Switzerland are currently the only countries to have a clear framework on the status of independent aggregators and their role and responsibilities in the market. The *Notification d'Echanges de Blocs d'Effacement (*NEBEF) mechanism, introduced in December 2013, allows curtailed load to bid as energy directly into the wholesale electricity market. The volume activated during the experimentation phase was 310 MWh in 2014, steadily increasing to 1,522 MWh (2015) and 10,313 MWh (RTE, 2016). Additionally, the balancing and capacity mechanism as well as ancillary services are also open to aggregated demand response.

UK Power Networks is the first European utility to use an open tender for flexibility services that could be addressed via aggregated demand-response services. The minimum clip size for service providers is 500kW of flexibility, which can be aggregated across multiple sites and smaller sized resources can also be considered depending on the characteristics of flexibility in each area.

4.2.1.3. Energy Communities

The active nature of emerging distribution networks with prosumers and DER, along with demand side management and local and distributed storage, pave the way for a new energy paradigm. It is based on the demand/supply balance inside a community of prosumers that share generation resources, storage devices, and loads. This is the so called Energy community, which can cover areas of varying sizes, with variable geometry designed on the basis of the availability of resources and energy needs at the time.

> *New emerging distribution networks will lead to the creation of local, quasi-independent energy communities*

4.2.2. Technologies and Infrastructure

The interface to the external world of loads and users will increasingly contain power and data exchanges. This is true for both passive and active single appliances and aggregated sets of loads for residential, tertiary, or industrial uses.

The power exchange will be represented by power electronics (PE) devices that act as a bridge to the emerging smart grid while the exchange of data will be enabled by smart meters that allow data flow over an Advanced Metering Infrastructure (AMI).

4.2.2.1. *Power electronics*

Power electronics are the power interface of the emerging power systems. Each device, be it load, generator or storage is connected to the grid though a power electronic interface through converters, inverters and rectifiers.

Much of the RES generation and non-conventional generation is inherently direct current (DC). Power electronics are the interface between RES and the network at the generation level (Power Electronics Interfaced Generation – PEIG), giving rise to various problems in terms of low values of short circuit power and lack of mechanical inertia that applies, at various scales and with different implications, at both the transmission and distribution levels.

At the load level many loads, such as computer systems and most electronic devices, are intrinsically DC and so are supplied trough AC/DC converters. Other AC loads, such as induction motors, are supplied though AC/AC inverters to enhance their controllability and improve their efficiency.

Converters are used at the transmission level for both long distance power transmission though DC lines or to decouple different systems by using back to back converters.

In addition, the operation of the system with power flow control, managing congestion of the grid issues, and voltage regulation can be enhanced by using Flexible AC Transmission Systems (FACTS) and Static Var Compensators (SVC). FACTS are crucial to providing more control over the transmission network and its power flows, allowing one or more alternating current (AC) transmission system parameters and variables to be regulated.

There are different types of interconnections to the grid at the distribution level such as distributed generation, traditional and emerging loads, and stationary and mobile storage. These interconnections are made through converters. Their control is crucial for the reliable and efficient operation of the grid from both the perspective of distribution networks connected to the transmission grid and in the case of islanded distribution networks such as microgrids.

Nowadays DC/DC converters are available with cost, dimensions, and efficiencies not far from the traditional AC transformers. It is even now possible to reconsider the historical choice of AC versus DC for electricity transmission and distribution made at the beginning of the previous century.

4.2.2.2. *Smart meters*

A smart meter is an electronic device that senses various physical quantities (power, current, voltage) and can exchange related information with retailers, DSOs, aggregators, and service providers as well as make them available at the consumer/prosumer premises.

Different time sampling of the quantities and different frequencies of data update to the control centre are possible. Typically, the sampling rate is from 5 minutes to one hour and the frequency of update is at least daily. Smart meters may be the digital and information interface of the customer with an advanced metering infrastructure that enables two-way communication between the meter and a data concentration centre. Communication from the meter to the network may be wireless or via fixed wired connections such as power line carrier (PLC).

Following EU Directives 2009/72/EC and 2009/73/EC, at least 80% of electricity consumers in Europe will be equipped with smart metering systems by 2020 where

roll-out of smart meters is assessed positively[144]. Various functionalities are bound to smart metering systems as recommended by the EC (Recommendation 2012/148/EU)

Of particular relevance are those functionalities that enable:

a) a time sampling rate that enables the provision of advanced energy services. These services include but are not limited to demand side management, services to support the distribution network operation and security, and energy savings.

b) consumer participation, particularly when coupled with advanced tariff schemes such as spot pricing of electricity.

At the transmission level, Wide Area Monitoring Systems (WAMS) based on phasor measurement units (PMU) represent additional tool for monitoring the stability of the transmission system. They also facilitate the maximum utilization of available transfer capabilities.

4.2.2.3. *Services and IT tools*

The functions discussed so far can be implemented by adopting new technologies and power/data infrastructures. They open a new way for the provision of ancillary services.

Transmission network operators and distribution network operators can co-operate in a coordinated manner to

guarantee the robustness and security of their electricity systems. They can also do this by using ancillary services at the distribution level. These services include frequency ancillary services (balancing of the system), and non-frequency ancillary services (voltage control, fast reactive current injections, inertia, and black-start capability)[145].

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[144]   European Smart Grids Task Force Expert Group 1 – Standards and Interoperability, October 2015.
[145]   EU Electricity Directive, Brussels, 30.11.2016 COM(2016) 864 final 2016/0380 (COD).

Acquiring system services from assets connected to the distribution network will facilitate more efficient and effective network management, resulting in increased demand-response and shares of renewables. Therefore, TSOs and DSOs in cooperation with market participants will need to set up ways of procuring system services in a coordinated way[146].

Information and communication technologies (ICT) have a major role to play. The development of automation and ICT is a de facto necessity to cope with the variations in energy systems and market interactions. For this reason ICT and digital technologies may generally be seen as a

key enabler to fostering DSO-TSO cooperation moving towards more flexible systems and ancillary services. They also represent a challenge to their current roles and responsibilities together with their associated business models, which may become a barrier during the transition process.

The digitalization of the energy sector brings both challenges and opportunities to the DSO, whose current mainly asset-based business model is being challenged. In this regard, European DSOs need to adjust current practices and to leverage business models on the rapid emergence of digital technologies in the electricity sector.

4.2.2.4. Data Hubs

Data hubs (or data exchange platforms) aim to improve data exchange processes between the various players connected to the electricity system and market. Most of the data hubs in the EU seek to reduce market entry barriers in the competitive parts of the energy supply chain such as generation and retail. They therefore enable a level playing field via non-discriminatory data access. Furthermore, the DSOs in most of the EU Member State are responsible for developing data hubs that collect data from smart meters. They are also responsible for obtaining safe and secure data transfer to all eligible market parties, and secure market processes such as switching, billing, etc.

In addition, current research focuses on how these data hubs could facilitate energy services beyond the retail market, i.e. ancillary services offered to the TSOs from providers connected to the distribution network, as well as services offered by new market entrants.

Again, this would certainly call for increased data exchange at the DSO-TSO interface, and as a result improve coordination between the DSOs and the TSOs.

As an example, the Estonian and Danish TSOs go even one step further than this by testing digital technologies to merge their data hubs so that data collected in each country are available for cross-border energy services.

The Estonian TSO has established a partnership with a blockchain-based renewable energy trading platform developer (WePower) to test digital solutions able to allow Estonians to invest in RES elsewhere in the world and foreigners to invest in local generation of green energy by using some form of cryptocurrency.

4.2.2.5. Distributed ledgers, energy communities

Distributed ledger technologies (DLTs)[147] have been in the spotlight in the last few years mostly due to Bitcoin's widespread adoption (Nascimento, S., et al., 2019). Bitcoin is a cryptocurrency created in 2009 and is based on the principle that there is no central entity that controls the

system and that transactions can succeed without the need for a trusted third party. A ledger with all of the transactions that ever happened in the history of the currency is saved on all participating nodes and is thus distributed across the whole network, hence the name distributed ledger.

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146   EU Electricity Directive, Brussels, 30.11.2016 COM (2016) 864 final 2016/0380 (COD).
147   There is a misconception that DLT and blockchain are the same thing and the terms are usually used interchangeably. The term blockchain is used in this report in order not to confuse the reader with the continuous interchange of the two terms but DLTs are referred to using blockchain or other similar technologies such as DAGs.

The transactions are saved in a tamper-proof and shared data structure composed of a list of blocks. This data structure is referred to as blockchain. New transactions are inserted in a block at the end of the chain and are linked to the previous block of transactions as each block references the previous block's hash.

The intrinsic nature of blockchains presents some interesting advantages. First of all, it provides disintermediation and uses a model that requires no trust. As a result all exchanges (or transactions) do not require intermediaries or trusted third parties. Moreover, the parties have full guarantee that the transactions will be executed as expected. The fact that there is no central entity that controls the system creates a very resilient system. There is no central point of failure and the system is very difficult to attack and restrain. As a result, the transactions and the data found in the blockchain are under the control of the user community.

Another very important characteristic of blockchains is that they are transparent and immutable. Every modification in the blockchain is visible to everybody. The transactions stored in a blockchain cannot be altered or deleted. Finally, transactions in the blockchain have almost no direct costs.

Even if cryptocurrencies are the first and main use case of blockchains, the technology can be used to implement other decentralized services apart from currency transactions. One of the main reasons for this is the extra features that can be incorporated on top of blockchain technologies. One of the most important ones is probably the use of smart contracts.

A smart contract is a computer program that is capable of executing or enforcing a predefined agreement using a blockchain if and when specific conditions are met. Its main goal is to enable two or more parties to perform a trusted transaction without needing intermediaries. Smart contracts inherit the characteristics of blockchains and so do not have any downtime, censorship, or third party interference.

The unique characteristics that blockchain technologies have, especially when combined with the use of smart contracts, make them very appealing to the energy market and even more so for microgeneration. How they could be used to foster a trusted and lively energy community market is described in what follows.

Microgeneration is the capacity of consumers to produce electrical energy in-house or in a local community. The concept of "market" indicates the possibility of trading the electricity that has been micro-generated among producers and consumers, where a user that acts both as a producer and as a consumer is called a prosumer. Traditionally, this market has been served by pre-defined bilateral agreements between prosumers and retail energy suppliers. This means that until now, electricity-generating prosumers have not had real access to the energy market, which remains a privileged playing field for the institutionalised energy suppliers. So far this fact has impacted heavily on the real large-scale diffusion of micro-generation due to the limited economic advantages this energy generation approach brings to prosumers.

One dominant solution for microgeneration is to have central-to-the-neighbourhood energy storage (see Figure 4.1). The energy is sent there from the producer and is stored until a consumer claims it. In this case prosumers are able to:

- Produce energy and store it in an in-house cache battery (for local energy consumption)
- Consume the stored energy
- Release excess energy to the grid and receive virtual coins in return
- Transfer/Exchange the virtual coins
- Redeem the virtual coins in exchange for energy

When energy is sent to the central storage, a smart meter linked to each producer continuously measures how much energy has been injected in total. These smart meters are the input source for the smart contract. After a predefined amount of energy has been sent to the storage, an energy coin is awarded to the corresponding prosumer.

The central storage is controlled by an application, a middleware controller, which interconnects it with the smart contract. As a result, the controller plays the role of invoking the smart contract at one end, and at the other receiving the readings from the grid, thereby facilitating communication between the two entities.

The energy grid is handled by its own smart contract. It is aware of the entities connected to it, it can transfer a specific amount of energy to a connected energy consumer, and it is aware of how much energy for consumption is available at any time, i.e., how much energy is stored in the central storage. The grid's smart
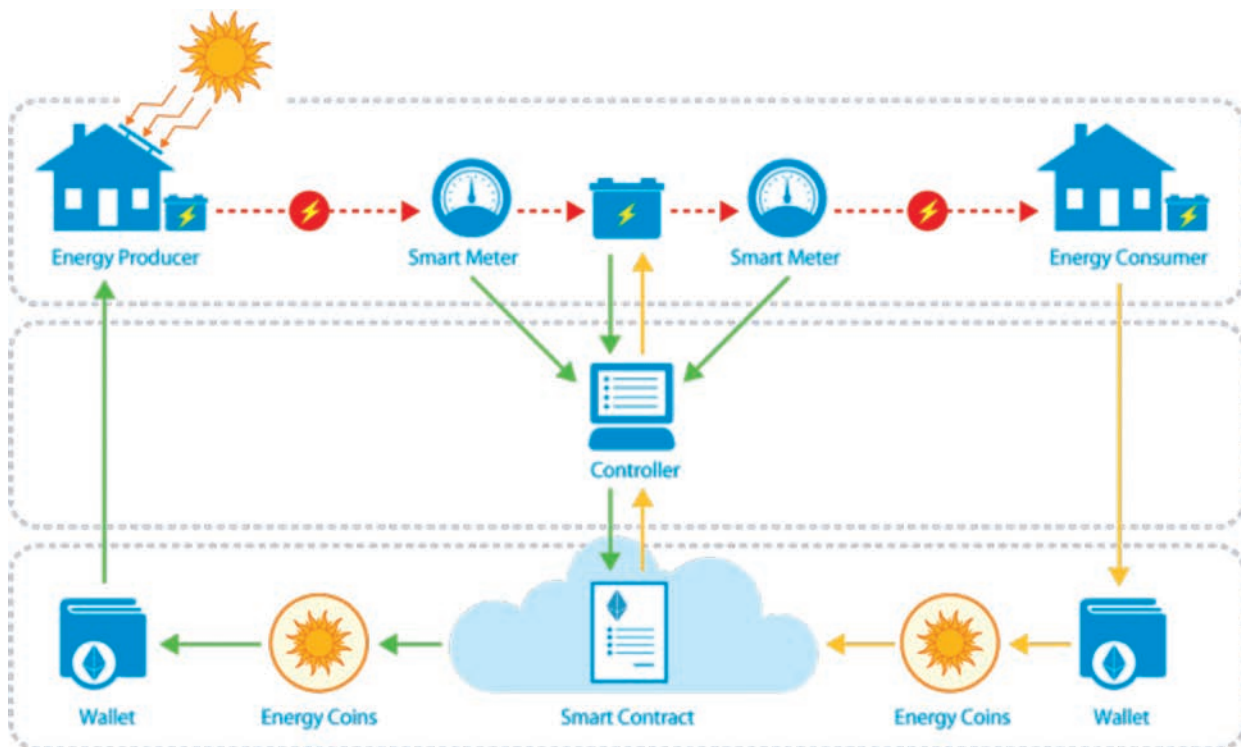
FIGURE 4.1: OVERVIEW OF MICROGENERATION MODEL.
Source: JRC.

contract takes energy coins as input and then releases the energy that corresponds to the amount of energy coins received in the payment made by the sender. All of the interactions and the basic layout of such a system are shown in Figure 4.1.

The way energy coins can be circulated in a market depends on their owners' interests and strategies. The simplest way would be for each owner to have a smart contract in which he sells energy coins in exchange for another asset or coin. It should be noted that the smart meters and the electrical grid in general is considered to be a trusted party, meaning that its measurements and operations are considered to be reliable and are treated as such.

This solution empowers prosumers and gives them control over the energy they produce. The agreements for the generation and redemption of energy coins are transparent and can be verified by any interested party. The same applies for all transactions on the system as well as on handling potential fees. Moreover, the solution is handled by the community and as a result it is in their own interest to keep it working and maintain it.

In terms of opportunities, distributed ledger technologies unveil new markets, with new services and capabilities. Decentralized apps promise to bring costs down, improve

data security and privacy, and bring active participation of consumers.

New capabilities involve outsourced distributed and parallel processing. This is of particular pertinence for tasks which are too resource intensive for a device to compute (such as small sensors or controllers), or tasks that require data beyond that locally available. This is especially true for the devices that comprise the Internet of Things. These devices are typically limited by lack of memory, processing power, and/or energy availability. Such low power devices could simply outsource intensive computations to an external, more capable machine. Such outsourced computations allow secure, permission-less participation for consumers and producers alike. The possibilities of smart devices to impact energy, finance, and health sectors among others are immense.

An example is the participation of timed (and non-timed to some extent) smart devices on real time power forecast for the intraday markets. A cooperation of component manufacturers, open source based projects, and service providers is able to foster a technological leap and innovation rush.

Apart from the positive aspects mentioned above, some disadvantages may be present in this solution as well.

One of the most important ones would be the privacy implications such a solution may have. Since all the transactions and energy exchanges are recorded on a blockchain that is shared between participating entities, anyone's transaction can be seen by others.

This is currently a common blockchain issue due to the nature of the technology. There are other blockchain systems that provide encrypted and privacy friendly transactions, but they do not offer the functionality of smart contracts yet. Nevertheless, it seems that blockchain privacy issues for targeted use cases could be solved in the near future.

Finally, another disadvantage is that users will need some extra equipment in order to use such a system. Even if this were a one-time purchase that is generally low cost, it could still increase the total overhead cost.

4.2.2.6. *Big Data*

The technical progress and widespread application of ICT devices in the physical network provide a new vision for engineers to create a smarter power system. The amount of data collected via the advanced metering infrastructure in power systems are increasing, and will continue to do so at a fast speed. For example, one million smart meters in an urban distribution network for recording customers' electricity consumption will generate 35.04 billion records per year with a sampling rate of every 15 minutes (Sagiroglu, et al., 2016) Much more data will be collected from various sources in the power systems listed in Figure 4.2 (Zhang, et al., 2018).

The referenced articles (Sagiroglu, et al., 2016; Zhang, et al., 2018) provide a discussion on the interaction between smart grids and big data.

> " *The flow of data through the new energy system will be as important as the flow of energy itself* "
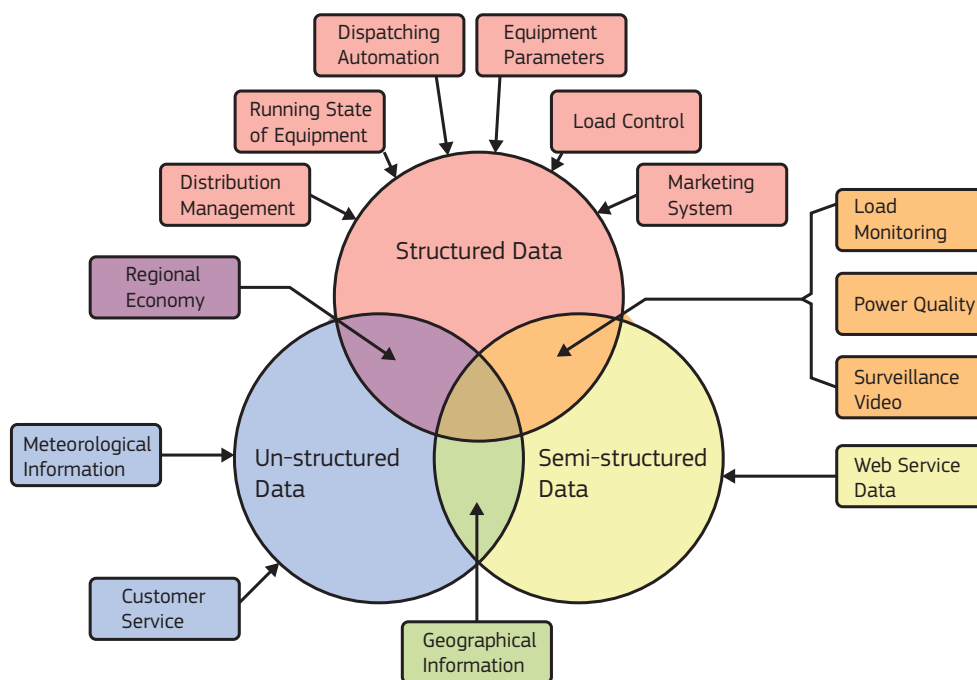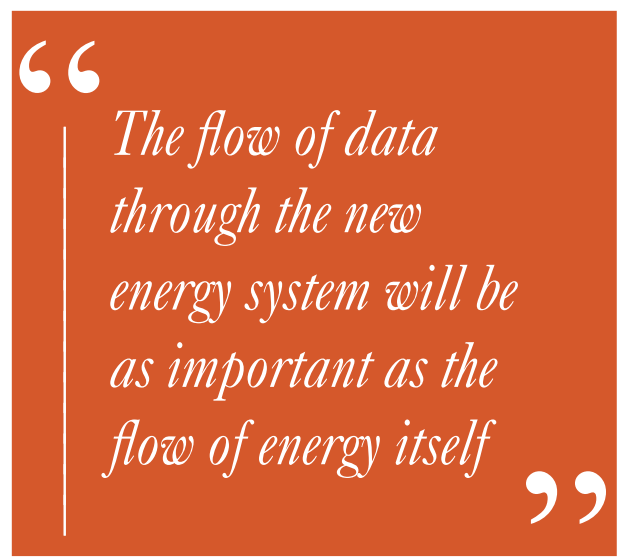
FIGURE 4.2: DATA SOURCES OF THE GRIDS.
Source: Zhang, et al., 2018.

4.2.2.7. *Artificial Intelligence*

Artificial Intelligence is the development of intelligent systems and agents with the ability to learn from circumstances and solve problems by themselves. Successful achievements in data science have attracted the public's attention to many advanced algorithms such as Deep Learning (DL) and Reinforcement Learning (RL), which are making breakthroughs in autopilot technology, image recognition, natural language processing, industrial robots, and so on. This also brings a promising possibility for transforming the traditional energy system into an intelligent one. Several applications of AI have been used or might be used in the future for power system including condition-based maintenance, power quality monitoring, renewable energy forecasting, demand profiling, non-technical loss detection, demand side response, transient stability analysis, power protection, etc..

The energy impact of AI is difficult to measure because AI is still in active development and has limited adoption so far. However, some recent trends can help evaluate its future energy impact. AI is a computational process which needs chips, memory, networking, cooling, infrastructure, etc. that has energy costs. The energy impact of AI will be significant due to widespread technology acceptance and competition unless mitigating factors are developed such as energy saving microprocessors, better infrastructure, and renewable energy usage.
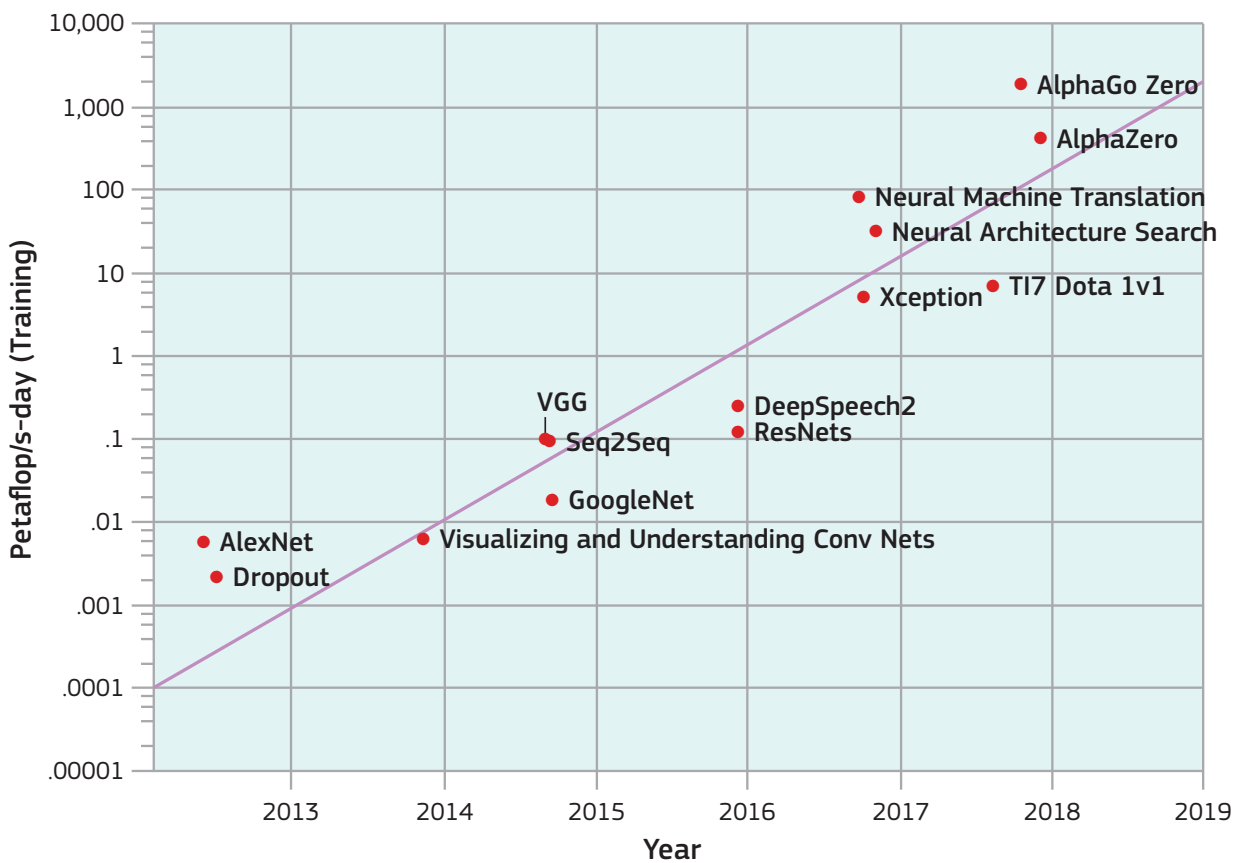
FIGURE 4.3: FROM ALEXNET TO ALPHA ZERO.
Source: OPEN AI (https://blog.openai.com/ai-and-compute/).

Since 2012, the amount of computational power used in the largest AI training runs has been increasing exponentially with a 3.5 month-doubling time and grown rate of more than 300,000x[148]. Figure 4.3 shows the total amount of computing in petaflop/s-days necessary to train relatively known AI algorithms. A petaflop/s-day (pfs-day)

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148   https://blog.openai.com/ai-and-compute/

consists of performing 10^{15} or 10^{20} neural net operations per second for one day. The largest training runs today employ hardware with costs in single digit millions of dollars. Currently the majority of AI computational power is still spent on inference (deployment) and not training. Government AI plans will shape computational power growth and possible energy impact. The European Commission proposes a new Digital Europe programme with an overall budget of €9.2 billion to shape and support the digital transformation of European society and its economy (European Commission, 2018). China wants to become AI world leader by 2030 with massive AI infrastructure investments with industry scale exceeding 1 trillion RMB (133 billion Euro), and with the scale of related industries exceeding 10 trillion RMB (1,330 billion Euro)[149]. The USA leads the world in AI companies, start-ups, research institutions, and universities and has the number one high performance computer "Summit" at the US Department of Energy's Oak Ridge National Lab.

The new emerging chips have substantial data processing and power efficiency. The industry experiments with field-programmable gate arrays (FPGAs) and application-specific integrated circuits (ASICs) as the next primary chips for AI and machine learning (ML). Both FPGAs and ASICs consume less energy than central processing units (CPUs) and graphics processing units (GPUs). Google has deployed an AI chip named Tensor Processing Unit (TPU) that achieves much better energy efficiency than conventional chips or 30x to 80x improvement in TOPS/Watt measure (tera-operations [trillion or 10^{12} operations] of computation per Watt of energy consumed), as shown in Figure 4.4.
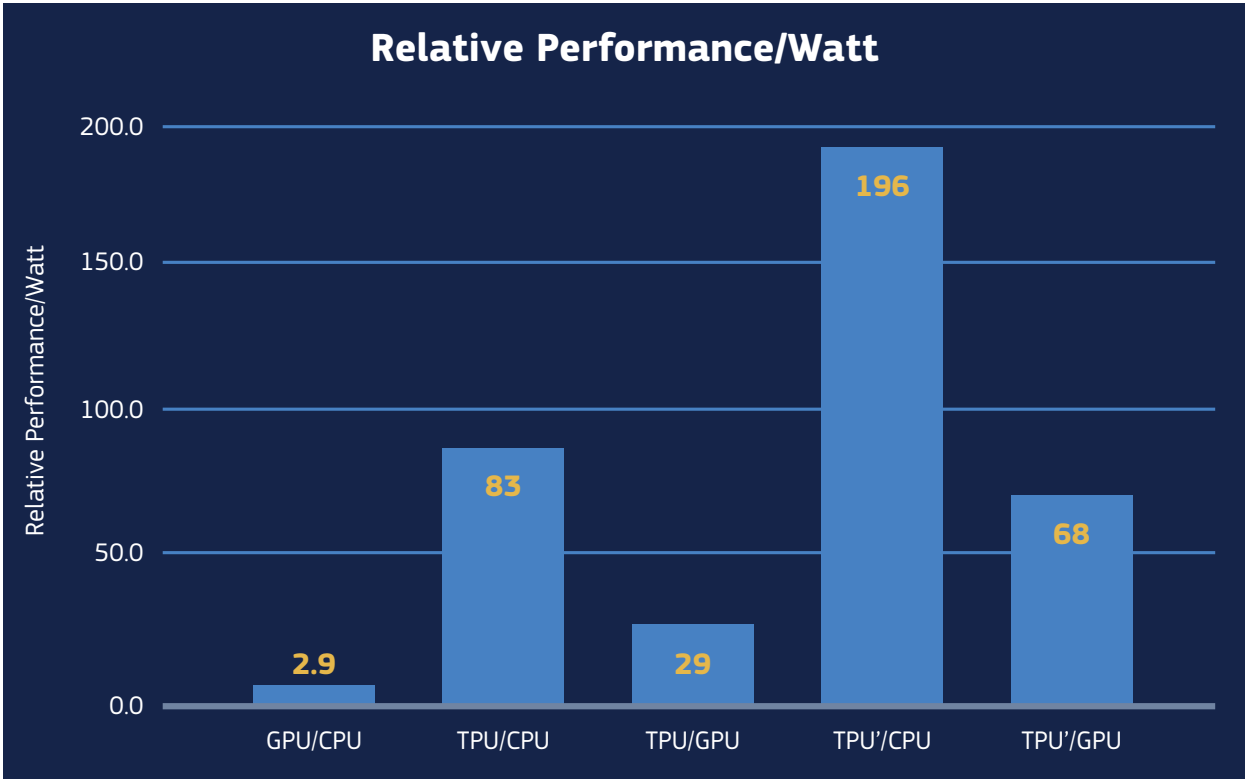
FIGURE 4.4: TPU ENERGY EFFICIENCY COMPARED TO CONVENTIONAL CHIPS.
Source: Google (https://cloud.google.com/blog/products/gcp/quantifying-the-performance-of-the-tpu-our-first-machine-learning-chip).

AI algorithms are an important component of datacentre infrastructure optimization for reducing energy consumption. DeepMind's AI algorithm achieved 40% energy reduction in cooling Google datacentres[150]. US technology giants including Apple, Google, and Facebook are increasingly powered by renewable energy, contributing to protecting the environment and reducing climate change. There is a trend among the world's ICT companies to invest in renewable energy project and purchase clean energy from utilities.

[149]   http://www.gov.cn/zhengce/content/2017-07/20/content_5211996.htm
[150]   https://deepmind.com/blog/deepmind-ai-reduces-google-data-centre-cooling-bill-40/

The short-term AI future energy forecasts are:

- AI computational power will grow dramatically. Widespread AI adoption could potentially increase energy demand and impact energy markets.

- The future AI and ICT infrastructure, especially the chips, will be very power efficient and usually powered by renewable energy sources.

4.2.2.8. *Cyber-Security*

Living in the Internet era means that machines can talk to other machines. This is what has been previously defined as the Internet of Things.

Bringing the concept of IoT to the next level, where entire facilities are interconnected and interact with other facilities and services, has paved the way to what today is called "Industry 4.0" i.e. a new complex and interleaved way of manufacturing where everything is interconnected within the supply chain.
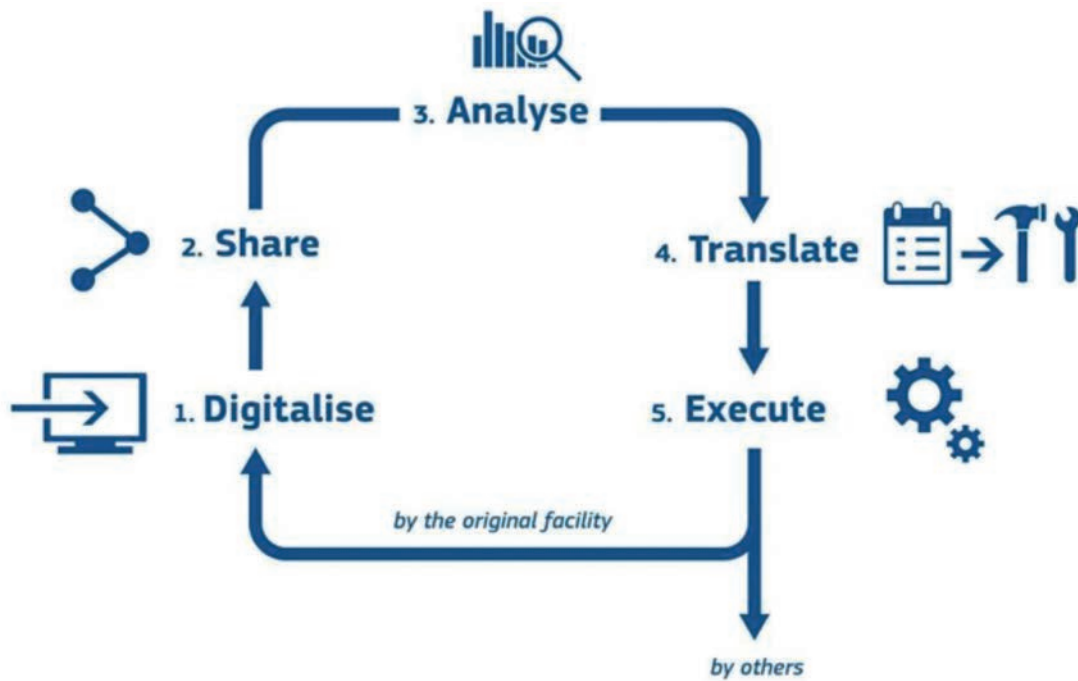
FIGURE 4.5: KEY STEPS OF INDUSTRY 4.0 OPERATIONS.
Source: JRC.

As shown in Figure 4.5, Industry 4.0 is based on 5 main steps:

- Data acquisition from the physical world (digitalise a physical status)
- Data sharing (within the same facility or with other facilities and services)
- Data analysis
- Decision making (possibly automated and driven by machine learning and artificial intelligence applications)
- Translation into physical actions...

- ...to be executed by the original facility or by others

It is clear that the potentialities of the Industry 4.0 paradigm are enormous, ranging from the optimisation of the supply chain to the possibility of developing personalised products with the economics of scale of mass production.

The implementation of this paradigm calls for a huge level of interconnection, thinning the barriers that traditionally protect industrial facilities.

This evolution involves all sectors of industry, and in the Energy sector it is at the root of the "Smart-grid revolution".

Figure 4. 6 depicts the evolution of threats to industrial systems in the last two hundred years. This process is also fully valid for the energy sector.
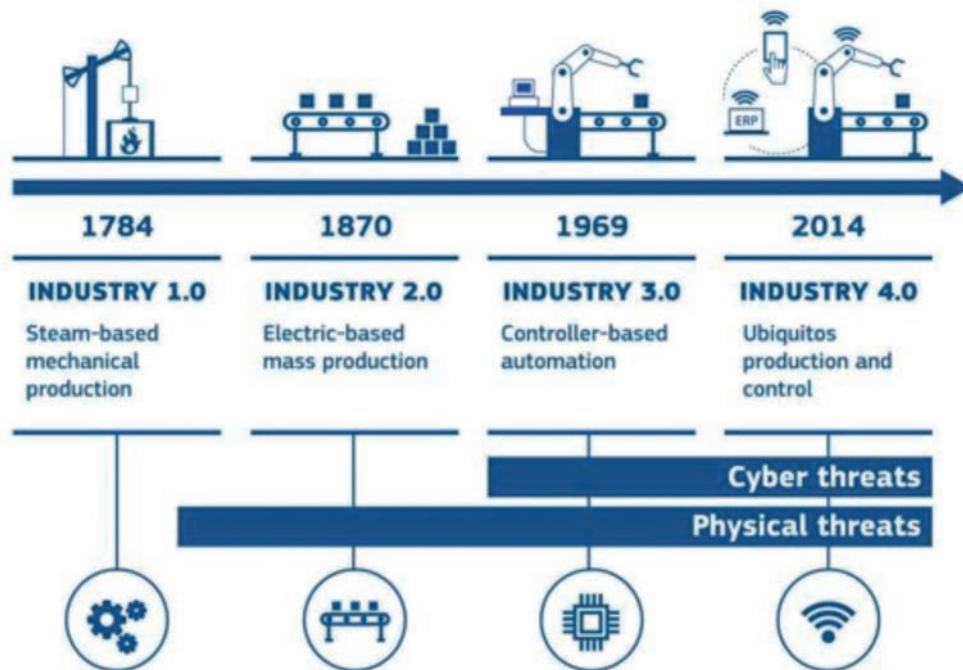
FIGURE 4.6: HISTORICAL EVOLUTION OF INDUSTRY.
Source: JRC.

While physical threats have been present since the beginning, it was only after the appearance of controller-based automation and the migration from serial communication to TCP that industry started facing the risk of cyber-attacks.

Since that moment, the evolution of industrial systems went side by side with the evolution of cyber-attacks, and in fact the most well-known were conceived to target energy installations: Stuxnet, Duqu, Black Energy 3 (used in the 2015 attack against the Ukraine energy infrastructure leaving 230000 citizens without energy for hours), are only few of the malwares developed to target the energy system.

But why are Energy infrastructures vulnerable?

There are many reasons for which energy infrastructures are potentially prone to cyber-attacks:

1. **Legacy Devices**: Industrial installations are expensive to build and maintain, especially in the case of big installations, so their evolution has typically followed an incremental, plug-in, approach. New technologies

were added on top of the existing layers to guarantee backward compatibility with the devices that for one reason or another could not be changed. Consequently, today modern IoT devices coexistence simultaneous with legacy devices. Legacy devices were deployed at a time when energy installations were considered "closed environment", hardly accessible remotely, hence designed without any specific form of protection against cyber-attacks. The shift of the paradigm due to the digitalisation of energy, with the need to abandon the old and secure "segregation" approach, has had the effect of potentially exposing legacy devices.

2. **Slow maintenance processes**: when a vulnerability is discovered, the vendors typically release appropriate patches to fix it. However, as the installation of a new patch might require the industrial process and an energy installation to stop, with huge costs, the time between the discovery of a vulnerability and its mitigation might be not negligible. Even worse, legacy devices might not be patchable at all.

3. **Complexity and Cascading effects**: Energy installations are complex, often composed of thousands

of devices, and this already constitutes an enormous challenge from a cyber-security perspective. In the era of energy digitalisation in which more and more installations are cooperating together (even at cross-national level), the establishment of cyber-security posture becomes even more complicated as cascading effects can impact segments of the grid very distant from the place in which a cyber-attack first hit. For example, if the integration between Smart-Grids, vehicle electrification, Smart-buildings is considered, it is clear what the cascading effects could involve, or how it could be triggered by infrastructures that are generally perceived as completely unrelated to the traditional concept of an energy grid.

4. **Governance of cyber-security:** the previous point introduces another extremely relevant problem, which is the governance of cyber-security. The energy grid is not only becoming more and more of a "system of systems" at the physical level but also at the control level. This implies that the global cyber-security of the energy grid has to rely on the cyber-security of each single infrastructure which is extremely heterogeneous due to different regulations, internal rules, etc. Hence the biggest challenge is to shift from the island model of cyber-security governance to a "cooperative model" where each party does its duties in terms of cyber-security for the well-being of the collective infrastructure.

The ICT infrastructures of the energy sector are technically similar to any other ICT devices so, in theory, cyber-security protocols should be similar to those adopted for general purpose ICT devices.

As previously stated above, what makes it harder to mitigate the risks here are:

1. The constraints on the operations in the plant (the so called "industrial processes") which might make the application of a particular common cyber-security practice impossible
2. The heterogeneity of the installed devices' security posture
3. The increasing pervasiveness and logical extension of these systems which makes identifying the boundaries of what to protect more difficult.

4. The deeper integration with services which are part of the citizen's daily life, implying citizen concerns about safety and data protection matters

Looking at the future evolutions, the second and last points are probably the most relevant and challenging. How do we ensure the cybersecurity of a system which does not have clear boundaries and relies on third parties who are not subject to the same security constraints?

The answer to this question contains the following points:

— Need for identification and enforcement of appropriate cybersecurity standards in industrial installations
— Introduction of the principles of cyber-security and data-protection in the design of the new installations
— Introduction of cybersecurity certification schemes ensuring a minimum level of cybersecurity in the devices deployed in industrial installations
— Need for a sound debate on the "governance" of cyber-security, especially about complex systems relying one on the services of others
— Introduce cybersecurity into the curricula of industrial and process engineers

The European Commission is already taking the first relevant steps on all these points, for example:

■ After 2 years of work and the involvement of more than 400 operators, in 2016 the Commission together with Energy Smart-Grid Task Force released a guide to the Best Available Techniques to securing smart-metering systems for the first time
■ In 2018 the Commission released the first Data-Protection Impact Assessment template, specifically designed to guide the energy operators in assessing the compliancy of their installations against the General Data Protection Regulation
■ In 2019 the Commission released the recommendation on cybersecurity in the energy sector to focus the attention of operators and MS on the subject

Indeed, these are clear signs that the energy community, the Commission, and the Member States are well aware of the risks from potential cyber-attacks against the energy grid.

4.2.3. Standardisation and Legal Framework

4.2.3.1. *Legal Issues*

Access rights to privately held data might play an important role in many IoT applications, for example, in smart homes or smart energy applications, so several stakeholders such as the tenants, the facility management, the producer of the devices as well as energy companies and others may have legitimate interests in the same data and may have contributed in producing them.

In 2017, the Commission stressed that it was essential to enable access to relevant non-personal or anonymised data to ensure functioning, efficiency, and profitability in the market of the energy sector.

Smart metering creates enormous amounts of data which, if shared and re-used, can create substantial efficiency and competitiveness gains for companies, and there is a clear awareness of the importance of facilitating data sharing in the sector as outlined in the Internal Electricity Market Directive and as put forward in the recast proposed Directive.

This Directive calls on Member States to organise the management of data so as to ensure efficient data access

> *The development of new automation and ICT-systems, as well as analysis of non-personal or anonymised data, are needed to adapt to changes in the energy sector*

and exchange, and agree on a common data format and a transparent procedure for this purpose (Articles 23 and 24).

4.2.3.2. *Interoperability*

Interoperability is defined as the ability of a piece of equipment to be integrated in a system and exchange meaningful information, understand the information exchanged and comply with the system rules, all while maintaining the required quality of service.

Connecting all of the pieces in a power grid gives rise to an interconnected network in which communication and analysis will take place in real time. Information and communication technologies such as machine-to-machine communicators, agent technology, and the Internet of Things will enable the migration of classic power system towards the modernisation of the grid.

Interoperability is an essential requirement for this migration since any operational, architectural, and functional failure will have high costs due to the

scale of the power system and its economy. Moreover, interoperability is crucial to having a market open to all vendors and integrators, where the operators can concentrate on the top-level functions independent from proprietary solutions. Consequently, interoperability is a technical imperative and at the same time is the enabler of an open market in which innovation and competition are able to flourish.

Furthermore, interoperability facilitates a single consistent and comprehensive security framework. The concept "security through obscurity" which implies that the secrecy of the design is used as the main means of security has already been proven to be ineffective.

According to the European Telecommunications Standards Institute (ETSI)[151], there are different types

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[151]   http://www.etsi.org/images/files/ETSIWhitePapers/IOP%20whitepaper%20Edition%203%20final.pdf

> **Interoperability is crucial for open markets and to avoid vendor lock-ins.**

of interoperability, namely the Technical, the syntactic, the Semantic, and the Organizational interoperability, as shown in Figure 4.7.

Technical interoperability is defined as a state that involves hardware and software components which enable communication between infrastructures. Syntactic interoperability concerns data formats and the way the messages that need to be transferred are formed. Semantic interoperability ensures that the information received is interpreted correctly by all the applications involved. Finally, organizational interoperability deals with the ability of organizations to communicate and exchange useful data.
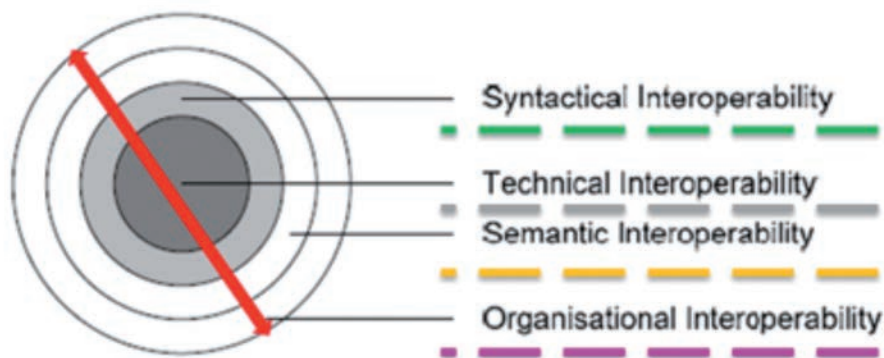
FIGURE 4.7: DIFFERENT TYPES OF INTEROPERABILITY ACCORDING TO ETSI.
Source: ETSI.

In the domain of smart grids, a framework that has been used for Interoperability purposes is the smart grids architecture model (SGAM) which is shown in Figure 4.8. SGAM is the main outcome of the Reference Architecture working group assigned by the EU 490 Mandate[152] titled "Smart Grid Mandate – Standardization Mandate to European Standardization Organizations (ESOs) to support European Smart Grid deployment".

There are five different layers of interoperability in the SGAM framework:
- Business layer, which represents the business view on the information (business models, market structures, business portfolios, etc.)
- Functional layer, specifying the functions and services
- Information layer, which is the data model to be used to ensure a common understanding of the data exchanged

- Communication layer, which is the communication technology (e.g. PLC or Ethernet) and the communication protocol for data transmission
- Component layer, which is the hardware to connect systems or devices such as power cables (physical distribution)

It also entails five power conversion domains (generation, transmission, distribution, DER, Customer Premises) and six zones focused on information management at different scales (process, field, station, operation, enterprise, market). The SGAM is an abstraction used to help different stakeholders (engineering community, policy makers etc.) to have a common and unified perception of aspects of Smart Grids.

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[152] https://ec.europa.eu/energy/sites/ener/files/documents/2011_03_01_mandate_m490_en.pdf.
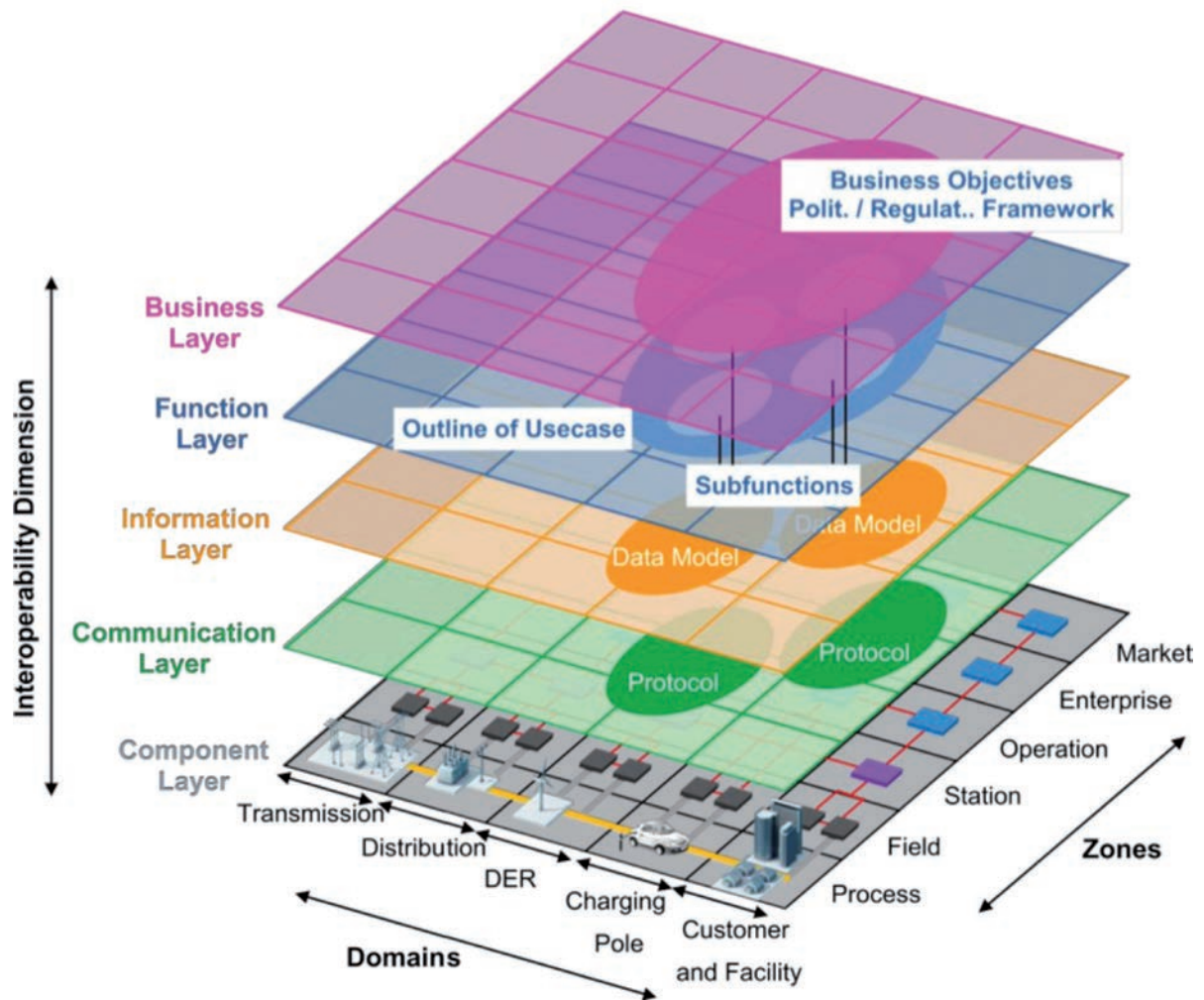
FIGURE 4.8: SMART GRIDS ARCHITECTURE MODEL (SGAM).
Source: CEN-CENELEC-ETSI.

4.2.4. Innovation, Business models, and Skills

4.2.4.1. *Digital energy start-ups*

The most essential elements of a modern economy are to create, exploit, and commercialise new technologies. Digital entrepreneurs and start-ups are one of the main vehicles by which digital potential is converted into economic benefits. Digital start-ups are more likely than existing businesses to pursue opportunities associated with radical innovations that may have transformative consequences for the society and economy. Indeed, the last two decades of the digital transformation has showed that such newcomers as Skype, Uber, or Airbnb quickly disrupt traditional industries.

In the past, the Energy sector has attracted many (digital) entrepreneurs because of the popularity of green energy technologies. While many of them have failed, some of them have managed to survive and succeed in the marketplace. For example, with valuation of nearly $10Bln, the Vital Renewable Energy Company is one of the most valued start-ups in the Energy sector. Based in Brazil, the company operates in the investment industry in renewable energy focused on the production of ethanol and sugar[153].

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[153]   https://app.dealroom.co/companies/vital_renewable_energy_company

Considering their key role in the digital transformation, this section looks at the number of Venture Capital (VC) investments in digital energy start-ups over the period between 2000 and 2017. It uses Venture Source by Dow Jones as a source of data for global venture capital (VC) activity and VC-backed start-ups. In order to identify digital energy start-ups, two sets of companies are considered:

■ Digital start-ups in the Energy sector: this set includes start-ups in the Energy sector whose description of activity includes any digital-related keyword.

■ ICT start-ups providing applications to the Energy sector: this set includes start-ups in the ICT sector whose description of activity includes any Energy-related keyword.

Figure 4.9 presents the total number of Energy start-ups and the percentage of digital start-ups in the Energy sector that received VC funding between 2000 and 2017. Out of 2578 Energy start-ups, 187 or 7% can be considered as digital start-ups. The figure shows that there was a growing number of VC-backed start-ups in the Energy sector at
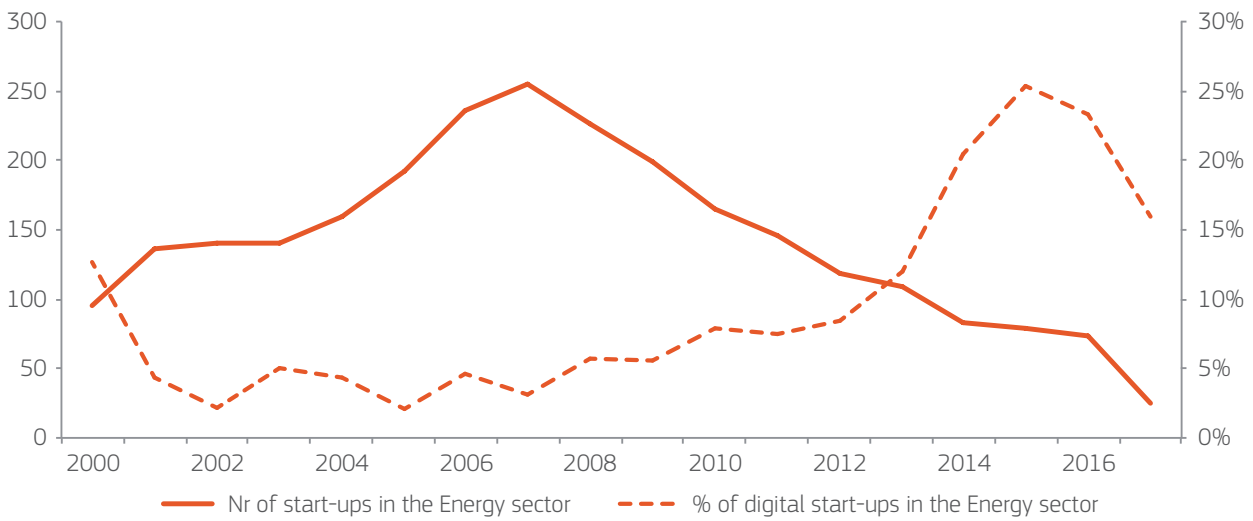
FIGURE 4.9: TOTAL NUMBER OF ENERGY START-UPS AND % OF DIGITAL START-UPS IN THE ENERGY SECTOR.
Source: JRC analysis based on Venture Source, Dow Jones data.
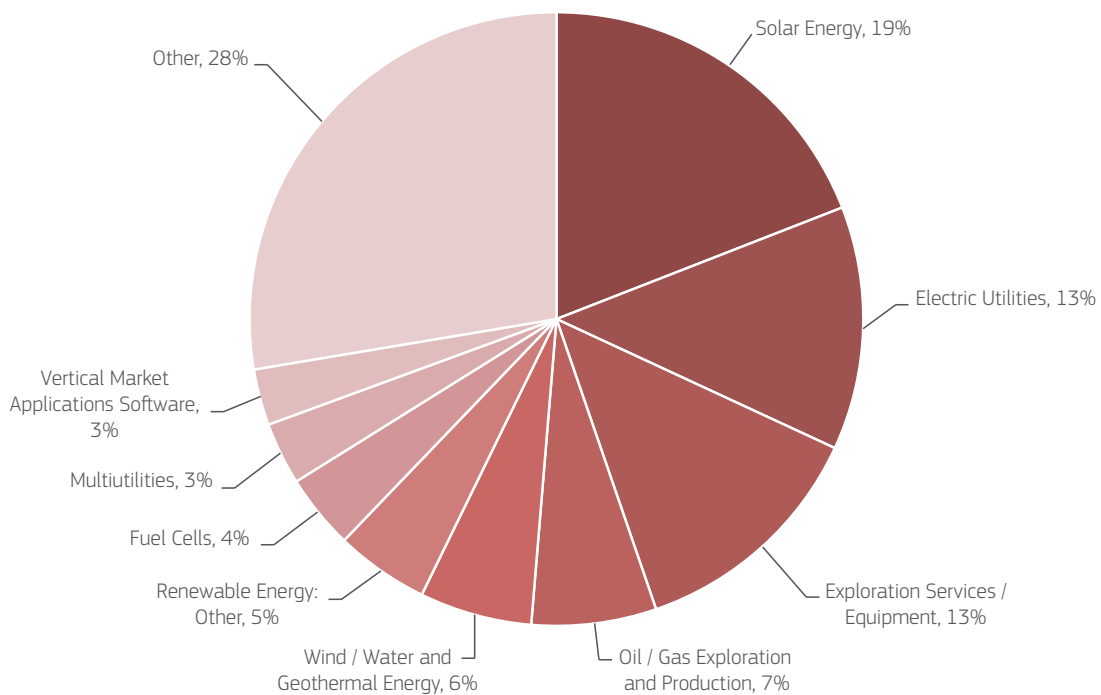
FIGURE 4.10: AREAS OF ACTIVITY OF DIGITAL START-UPS IN THE ENERGY SECTOR.
Source: JRC analysis based on Venture Source, Dow Jones data.
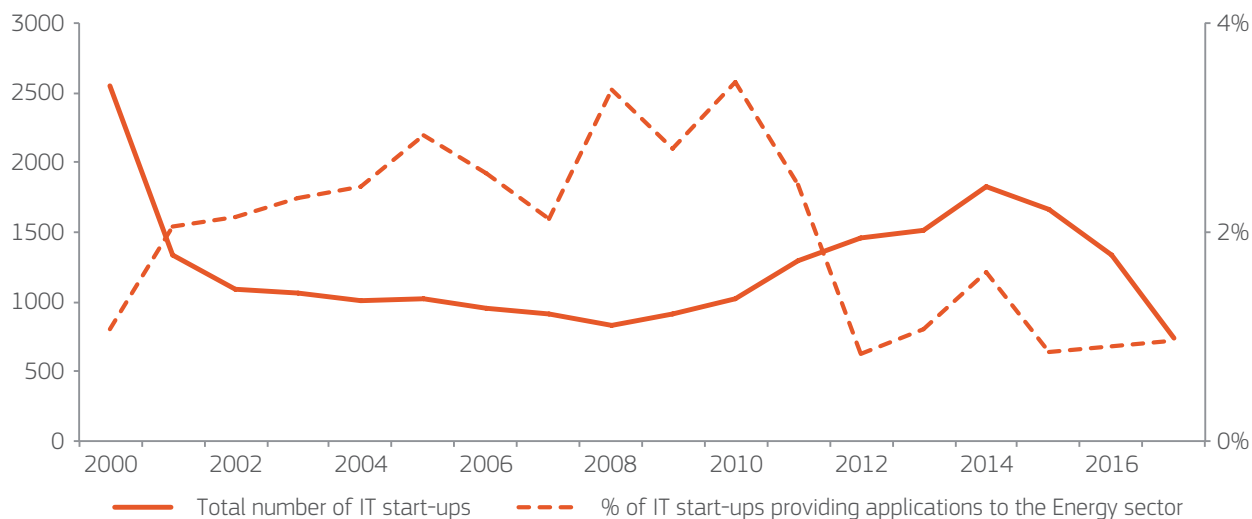
FIGURE 4.11: TOTAL NUMBER OF ICT START-UPS AND % OF ICT START-UPS PROVIDING APPLICATIONS TO THE ENERGY SECTOR.
Source: JRC analysis based on Venture Source, Dow Jones data.
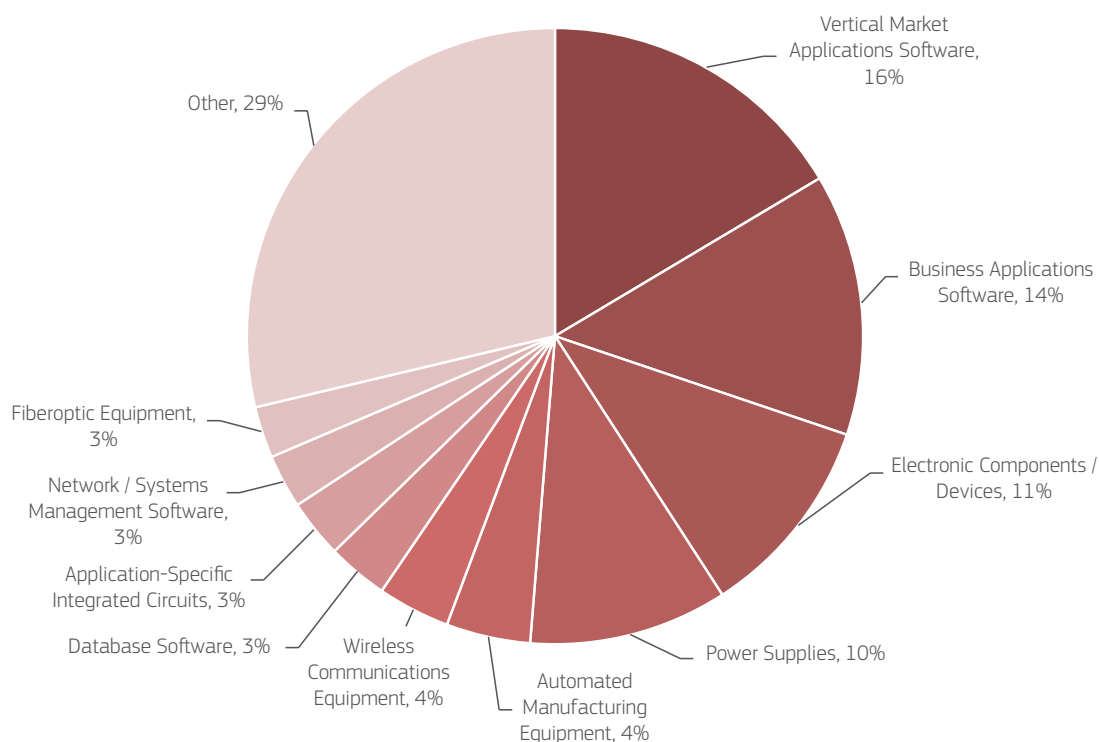
FIGURE 4.12: TYPE OF APPLICATIONS PROVIDED TO THE ENERGY SECTOR BY ICT START-UPS.
Source: JRC analysis based on Venture Source, Dow Jones data.

the beginning of the 2000s. This trend lasted until 2007. At the beginning of the last economic crisis, the number of VC-backed Energy start-ups considerably decreased. However, at the same time the share of digital start-ups in the Energy sector increased and reached its maximum in 2015. In this year, 25% of Energy start-ups were digital start-ups. Their most common activities include Solar Energy (19%), Electric Utilities, and Exploration Services (both 13%) (see Figure 4.10).

Figure 4.11 shows the total number of start-ups in the ICT sector and the percentage of start-ups in the ICT sector that provide applications to the Energy sector and which received VC funding between 2000 and 2017. Out of 22548 digital start-ups, 404 developed and provided ICT applications targeting the Energy sector. During the first decade of the twenty-first century, the share of ICT start-ups supplying applications to the Energy sector showed an upward trend. It reached its peak in 2008. Following

the beginning of the last financial crisis, the share of ICT start-ups supplying applications to the Energy sector continued to decrease. In 2017, approximately 1% of all ICT start-ups developed and supplied digital applications to the Energy sector. The most common applications provided by digital start-ups to the Energy sector include "vertical market application software", "business application software", and "electronic components/devices" (see Figure 4.12).

Figure 4.13 displays the total amounts of VC investments in digital energy start-ups by world regions between 2007 and 2017. The US start-ups received the largest amount of VC investments, i.e., over €6.35Bln. Second in the ranking is China followed by Europe. VC funds invested nearly €0.8Bln in digital Energy start-ups in each region.

The following conclusions can be drawn from the analysis of digital energy start-ups shown above:

- While the total number of VC-backed start-ups in the Energy sector has been constantly decreasing over the last few years, the share of digital start-ups in the Energy sector increased. However, at the same time the share of ICT start-ups providing applications to this sector decreased.
- The most common activities of digital start-ups in the Energy sector include Solar Energy, Electric Utilities, and Exploration Services. Digital applications addressing the needs of the Energy sector include "vertical market application software", "business application software", and "electronic components/devices".
- The US attracted 75% of global VC investments in digital energy start-ups. China and Europe account for 9% of total investments each.
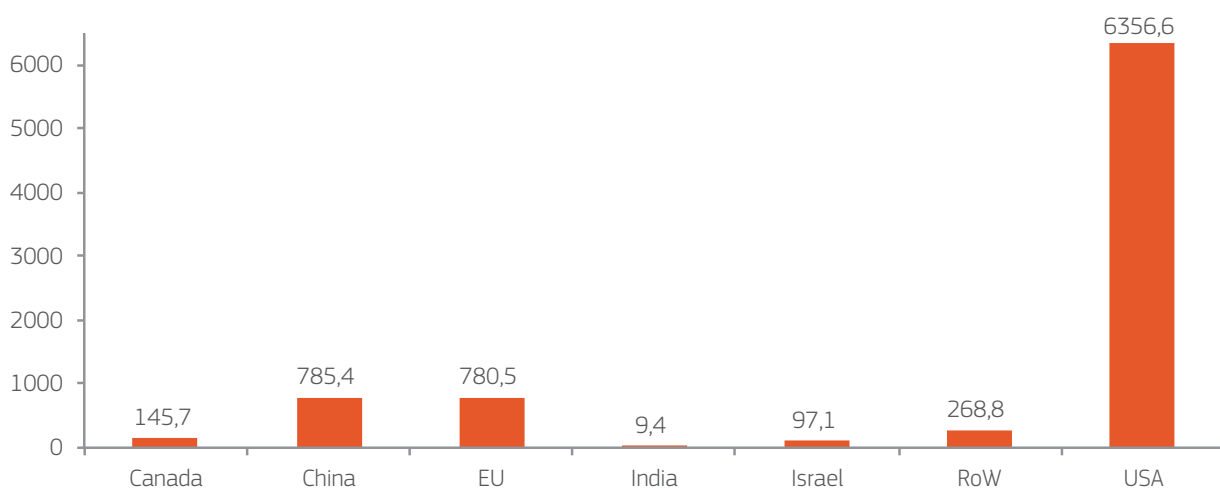
FIGURE 4.13: VC INVESTMENTS IN DIGITAL ENERGY START-UPS BY REGION, 2000-2017, M€.
Source: JRC analysis based on Venture Source, Dow Jones data.

4.2.4.2. *Smart Specialisation*

The European Commission's Cohesion Policy aims to reduce differences between regions and to ensure growth across Europe. Structural Funds are one of its main tools. Its efficient use and management is a crucial factor in ensuring growth in many regions in Europe. Consequently, developing a *Research and Innovation strategy for Smart Specialisation* (RIS3) is currently a prerequisite in receiving funding from the European Regional Development Fund (ERDF).[154]

Smart Specialisation is a policy concept whose objective is to support local and regional innovation through the establishment of partnerships between industry, public entities, and knowledge institutions (Triple Helix model[155]).

The official definition of Smart Specialisation Strategy, as per the Regulation (EU) No. 1303/2013 of the European Parliament and of the Council, reads:

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[154] https://ec.europa.eu/jrc/en/research-topic/smart-specialisation
[155] https://triplehelix.stanford.edu/3helix_concept

'Smart specialisation strategy'(S3) means the national or regional innovation strategies which set priorities in order to build competitive advantage by developing and matching research and innovation own strengths to business needs in order to address emerging opportunities and market developments in a coherent manner, while avoiding duplication and fragmentation of efforts; a smart specialisation strategy may take the form of, or be included in, a national or regional research and innovation (R&I) strategic policy framework.'

Following the Communication titled *'Regional Policy contributing to smart growth in Europe 2020'*, the Smart Specialization Platform (S3P) was established in 2011. The role of the S3P is to provide information, methodologies, expertise, and advice to national and regional policy makers as well as contributing to academic debates around the concept of smart specialisation. The S3P is hosted by JRC's Growth and Innovation Directorate (Dir. B) in Seville, and the activities are carried out by Dir. B and Dir. C (Energy, Transport, and Climate) in close collaboration with DG REGIO and DG ENER.

The Smart Specialisation Platform proposes services such as:

- Providing guidance material and good practice examples,
- Organising information sessions for policy makers and participating in conferences,
- Providing training to policy-makers,
- Facilitating peer-reviews,
- Supporting access to relevant data,
- Participating in high quality research projects to inform strategy development and policy making.

Smart Specialisation Platform on Energy

Energy is a topic of great interest to the Member States and regions registered on the S3 Platform.

The Smart Specialisation Platform on Energy (S3PEnergy) is one of the three S3 thematic platforms, the others being *Agrifood* and *Industrial Modernization*. S3PEnergy is a space where Member States (MS), regions, and community members receive support for the optimal and effective uptake of Cohesion Funds for sustainable energy.

The main objectives of S3PEnergy are:
- to support the implementation of the smart specialisation strategies of those regions/countries that have chosen energy-related priorities in their S3 (under Thematic

> **Smart Specialisation in the energy sector increasingly supports innovation through partnerships between industry, public entities, and knowledge institutions**

Objective 1) especially regarding energy innovation activities at (sub)national, regional, and local levels.
- to assist countries in taking up Cohesion Policy funding opportunities for energy (under TO 4 and 7e);

S3PEnergy collaborates with interested regions and Member States (MS) to: (i) analyse current energy priorities and policies, and (ii) identify good practices and roadmaps for bottom-up transregional and transnational cooperation.

The next goal is to set up a collaborative framework which will accelerate the development and deployment of innovative low carbon technologies. The platform's tasks are to prepare thematic papers and carry out active outreach activities, to build and disseminate knowledge to MS, regions, and other interested stakeholders about taking advantage of investment opportunities from the Cohesion Policy funds for energy projects. It also supports the identification of common challenges and the establishment of solutions, including by mapping S3 priorities in energy and sharing good practices.

The main tasks of the S3PEnergy platform are divided into four work packages, shown in Figure 4.14:
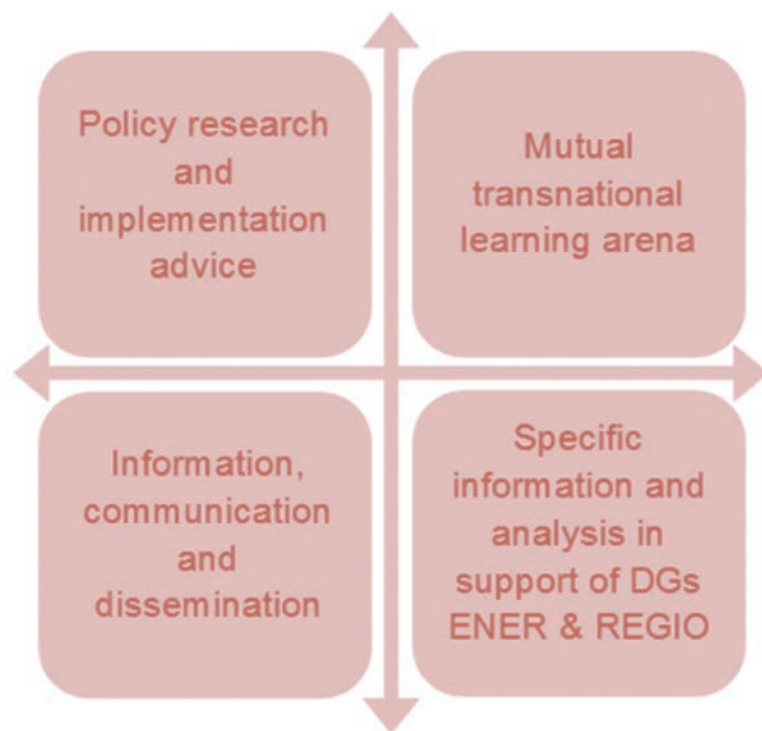
FIGURE 4.14: S3PENERGY WORK PACKAGES.
Source: JRC.

S3PEnergy not only promotes cooperation within regions but also between regions. Proactive 'match-making' is provided to MS and regions that have planned investments in energy innovation. In this context, S3PEnergy is currently supporting the regions that share similar/complementary energy priorities in their S3 strategies to mobilize concrete investment projects by facilitating the creation of *S3 Energy Partnerships*[156] that offer interactive and participatory arenas for interregional cooperation. S3PEnergy

collaboration helps regions combine complementary strengths, use their competences in R&I, build necessary research capacities, overcome the lack of critical mass and fragmentation, improve access to the global value chains, and foster partnerships and/or co-investment.

There are currently five partnerships hosted by S3PEnergy: Bioenergy[157], Marine Renewable Energy[158], Smart Grids[159], Solar Energy[160], and Sustainable Buildings[161].

4.2.4.3. *Territorial aspects: Contribution of Digital Innovation Hubs to Digital Transformation in the Energy Sector*

Digital Innovation Hubs[162] (DIHs) are one-stop-shops that help companies become more competitive in their business/production processes, products, or services by using digital technologies. They are based on technology infrastructures (competence centres) and provide access to the latest knowledge, expertise, and technology to support

their customers with piloting, testing, and experimenting with digital innovations.

DIHs also provide business and financial support so that these innovations can be implemented across the value chain. As proximity is considered to be crucial, they act

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[156] http://s3platform.jrc.ec.europa.eu/s3-energy-partnerships
[157] http://s3platform.jrc.ec.europa.eu/bioenergy
[158] http://s3platform.jrc.ec.europa.eu/marine-renewable-energy
[159] http://s3platform.jrc.ec.europa.eu/smart-grids3
[160] http://s3platform.jrc.ec.europa.eu/s3-energy-partnerships-solar-energy
[161] http://s3platform.jrc.ec.europa.eu/sustainable-buildings
[162] http://s3platform.jrc.ec.europa.eu/digital-innovation-hubs

as an initial regional point of contact and strengthen the innovation ecosystem. A DIH is a regional multi-partner cooperative organisation, including organizations such as research and technology organisations (RTO), universities, industry associations, chambers of commerce, incubator/accelerators, regional development agencies, and even governments. DIHs can also have strong links with service providers outside their region, supporting companies with access to their services.

Digital Innovation Hubs in Member States and regions are contributing to the digital transformation of enterprises in many sectors.

Indeed, 93 fully operational DIHs in the energy sector (and selecting "Electricity, Gas & Water supply" in the online DIH catalogue of the S3P[163]) state that they are offering digitisation services to companies and contributing to the digital transformation process in the energy sector[164].

Country distribution of Fully Operational Energy DIHs

The 93 above-mentioned DIHs that provide digitalisation services in the Energy sector are distributed by EU country as shown in Figure 4.15.
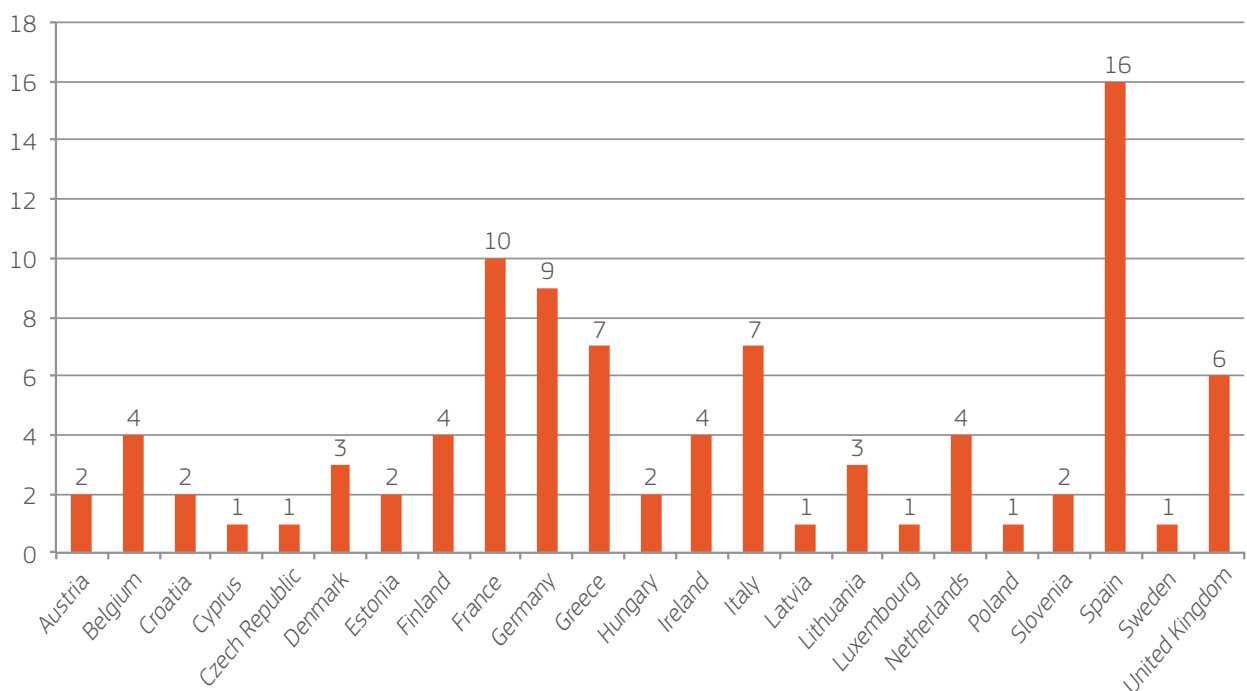
FIGURE 4.15: NUMBER OF DIHS SPECIALISING IN THE ENERGY SECTOR BY EU COUNTRY.
Source: JRC analysis.

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163   http://s3platform.jrc.ec.europa.eu/digital-innovation-hubs-tool
164   **Disclaimer**: The DIH Catalogue website is a "yellow pages" of Digital Innovation Hubs. The information provided about each entry is based on self-declaration. The European Commission cannot take any responsibility for the information provided. Currently all of the entries in the catalogue are being verified (based on the information provided) as to whether or not they comply to the following 4 criteria:
1. Be part of a regional, national, or European policy initiative to digitise the industry;
2. Be a non-profit organisation;
3. Have a physical presence in the region and present an updated website clearly explaining the DIHs' activities and services provided related to the digital transformation of SMEs/Midcaps or industrial sectors currently insufficiently taking up digital technologies
4. Have at least 3 examples of how the DIH has helped a company with their digital transformation, referring to publicly available information, identifying for each:
    – Client profile
    – Client need
    – Provided solution to meet the needs
The purpose of the catalogue is to support networking of Digital Innovation Hubs and to provide an overview of the landscape of Digital Innovation Hubs in Europe, supported by Regional, National, and European initiatives for the digitalisation of industry. There is no relation between being present in the catalogue and being able to receive funding from the European Commission.

Frequency of technical competences of Fully Operational Energy DIHs ("Electricity, Gas, and Water supply")

The identified DIHs possess a number of technical competences and offer a range of services to businesses in the Energy sector. Information on the frequency of technical competences and the range of services provided is presented in the list that follows (see also Figure 4.16).

- Organic and Large Area Electronics (OLAE)
- Laser based manufacturing
- Other
- Screens and display technologies
- Gamification
- New Media technologies

- Internet services (e.g. web development, web production, design, networking, and e-commerce)
- Photonics, electronic, and optical functional materials
- Micro and nano electronics, smart system integration
- Broadband and other communication networks (e.g., 5G)
- Advanced or High performance computing
- Additive manufacturing (3D printing)
- ICT management, logistics, and business systems
- Cyber security (including biometrics)
- Interaction technologies (e.g. human-machine interaction, motion recognition, and language technologies)
- Cloud computing
- Software as a service and service architectures
- Location based technologies (e.g. GPS, GIS, in-house localization)
- Cyber physical systems (e.g. embedded systems)
- Augmented and virtual reality, visualization

Frequency of technical competences

Competence	Value
Internet of Things (e.g. connected devices, sensors and actuators networks)	86
Artificial Intelligence and cognitive systems	76
Data mining, big data, database management	74
Robotics and autonomous systems	66
Cyber physical systems (e.g. embedded systems)	63
Simulation and modelling	61
Augmented and virtual reality, visualization	59
Sensors, actuators, MEMS, NEMS, RF	58
Cloud computing	58
Software as a service and service architectures	57
Interaction technologies (e.g. human-machine Interaction, motion recognition and language technologies)	56
Location based technologies (e.g. GPS, GIS, in-house localization)	54
Cyber security (including biometrics)	53
ICT management, logistics and business systems	52
Advanced or High performance computing	47
Broadband and other communication networks (e.g. 5G)	44
Additive manufacturing (3D printing)	42
Micro and nano electronics, smart system integration	41
Internet services (e.g. web development, web production, design, networking, and e-commerce)	40
Photonics, electronic and optical functional materials	35
Gamification	31
New Media technologies	31
Other	24
Screens and display technologies	22
Laser based manufacturing	19
Organic and Large Area Electronics (OLAE)	14

FIGURE 4.16: FREQUENCY OF TECHNICAL COMPETENCIES OF DIHS SPECIALISING IN THE ENERGY SECTOR.
Source: JRC analysis.

- Robotics and autonomous systems
- Sensors, actuators, MEMS, NEMS, RF
- Simulation and modelling
- Artificial Intelligence and cognitive systems
- Data mining, big data, database management
- The Internet of Things (e.g. connected devices, sensors, and actuator networks)

Most common services offered by Fully Operational Energy DIHs ("Electricity, Gas, Water supply")

There is a broad range of services provided by DIHs depending on their capacities and also on the level of maturity of SMEs in their process of digital transformation. The types of services most commonly mentioned by DIHs that provide support to SMEs in the Energy sector are the following (see also Figure 4.17):

- Concept validation and prototyping
- Awareness creation
- Education and skills development
- Collaborative Research
- Ecosystem building, scouting, brokerage, and networking

Frequency of services provided

Service	Value
Ecosystem building, scouting, brokerage, networking	88
Collaborative Researchs	85
Education and skills development	79
Concept validation and prototyping	78
Awareness creation	77
Testing and validation	73
Incubator/accelerator support	67
Mentoring	55
Visioning and Strategy Development for Businesses	53
Digital Maturity Assessment	45
Access to Funding and Investor Readiness Services	40
Market intelligence	36
Pre-competitive series production	29
Voice of the customer, product consortia	28
Commercial infrastructure	25
Other	23

FIGURE 4.17: FREQUENCY OF SERVICES PROVIDED BY DIHS SPECIALISING IN THE ENERGY SECTOR.
Source: JRC analysis.

Examples of digitalisation services in Energy

DIHs are already contributing to the digital transformation of businesses in the Energy sector in Europe and their role will be increasingly important in the future. The following are some examples of different kinds of digitisation services provided by DIHs in different countries to beneficiaries in the Energy sector:

I. Energy Management Solution DIH nZEB Smart House in Greece (https://smarthome.iti.gr) provides digitisation services for near-Zero Energy buildings.

Need: With implicit and explicit demand side management (DSM) strategies flooding the energy market, there is a need for smart infrastructures that monitor and control so that innovative energy efficiency in buildings (Smart Everything Solution) can be optimised.

Services: Real-time energy monitoring (production, consumption), advanced control capabilities, automated decision support system, and grid-connected and islanded mode capabilities. By digitizing information about all energy-related aspects, it becomes easier to find where energy flexibility is

available and fully exploit DSM services, such as demand-response signals, by taking into account building occupancy in real-time.

Customer Examples:
WATT-&-VOLT
Pragma-IoT
More details: https://smarteverything.gr/landing

II. Building and Energy Applications In Belgium DIH Centre de recherche en aéronautique ASBL, Cenaero (http://www.cenaero.be/) is mainly active in the aerospace (particularly turbomachinery), process engineering, energy, and building sectors.

Simulation and HPC technologies adoption, which is driving innovation-based competitiveness and industry decarbonising, is a shared challenge in EU industrial transformation. This is particularly critical for the SME and so-called low-tech sectors such as the construction industry for which both technology transfer and domain cross-fertilization have been identified as key elements in succeeding in the future. Initially supporting Aerospace companies, since then the DIH has impulsed several joint support actions with the Belgian Building Research Institute and other industry clusters (CAP2020, Greenwin, etc.).

Five "Simulation for Building & Energy Applications" regional exchange days and master classes have been organized in the last 5 years, attracting more than 200+ companies (70+% of SME). This impulse has also delivered success stories such as the DIH accompanied Construction SME Stûv, which designed a highly efficient and ergonomic pellet stove (winning a Red dot award for product design in 2016), 3E, by further developing an IoT and a model based predictive control platform for buildings energy management, Cover Group and 1Spatial, by automatically connecting simulation tools in their building frame modeller and GIS city database software for providing new applications through the Cloud, therefore offering new applications using these tools.

4.3 | Impacts of Digital Transformation on Energy

4.3.1. Economic impacts

With electrification and decentralization, the digitalization of the grid is bound to contribute to game changing disruptions in the energy sector. Grid edge technologies such as smart meters, smart sensors, automation, the Internet of Things, and a surge of power-consuming connected devices will bring about a new range of opportunities.

Three factors fuel these grid edge technologies' potential for disruption:
1. Their decreasing costs and continuous technical enhancements.
2. Their role enabling innovative business models built around empowered customers.
3. The sizeable improvement to the electricity system's asset utilization rate, which are typically around 60%[165].

With the expansion of industrial production expected to continue through the coming decades, particularly in emerging economies, the value of digitalization in improving the efficiency of energy and material use will only increase. While it is expected that digitalization in industry will continue in an incremental manner in the short term, some digital technologies may have far-reaching effects on energy use in certain areas, especially when they are applied in combination.

Although industry contains many different subsectors, processes, and outputs, many of the benefits from digitalization are similar. For example, increased data collection and analysis to optimise production processing, to improve energy efficiency, and to reduce waste apply to all production processes[166].

Data from smart devices and distributed resources in general will be critical to new business models and in facilitating customer engagement and adoption of grid edge technologies. Properly shared and detailed, data has the potential to improve the customer's experience in several ways such as improving customer service by improving access to more information and by enabling

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[165]   WEF 2017.
[166]   IEA 2017.

> *Data from smart devices and distributed resources will be critical to new business models and in facilitating customer engagement*

automated operations that will help customers manage their electricity demand and optimize costs.

Integrating and utilising distributed energy resources in the electricity system will open up new revenue streams at both distribution and retail levels. Distribution network operators will be able to offer new services, including the qualification, verification, and settlement of distributed energy resources – compliance obligations that are required and similar to traditional generators. At the retail level, a full

set of services related to distributed resource management, provision, operation, and installation is possible.

Business models are shifting from asset-intensive services to provider platforms. Distributed resources and digitalization create promising alternatives for network operators compared to building more network infrastructure. The network becomes a platform that maximizes the value of distributed resources and enables them to exchange services with others across the grid. As a platform the network also enables other market players to offer services without owning expensive assets.

In Europe, automakers and utilities are partnering new business model development such as the development of energy storage facilities that rely on used electric vehicle (EV) battery modules, or ancillary services provided by vehicle-to-grid (V2G) technology. Partnerships could also hasten the development of innovative business models that encourage the electrification of private sector fleets.

Three examples of emerging business opportunities attracting cross-sector partnerships are storage-as-a-service (which can be attractive for commercial and industrial customers), transportation-as-a-service (which can improve fleet utilization with the advent of autonomous driving), and blockchain technology. All three support the shift from asset-intensive business models to service provider platforms. Their business models require a new set of digital capabilities and internal operating models that embrace the digital transformation.

4.3.2. Social impacts

4.3.2.1. *The digital transformation and employment in the energy sector*

In 2015, the energy sector employed nearly 1.2 million Europeans and generated nearly 220 billion Euros of added value[167]. The energy sector is primarily affected by policies aimed at tackling climate change, reducing greenhouse gas emissions, cutting energy consumption, and increasing the use of renewable sources. The big challenge is to meet the EU's decarbonisation objective while at the same time ensuring security of energy supply, competitiveness, and growth.

The increasing adoption of digital technologies is also a crucial factor which may affect the sector by changing the amount of labour input necessary to carry out different tasks or jobs, thereby transforming the occupational structure within the sector.

According to a recent study[168] conducted by Eurofound, the digital revolution will transform work and employment through three vectors of change, which often act simultaneously:

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[167]   Eurostat - Annual enterprise statistics for special aggregates of activities (NACE Rev. 2).
[168]   https://www.eurofound.europa.eu/publications/blog/three-vectors-transforming-work-in-the-digital-revolution

> **In 2015, the energy sector employed nearly 1.2 million Europeans and generated nearly 220 billion Euros of added value**

automation of work, digitalisation of processes, and coordination by platforms.

- Automation of work consists of the replacement of human labour input by digitally-enabled machine input for some types of tasks within production and distribution processes;
- The digitalisation of processes consists of the use of sensors and rendering devices to translate parts of the physical production process into digital information and vice versa, and involves changes in tasks and occupations;
- Coordination by platforms consists of the use of digital networks to coordinate economic transactions by "algorithmic management" according to which a task not only specifies what is to be done but how it is to be done and the exact time allocated to it.

All three vectors of change can affect the structure of employment by occupation and sector as well as working conditions, industrial relations, and the social organisation of production (Fernández-Macías, 2018).

To investigate the extent to which the digital transformation may have affected the energy sector, an empirical analysis

drawing on data from Eurofound's European Jobs Monitor (1995-2014) was carried out. In particular, it showed:

I. how employment in energy has evolved during the past 20 years;

II. how occupations in energy have shifted during the same period;

III. which task content, methods, and tools are used in the three main occupations in the sector.

Evolution of employment in energy over time

To illustrate the evolution of employment in the energy sector over time, first the relevant NACE codes[169] need to be identified. Before 2008 the energy sector corresponded to NACE code 40 (Electricity, gas, and water supply) but from 2008 onwards, the sector has corresponded to NACE code 35 (Electricity, gas, steam, and air conditioning supply).

In order to compare levels of employment in the energy sector with employment in all other sectors, two indices were built with base 1995=100 and cumulative growth calculated.

Figure 4.18 compares the evolution of employment in the energy sector with the rest of the economy across 28 European Member States between 1995 and 2014. It also includes a chart for the 15 countries which have been part of the European Union since 1995.

Despite the substantial heterogeneity across countries, several common trends can be identified: employment in the energy sector (blue line in Figure 4.18) appears to have fallen more rapidly than employment in all other sectors (red dashed line in Figure 4.18) in most countries for nearly the entire period under examination. However, in some large countries where investment in renewable energy has expanded the most (e.g., Germany and Spain) there was a steady increase, especially in the second half of the period.

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[169]   NACE: European Classification of Economic Activities.
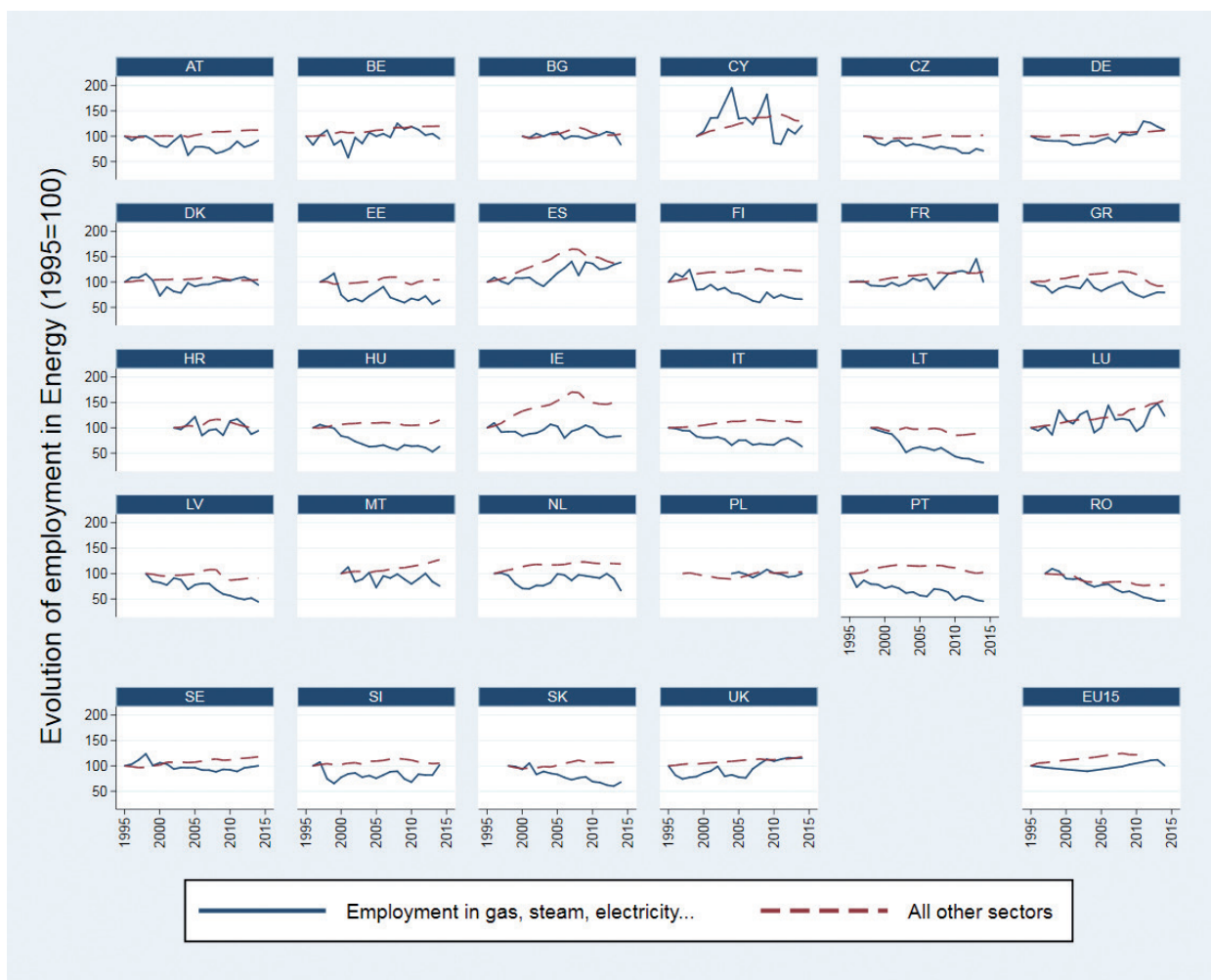
FIGURE 4.18: EVOLUTION OF EMPLOYMENT IN THE ENERGY SECTOR COMPARED TO THE REST OF THE ECONOMY (1995-2014).
Source: JRC analysis using European Job Monitor data – EU15 includes: Belgium (BE), Denmark (DK), France (FR), Germany (DE), Greece (GR), Ireland (IE), Italy (IT), Luxembourg (LU), Netherlands (NL), Portugal (PT), Spain (ES), the United Kingdom (UK), Austria (AT), Finland (FI), and Sweden (SE).

What are the main occupations in energy?

To investigate whether occupational shifts have occurred in the energy sector, the top 15 occupations (International Standard Classification of Occupations, ISCO, 2 digits) in 1995, 2010, 2011, and 2014 were examined. The change is calculated for two separate periods to account for the revision in the ISCO classifications.

Table 4.1 summarises the relative weight of the top 15 occupations in energy and shows whether it has increased, decreased, or remained the same through time (fourth and eighth column).

The highlighted cells indicate the main occupations in the sector – "Metal, machinery, and related trades work"

in 1995-2010 and "Science and engineering associate professionals" in 2011-2014 – which account for about a fifth of the total occupations in both periods. However, it is worth noting that while the main occupation in the past used to be medium to low skilled, in more recent times the energy sector has employed a much larger number of high skilled workers. Furthermore, in both periods workers in high skilled occupations – managers or engineers or science professionals – appear to have increased their weight compared to others. The occupational structure shifted significantly over the 20 year period analysed suggesting that energy has been relatively subject to more skill-biased technical change than other types of economic activity.

	1995	2010	Change		2011	2014	Change
Corporate managers	6%	7%	⬆	Administrative and commercial managers	3%	3%	–
Physical, mathematical, and engineering science professionals	8%	13%	⬆	Production and specialised services managers	2%	3%	⬆
Other professionals	2%	4%	⬆	Science and engineering professionals	12%	11%	⬇
Physical and engineering science associate professionals	10%	13%	⬆	Business and administration professional	4%	6%	⬆
Other associate professionals	7%	8%	⬆	Information and communications technology	2%	2%	—
Office clerks	17%	10%	⬇	**Science and engineering associate professionals**	**18%**	**18%**	—
Customer services clerks	1%	3%	⬆	Business and administration associate professionals	9%	8%	⬇
Personal and protective services workers	1%	1%	—	General and keyboard clerks	6%	5%	⬇
Extraction and building trades workers	10%	8%	⬇	Customer services clerks	3%	3%	–
Metal, machinery, and related trades work	**22%**	**17%**	⬇	Numerical and material recording clerks	3%	6%	⬆
Stationary-plant and related operators	6%	7%	⬆	Building and related trades workers, etc	4%	4%	—
Machine operators and assemblers	3%	2%	⬇	Metal, machinery, and related trades work	4%	4%	—
Drivers and mobile plant operators	2%	2%	—	Electrical and electronic trades workers	13%	12%	⬇
Sales and services elementary occupation	2%	2%	—	Stationary plant and machine operators	3%	3%	—
Labourers in mining, construction, manuf.	2%	1%	⬇	Drivers and mobile plant operators	2%	2%	⬇

TABLE 4.1: OCCUPATIONAL CHANGE WITHIN ENERGY (ELECTRICITY, GAS, STEAM, AND AIR CONDITIONING).
Source: JRC analysis based on European Job Monitor data, 1995-2014.

A task-based analysis of occupations in the energy sector

The idea of jobs as bundles of tasks is central to understanding the impact of the digital transformation. David Autor defines a task as "a unit of work activity that produces output". Technological and economic forces in the task-based approach determine the division of labour between labour (tasks) and capital (tasks) (Acemoglu, D. & Autor, D.H., 2011; Autor, D., 2013) capital typically takes over tasks previously performed by human labour once they become routine or standardised. However, even when a task becomes fully codified it is only automated if it makes economic sense – i.e. if capital inputs are cheaper than labour inputs.

Jobs that mainly consist of routine tasks are more susceptible to be partly or fully automated. By illustrating the task content, methods, and tools in the three main occupations of the construction sector, it is possible to speculate about which impact the digital transformation is likely to have in the future.

The indicators summarised in Figure 4.19 are based on the work done by Fernández-Macías, Hurley, and Bisello (2016) The three occupations analysed in Figure 4.19 are a high skilled one, "Science and engineering associate professionals"; a medium skilled clerical one, "numerical and material recording clerks"; and a semi-killed manual one "electrical and electronic trades workers".

These three typical occupations of the energy sector share some key attributes: they involve relatively little social task content, relatively high technical task content and with some degree of standardisation. Among them, the semi-skilled manual occupation of "workers in electric and electronic trades" involves more physical task and more machinery use while the clerical occupation of "numerical

and material recording clerks" involves very little physical and social tasks as well as less machine use and more repetitiveness and standardisation.

According to the specialised literature (Fernández-Macías, E., 2018), the task profile of the two mid-skilled occupations of the sector (with relatively high repetitiveness and standardization, limited social task content) will be associated with a relatively high risk of automation with the diffusion of advanced robotics and AI-enabled machinery.
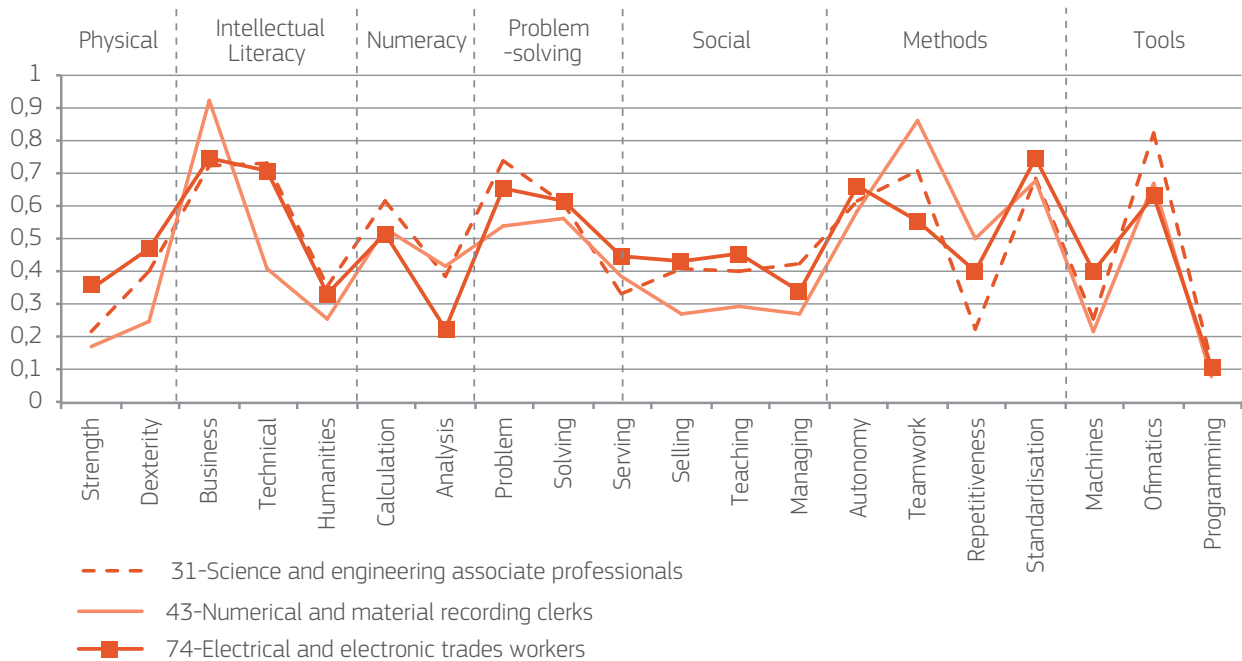
FIGURE 4.19: TASK BASED ANALYSIS OF THE THREE MAIN OCCUPATIONS IN ENERGY.
Source: JRC analysis based on European Job Monitor data, 2014.

4.3.2.2. *Consumers' concerns and acceptance*

Digital technologies in the energy sector give rise to a broad range of issues such as cost, loss of control (including utilities' ability to arbitrarily or accidentally shut the service off), health effects of radio frequencies, safety, privacy and data protection, fairness, uneven distribution of effects, and the impact that smart grid may have on vulnerable groups such as the fuel-poor, the elderly, or people who are less familiar with IT. These concerns have been reported worldwide (Krishnamurti, et al., 2012; Mah, et al.., 2014) and have emerged from the analysis of smart grid projects in the EU (Mengolini, A., 2016).

Because of these general concerns, consumers' acceptance becomes a key element for the penetration of digital transformation in the energy sector. In Buchanan, et al. (2016) the authors provide some suggestions to enhance consumers' acceptance of smart meters. Based on four focus groups, they conclude that: (a) consumers perceive both threats and opportunities in smart metering initiatives; (b) consumers are concerned about autonomy issues, privacy, and mistrust of suppliers; (c) consumers appreciate the smart meter's potential for more accurate billing and enabling future ICT services.

In Bigerna, et al., (2016), a quite extensive review of the literature looking at different aspects associated with the implementation of smart grid development is presented. Among papers looking at the socio-economic perspective (50% of the papers reviewed), the main topics/interests are presented in Figure 4.20.
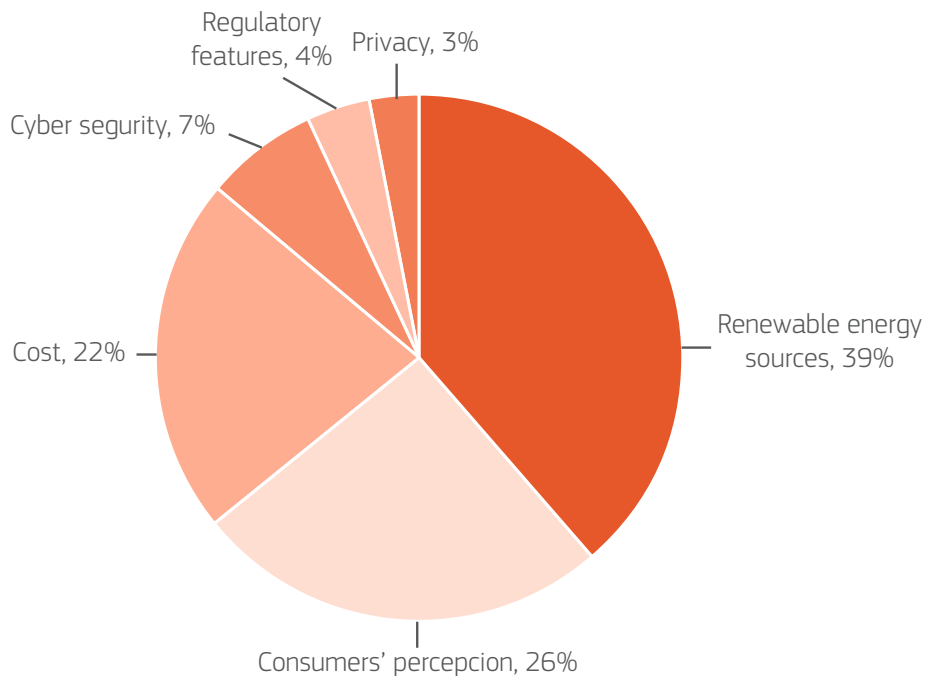
FIGURE 4.20: SOCIO-ECONOMIC PERSPECTIVE OF SMART GRID DEVELOPMENT.
Source: Bigerna et al., 2016.

Some of the main findings point to smart grids being seen as one of the key elements in both climate change and security of the electricity supply. Furthermore, in this case the literature seems to agree on the need to motivate consumers to engage and promote smart grids projects. Consumers seem to be quite interested in the opportunity of reducing energy costs by adjusting consumption through smart meters.

Customers' privacy is a new issue analysed by the literature in connection with the development of smart grids. It appears that there are two levels of privacy: the privacy of the home in an external context (sharing data with third parties) and the internal privacy of the home (household dynamics).

That consumer acceptance mainly depends on potential benefits in terms of savings and on the possibility to see how smart meters work in the context of neighbourhoods is shown in Feinberg, et al. (2016). When the potential risks of smart meter technology are placed into the picture, consumers' acceptance becomes more challenging, requiring measures by industries and institutions to provide evidence to counter the risk arguments (also see Sovacool., et al. (2017) for an extensive discussion on risk perception).

> " *Consumer acceptance is a key element for the successful digital transformation of the energy sector* "

According to Smart Energy outlook, a survey[170] run by Smart Energy GB among people within UK using smart meters: (a) 73% (6.3 million) would recommend it; (b) 82% say that smart meters provide them with a better idea of what they are spending on energy; (c) 81% think their energy bill is accurate (only 67% of those with a traditional analogue); (d) 82% have taken steps to reduce energy waste.

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[170] https://www.metering.com/industry-sectors/data_analytics/smart-energy-gb-uk-smart-meters/

Positive impacts of smart meter rollout in UK were discussed and also questioned in Mengolini, et al. (2016) where the authors reviewed the vast literature on the topic.

A survey[171] on the other side of the Atlantic run by The Smart Grid Consumer Collaborative shows a clear increase in citizens' awareness of the existence of smart meters technology (70%). In addition, in this case energy savings were considered to be among the most significant benefits. While home energy efficiency was consider to be of great importance, consumers do not feel knowledgeable enough about ways to improve it.

4.3.2.3. *Local energy community: the importance of demand-side management*

Linked to consumer engagement is the role of demand-side management (DSM) in enhancing a more collective dimension of energy use. Energy communities are considered to contribute to the transition to the future electricity systems by adding elements of resilience and inclusiveness, e.g., local energy communities (micro-grids) can increase resilience during an emergency by rapidly connecting/disconnecting from the surrounding grid when required.

From the point of view of distributive fairness, energy communities are more inclined to bear the costs and benefits of the technology deployed. From the point of view of procedural fairness, the local community in community level projects and schemes is involved in the decision making process.

There is an increasing interest in DSM in the electricity sector. As of 2014, over 3.5 billion Euros had been earned annually by the local economy through Demand Response.[172] The Joint Research Centre of the European Commission (JRC) regularly monitors the number and type of smart grid projects through the Smart Grid Projects Outlook.[173] More

> *Energy communities add elements of resilience and inclusiveness to the future energy systems*

than one third (321) of 833 projects are associated with Demand Side Management activities of which 192 are demonstration and 129 are R&D related. Looking at the time dimension, Figure 4.21 shows a clear peak for project starts in 2012 and a clear peak for projects ending in 2015.

> *In Europe, the highest investments are in smart network management (34%), demand-side management (25%), and integration of distributed generation and storage (22%). These three taken together account for around 80% of total investments*

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[171]   https://www.prnewswire.com/news-releases/survey-reveals-consumer-perspectives-on-smart-grid-and-related-products-and-services-300465652.html
[172]   Source Joule assets.
[173]   http://ses.jrc.ec.europa.eu/smart-grids-observatory. The latest figures refer to 2015.

Number of starting projects related to DSM

Number of ending projects related to DSM
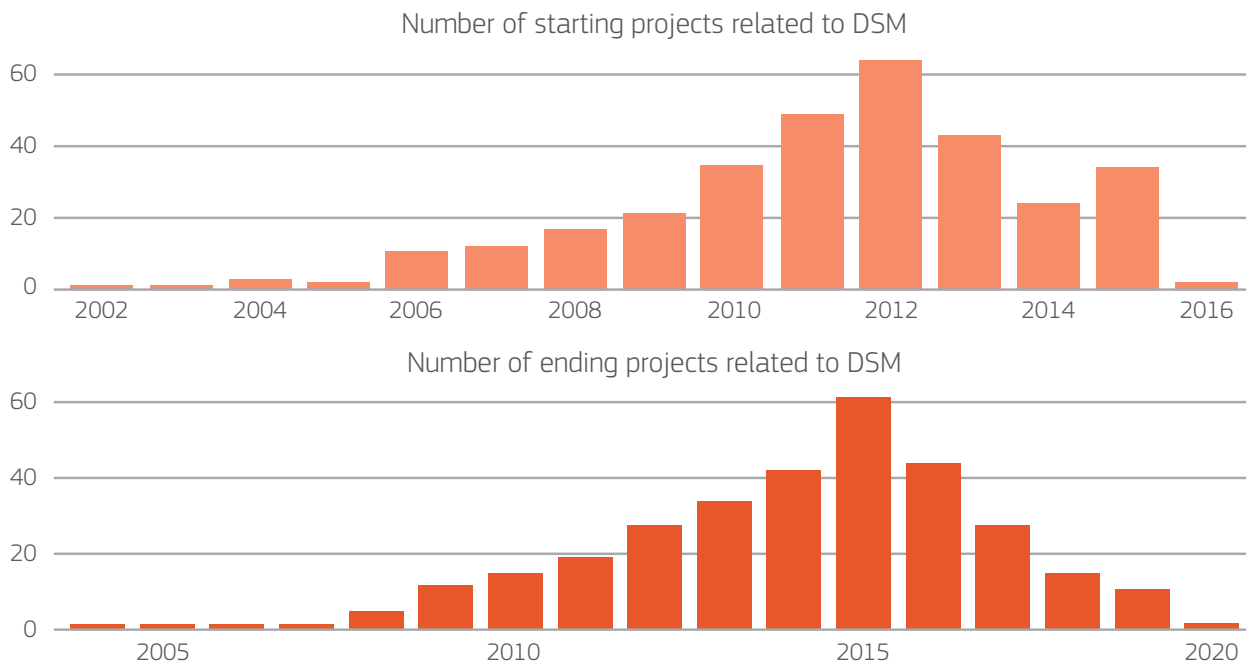
FIGURE 4.21: NUMBERS OF PROJECT STARTS (TOP PANEL) AND ENDS (BOTTOM PANEL).
Source: JRC analysis.

Differences between individual countries are reported in Figure 4.22. In particular, the total number of projects (light blue bars) and their time-spans (box plots) by country are shown. One can see that the number of projects does not depend on country size only (Denmark having the largest number of projects). The average duration is around 4 years.

In terms of investment, the latest JRC Smart grid projects outlook 2017 (Gangale, et al., 2017) reports that the

Number of projects related to DSM
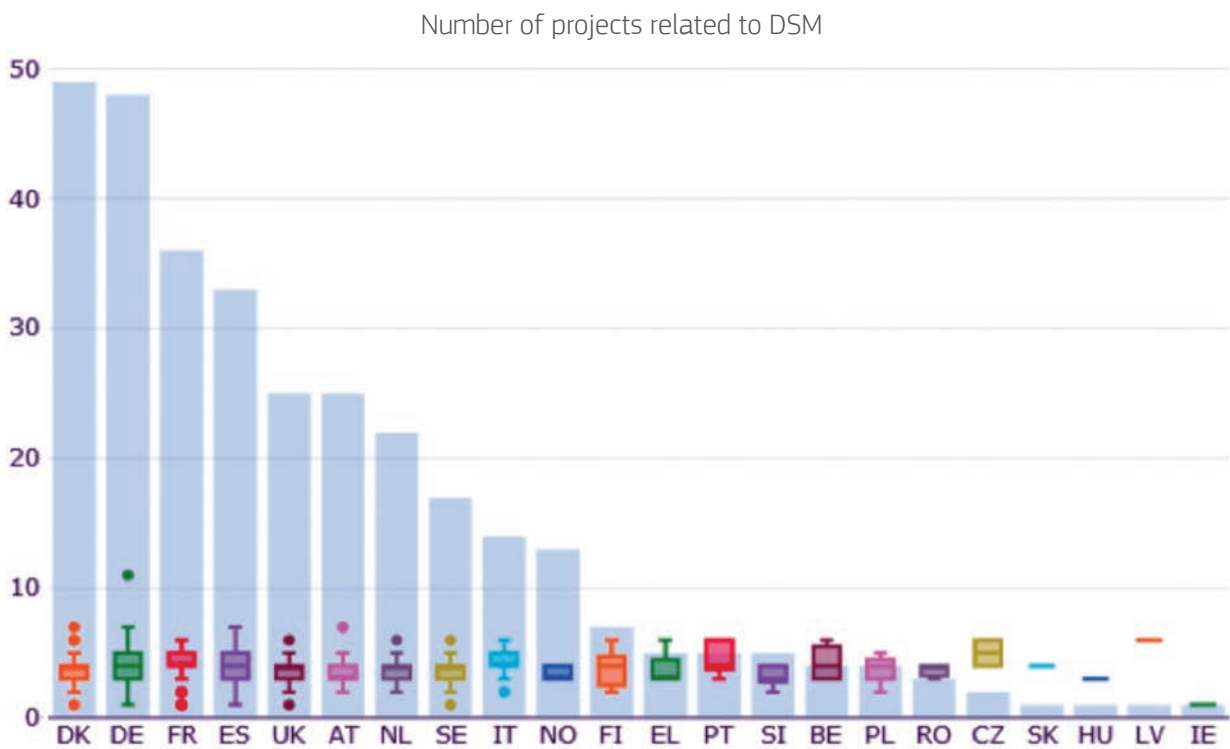
FIGURE 4.22: NUMBER OF PROJECTS (LIGHT BLUE BARS) AND THEIR TIME SPAN DISTRIBUTIONS (BOX PLOTS).
Source: JRC analysis.

domains with highest investment in Europe are smart network management (34%), demand-side management (25%), and integration of DG&S (22%), together accounting for around 80% of total investment.

In contrast, only 16% of investments in North America do not take demand-side or demand-response management into account (see Figure 4.23).

Level of investments in demand response and demand-side management among utilities in the U.S. and Canada as of January 2017
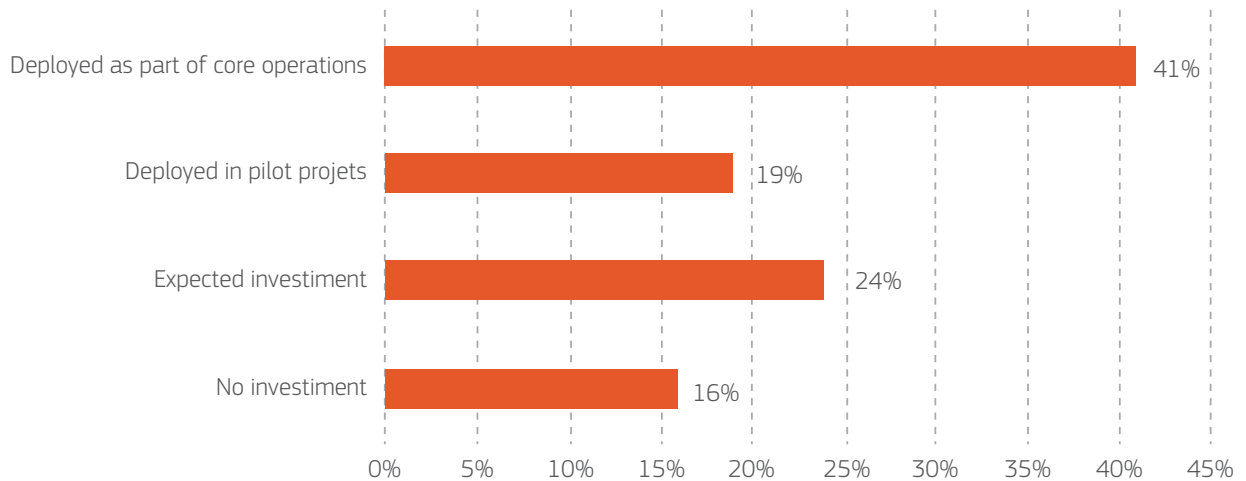
FIGURE 4.23: U.S. AND CANADA: SHARES OF INVESTMENTS IN DSM/DRM.
Source: JRC analysis.

Energy savings

Demand side management could also play a role in coping with losses occurring in the transmission and distribution (T&D) systems. To give a sense of the numbers involved,

T&D losses for different individual countries or aggregations of countries[174] are shown in Figure 4.24.
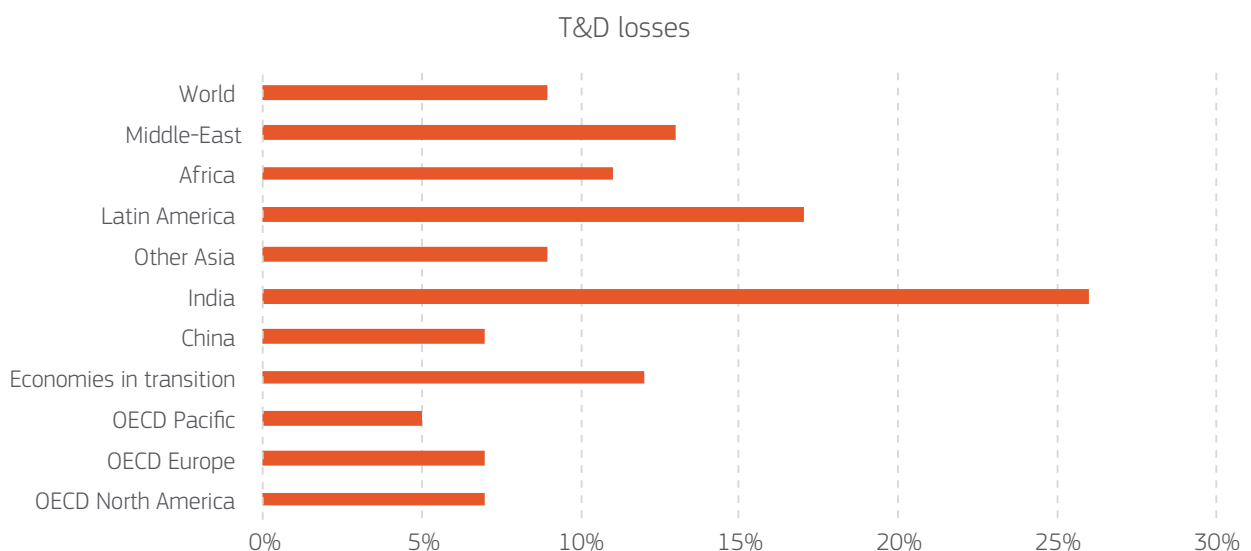
T&D losses

FIGURE 4.24: TRANSMISSION AND DISTRIBUTION LOSSES.
Source: International Energy Agency.

174   Energy Technology Perspectives 2010 – Scenarios & Strategies to 2050", International Energy Agency, 2010. [Online]. Available at https://www.iea.org/publications/freepublications/publication/etp2010.pdf

Miceli (2013) shows how DSM can enhance the energy efficiency of the grid to the benefit of end-users by both coordinating and scheduling low priority home devices so that their power consumption takes advantage of the most appropriate energy prices and/or energy sources at a given time.

In order to assess how digitalization could reduce energy losses, Miceli defines three possible scenarios (a) Scenario 1: house with intelligent on/off; (b) Scenario 2: house with intelligent on/off plus advanced actions; (c) Scenario 3: house with intelligent on/off plus advanced control, and he compares the reduction in losses compared to a baseline. Results of the simulation are reported in Figure 4.25.

Reduction with respect to baseline

■ Italy ■ France ■ Germany ■ UK
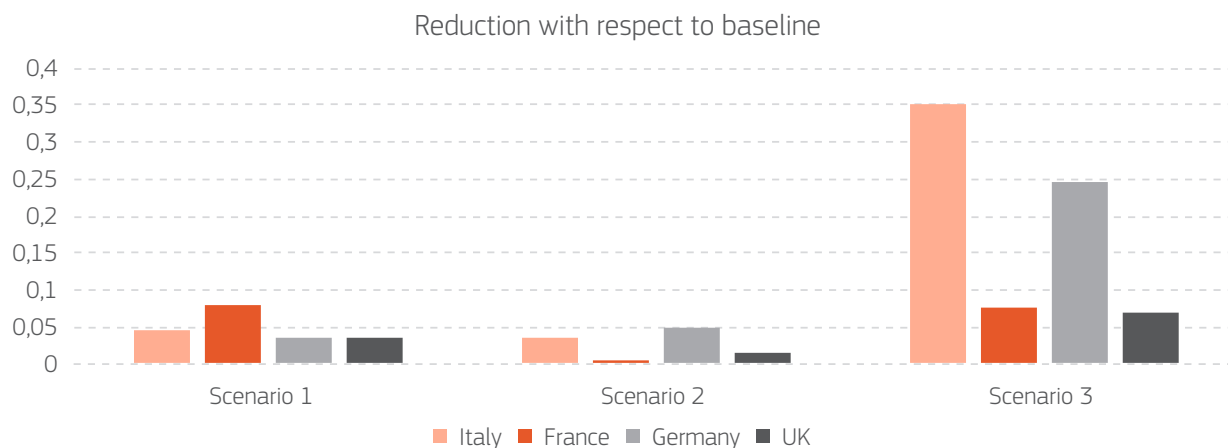
FIGURE 4.25: REDUCTION OF ENERGY LOSSES.
Source: adapted from Miceli, 2013.

Energy poverty and digital technologies

Energy poverty is about a structural deficit regarding the accessibility and affordability of energy, e.g., the rate of energy price rises versus income growth, the ability to have access to cheaper energy prices, the household energy needs, the lack of efficiency of energy use, the efficacy of social policy interventions. The recent literature recognizes that energy poverty is caused by an interaction between high energy bills, low income, and poor energy efficiency in addition to supplementary determinants such as housing tenure and quality of energy supply.

Through the ongoing analysis of smart grid projects in Europe, JRC will investigate how energy poverty and digitalization relate to each other for the purpose of providing early identification of potential problems and opportunities associated with vulnerable households and digital technologies.

" High energy bills, low income, poor energy efficiency, housing tenure, and quality of energy supply, all interact to cause energy poverty "

4.4 | Conclusions: the way forward for Policy and Research

Climate change related to greenhouse gases (GHG), the emission of pollutants, and reducing reliance on fossil sources are the key drivers of the ongoing clean energy transition.

Renewable energy sources have less predictable and controllable behaviour compared to traditional sources. Renewable resources have more potential for distributed generation from a systemic point of view than traditional fossil fuels, thus offering the opportunity of developing new energy paradigms such as micro grids and energy communities.

In this context, electricity seems to play a major role in the energy transition, although it should be coordinated in the short- to mid-term with other commodities and energy vectors such as gas, hydrogen, and district heating.

In the future, it is expected that the EU's population will increasingly move from rural areas to cities and large towns. We will move from the present situation to the so-called "smart city" in which the energy dimension and

> *Climate change and reducing reliance on fossil sources are the key drivers of the ongoing clean energy transition.*

its interplay with all the other dimensions (social, market, transport, water, and food) will play major role.

Smart energy is needed for smart cities. Smart cities will be equipped with a double backbone in terms of both

energy distribution infrastructures and data exchange channels and platforms.

There are different matters to consider:

a) First of all smart energy is a matter of "conceptual" smartness, implemented though smart functions based on the empowering of the consumer. Fundamental energy processes such as distributed generation, demand side management, new kinds of loads, concentrated and distributed storage, and electrification of final energy uses will be within the consumer's reach and the consumer/prosumer will have a key role in managing them.

b) The second important matter concerns the implementation of the "technical smartness" in the grid. There is the pressing need of an upgrade and enhancement of the grid itself with massive deployment of ICT technologies, making the components and devices "intelligent" in terms of sensing, computational, and communication capabilities.

c) Third, new ways of managing the energy system in a scenario where the amount of available data will be huge and increase very quickly is needed. New data analytics techniques and artificial intelligence approaches are certainly needed to manage this data and use them to provide added value in all sectors from network management to market operation.

The emerging smart energy schemes need to be formalized and conceptualised. The Smart Architecture Model provides an excellent EU reference framework in which the function can be described and their interactions assessed ex ante. The EC funded a series of projects in this area that lead to demo implementation being deployed[175].

Regulation needs to follow-up and even anticipate the evolution of the system and it has in some cases, providing for the testing of new paradigms and consolidating new regulation schemes in support of the new paradigms.

The concept of interoperability[176] is crucial in the implementation of technical smartness in the grid.

Developing the new electricity and energy infrastructures at the distribution level needs a "plug and play approach"

for all of the components, for both power and data interfaces. This approach can be achieved by developing a framework for interoperability based on technical standards and independent test facilities, capable of providing certificated compliance tests. In addition, enhancement of the network requires considerable investment by DSOs and these might be not easy under traditional regulatory schemes. New schemes should therefore be considered at the regulatory level.

Business cases that can encourage companies, who are attracted by the business opportunities, to invest in this area must be created for all of the services and functions.

Research on new technologies in both the power and ICT sectors is needed and must be followed-up by "in-vitro" and

> " *The digital transformation can lead to the creation of high value jobs, based on new digital services and activities, and a new industrial value chain. These can mitigate job loss when traditional power plants close* "

[175] https://ses.jrc.ec.europa.eu/inventory
[176] SG-CG/M490/I_Smart Grid Interoperability, Methodologies to facilitate Smart Grid system interoperability through standardization, system design, and testing, 31 OCT 2014.

"on-field" testing before deployment. In particular, the ICT technologies (computation, communication, and control) should be developed and tested in a harmonized research playground in which the interaction with the physical infrastructures, the market, and the social environment are considered in a holistic approach.

Research and experimental testing of new techniques for extracting added value is needed for the management of the energy system. This is at an early stage and more investment in research and testing is necessary in order to develop suitable methodologies and algorithms, and also concentrated and distributed computational facilities.

Digitalization is expected to provide considerable benefits but is also expected to encounter some barriers.

In terms of barriers the customer's habits and possible negative individual perceptions need to be addressed by using appropriate communication strategies. This will empower consumers, allow them to get the best out of digitalization, and make them synergic to global sustainability goals.

In addition, the economic issues related to the high initial infrastructural investments for network digitalization and modernization along with the higher cost of the plants inside the consumer/prosumer premises are an issue. This transformation needs to face the technological lock-in of pre-existing investments and the "inertia" of existing infrastructures.

In terms of benefits, the increase in the penetration of renewable energy sources into the whole energy system and its effect on the decarbonisation rate leads to the creation of a sustainable energy system. There are positive socio-economic effects as well. The digital transformation can create a market for a qualified workforce, creating new services and activities with a new industrial value chain that can at least partially replace the jobs lost due to the closure of traditional power plants.

What is clear is that the impact will be enormous and disruptive: the physical, social, market, and business configurations of the energy system in the future will be very different from today.

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List of abbreviations and definitions for Part 4 – Digital Transformation in Energy

AC	Alternating Current
AMI	Advanced Metering Infrastructure
AI	Artificial Intelligence
ASIC	Application-Specific Integrated Circuits
CPU	Central Processing Unit
DER	Distributed Energy Resources
DC	Direct Current
DIH	Digital Innovation Hub
DL	Deep Learning
DLT	Distributed Ledger Technologies
DSM	Demand-Side Management
DSO	Distribution System Operator
ERDF	European Regional Development Fund
ETSI	European Telecommunications Standards Institute
EV	Electric Vehicle
FACTS	Flexible AC Transmission Systems
FPGA	Field-Programmable Gate Arrays
GHG	Greenhouse Gases
GPU	Graphics Processing Units
IoT	Internet of Things
ISCO	International Standard Classification of Occupations
ML	Machine Learning
MS	Member States
NACE	European Classification of Economic Activities
NEBEF	Notification d'Echanges de Blocs d'Effacement
PE	Power Electronics
PEIG	Power Electronics Interfaced Generation
PMU	Phasor Measurement Units
RES	Renewable Energy Sources
RIS3	Research and Innovation Strategy for Smart Specialisation
RL	Reinforcement Learning
RTO	Research and Technology Organizations
S3	Smart Specialisation Strategy
S3P	Smart Specialisation Platform
S3PEnergy	Smart Specialisation Platform on Energy
SVC	Static Var Compensators
T&D	Transmission & Distribution
TCP/IP	Transmission Control Protocol/Internet Protocol
TOPS	Tera-Operations Per Second
TPU	Tensor Processing Unit
TSO	Transmission System Operator
V2G	Vehicle-2-Grid
VC	Venture Capital
WAMS	Wide Area Monitoring Systems

5

DIGITAL TRANSFORMATION IN GOVERNMENT AND PUBLIC ADMINISTRATION

⑤ DIGITAL TRANSFORMATION IN GOVERNMENT AND PUBLIC ADMINISTRATION

Summary

Digital transformation (DT) of government and public administration is nowadays often referred to as "digital government" (rather than simply "eGovernment") in order to highlight the potential of digital technologies for contributing to a more open, participatory, trustful and innovative government and public administration. Contrasting with the case of industrial and commercial sectors, the constitutional roles and functions that public institutions fulfil in the society under the rule of law and the legal, financial and political dimensions that characterise government and public administration require adequate approaches and terminology, in line with these characteristics. This report provides an overview of policy initiatives, concepts, benefits and challenges regarding DT in government and public administration, and suggests multidisciplinary scientific research to adequately support policies and to understand impacts.

The main functions of governments are policy design, implementation and administration, through policy instruments encoded in law by the relevant national or regional legislators. Public administration executes the law provisions under the rule of law. DT occurs in governments and public administration in the general context of exercising their legislative, executive and judiciary powers, which also include design of specific policies underpinning DT of the entire economy and society.

By its attributions and responsibilities, the public sector is a major economic actor in society, contributing to growth, delivering goods (roads, parks, broadcasting, etc.) and services (utilities, health, education, security, etc.), regulating behaviour (law, permissions, information campaigns, etc.) and redistributing income between citizens, public or private entities (subsidies, grants, etc.). DT does not change the nature of the public functions, but it changes costs, the way of doing, processing, communicating, and adds new requirements and partnerships. The approach to explore, analyse, plan or measure DT in this sector should then be from the perspective of policy design and implementation, where technology-enabled policy instruments are put in place at the design phase, considering which technology development fits better to each different instrument type and aim, under the specific policy goal and socio-economic context.

DT in the public sector is also confronted with the complexity characterising the necessary alignment and coordination of a variety of public bodies at all levels of governance under a common strategy, recognised leaderships and acknowledged collaborative culture, while keeping accountability, stability and citizens' engagement. Good governance rules are fundamental for DT of governments and public administration, although there is no leading model of governance for digital government, as demonstrated by the analysis of several national governance structures.

In line with the EU principles of subsidiarity and proportionality, the main responsibility for implementing digital government practices lies with the Member States. However the EU plays an important role by associating DT to the broader policy objectives of realisation of the Digital Single Market, putting in place common policies enabling DT and innovation, removing barriers, while promoting the development of technological and conceptual solutions and guarantying the policy coherence across sectors regarding digitally transformation in society.

Public sector reform is a constitutional policy and legal matter to which digital technology must contribute without friction in order to effectively support change. Innovation relates to how to positively incorporate digital technology into this specific environment. Opportunities resulting from DT of the public sector are potentially huge but technology cannot be uncritically applied. New technologies adoption in the public sector raises challenges that policy and research have to address with robust and rigorous evaluation, looking at the legislative, political, accountability, transparency, scrutiny and non-discrimination aspects. Implementing solutions based on emerging technologies also require from governments and regulation bodies the protection and respect of citizens' rights, freedoms and values. The research agenda in this domain is therefore significant.

An example is the use of Artificial Intelligence (AI). AI solutions hold remarkable potential benefits for both the public and the private sector, also helping to address societal and environmental challenges. Governments invest in AI in domains like defence, waste management,

health, agriculture, smart communities and other applications. The rapid deployment of automation and AI is raising a variety of challenging aspects when applied to government and public administration. AI tools that derive rules from big data or from historic data to make inferences or predictions (often using machine learning) can fail to live up to principles of transparency, accountability and equality before the law. The good alinement with those principles depends upon the appropriateness of design choices, ensuring that it reflects values adequate to the kind of decision being supported or made. In certain cases, the impact on people of decisions influenced by algorithmic decision systems (ADS) may raise a variety of different ethical, political, legal, or technical issues. Great care is necessary to analyse and address them correctly. Otherwise, the expected benefits of these systems may be negated by the variety of risks for individuals (discrimination, unfair practices, loss of autonomy, etc.), for the economy (unfair practices, limited access to markets, etc.), and society as a whole (manipulation, threat to democracy, etc.).

Another example is data sharing. Data is a fundamental asset for policy making and a fundamental resource within DT. Public sector data come in different forms with different characteristics. Different data sets can be governed by different legislations and their use have different political accountabilities, determined legally or constitutionally. This consideration is important in data governance, as well as regarding open data policies. Several aspects associated with making data available for reuse are still subject to further attention, like how to discover, secure and access to public sector data and private data of public interest. But also transparency on data processing and big data to inform policy making and communication requires particular care. The value of data as prime input for policy making and for innovative quality services and products is recognised but difficult to quantify.

Digital technologies are introduced in policy making, in design of policy instruments, and in the interaction, communication and engagement with citizens, private entities and NGOs, where they enable innovation at different levels, new partnerships and new business models. Empowering beneficiaries and communities by informing and engaging them through online channels, social media platforms, or smartphones, or in providing feedback on services' content and quality, has a social impact not yet measured.

Government and public administration take measures to avoid digital exclusion, reducing this gap with various specific solutions, while acting on other related policies like reforming the national education system. Converting the digital challenges in opportunities for the society can be addressed by the policy makers and research.

DT of government services and public administrations can however result in higher potential cybersecurity risks due to the fact that the "cyber" attack surface enlarges as a result of the services enabled by digital technologies and the uptake of new technologies whilst at the same time the impacts of successful cyberattacks have a greater potential to disrupt society and governmental essential services, giving potentially strong motivations to many threat agent groups to conduct such attacks.

Different speeds and paths for DT inevitably occur from country to country. Also within a country DT may not happen equally in all administrative regions and at all levels of administration. Therefore, at a certain point in time, the impact of digital government differs between countries but may also differ within them.

DT generates new relationships and dynamics, involving actors and resources outside public organisations, and modifying the ways by which the value embedded in the services is produced. Economic impacts of DT can be seen within the functioning and efficiency of the public sector, including all its attributed roles. But it is also relevant to consider the economic impact that digital government policy design and implementation have on other policy areas and on businesses.

Economic and social impacts of DT for many aspects have to be seen together as they influence each other. A multiplicity of factors, national and local contextual situations and diversity of inter-related areas, make the impact evaluation a complex and multi-metrics exercise with different time scales, involving simultaneously quantitative and qualitative dimensions.

A comprehensive overview of the social impact of DT should cover three distinct areas which may be part of the future research agenda:

— the impact of technology used in society on the processes of governing, for example social networks;
— the impact of technology on society that needs a policy intervention e.g. regulatory, information campaign;
— the impact on society of the use of digital technology within policy-making, politics and/or public administration.

Empirical observations, perceptions, philosophies or partial analysis cannot replace the coherent, multidimensional and rigorous scientific approach systematically planned and conducted by interdisciplinary teams.

5.1 | Overview of Digital Transformation in Government and Public Administration

This part of the report addresses the digital transformation of government and public administration, which have been going through what is called eGovernment and evolving into the current concept of Digital Government, pointing to the constitutional roles that institutions fulfil under the Rule of Law and specific legal, financial, and political dimensions that characterise government and public administration in contrast to the industrial and commercial sectors. This part provides an overview of policy initiatives, concepts, and discussions on the digital transformation in government and public administration, identifying previously unperceived questions when this perspective is missing and suggesting objective scientific research opportunities for the JRC so that the JRC can support appropriate policies. Therefore, it is not the purpose of this report to review the exhaustive literature on all of the fundamental aspects raised by the digital transformation, but rather to highlight the multidisciplinary nature of the issues that need to be addressed and the need for interdisciplinary teams to carry out research in this area.

Other subject studies published or under preparation by the JRC, such as flagship reports or others, are not extensively addressed here.

In this first section the digital transformation of government and public administration is introduced. After referring to the functions and roles of government and public administration, different concepts of eGovernment and digital government are presented, including opportunities and challenges. Some relevant

policy initiatives undertaken until the end of 2018 illustrate the EU enablers that facilitate progress in digital transformation. Finally, existing benchmarking exercises at European level are discussed, also making brief reference to others in the international context. Section 5.2 addresses enablers and barriers to the digital transformation in the public sector. Some indications on economic and social impacts of digital transformation are included in Section 5.3, recognising the diversity and multiplicity of issues to be addressed and the need for a more comprehensive analysis in that area. The conclusions reflect the observations made in the previous sections and point to possible areas for research by the JRC.

5.1.1. Introduction

The digital transformation of governments and public services across Europe is one of the cornerstones for achieving the objectives for the Digital Single Market as well as achieving the broader EU2020 goals (European Commission, 2016a).

What makes the digital transformation in Governments and public administration so important is their constitutional role and functions in the society in exercising executive, legislative, and judiciary power, including the underpinning

policies designed to enable the effectiveness and efficiency of the digital transformation of the entire economy and throughout society. At the same time, the usual problems encountered with digital transformation in any policy area are amplified in the public sector by the rule of law and by the complexity that characterises the alignment and coordination of a variety of public bodies under a common strategy and recognised leaderships needed at all levels of governance. Governmental bodies and public administrations have to do this while continuing to support

> *Digital transformation (DT) in governments and public administration applies to legislative, executive and judiciary powers, including in design of policies to support DT in the general economy and in society*

accountability and stability, and facilitating citizen's engagement, including addressing behavioural changes and the necessary collaborative culture.

By its attributions and responsibilities, the public sector[177] is also a major economic actor in society, contributing to growth, delivering goods (roads, parks, broadcasting, etc.) and services (utilities, health, education, security, etc.), regulating behaviour (law, permissions, information campaigns, etc.) and redistributing income between citizens (subsidies, grants, etc.). The public sector is governed by public law, which is the area of constitutional,

administrative, criminal, and international law that focuses on the organization of the government itself, relations between the state and its citizens, and the responsibilities of government officials. As conceived in most cultures, any government comprises the legislative, executive, and administrative bodies, all of them legislatively created by constitutional law or administrative law, the latter carrying out the functions of achieving policy goals with political accountability (Waller and Weerakkody, 2016). The work of public servants is also governed by administrative law and other parts of the system – courts, tribunal, and ombudsmen – provide redress and supervise the correct execution of administrative law. The digital transformation of government and public administration does not change the very nature or the public functions but it changes the way of doing, processing, and communicating, and so adds new requirements and financial burdens. Therefore, when analysing, planning, or measuring the digital transformation of this sector, its specific nature is very different from any commercial or industrial body and so it should be considered and addressed accordingly. Waller and Weerakkody (2016) asserted that this is not always the case in the literature, in research, or in practice and consequently inappropriate theories and models are applied to interpret and address the digital transformation of government. The terminology used when a term may have several different meanings leads to inaccurate semantics that often contributes to misunderstandings or inaccurate premises. As an example, both words in the term "public service" may have multiple meanings: "service" is used to apply to things like education or healthcare systems, by processes and transactions, but also to a piece of computer code for executing an online payment; "public" as a noun in relation to a government is the collective community; "public" as an adjective can mean either "of, relating to, paid for by, or working for a government, or "able to be used by anyone, not private"; "public service" can mean city transportation even if provided by a private company, or an administrative function of a government in the form of a state-funded and politically accountable organisation" (Waller and Weerakkody, 2016).

The JRC has the opportunity to apply a new approach and analytical methods so that the transformations and impacts resulting from digital technologies applied to government and public administration can be understood

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177   The public sector: State, regional, or local authorities, bodies <u>governed by public law</u> and associations formed by one or several such authorities or one or several such bodies governed by public law (data.gov.uk). The public sector is that part of an economy consisting of state-owned institutions, including nationalized industries and services provided by local authorities https://www.collinsdictionary.com/dictionary/english/public-sector

and to develop and propose appropriate methodologies, models, and technical solutions in line with the specific requirements of this sector.

The functions of Governments are policy design, and to implement and administer policy decisions using a set of policy instruments encoded in law by the relevant national or regional legislature. The public administration executes the legal provisions under the rule of law. Most of the public sector can be classified as either instruments in themselves (such as healthcare, transport, or prison services), or organisations administering instruments like taxes and benefits (Waller and Weerakkody, 2016). Consequently, digital transformation of government and public administration involves the impact of information and communication technologies (ICT) on policy making, policy implementation, legislation, and administration (Waller and Weerakkody, 2016). In that context, a public service means a government-funded organisation, employing public servants (Waller 2017). Considering societal trends that relate to the Internet and their implications for policy making, Margetts (2009) points out the need to look at how these trends might affect each of the four 'tools' of government policy: nodality[178], authority[179], treasure[180], and organisational capacity[181] in terms of sustaining the operations of government and driving innovation, asking which values one might expect to bring from it to policymaking.

DT in public administrations does not change the nature of the public function but may transform how public administrations perform these functions, their costs, and how the public perceives public services

It is frequently asserted that digital technologies offer opportunities to increase efficiency of public services by reducing the administrative burden (European Commission, 2014), applying the *once-only* principle aiming to ensure that citizens, institutions, and companies have to provide certain information to the authorities and administrations only once, as public administrations *reuse* and exchange data with each other whenever relevant (European Commission, 2016a), having faster access to data but also maximising their quality and diversity by using the most up-to-date and quality controlled data, facilitating access by citizens, industry, and private bodies in general including in a transboundary context while empowering beneficiaries and communities (*transparency)*. In this context, digital technologies, together with an *open data policy*, facilitate the increasing use of large data sets

across the public sector, data integration, and analytics for the free flow of data in society and better policy making.

Zwahr et al, (2005) argue that eGovernment means much more than merely increasing the use of ICT tools in public administration. It also involves rethinking and redesigning organisations and processes as well as developing new ways of delivering public services and policy making. In addition, the OECD (2017d) asserts that digital transformation also affects the policy making process, governance, the way of organising, coordinating, and executing the duties internally and across public offices at all levels of administration. To leverage these new digital opportunities implies considering how the public sector organisations, functions, and their processes can choose

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[178] Nodality denotes the property of being 'nodal' to information and social networks and having the capacity to disseminate and collect information.
[179] Authority denotes the possession of legal or official power to demand, forbid, guarantee, or adjudicate.
[180] Treasure denotes the possession of money or that which can be freely exchanged.
[181] Organizational capacity denotes the possession of a stock of people and skills, land, buildings, materials, computers, and equipment.

the most appropriate technology mix to support each of them, including establishing the governance of digital technologies used in government (OECD, 2017d) and the regulatory environment concerning these new (potentially disruptive) technologies. It requires organisational and regulatory barriers to be overcome and the necessary policy measures to use digital technologies within the public sector and across the public, private, and voluntary sectors. The cultural change represented by the sharing of data, resources, and knowledge and innovative collaborative initiatives facilitated by digital technologies is of a different nature.

EGovernment has been the dominant term used by policy-making in the European Union (EU) during the last 20 years. It refers to digital transformation where the application of ICTs improves the way public services and administration work.

The concept of digital government has also been introduced into EU policy-making – a concept that extends and goes beyond the eGovernment model by building on the notion of new services that public sector open data can support as well as the collaborative communities created by public authorities, businesses, citizens, and civil society that can develop them. Several definitions exist for digital government, and this has often made research very variable in nature and quality, with vague terminology and hardly any firm basis in theory. According to Gartner (2018),

"digital government leverages advances in technologies and relies on the use and reuse of data and analytics to simplify (digital as well as offline) transactions for end users (citizens, businesses, and government agencies). It creates information from data to support and enhance decision making by government and it fosters the creation of new, collaborative, and more efficient service delivery models. In the process, underlying service models are redesigned and re-engineered". It seems that e-government and DT of government have primarily been addressing the automation of public administrative processes, an online information and transactions model, without recognising the fact that they are legislative constructs, and also aspects of policy making and administration.

According to Waller and Weerakkody, (2016) "Digital transformation of government" can be defined as "changing the set of instruments that a government selects in order to implement a particular policy: this gives a level of granularity that is specific and identifiable, independent of the structure of a government or public administration, independent of technology, and usable across different governments. Its realisation can only occur through policy (re)design, not operational or organisational change. To examine how digitally-enabled transformation of that nature might be achieved, it is necessary to address the potential impact of ICT on the choice and implementation of instruments during policy design, or re-design".

5.1.1.1. *Challenges and opportunities*

Beside the changes brought about by digital technologies directly affecting processes in and of public administration, there are many megatrends changing the identity and self-conception of individuals in their role as citizens. Hyper connectivity and social changes also modifies citizens' perception and expectations of government delivery (Farrel and Gooddman, 2013). In this context, governments face multiple challenges as well as opportunities for public services.

Digital government faces challenges like: (i) The *digital divide* as consequence of citizens who do not have the skills or access to the Internet or with disability to use online public services so they are obliged to use other means of providing these services (mostly through intermediaries such as charities, NGOs, local communities of volunteers, etc.). This selective Internet model for the

administration of policy and law which must apply equally to everyone forces action in policy design to create an inclusive administrative model employing technology and that transitional solutions are foreseen. (ii) *Protection of personal and sensitive data and cyber security* of the online digital services and the infrastructure that supports them; (iii) *Management of organisational and cultural change* in public administration as the time required for change is getting longer than the speed of technological change. In most of cases change in the organisation of public bodies is effected by a legislative process. The change is related to the national, federal, regional, or local political, economic, and cultural context.

The digital transformation of governments and public services requires new forms of partnerships and engagement, new skills and accountability models, and

a new definition of process for the public sector (OECD, 2017a). Processes refer to the public management practices and procedures undertaken by governments to implement policies. These address the means used by public administrations to fulfil their duties and achieve their goal. They are essential for ensuring the rule of law, accountability, fairness, and openness of government action (OECD, 2017b).

ICT enables new partnerships and access to data and information to emerge. Collaborative frameworks and strategic partnerships are appearing as the new way to share resources, share costs of tools or of implementing measures enabling them to benefit from the scaling effects, exchange of knowledge and good practices, or to fulfil the requirements of new skill often available in the private sector. This enables new forms of engagement with civil society and the private sector as well as within public bodies to address complex social and economic problems. Waller (2017) points out that a legal basis is required for these different forms of partnership and, through the contracts, the accountability chain remains.

5.1.1.2. *Open Government*

The concept of Open Government often appears in the literature with different definitions and scope, often connected to ideas of government transparency and accountability, sometimes confused with open government data or associated with technology. Yu H. and Robinson D.G. (2012) discuss these distinctions and define open government in terms of service delivery and public accountability and assert that technology can be used to facilitate disclosure of information, but that the use of open data technologies does not necessarily equate to accountability. Open government and open data can each exist without the other.

The OECD definition for open data is "the opening up of government processes, proceedings, documents, and data for public scrutiny and involvement, considered as a fundamental element of a democratic society"[182]. Open government is founded on the belief that greater transparency and public participation can not only lead to better policies and services, but also promote public sector integrity, which is essential for citizens to trust in public administrations (OECD, 2016). According to the OECD (2017c)[183], countries are increasingly institutionalising the open government principles of transparency, accountability, and participation, with about half of the OECD countries (17 out of 35 countries) having adopted a national strategy on open government.

5.1.1.3. *Data – Open data*

Public sector data comes in various forms having different characteristics. Different data sets can be governed by different legislation and their use has different political accountabilities determined either legally or constitutionally. This is important in data sharing between public bodies as well as for open data. Generally speaking, public sector data may be composed of the following categories:

- Non-personal, research, and operational data such as air quality measurements, etc. where there are no barriers to publication and interest in reuse by third parties

- Non-personal data collected as part of a public body's main functions, with its collection, use, and publication governed by specific legislation, e.g., official statistics, environmental data, economic data, and reference geospatial data
- Personal data collected for research or operational purposes, e.g., health data or data about people affected by potential policy decisions, governed by general data protection law
- Administrative data, often personal, collected in the course of administering statutory processes e.g. benefits, tax, licensing, and judicial, governed by the specific administrative law they come under.

[182]   http://www.oecd.org/gov/open-government.htm
[183]   http://www.oecd.org/governance/pem/govataglance.htm

> **Public sector data can be ruled by different types of legislations and used under different political accountabilities, determined legally or constitutionally**

While recognising intrinsic benefits to reuse of public sector data, often enabling useful applications to be developed by third parties, data in statutory administrative systems require great care and clarity on their purpose, use, re-use, portability, value, and security.

Open data is an instrument that supports transparency, reuse, engagement of citizens, and innovation. Numerous governments have adopted open data initiatives and open government services. The term Open Data is very specific and covers two different aspects of openness:

(i) The data is legally open, which in practice generally means that the data is published under an open licence and that the conditions for re-use are limited to attribution;

(ii) The data is technically open, which means that the file is machine readable and non-proprietary where possible.

Open Government Data refers to the information collected, produced, or paid for by the public bodies (PSI) and made freely available for re-use for any purpose. Open Government Data is published under an open licence and is free to use within private and public domains (European Data Portal[184]).

5.1.1.4. Open eGovernment services

Open eGovernment Services (OGS) are "open, collaborative, and digital based services characterised by a deliberate, declared, and purposeful effort to increase openness and collaboration through technology in order to deliver increased public value (Galasso et al., 2016). The study by Galasso et al. (2016) developed a *taxonomy of open eGovernment services* (page 30-40), clustering them into three categories[185] and then further elaborating on them by policy instrument type, as defined by Waller and Weerakkody (2016): "the tools that governments choose from to intervene in the economy, society, and environment to make change, such as taxes, benefits, licences, information campaigns, and more tangible things like public services and infrastructure".

5.1.2. Policy initiatives

The main responsibility for implementing digital government practices in the EU lies with the Member States and the use of European Union competences is governed by the principles of subsidiarity and proportionality. However, the EU plays an important role by associating the digital transformation to the broader policy objectives of creation of the Digital Single Market, setting up common policies enabling the digital transformation and innovation, removing barriers while promoting the development of technological and conceptual solutions, guaranteeing

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[184]   https://www.europeandataportal.eu/en/providing-data/goldbook/open-data-nutshell

[185]   *Human services* (final users citizens and business, e.g. health, education, culture), *Administrative services* (necessary to the functioning of government, cover collaborative services to citizens and business and other government agencies) and *Participatory services/policymaking* (open, participatory decision-making, policy-making aspects across government).

the policy coherence across sectors regarding digital transformation in society. This is particularly important in cross-border contexts. EU efforts are focussed on several fundamental areas and exhaustive reference to them all is beyond the scope of this report. Consequently, only a few examples are highlighted here, most of them dealing with data and digital services, to demonstrate the added value of a European legal framework in which individual national policies are unable to achieve the same goals. The General Data Protection Regulation (GDPR)[186] (Regulation 2016/679) on the protection of natural persons with regard to the processing of personal data and on the free movement of such data is a fundamental element in safeguarding private data. EU initiatives also concern cybersecurity, reuse of public sector information (PSI Directive), and support for the interoperability programme[187] implementing public administration-related initiatives of the digital single market strategy, fulfilling the 2016-2020 eGovernment Action Plan[188], but also providing funding for digital government development via various EU instruments such as the Connecting Europe Facility[189] (CEF), the ISA² programme (Interoperability solutions for European Public Administrations), and Horizon 2020. Other financing possibilities for eGovernment in the EU are available from the European structural and investment funds[190] (ESIF), the Justice Programme[191], and the Structural Reform Support Service[192] (SRSS).

Directive 2007/2/EC established the Infrastructure for Spatial Information in the European Community (INSPIRE[193]), which applies to public authorities[194] and third parties[195] working on behalf of public authorities, at all levels of government (Art. 4), whose scope not only includes technical aspect of digital interoperable data and services, (Commission Regulation (EU) 1253/2013)[196]

and network services to serve data (Commission Regulation (EU) No 976/2009)[197], but also the necessary organisation and coordination of public authorities (Art. 18), including the obligation to monitor the progress of implementation (Art. 21), and to share data (Art. 17) according to Commission Regulation(EU) 268/2010[198]. The INSPIRE Directive is assisting policy-making in relation to policies and activities that may have a direct or indirect impact on the environment. The scope of this Directive is the interoperability of a wide range of 34 digital data themes across policy areas as diverse as health, energy resources, industrial facilities, agricultural facilities, or natural risks zones, including the core geospatial reference data. In fact, it is cross-sector and cross-border infrastructure of the European digital transformation of government and the public sector. In this innovative framework policy, the collaborative, transparent, and participatory approaches have been taken at all levels of the policy cycle and the principles of digital by default and by design translated into legal provisions.

The eGovernment Action Plan and its policy priorities for 2016-2020[199], accelerating the digital transformation of Governments (European Commission 2016a), aims to take actions in priority areas: modernisation of public administration with ICT, for which the uptake of Key Enablers is important in creating digital public services, enabling cross-border mobility, and accessing markets through interoperability, and facilitating digital interaction between administrations and citizens/businesses. The corresponding supporting actions promote seven principles:

(i)   *Digital by Default* as the preferred option, while still keeping other channels open for those who are disconnected;

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186   https://ec.europa.eu/info/law/law-topic/data-protection/data-protection-eu_en
187   https://ec.europa.eu/isa2/eif_en
188   https://ec.europa.eu/digital-single-market/en/news/communication-eu-egovernment-action-plan-2016-2020-accelerating-digital-transformation
189   https://ec.europa.eu/inea/en/connecting-europe-facility
190   https://ec.europa.eu/info/funding-tenders/funding-opportunities/funding-programmes/overview-funding-programmes/european-structur-al-and-investment-funds_en
191   http://ec.europa.eu/justice/grants1/programmes-2014-2020/justice/index_en.htm
192   https://ec.europa.eu/info/departments/structural-reform-support-service_en
193   https://inspire.ec.europa.eu
194   Public authority means: (a) any government or other public administration, including public advisory bodies, at national, regional, or local level; (b) any natural or legal person performing public administrative functions under national law, including specific duties, activities, or services in relation to the environment; and (c) any natural or legal person having public responsibilities or functions, or providing public services relating to the environment under the control of a body or person falling within (a) or (b).
195   'third party' means any natural or legal person other than a public authority.
196   https://inspire.ec.europa.eu/documents/commission-regulation-eu-no-12532013-21-october-2013-amending-regulation-eu-no-10892010
197   https://inspire.ec.europa.eu/documents/commission-regulation-ec-no-9762009-19-october-2009-implementing-directive-20072ec
198   https://inspire.ec.europa.eu/documents/regulation-inspire-data-and-service-sharing
199   https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52016DC0179

(ii) *Once only principle* ensuring that citizens and businesses supply the same information to a public administration only once so that no additional burden falls on citizens and businesses;

(iii) *Inclusiveness and accessibility*, designing digital public services that are inclusive by default and cater for different needs such as those of the elderly and people with disabilities;

(iv) *Openness & transparency* as public administrations should share information and data between themselves and enable citizens and businesses to access control and correct their own data, enabling users to monitor administrative processes that involve them;

(v) *Cross-border by default* making relevant digital public services available across borders. In this case, additional issues of accountability and court jurisdiction may need to be addressed;

(vi) *Interoperability by default*, public services should be designed to work seamlessly across the Single Market and across organisational silos, relying on the free movement of data and digital services in the European Union;

(vii) *Trustworthiness & Security* as all initiatives should go beyond compliance with the legal framework on personal data protection and privacy, and IT security, by integrating those elements in the design phase.

Action 19 of the eGovernment Action Plan 2016-2020 states its aim is to "Accelerate the deployment and take-up of the INSPIRE Directive data infrastructure".

Since 2016 the ISA² programme[200] has supported the development of digital solutions that enable public administrations, businesses, and citizens in Europe to benefit from interoperable cross-border and cross-sector public services and it has been implemented by annual rolling work programmes. The actions of the work programme are implemented by the EC services in charge of the specific actions and related initiatives, such as the JRC, have been undertaken through cross-delegation.

The new European Interoperability Framework[201] (EIF) is part of the Communication (COM (2017)134)[202]. This framework gives guidance on how to set up interoperable digital public services, and provides recommendations on how to improve governance, establish cross-organisational relationships, streamline processes supporting end-to-end digital services, and ensure that both existing and new legislation do not compromise interoperability efforts. The EIF 2017 is policy aligned with the DSM, INSPIRE Directive, Revised Directive on Public Sector Information (PSI), eIDAS[203] Regulation, and e-Government Action Plan 2016-2020[204]. It acknowledges the importance of trust in promoting the adoption of e-government services. Privacy-by-design and Security-by-design are recognised as driving principles of e-government services.

The potential of blockchain technology has been publicly recognized over the last few years by the European Commission (EC) and European Parliament (2017). In order to track key developments of the blockchain technology, the EC has launched the EU Blockchain Observatory & Forum and more recently announced plans to build EU-wide blockchain infrastructure. In addition, the EC supports development of blockchain technology through the research programmes FP7 and Horizon 2020 aiming to create and test new blockchain-based services in the most promising areas. The EC (European Commission, 2018) has indicated several use cases which are particularly interesting for the public sector: taxation reporting (VAT and Customs); land titles and business registries; e-Voting; citizens' ID management; health records management, medicines registration; social aid and refugee management.

Artificial Intelligence (AI) has gained prominence on the EU policy and research agenda. In 2018 the Commission published the European Strategy on Artificial Intelligence for Europe COM (2018) 237 and the Coordinated Plan on Artificial Intelligence COM (2018) to work closely with Member States. It provides a strategic framework for national AI strategies and makes direct reference to the role of the JRC: "In 2019, Member States and the Commission will also agree on common indicators to monitor AI uptake and development in the Union and the success rate of the strategies in place, with the support of the AI Watch developed by the Joint Research Centre of the Commission."

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[200] https://ec.europa.eu/isa2/isa2_en
[201] https://ec.europa.eu/isa2/eif_en
[202] http://eur-lex.europa.eu/resource.html?uri=cellar:2c2f2554-0faf-11e7-8a35-01aa75ed71a1.0017.02/DOC_1&format=PDF
[203] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2014.257.01.0073.01.ENG
[204] EIF's Interoperability Action Plan Action 17 states "Further support the implementation and enhancement of the INSPIRE Directive though the use of geospatial data in digital public services".

The Commission has appointed 52 experts to the <u>High Level Group on Artificial Intelligence</u>[205]. The Group, consisting of representatives from academia, business, and civil society, supports the implementation of the EU Communication on AI published in April 2018. The High-Level Expert Group makes recommendations on how to address mid-and long-term challenges and opportunities related to AI which will feed into the policy development process, the legislative evaluation process, and the development of a next-generation digital strategy. The Group also prepares draft ethics guidelines presented to the Commission covering issues such as fairness, safety, transparency, the future of work, and more broadly the impact on upholding fundamental rights, including privacy and personal data protection, dignity, consumer protection, and non-discrimination.

Concerning the Member States' high level commitment, the ministers in charge of eGovernment policy and coordination from 32 countries in the EU and the European Free Trade Area (EFTA) have unanimously approved the <u>Tallinn Declaration</u> (Estonia Presidency of Council, 2017), recognising that "Digital progress is transforming our societies and economies to the core, challenging the effectiveness of previously developed policies in a broad range of areas as well as the role and function of the public administration overall. It is our duty to anticipate and manage these challenges to meet the needs and expectations of citizens and businesses". The Declaration also recognises that "the ongoing work by the Organisation of Economic Cooperation and Development (OECD), the United Nations (UN), and the G20 on globalisation and digital transformation has shown several opportunities to reform the current policy frameworks in the coming years in the context of digital development. Development of eGovernment has a central role to play to meet these challenges and make use of the emerging digital opportunities." Furthermore, Ministers agreed to take steps in the next five years (2018-2022) towards the objectives of the EU eGovernment Action Plan 2016-2020 in their public administrations, calling for policy action lines at National and EC levels and for other EU institutions.

5.1.2.1. *International level*

At international level, the Council of the Organisation for Economic Co-operation and Development (OECD) adopted what is an international instrument on digital government, that is, the OECD Recommendation on Digital Government Strategies (OECD, 2014). Although it is not legally binding, all OECD member countries, including the 21 EU Member States who are members of the OECD[206], are expected to implement it. The Recommendation asks governments to develop strategies that ensure greater transparency, openness, and inclusiveness; that they encourage the participation of public, private, and civil society stakeholders in policy-making as well as service design and delivery; and that they create a "data-driven culture" in the public sector. It also calls on member countries to strengthen cooperation with other governments in order to serve citizens and businesses across borders, to share knowledge, and to coordinate digital government strategies. OECD (2016 a) grouped the recommendations into three pillars: openness and engagement[207], governance and coordination[208], and capacities to support implementation[209].

Similarly, the United Nations Department of Economic and Social Affairs (UNDESA) have been publishing the United Nations E-Government Survey since 2001. The survey report of 2018 recognizes that each country should decide on the level and extent of its e-government initiatives in keeping with its own national development priorities and achieving the Sustainable Development Goals (SDG). The survey acts as a development tool for countries to learn from each other, identify areas of strength and challenges in e-government, and shape their policies and strategies in this area, facilitating and informing

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[205]   https://ec.europa.eu/digital-single-market/en/news/commission-appoints-expert-group-ai-and-launches-european-ai-alliance

[206]   Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Luxembourg, Netherlands, Poland, Portugal, Slovak Republic, Slovenia, Sweden, Spain, and the UK.

[207]   (1) Openness, transparency, and inclusiveness, (2) Engagement and participation in a multi-actor context in policy making and service delivery, (3) Creation of a data-driven culture, (4) Protecting privacy and ensuring security.

[208]   (5) Leadership and political commitment, (6) Coherent use of digital technology across policy areas, (7) Effective organizational and governance frameworks for coordination, (8) Strengthen international cooperation with other governments;

[209]   (9) Development of clear business cases, (10) Reinforced institutional capacities, (11) Procurement of digital technologies, (12) Legal and regulatory framework.

discussions of intergovernmental bodies, including the United Nations General Assembly, the Economic and Social Council, and the High Level Political Forum on issues related to e-government and to the critical role of ICTs in development (United Nations, 2018).

5.1.3. Benchmarking

International comparisons or benchmarking of e-government or digital government have been created and published for many years, giving partial and not always concordant results as they lack interpretation in a national or regional socio-economic context in most cases. Benchmarking drives practice but there is a significant risk that the in-depth analysis and contextualisation, necessary when transferring a policy programme between nations (Rose, 2004), is omitted.

EU Member States rank rather high in the global eGovernment benchmarks. The UN produces a global survey of eGovernment every two years[210]. In the 2016 survey, Europe was the highest-ranking region overall for eGovernment. The 2018 UN eGovernment survey (United Nations, 2018) focuses more on the way governments operate and interact with people supporting transformation towards sustainable, inclusive, equitable, and resilient societies and technologies that can have a far-reaching impact on the realization of the SDGs. The survey focuses more on outcomes and impacts rather than on inputs, seeing the SDGs as policy goals and looking at how ICTs accelerate the achievement of the 2030 Agenda.

Government at a Glance (OECD, 2017c)[211] provides data on the functioning and performance of public administrations in OECD countries. It includes contextual information as well as indicators regarding *input* (how much and what kind of resources the governments use), *process* (what and how governments do it), *output* (what are the goods and services the governments produce) and *outcome* (what is the resulting impact on citizens).

Benchmarking and establishment of quantitative and qualitative indicators in the EU are part of the Open Method of Co-ordination (OMC) formally initiated by the Lisbon European Council in 2000 as a policy-making process or policy instrument which aims to spread best practice and achieve convergence on EU goals in those policy areas which fall under the partial or full competence of Member States. The OMC has been increasingly criticised in terms of method, legality, effectiveness, and in particular when applied in areas of national competence[212]. Government and public administration is clearly one of these areas (European Union Treaty Art. 2; Art. 4; Art. 5).

EU eGovernment actions and targets are measured regularly and communicated on the Digital Scoreboard[213]. The digital scoreboard includes data from the Digital Economy and Society Index (DESI)[214] and the European Digital Progress Report (EDPR). In this context, the digital public services dimension is represented by four indicators:

(i) the percentage of Internet users who have sent completed forms to a public administration via the Internet;
(ii) the level of sophistication of a country's eGovernment services using the pre-filled forms indicator[215];
(iii) the level of completeness of a country's range of eGovernment services via the online service completion indicator[216];
(iv) and the government's commitment to open data, measured by the open data indicator.

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[210] https://publicadministration.un.org/egovkb/en-us/reports/un-e-government-survey-2016
[211] http://www.oecd.org/governance/pem/govataglance.htm
[212] http://www.europarl.europa.eu/EPRS/EPRS-AaG-542142-Open-Method-of-Coordination-FINAL.pdf
[213] https://ec.europa.eu/digital-single-market/en/policies/scoreboard
[214] The Digital Economy and Society Index (DESI) is a composite index that summarises relevant indicators on Europe's digital performance and tracks the progress of EU Member States in digital competitiveness. It has five dimensions: Connectivity, Human capital, Use of the Internet, Integration of digital technology, and Digital public services (European Commission, Digital Scoreboard 2017).
[215] The pre-filled forms indicator measures the extent to which data that is already known to the public administration is pre-filled in forms presented to the user.
[216] Online service completion indicator, measuring the extent to which the various steps in an interaction with the public administration can be performed completely online.

Although these indicators are very relevant for the monitoring of the aspects in question, they currently do not fully cover the eGovernment or Digital Government dimension including, for example, interactions between public bodies to implement and monitor sectorial policies, policy relevance across sectors, and adapting effectively to contextual national, regional, or local conditions. In this context, Waller and Weerakkody (2016) assert that "the significant elements studied (i.e. directly related to a governmental function of the administration) are only either information about policy instruments or transactions comprising part of the administration of a policy instrument (itself part of a set of instruments implementing a policy)".

According to the eGovernment Benchmark 2017, overall eGovernment performance in Europe is showing progress. The indicators used relate to EU policy priorities, and are not necessarily related to national developments and achievements[217]. The eGovernment Benchmark 2018[218] reveals the progress accomplished using the same indicators. Benchmarking, metrics, and comparisons often look at what is on an administration's web site, typically looking for the presence of a predetermined list of information and transactions. Consequently, these tools measure inputs to policy goal realisation, not outcomes (Millard, 2008).

Progress towards eGovernment in the Member States is also monitored by the National Interoperability Framework Observatory (NIFO)[219] of the European Commission, which has published the report 'State of Play of Interoperability in Europe 2016'[220] and the eGovernment Factsheets[221] for each Member State. This is an annual exercise, and the eGovernment factsheets anniversary report[222] (10 years) has been published.

Another comprehensive approach is taken by Capgemini et al., (2017) who use the following indicators to measure a government's characteristics: (i) *Quality*, which aims to summarise a proxy of governments' actions in one number. It is composed of four components: *Regulatory Quality* that captures perceptions of the government's ability to formulate and implement sound policies and regulations that promote and facilitate private sector development; *Rule of Law*, which captures perceptions of the extent to which agents have confidence in and obey the rules of society, in particular the quality of contract enforcement, property rights, policing, and the courts as well as the likelihood of crime and violence; *Government Effectiveness* captures perceptions of the quality of public services, the quality of the civil service, and the degree to which it is independent from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to these policies; *Reputation* considers the reputation of the government and the indicator selected is "Perceived Corruption", calculated by Transparency International, which measures the perceived level of public sector corruption worldwide; (II) *Openness*, which is an indicator aiming to identify the openness of each country from an Open Government perspective by taking two different aspects into consideration: *Open Data*, which is a DESI indicator that measures the extent to which countries have an Open Data policy in place (including the transposition of the revised PSI Directive), the estimated political, social, and economic impact of Open Data and the characteristics (functionalities, data availability and usage) of the national data portal; *Voice and Accountability* is a World Bank indicator that captures perceptions of the extent to which citizens are able to select their government as well as freedom of expression, freedom of association, and free media. Other indicators are computed for the eGovernment Benchmark 2017, as explained in the Final Background Report – Volume 2[223].

Waller & Weerakkody (2016) suggest that the conceptual framework for DT of government and public administration should be approached from

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[217] "The User-centric government benchmark scores 80% for the EU28+. Mobile friendly public services are becoming more widespread, on average 1 in 2 public websites is mobile friendly. The Transparent Government benchmark stands at 59% for the EU28+. The Cross-border Mobility benchmark stands at 63% for the EU28+. Cross-border business start-up services and cross-border services for students reach an online availability of 73% and 74% respectively. This implies that information is easy for foreign online visitors to access (86%) and approximately 3 in 5 services is online is available to foreign online users (60%). Authentic Sources, the indicator that assesses to what extent personal data is pre-filled on online forms, holds at 47%. The indicator for eID reaches 52% while for 1 in 2 services it is not possible to use an eID. The indicator for eDocuments is 61%.

[218] https://ec.europa.eu/digital-single-market/en/news/egovernment-benchmark-2018-digital-efforts-european-countries-are-visibly-paying
[219] https://ec.europa.eu/isa2/actions/fostering-national-interoperability-frameworks-across-europe_en
[220] https://ec.europa.eu/isa2/sites/isa/files/docs/publications/report_2016_rev9_single_pages.pdf
[221] https://joinup.ec.europa.eu/collection/national-interoperability-framework-observatory-nifo/egovernment-factsheets
[222] https://joinup.ec.europa.eu/sites/default/files/custom-page/attachment/2019-03/10egov_anniv_report.pdf
[223] https://www.capgemini.com/wp-content/uploads/2017/11/2017-egovernment-benchmark_background_v7.pdf

> *The approach to explore or measure DT in government and public administrations should be from the perspective of policy design, policy instruments, and ease of use for citizens, seen within the specific policy goals and socio economic contexts*

the perspective of policy design and implementation, where the technology-enabled policy instruments are put in place at the design phase, considering which technology development fits each different instrument type better under the specific policy goal and socio-economic context. According to this framework, the instruments are grouped in four classes, the key design factor[224] for each of them is identified, the citizen's perspective is then considered, and the corresponding implied approach decided.

Analysing the 'quality of government' (QoG), which is defined as low corruption and as high protection by the rule of law, government effectiveness, and accountability – at both national and regional levels in the EU MS, Charron et al. (2014) found three clusters of countries scoring respectively high, medium, and low QoG, findings based on the EU QoG Index (EQI) defined by the study. It is interesting to note that this index shows notable cross-regional variations even within the same country. The EQI used in this study was correlated strongly with regional indicators of socio-economic development and levels of social trust.

5.1.3.1. Conclusion

The policy implementation system for the same policy goal or social outcome will be different in each country. So comparison and transferability of approaches, measurements, and benchmarking are not straightforward (Galasso et al, 2016; Waller and Weerakkody, 2016; Waller, 2017):

- Governments use different combinations of instruments for the same policy goals - depending on legal style, history, political preferences, and social culture
- All policy implementations result in a complicated system of instruments and actors
- Countries operate policy implementations at different geographical levels of administration

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[224] Key design factors "beside achieving the outcome intended and avoiding traps, should be the reduction of administrative burden (on both the public and public administration) caused by policy interventions, and the effective matching of demand on the system to its capacity, while making information and resources available to those who need them in appropriate ways" (Waller & Weerakkody, 2016).

- Citizen interaction and information provision is determined by local legislation
- Sometimes there are no comparable instruments, data, certificates, etc. between each country's national policies, instruments, and legislation changes.

However, there is definitely merit in learning from approaches taken by other countries, and not necessarily by copying them. A prerequisite is to gain a deep understanding of what has been done and why before consciously adapting an approach to the local context.

5.2 | Digital Transformation Enablers and Barriers in Government and Public Administration

This section discusses the enablers that accelerate the DT of the public sector and society, and common barriers that governments and public administrations have to overcome. Converting the digital challenges into opportunities for society has been addressed by policy makers and by research. Digital technologies offer opportunities that should be explored but not uncritically applied. Without aiming to introduce all of the digital technologies in use or with the potential to be used by public administrations, the few examples selected relate to ongoing policy initiatives or they illustrate that technologies are selected, developed, tested, and applied to satisfy specific requirements and conditions, and because they are fit for purpose. Considerations on organisation, governance, and legal frameworks as enablers are discussed. Several aspects of innovation are mentioned and differences between the public and private sector innovation are noted. Skills that are acting as enablers and barriers to DT are then discussed, examining ways to overcome gaps, including by the formation of new strategic partnerships.

5.2.1. Technologies and Infrastructures

DT embraces a diversity of evolving technologies which should be selected, integrated, or adapted to specifically fit the nature and requirements of the public sector's current reality and the national strategy of digital transformation – rule of law and non-discrimination – very different from the commercial or industrial context. Only in this way is it possible to ensure successful results and harness the opportunities and benefits offered by these technologies. Consequently, the choice of digital technologies and the way to make them work in supporting the public sector have a strategic role and their selection and coordination are the competences of digital government.
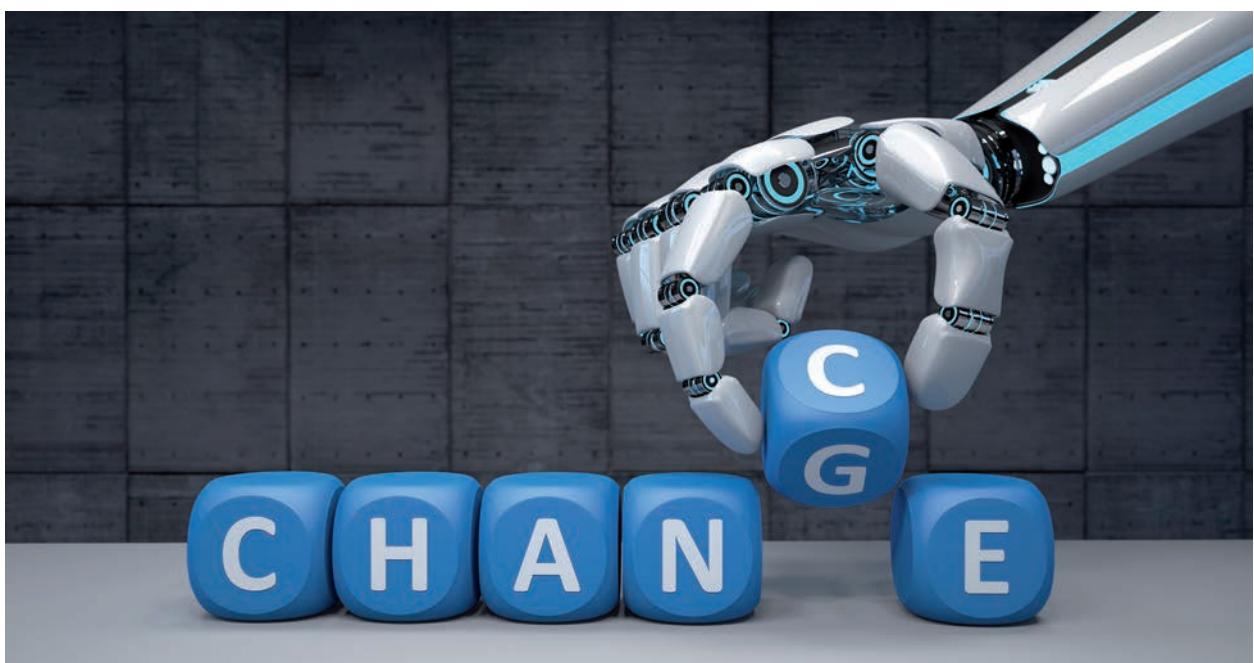
Updates and improvements to public sector digital solutions and systems are necessary, safeguarded from exposure to various types of threats and in step with the evolution of technologies and society, the accumulation of experience and the expectations of citizens and businesses. Furthermore, Margetts, H. (2009) highlights the importance of understanding the technological, social, and economic shifts associated with the Internet when analysing or making public policy. The widespread use of the Internet and Internet-enabled services by citizens, firms, government, and voluntary organisations now have a role and impact on policymaking.

For the public sector to embrace some of the technologies now used by the private sector such as blockchain, Artificial Intelligence (AI), cloud computing, or big data analytics raises challenges that policy and research have to address by examining the legislative, political, accountability, transparency, scrutiny, non-discrimination aspects of the public sector context. A robust and rigorous evaluation of their role and value in the public sector context is fundamental but has not been fully accomplished yet. This includes understanding their adherence to these specific requirements and what still needs to be elaborated further. The research agenda has significant fields of work in this domain because government and public administration are not in the position to face technological risks. A partnership with the private sector is one option for technological development and adoption, as discussed in 5.2.3. Testing under known conditions is a fundamental practice to be undertaken before operational use of disruptive technologies in a specific use case. This section neither introduces nor describes all digital technologies in use or with potential to be used by a public administration. Instead, a few examples are mentioned for the purpose of demonstrating that digital technologies should be developed and applied to satisfy specific requirements and conditions, and that what proved to be helpful for certain applications can be inadequate when used in different contexts.

Blockchain technology (Nascimento, S., et al., 2019) is a computer design which enables tamperproof record keeping and transfer of asset ownership between anonymous agents. Each transaction is cryptographically signed and once a block of new records is validated, the transactions registry (called a ledger) is irrevocably appended and the new state of the system is immediately shared by all participants in a network. This design was originally proposed to establish a reliable and secure peer-to-peer value transfer of Bitcoin tokens. Recently, blockchain technologies have been increasingly recognized outside cryptocurrencies and even outside value-exchange transactions. Advanced blockchain functionality, known as programmable smart contracts, enables reliable settlement of complex transactions and processes. Smart contracts are pieces of computer code running on a blockchain infrastructure which automatically execute processes involving many entities and multiple steps, each triggered by an event such as humane or machine action or a signal from a connected 'thing'. The ledger is automatically updated by any new step and all parties see and process the same consistent state of data, eliminating the need for intermediation between isolated data systems and implementation of flexible governance structures across participants.

These characteristics and the distributed registration and exchange of records, in contrast to a centralized system, have specific implications in the context of digital governments. Impacts from the adoption of blockchain technology by governments result from two complementary perspectives: technological and institutional (Davidson, De Filippi, Potts, 2016). The first considers blockchain as a new general purpose information technology of record keeping and settlement of complex transactions, assuming that it could augment current information systems, generate efficiency gains and lower transaction costs by increasing automation, security, transparency, and auditability of these records. The second considers blockchain as a new institutional technology for decentralized coordination and governance of economic and social interactions, competing with other coordination institutions such as corporations, markets, and governments. Atzori (2015) claims that blockchain technology could reshape the way governments interact with citizens, businesses, and each other. Decentralized governance substitutes full control of governments over transactions because control is shared by and distributed to many participants., Most applications would need new legislation for public sector functions setting out disintermediation of the public sector and no state control.

The technology is in its infancy and needs to overcome several bottlenecks in scalability, performance, confidentiality, and compliance with law. Interest in exploring blockchain's potential in the public sector is seen in the increased experimentation, yet the number of projects is limited and operational adoption is lacking. Gartner (2018)

illustrates an exception in the government of Georgia using blockchain to register land titles and validate property-related government transactions since land title data is public under Georgian law, therefore its integration with legacy systems was relatively easy as it does not replace the legacy system but provides additional functionality. Analysing distributed ledger technology and blockchain for digital government based on pilot deployments of nine different use cases in the public sector[225], Gartner (2018) concluded that this technology is not at present a radical innovation for the public sector as it does not present direct disintermediation for either government or public administration. Often the blockchain infrastructure is used as a separate system next to a centralised database. According to the same study, when blockchain technology is leveraged by a government for their public services, a permissionless blockchain infrastructure does not seem to satisfy the user authentication criteria. An existing user management system for the services provided by these infrastructures is often used or required. Observed pilots do not introduce truly new services nor paradigmatic change to citizen-government relationships. Furthermore, based on the pilots analysed, passing on to a production phase in a blockchain system requires the adoption of other digital legal tools such as the digital signature, but currently this is not recognised as a legal means for the transaction of properties.

The JRC has recently investigated the effects of eight ongoing pilot deployments in the public sector (Allessie et. al., 2019). In recognizing that technology has yet to mature, this study recommends that the EC focuses on setting the right conditions and approach for developing blockchain technology by undertaking several courses of action:

- guidance and knowledge sharing;
- pilot development;
- standards definition;
- creation of dedicated infrastructures
- connecting blockchain building blocks across Member States.

Cloud computing offers the prospect of reducing the cost of ICTs for public authorities through economies of scale while at the same time supporting rapid deployment of new and innovative public services. The Communication on a European Cloud Initiative "Building a competitive data knowledge and economy in Europe"[226] (COM (2016) 178), builds on the achievements of the European Cloud Strategy and the High Performance Computing (HPC) Strategy, building on the policy developed in the Communication on Big Data[227] and supporting the European Open Science policy agenda. Complex issues regarding data protection, security, reliance on a small number of large suppliers, and legal issues in some MS are some of the aspects yet to be analysed in relation to the use of these technologies by the public sector.

Data is a key asset of public administrations, and an asset for the economy and society. Whether it is geospatial data, statistics, weather data, research data, transport data, energy consumption data, health data, public administrations collect, produce, use, and integrate authoritative data that supports statutory processes inside and between MS, representing enormous value for business, citizens, and policy. The need to use and to integrate different types of data from different sources is leading to interoperability requirements and innovation in technology, development of new tools and new skills, bringing new opportunities to improve policy making and to create new products tailored to the specific requirements of business, citizens, or policy. However, eGovernment services being in the position to aggregate data reflecting many aspects of the personal life of the citizen, the use and management of this data must not

> " *Representative data is a fundamental asset for evidence-based policymaking* "

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[225]   Number of pilots by maturity level: Ideation 1; Proof of Concept 2; Initial pilot 3; Refined pilot 1; Production 2.
[226]   https://ec.europa.eu/digital-single-market/en/news/communication-european-cloud-initiative-building-competitive-data-and-knowledge-economy-europe
[227]   COM(2014) 442 final.

infringe privacy. The General Data Protection Regulation (GDPR) (Regulation (EU) 2016/679) is a fundamental element in safeguarding private data and so in increasing trust in digitally enabled services.

Digital public services should be supported by effective data infrastructures for data governance, interoperability, maintenance, and access. Standards and technical specifications are fundamental to achieving interoperability. Art. 3 of the INSPIRE Directive defines interoperability as "the possibility for spatial data sets to be combined, and for services to interact without repetitive manual interaction in such a way that the result is coherent and the added value of the data sets and services is enhanced". Interoperability is a prerequisite for enabling electronic communication and exchange of information within and between public administrations. Interoperability programmes in the EU have evolved through time. At first they were concerned with achieving interoperability in specific domains, then evolving by putting common infrastructure in place, addressing interoperability at the semantic level, and pointing out the central role of coordination and organisation across public administration sectors. The European Infrastructure for Spatial Information is an example of such a legal framework (Cetl, V., et al., 2018). The infrastructure components are covered by interoperability agreements reached outside the scope of a particular public service, but considering all levels of administration – EU, national, regional, and local. It requires a holistic approach, including considerations on scalability, availability of reusable building blocks, and its sustainability through time.

Data interoperability was obtained following an open and participatory process resulting in a Regulation on interoperability of spatial data covering 34 data themes, containing agreed data models based on the Generic Conceptual Data Model, common encoding rules, harmonised vocabularies, and registers. Together they form the key pillars of data and service interoperability and they are part of the legal provisions of the Directive, representing the minimum set of spatial objects and their associated attributes that must be shared across public administrations and must be publicly available. The spatial object characteristics (properties) are described by

the commonly agreed semantics, expressed in the form of enumerations or code lists accessible via the INSPIRE registry service, an online system providing access to several centrally-managed registers. Re3gistry[228] is a reusable open source solution for managing and sharing 'reference codes' across sectors, a trusted and authoritative source of information digitally reused which is both human and machine-readable, where one organisation is accountable for the collection, use, updating, and storage of information.

Having spatial data infrastructure duly connected with non-spatial data and other fundamental national infrastructures and applying the principles that data must be managed and updated at the place where it is most sustainable, and allowing the reuse of data in an interoperable environment, creates the right conditions for data reuse, integration, and analytics tailored to the requirements of public administration and all of society. Open data and reuse of data must be non-discriminatory, meaning that data can be found, discovered, and processed. Currently, there are still barriers to the use of open data. One of them is that the right to access and reuse open data is not clearly communicated in a standardised way, readable by humans and machines.

Opportunities that Big Data offers business lead to the idea that Big Data is also a help in data-driven policymaking. Poel, M., et al. (2018) find that use of Big Data[229] for public policy is "at an early stage, with expectations far outstripping the current reality", and is "used more often in the policy cycle for foresight and agenda setting, or interim evaluation and monitoring, rather than for policy implementation and ex post evaluation". In addition, according to these authors, "in government and in the third sector, Big Data is often used for transparency: scientific validity here is an issue when inclusion and representativeness are at stake, and when the complexity of the analysis decreases transparency because knowledge can only be assessed by experts". The possibility of verifying the results and of replicating the method of analysis are also fundamental in accepting the reliability of results.

Data is also increasingly an asset for the development Artificial Intelligence[230] (AI). Craglia, M. et al. (2018),

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[228] https://inspire.ec.europa.eu/news/new-release-re3gistry-software

[229] Big Data is a step change in the scale and scope of the sources of materials (and tools for manipulating these sources) available in relation to a given object of interest" (Schroeder, 2014), cited in Poel, M., et al. (2018).

[230] Communication Artificial Intelligence for Europe, https://ec.europa.eu/digital-single-market/en/news/communication-artificial-intelligence-europe.

presents the European view of AI, defining AI "as a generic term that refers to any machine or algorithm that is capable of observing its environment, learning, and based on the knowledge and experience gained, take intelligent actions or propose decisions. Autonomy of decision processes and interaction with other machines and humans are other dimensions that need to be considered". The application of AI solutions holds remarkable potential benefits for both the public and the private sectors, also helping to address societal and environmental challenges. Governments have made investments in artificial intelligent across domains like defence, waste management, health, agriculture, and smart communities. The rapid deployment of automation and artificial intelligence is creating a variety of narratives, and challenging aspects have been analysed when applied to government and public administration. Its potential for improving access to justice and benefitting for historically marginalised populations, and other questions have all to be examined in specific legal or factual contexts such as in regard to administrative law or law enforcement (Oswald, M., 2018).

Zalnieriute, M. et al. (2019) investigated how principles of the rule of law are affected by the increasing use of two kinds of automation: human-authored pre-programmed rules (such as expert systems) and tools that derive rules from historic data to make inferences or predictions (often using machine learning), focusing on three core rule of law concepts, that is, transparency and accountability, predictability and consistency, and equality before the law. This study demonstrates that systems of both types can fail to live up to rule of law ideals, the latter particularly raise greater issues for transparency and accountability. Good alignment with those ideals depends on the appropriateness of design choices ensuring that system design reflects rule of law values which are appropriate to the kind of decision being supported or made.

Castelluccia, C., Le Métayer, D. (2019) review the opportunities and risks of using *Algorithmic Decision Systems* (ADS), present options to reduce these risks, and explain their limitations. ADS often rely on the analysis of large amounts of personal data to infer correlations or, more generally, to derive information deemed useful in making decisions. Human intervention in the decision-making may vary, and may even be completely out of the loop in entirely automated systems. In many situations, the impact of the decision on people can be significant such as on access to credit, employment, medical treatment, judicial sentences,

> *Entrusting Algorithmic Decision Systems to make or to influence certain decisions raises ethical, political, legal, and technical issues. If neglected, these may pose risks for individuals, for the economy and for society as a whole*

among other things. Entrusting ADS to make or to influence such decisions raises a variety of different ethical, political, legal, or technical issues. Great care must be taken to analyse and address them correctly. If they are neglected, the expected benefits of these systems may be negated by the variety of risks for individuals (discrimination, unfair practices, loss of autonomy, etc.), the economy (unfair practices, limited access to markets, etc.), and society as a whole (manipulation, threat to democracy, etc.). However, most of the risks encountered with ADS may also happen without the use of ADS. For example, discrimination by ADS may result from different types of biases arising from the training data, technical constraints, or societal or individual biases, but on the other hand humans have their own sources of bias that can affect their decisions and, in some cases, these could be detected or avoided using ADS.

Floridi, L. et al. (2018) asserts that "ensuring socially preferable outcomes of AI relies on resolving the tension between incorporating the benefits and mitigating the potential harms of AI, in short, simultaneously avoiding the misuse and underuse of these technologies. In this context, the value of an ethical approach to AI technologies comes into starker relief. Compliance with the law is merely necessary (it is the least that is required), but significantly insufficient... Adopting an ethical approach to AI confers what we define as a *"dual advantage"*. On the one hand, ethics enables organisations to take advantage of the social value that AI enables. This is the advantage of being able to identify and leverage new opportunities that are socially acceptable or preferable. On the other hand, ethics enables organisations to anticipate and avoid or at least minimise costly mistakes". These authors further argue that the dual advantage of Ethics can only function in an environment of public trust and clear responsibilities more broadly. Public acceptance and adoption of AI technologies will only occur if the benefits are seen to be meaningful and risks are considered to be potential, yet preventable, minimisable, or at least something against which one can be protected by applying risk management (e.g. insurance) or can be redressed.

Deriving value and actions from information collection and analysis is central to many government policies. Meyers, M. et al. (2015) assert that the Internet of Things (IoT) can increase value by both collecting better information about how effectively public servants, programs, and policies are addressing mission challenges, and helping government deliver services based on real-time and situation-specific conditions. *Smart Cities* and

the vast amount of data produced by *sensors* supports the development of dynamic *platforms and systems,* providing contextualized, real-time, location-based data from IoT or crowdsourcing to business partners and start-ups, giving them opportunities to create new services or improve existing ones.

Platforms are a new way of building digital services. They are increasingly implemented by governments at all levels of public administration[231] or Government[232]. Brown, A. et al. (2017) argue that *Government as a platform* is not solely about technology and the building of technical components, it is a disruptive embrace of a new economic and organisational model with the potential to improve the way Government operates, helping resolve the political debate about centralised versus localised models of public service delivery.

As technical pre-conditions for eGovernment service provision, eID (electronic identification), biometric authentication, eDocuments, adoption of Authentic Sources, and Single Sign On are important building blocks of the digital infrastructure. The re-use of emerging joint solutions under the Connecting Europe Facility (CEF) programme or other common frameworks like those implemented by ISA2, in particular eID, eSignature, eDelivery, eProcurement, and eInvoicing is promoted by the EC while avoiding sectoral duplication of service infrastructures. eProcurement has the potential to facilitate access to intra-EU markets. However, there is also a risk of market fragmentation if national systems are not interoperable. The use of jointly developed solutions is a way of eliminating potential barriers.

5.2.1.1. *Potential of Biometrics as critical enabler*

Biometrics has been introduced in eGovernment as a means of mapping processes that require strong authentication and in order to introduce an additional element of security. Firstly, there are situations where the use of an eID needs a verified link to a specific person who has a proper entitlement. It should not be possible to transfer the relevant credentials to another person. A simple example is eVoting but it applies to any process where someone would otherwise be obliged to present him/herself in person. The use of biometric authentication,

using fingerprints, and face or iris recognition, provides an efficient and convenient alternative, including remotely. Secondly, the introduction of biometric identifiers in governmental eDocuments (like passports and ID cards) facilitates verification of ownership of the documents.

On the other hand, two crucial obstacles have been encountered since its initial introduction for eGovernment in early 2000s:

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231 https://inspire.ec.europa.eu/pr_searchx.cfm?i=5&id_search=70031
232 https://www.gov.uk/government/policies/government-as-a-platform

- The underestimated technicality of biometrics – Biometrics is a cross-cutting technology, originally with a forensics background that uses specific parts of the human body to clearly distinguish between persons. The problem here is data quality, i.e., the mapping of the physical traces into digital information. Whether law enforcement experts take fingerprints of a suspect or whether fingerprints are used for remote authentication in web application makes a difference. Depending on the particular use case, data quality may not be sufficient to verify the identity of a person or to find that person in a million records. In addition, the ageing problem of biometric identifiers for children and juveniles has not been recognised properly in the past[233].

- User acceptance – Using fingerprints or face recognition to open the screen of a smart phone has become widely accepted, in particular among young people. The situation is different when using biometrically enhanced governmental tokens like passports or ID cards for eGovernment or eCommerce. According to a survey published by Accenture in 2018, only half of the respondents would share their fingerprints with the government in order to facilitate governmental services[234]. Surprisingly, the share of millennials that would agree to share their biometrics is significantly smaller than for older age groups (Ziadeh, 2018).

Increasing the availability and quality of open government data of value to the economy and society implies adopting the open-by-default approach or having a coherent and standardised policy framework for data sharing and re-use, but also enabling the automatic linkages to databases, for example, by Application Programming Interfaces (APIs), incorporated into the design of public administration services. APIs have become a technological component of modern digital architectures, impacting every sector of the global economy. API is a set of clearly defined methods of communication between the service and any other software or components[235], so it is essentially a software intermediary that allows two applications to interact with each other, or to exchange data and/or request services. There are many different types of APIs. As an example, web services expose web APIs as endpoints that any internet-enabled language or software can access in exactly the same way browsers access websites and services[236]. In particular, web APIs are an interface for web applications, or applications that need to connect to each other via the Internet in order to communicate[237]. The popularity and adoption of Web APIs is a result of their simplicity and transparency. While the more traditional APIs are used as integration points within systems hidden from view, tens of thousands Web APIs have been made available publicly, especially by private companies.

In the public sector, APIs provided by both public and private actors are used efficiently (Gartner, 2018), and have also been created to enable efficient cross-department and cross-border sharing of information. Developers, private companies, and ultimately citizens can consume them through the Internet or mobile based applications. MS are mainly implementing APIs for G2G in order to increase collaboration and to have a single point of trust, facilitating interaction between all kinds of systems and processes, but also G2C and G2P. Public sector applications use either what API producers offer or otherwise develop their own APIs or reusable components depending the strategy they want to follow. In that case the recommendation is to use the APIs produced by others to support actions and not for the core business.

APIs are used by the public sector to help them achieve their goals in four main ways:

- Enabling ecosystems, also with the private sector
- Overcoming complex integration of large systems
- Supporting Open Government initiatives
- Enabling innovation and economic growth

Developers that use Web API solutions also create extended interrelationships enabled by the applications they create. These applications link a number of different stakeholders (e.g. governments, other developers, citizens, private companies) creating API based ecosystems. A well-designed government ecosystem could help minimise the frequency that citizens or businesses have to provide the same information, establishing an accurate single source of the authoritative data and a single point

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[233] http://publications.jrc.ec.europa.eu/repository/bitstream/JRC85145/fingerprint%20recognition%20for%20children%20final%20report%20%28pdf%29.pdf

[234] https://governmentciomedia.com/are-you-willing-share-your-biometric-data-better-government-services

[235] https://www.definition.net/define

[236] https://federaltechnologyinsider.com/government-agencies-leading-app-economy-using-innovation-drive-economic-growth/

[237] https://www.definition.net/define/api

of trust. This also supports the Once Only Principle. Lastly, API infrastructures are currently being used to overcome the restrictions of traditional integration solutions[238].

Externally facing public sector APIs for various applications involve the movement of sensitive data. This is addressed by security features and various access rights. The lack of standards (except in the geospatial/mapping space) in some ways does hinder both internal and external interoperability with government agencies (Gartner, 2018).

Strategic policy documents indicate that digital public services should be designed and delivered following the principles of *user-centricity*[239], which means: "accessibility, cybersecurity, availability, and usability, reducing the administrative burden on citizens and businesses, namely by optimizing and/or creating digital processes and services, empower citizens and businesses to voice views, correct errors, comply with the general data protection regulation and privacy requirements in the EU and national levels." To that end, those requirements should already be taken into account in the inception and design phases of the digital tool or web site, adopting the by-design principle followed in the cybersecurity, privacy, and data protection domains. In several circumstances accessibility implies the use of different channels for the services to avoid digital exclusion.

5.2.2. Standardisation, Organisation, Governance, and the Legal Framework

As per the European Union Treaty, the Union is founded on the values of respect of the rule of law (Art. 2[240]) and the limits of Union competences are governed by the principle of conferral. The use of Union competences is governed by the principles of subsidiarity and proportionality (Art. 5.1): the Union shall only act within the limits of the competences conferred upon it by the Member States in Treaties; competences not conferred upon the Union in the Treaties remain with the Member States (Art.5.2). Under the principle of subsidiarity, in areas which do not fall within its exclusive competence, the Union shall only act if and in so far as the objectives of the proposed action cannot be sufficiently achieved by the Member States, either at central level or at regional and local level, but rather, by reason of the scale or effects of the proposed action, can be achieved more satisfactorily at Union level (Art. 5.3). Those Articles establish the *governance* and they are the basis of any legislative or other type of action by the Union and Member States. In this light, the legality of making judgements regarding the "progress" and scoring MS governments on digital government is also questionable except for the monitoring of provisions established by specific legislation and their related regulatory reporting when applicable.

To reap the opportunities and benefits of the digital transformation requires Governments not only to define a strategy for National but also for regional and local governance, formulating policies and passing legislation accordingly. To ensure that all policies are mutually reinforcing and aligned in one coherent national digital strategy, policies creating the foundation of the digital transformation and enabling it to work for the economy and society need to be co-ordinated by ministries and other bodies at all levels of government as well as with all key stakeholders involved in policy making and implementation (European Commission, 2007), (OECD, 2017a). Countries have different national digital strategies, which may be adjusted along the way to take changes in the different contexts into consideration (national, local, or international). Some examples below illustrate these statements.

The Danish Digital Strategy 2016-2020[241] sets the course for Danish public sector digitisation efforts and their interaction with businesses and industry (Agency for Digitisation, 2016). The government Digital Strategies concern the authorities at all levels of government, from State, to regions, to local councils – i.e., both the administrative institutions such as ministries, agencies,

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[238]   As an example, the X-Road Platform is the backbone of e-Estonia. Invisible yet crucial, it allows the nation's various public and private sector e-Service databases to link up and function in harmony. https://e-estonia.com/solutions/interoperability-services/x-road/

[239]   The term user-centricity applies to the digital tools used, not to public administration that implement policies, achieving policy objectives through the application of policy instruments and the administration of ensuing legislation, where the concept of "user" is not adequate.

[240]   "The Union is founded on the values of respect for human dignity, freedom, democracy, equality, the rule of law, and respect for human rights, including the rights of persons belonging to minorities. These values are common to the Member States in a society in which pluralism, non-discrimination, tolerance, justice, solidarity, and equality between women and men prevail."

[241]   https://en.digst.dk/policy-and-strategy/digital-strategy/

municipal and regional administrations, and the executive institutions such as hospitals, public schools, universities, etc. This Digital Strategy 2016-2020 sets three goals for the development of a more digital public sector in the years to come: I) digital solutions must be easy-to-use, quick, and ensure high quality, II) Public sector digitisation must provide good conditions for growth, III) Security and confidence must be in focus at all times.

The eGovernment concept in Lithuania[242] aims at "improving (by using digital technologies) the delivery of public services to public and municipal authorities and institutions, to business people and the population, engaged to develop effective means allowing to adapt public administration to modern needs; to analyse and reform the decision-making process to such an extent that public administration would suit the modern knowledge management; to increase the speed of services of public institutions and improve their quality by applying IT to data processing, management, and service delivery through digital channels". A comprehensive overview is available in the *platform eLithuania, eGovernment solutions*[243].

Strategic reform of public administration carried out in the Republic of Ireland (2014-2016) focused on Service users, Efficiencies, Openness and Leadership, and Capability. The accompanying Public Sector ICT Strategy is built on the Strategic Pillars such as building shared infrastructure, driving digitisation and innovation, supporting data sharing, improving governance, and increasing capabilities.

The Norwegian Government announced its "intention to enable Norway to exploit the opportunities ICT usage offers for value creation and innovation" in the white paper Digital Agenda for Norway[244]. The white paper describes how improved access to ICT competence in the public and private sectors, regulation more suitably adapted to a digital society, and the public sector as a demanding customer will serve as policy instruments to achieve these goals. The Government also facilitates the participation of Norwegian enterprises in the digital single market in Europe (OECD, 2017d).

Implementing a digital strategy may focus on harmonised long-term efforts rather than fast short-term gains. It does not exclude recognising that incremental innovation in certain conditions may lead to significant improvements that may facilitate faster and more important steps at a later date.

Different ideological trends in relation to governance and organisational change in the public sector have influenced management and research approaches. The New Public Management (NPM) paradigm emerged throughout the 1980s and is characterised by a tendency toward outsourcing and the adoption of private sector management principles, driven by the belief that this will improve the public sector's ability to deal with a changing and more uncertain environment (Windrum, 2008). This approach dominated through the 1990s and remains influential. Additional developments of NPM have emerged, including notions of 'joined up government' and the network focused 'New Public Governance'(NPG). For example, Hartley (2005) describes NPG as highlighting the need for increased collaboration, both within government and with external stakeholders.

Coordination, communication, and monitoring achievements and challenges are important for successful governance of digitisation efforts. Public service provision often requires different public institutions to work together to carry out its functions efficiently. This requires coordination, governance by the authorities with a mandate for planning, implementing, and operating public services, and a decision-making process regarding the stakeholders involved. The governance process needs to evaluate whether digitalization programs are performing well on a regular basis, and adjust these programs as conditions change. OECD (2017d) asserts "The need to establish a governance model that enables and strengthens collaboration and coordination and tackles silo-based approaches, roles, and responsibilities is part of the digital government performance, agreed by the government and involving all stakeholders acting in the public sector, to secure adequate leadership. It is also necessary to ensure multi-stakeholder cooperation and engagement as well as the co-responsibility of public, private, and civil actors. This is also essential in creating shared ownership of results, which supports joint and integrated efforts". Good governance rules need to be at the centre of the digital transformation of governments (Millard 2015).

[242] https://ivpk.lrv.lt/en/news/egovernment-development-in-lithuania
[243] https://digital-lithuania.eu/digitalgovernment/
[244] https://www.regjeringen.no/en/aktuelt/digital-agenda-for-norway-digitisation-vital-for-welfare-and-jobs/id2484184/

Referring to EU policy initiatives, the EIF interoperability conceptual model[245] considers four layers of interoperability: legal, organisational, semantic, and technical interoperability as well as a cross-cutting component of the four layers called 'integrated public service'. The background layer is the *'interoperability governance'*, which refers to decisions on interoperability frameworks, institutional arrangements, organisational structures, roles and responsibilities, policies, agreements, and other aspects of ensuring and monitoring interoperability at national and EU levels. *Legal interoperability* is about ensuring that organisations operating under different legal frameworks, policies, and strategies are able to work together. This is valid at EU[246] and at national levels with the national legislation and transposition of relevant EU legislation. *Organisational interoperability* refers to the way in which public administrations align their business processes, responsibilities, and expectations to achieve commonly agreed and mutually beneficial goals. *Semantic interoperability* ensures that the precise format and meaning of exchanged data and information is preserved and understood throughout exchanges between parties. *Technical interoperability* covers the applications and infrastructures linking systems and services other than data interoperability.

There is no leading model for eGovernment. The report of Winner et al. (2018) on interoperability governance models[247] concludes that e-Government has no unique natural "home" in the political structures of different countries. The analysis of several national governance structures shows that countries have different approaches to the governance of e-government. Waller and Weerakkody (2016) pointed out that "different governments have different policy goals and instrument preferences. Legislative norms and the form and governance of nations' public sectors vary widely. Consequently, it is not valid to assume that the application of technology in policy implementation can be the same in different geopolitical settings, including where policy objectives are broadly similar".

Legal frameworks for digital government enable progress of digital transformation towards shared goals, removing barriers, and creating conditions for cross-border activities. Although government and public services enabled with digital technologies are the competence of MSs, EU legal frameworks act as enablers of the DSM in various fundamental common elements of digital government that need to be addressed at European level. As an example, to strengthen the security and resilience of public administration and services, the need to increase the strategic, operational, research and development capacity in the area of cybersecurity is recognised, especially with the implementation of the network and information security (NIS) Directive[248]. With the introduction of the General Data Protection Regulation (2016/679)[249] (GDPR) and the revision of the ePrivacy rules[250], the EU has set up a solid framework for digital trust outside the cases where administrative law is not applicable or is silent on the matter. The GDPR guarantees a high level of data protection and at the same time ensures the free movement of personal data within the EU. Compliance with the EU privacy and personal data protection regulatory framework can be seen as a condition for the development of user-centric digital services as well as an enabler facilitating their deployment and stimulating their adoption (De Hert, P. , et al., 2017).

The *data package of measures*[251] further facilitates the reuse of public data in the proposal for a review of the Directive on the re-use of public sector information (the PSI Directive), a technical update of the Recommendation on access to and preservation of scientific information, and guidance on sharing private sector data. This guidance builds on the principles for data sharing between businesses and between business and the public sector, which is laid down in this Communication (COM/2018/232).

Several EU initiatives help to *preserve coherence between legal frameworks* and to make the best use of the existing ones. As examples, the Geographical Information System of the Commission (GISCO)[252], is a permanent

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[245] https://ec.europa.eu/isa2/sites/isa/files/eif_brochure_final.pdf
[246] EU Better Regulation: Delivering better results for a stronger Union COM(2016) 615 final https://eur-lex.europa.eu/legal-content/EN/TXT/PD-F/?uri=CELEX:52016DC0615&from=EN
[247] https://joinup.ec.europa.eu/sites/default/files/document/2018-04/SC439_D03.01%20Interoperability%20governance%20models%20v3.00.pdf
[248] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32016L1148
[249] OJ L 119, 4.5.2016, p. 1.
[250] COM(2017)10 final.
[251] Final Communication COM/2018/232 "Towards a common European data space". https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=COM:2018:0232:FIN
[252] http://ec.europa.eu/eurostat/statistics-explained/index.php/Geographical_information_system_of_the_Commission_(GISCO)

service provided by Eurostat that answers the needs of Eurostat and the European Commission for geographical information at EU, Member State, and regional levels.

Following the Communication on data, information, and knowledge management in the Commission (C(2016) 6626) setting out a strategy and objectives for improving the efficiency and effectiveness of EU institutions, a senior-level governance structure was created by the *Information Management Steering Board (IMSB)* and supported by an Information Management Team (IMT). The IMSB is mandated to steer and oversee the implementation of the Commission's data, information, and knowledge management strategy[253].

5.2.3. Innovation, Business models, and Skills

Innovation not only involves new technologies, it also occurs by the application of collaborative, transversal, and open approaches, and is introduced in new planning and working processes, user-centric service delivery (Estonian Presidency of the Council of the EU 2017), communication and interaction with citizens, through the action of business and entrepreneurs, citizens' engagement, and participatory policy making. The sharing and reuse of data, information, and knowledge is a real cultural change.

As mentioned above, the "business" of government is policy design, legislation, administration, enforcement, etc., using policy instruments, and following political philosophies. Innovation involves solving the problem of how to bring digital technology to bear on this type of business in a positive way, and from this point of view it opens the way for new approaches in which innovation is introduced in policy making, design of policy instruments, interaction, and communication with citizens, private organisations, and NGOs. Public sector innovation is not the same as innovation in the private or not-for-profit sectors as its operations are typically embedded in a legal, regulatory, and administrative set of frameworks that would require enactment of policy

[253] In its WP 2018/2019, IMSB includes Action 5.4 "Strengthen spatial data management in the European Commission and EU agencies (using coordinated thematic priorities building on the progress made in the implementation of the INSPIRE Directive and under the umbrella of COGI)". This action, owned by JRC, ESTAT, and ENV, has CNECT, DIGIT, GROW, OP, REGIO, and the EEA as stakeholders as well as all other interested DGs and EU agencies through the Inter-Service Group on Geographic Information (COGI).

changes through legislation, administrative code, or other mechanisms.

Kay, R. and Goldspink, C. (2016) discuss the differences between public and private sector innovation, arguing the assumption that private sector ideas and models are equally applicable in the public and private sectors is far from true, and is counterproductive to innovation in the public sector. So a different specific public sector approach is required. They stress that the public sector is innovative but the nature and form of that innovation is different to the private sector, which arises out of fundamental differences in the two sectors' measures of success and from the greatest distinction between public and private sector governance and organisational structure.

Bremers and Deleu (2016) identified seven drivers as the main motivations for public administrations to adopt an innovative approach: better control and better policy making; better quality of service and enhanced user experience; social benefits and public value; cost efficiency; economic growth and jobs; international mobility; and demand from civil society and/or business associations.

In specific cases, APIs enable new innovative service models using solutions developed using data from private partners or citizens and existing public administrations, bringing skills not available in a specific public administration

body, and also opening up a market for third parties to innovate. Cities and local governments often collaborate with the automotive, insurance, health, and other sectors to create "ecosystems" powering applications and other services that meet citizen demands. Government also plays a role in enabling social innovation by enhancing supply of innovation by setting up initiatives such as grants for incubators, enhancing demand (e.g. by providing tax incentives), and matching supply and demand as with innovation hubs.

Putting administrative information and transactions online for the public to use directly can make them less accessible or usable to certain groups. According to the OECD (2017c), the use of digital services varies according to education, income, and age. In 2016, 54 % of individuals with a higher education qualification submitted forms online compared to 17% of individuals with a low level of education, while 49% of the top income quartile submitted online compared with only 25% of the poorest. Furthermore, 42% of individuals aged 25-54 did so compared to 24% of those aged 55-74. The Digital Economy and Society Index (DESI) also measures the digital skills needed to realise the potential offered by a digital society (see Figure 5.1). These skills range from basic user skills, which enable individuals to interact online and to consume digital goods and services, to advanced skills that empower the workforce to use technology to enhance productivity and foster economic growth.
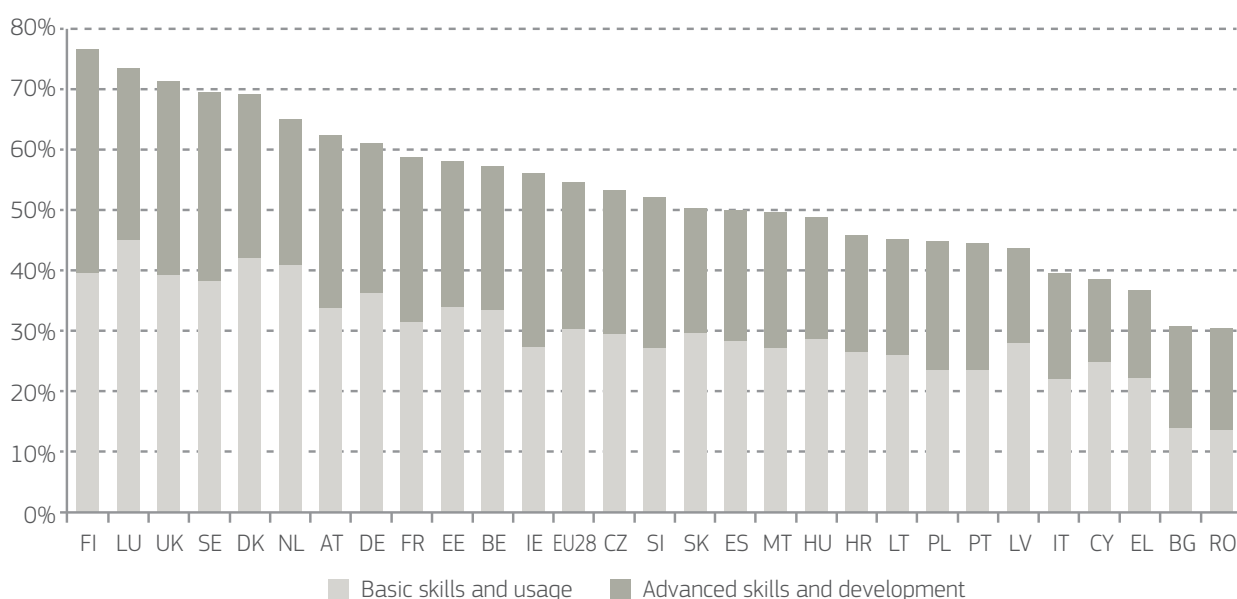
FIGURE 5.1: DESI HUMAN CAPITAL COMPONENT 2017 BY COUNTRY.
Source: European Commission, DESI 2017 Report.

There are large disparities in the share of adults without digital skills between Member States. Only a small fraction of the EU's adult population has advanced software and content creation skills, which are becoming increasingly critical to accessing the labour market. It still represents a clear barrier to widening and deepening the use of data and analytics in eGovernment and make full use of data for better decision-making. Ebbers, W.E et al. (2016) assert that digital skills gaps have an influence on satisfaction – the more digitally skilled citizens are, the more satisfied they are with online services – but not on uptake of digital government services.

According to the EDPR (European Commission, 2017b) and based on EUROSTAT data, 79% of EU citizens go online weekly and 63% of disadvantaged people use the internet weekly. Despite ongoing improvements, disadvantaged population groups such as the elderly and those with low education levels or on low incomes continue to be at risk of digital exclusion. 14% of the EU population has still never used the Internet. Among the citizens needing to submit forms to public administrations in 2016, 13% used the offline channel because they do not use the Internet at all. Of the remainder, all Internet users, 52% chose the online channel, while 35% preferred an offline interaction with the public authorities. However, it does not mean that all citizens who preferred the online channel to submit forms to public administration used their digital skills. Among them are those who have no conditions to do so and pay a private entity to perform the service.

Governments and public administrations take measures to avoid digital exclusion, reducing this gap with solutions while acting on other policies like reforming the national education system. Different types of initiatives are currently occurring to fit the diversity of individuals' conditions: communication campaigns by public administrations informing and training citizens regarding the use of digital services available in several governmental platform, set-up of help points at local administration level, private service providers acting as intermediary between citizens and public administration and, in many cases, keeping the possibility of non-digital service open using a multi-channel strategies to reduce the digital divide (Pieterson, W., Wolfgang, E. 2008). The current risk of digital exclusion can be mitigated by applying multi-channel strategies (Waller, P., Weerakkody, V. 2016) so that the public administration can interact with citizens. Within the public administration, addressing

> *Governments have the responsibility to reform national education systems, including education curricula, to increase DT take-up opportunities*

the challenges of an increasingly digital society requires changes to current skills policies, although not all departments and agencies of public administration can afford or even justify high digital skills. In these cases, solutions experimented by MS are either to concentrate certain specialised qualifications inside the public administration or to contract them out to the private sector, in most cases SMEs.

Lifelong learning programs are important in facing the fast speed of technological change. A way of facilitating DT processes and reducing digital exclusion is to define competencies, and upskilling and reskilling strategies, not only for public servants but also for the population in general. This includes *defining a different sort of skill-set for employment*, skills in the area of ICT, data analytics, data management and communication, to be integrated with other new areas in specific domains. "Governments in collaboration with stakeholders are responsible for defining skills policies to facilitate take-up opportunities and promote inclusive growth, ensuring that initial education equips all students with solid literacy, numeracy, and problem-solving skills as well as basic ICT skills and complementary socio-emotional skills such as teamwork, flexibility, and resilience." (OECD, 2017b).

An interesting initiative launched by the EC regarding digital skills is the Digital Skills and Jobs Coalition[254] to bring together Member States and stakeholders, "aiming at developing a large digital talent pool, ensuring that individuals and the labour force in Europe are equipped with adequate digital skills". Its annual progress will be monitored as part of the EDPR. According to European Commission (2017a), "the swift implementation by Member States of the skills agenda and initiatives must be a priority to accompany the digital transformation".

As previously explained, business model means the accomplishment of roles and functions of government and public services. Business model is a different concept in public administration compared to commerce. As Waller (2017) argues, it can cover anything from a policy design to a transactional process to a hands-on local operational function, or a mixture of all of them.

> " *The business model in public administrations is different from commerce or industry* "

Among other things, reuse of public sector data can potentially reduce administrative costs significantly. Examples applying the 'once only' principle show increased effectiveness of process, greater operational efficiency, increased tax collection owing to customised services and data integration, and adopting automated data analytics leading to less fraud and fewer errors. Simultaneously, it enables the development of new products, services, and opportunities for private and research communities in particular. Deployment of sensor data and its integration with other types of data is increasingly important in policy making and implementation.

The new business model developments are supported by digital technologies. *Government platforms* are already in place or in the stage of advanced planning, enabled by *digital by design* in the context of digital government. Examples are the Flemish Government streamlining service to Citizens[255] (Arents, H., 2016; Vanderstraete, T., 2017; OECD, 2010), and a regional georeferenced platform[256] which combined the multiple resources of public bodies, benefitting citizens and public services.

Janowski, T. et al. (2018) contend that citizen-administration relationships have been shaped by changes in governance paradigms. A recent trend has been the "platform paradigm" in which "the administration empowering citizens to create public value by themselves, through socio-technical systems- platforms- that bring data, services, technologies and people together to respond to changing societal needs" and offer a conceptual framework for citizen-administration relationships under this paradigm (empower, learn, coordinate, create, and collaborate).

Strategic partnerships play an important role in creating the conditions for delivering services and products in line with requirements of the society and the flow and appropriation of ideas. This in turn gives rise to new business model (Blakemore, M., Wilson, F., 2009) when one of the partners brings its great competence to help achieve a goal of common interest, expecting to receive the equivalent benefit in a win-win situation. These strategic partnerships not only occur between public bodies, but also between public and private entities especially with SMEs who may provide the technological support needed by activities and programmes designed by government and so that policy can be implemented.

Waller (2017) proposes and discusses a multi-actor, multi-instruments system model, summarising the role of the governmental and the non-governmental actors when joining forces to achieve a social goal in which ICT has an enabling value in the working of the system and of its actors as well in its design process *co-creation and co-production*) and engagement (*eParticipation*).

A conceptual framework for open governance systems enabled by ICT is also proposed by Millard (2015) by building up a system of open assets, open services, and

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[254] https://ec.europa.eu/digital-single-market/en/digital-skills-jobs-coalition
[255] http://www.dxc.technology/application_services/success_stories/140494-flemish_government_streamlines_service_to_citizens
[256] http://geobretagne.fr

open engagement for which broader societal-wide open governance systems are also necessary, which both reach across many parts and levels of the public sector as well as reach other appropriate actors outside government." This involves huge challenges: technically, politically, legally, organisationally, and in terms of working cultures. The vision is of a 'whole-of-government' approach embedded in and interacting with the reality of society as a whole".

According to Galasso et al., 2016, Open eGovernment Services (OGS) include initiatives for transparency and open data regarding both public service provision and involvement in policy decision, services where government plays a role as leader or enabler, and services where non-government parties play different roles – as lead or contributor, or providing simple input in the design. Their main features are openness, collaboration, and technology.

Linders, D. (2012) suggest a typology for categorizing citizen coproduction initiatives enabled by ICT developments, to help public administrators and researchers improve understanding and comparison as well as guide implementation of initiatives by recognizing the variability and appropriate applications of different coproduction designs.

5.2.3.1. Territorial aspects: the contribution of Digital Innovation Hubs to digital transformation in Public Administration

Digital Innovation Hubs (DIHs) in MS and regions are contributing to the digital transformation of enterprises and public administrations. When it comes to Public Administration (and selecting "Public Administration & Defence" in the online DIH catalogue of the S3P[257]), 76

fully operational DIHs in EU28 countries state that they offer digitisation services to public administrations, to the defence sector, and have contributed to the digital transformation process in this sector[258]. Their geographical distribution can be seen on the online Catalogue's map.
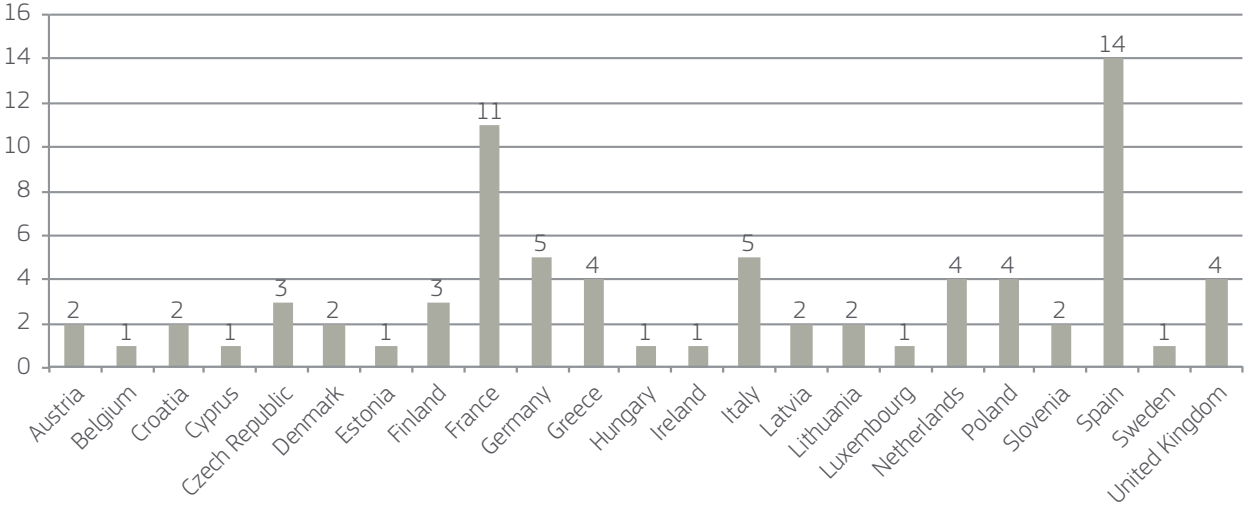
FIGURE 5.2: NUMBER OF DIHS SPECIALISING IN THE PUBLIC ADMINISTRATION AND DEFENCE SECTORS PER EU COUNTRY.
Source: JRC analysis.

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257   http://s3platform.jrc.ec.europa.eu/digital-innovation-hubs-tool
258   Disclaimer: The DIH Catalogue website is a "yellow pages" of Digital Innovation Hubs. The information provided about each entry is based on self-declaration. The European Commission cannot take any responsibility for the information provided. Currently all the entries in the catalogue are being verified (based on the information provided) as to whether or not they comply with the following 4 criteria:
1. Be part of a regional, national, or European policy initiative to digitise the industry;
2. Be a non-profit organisation;
3. Have a physical presence in the region and present an updated website clearly explaining the DIHs' activities and services provided for the digital transformation of SMEs/Midcaps or industrial sectors currently insufficiently taking up digital technologies
4. Have at least 3 examples of how the DIH has helped a company with their digital transformation, referring to publicly available information, identifying for each: Client profile, Client need, and Solution Provided to meet the needs.
The purpose of the catalogue is to support networking of Digital Innovation Hubs and to provide an overview of the landscape of Digital Innovation Hubs in Europe supported by regional, national, and European initiatives for the digitisation of industry. There is no relationship between being present in the catalogue and being able to receive funding of the European Commission.

Country distribution of Fully Operational DIHs in Public Administration and Defence

The country distribution of the above-mentioned 76 DIHs that provide digitisation services to Public Administration and Defence sectors are distributed in EU countries as shown in Figure 5.2.

The DIHs identified possess a number of technical competences and offer a range of services to stakeholders in the public administration and defence areas. The following provides information on the frequency of technical competences and the range of services provided.

Frequency of technical competences of Fully Operational DIHs in Public Administration and defence

Most frequent technical competences declared by DIHs in the public administration and defence sectors are the following (see Figure 5.3):

- Internet of Things (e.g. connected devices, sensors, and actuator networks)
- Artificial Intelligence and cognitive systems
- Data mining, big data, database management
- Augmented and virtual reality, visualization
- Cyber physical systems (e.g. embedded systems)

Frequency of technical competencies

Technical competency	Value
Internet of Things (e.g. connected devices, sensors and actuators networks)	69
Artificial Intelligence and cognitive systems	66
Data mining, big data, database management	60
Augmented and virtual reality, visualization	53
Cyber physical systems (e.g. embedded systems)	53
Robotics and autonomous systems	52
Interaction technologies (e.g. human-machine Interaction, motion recognition and language	50
Simulation and modelling	50
Location based technologies (e.g. GPS, GIS, in-house localization)	49
Software as a service and service architectures	48
Cloud computing	46
Cyber security (including biometrics)	45
ICT management, logistics and business systems	44
Sensors, actuators, MEMS, NEMS, RF	43
Advanced or High performance computing	38
Broadband and other communication networks (e.g. 5G)	37
Internet services (e.g. web development, web production, design, networking, and e-commerce)	33
Micro and nano electronics, smart system integration	32
Photonics, electronic and optical functional materials	31
Additive manufacturing (3D printing)	30
New Media technologies	27
Gamification	25
Other	18
Screens and display technologies	17
Laser based manufacturing	13
Organic and Large Area Electronics (OLAE)	11

FIGURE 5.3: FREQUENCY OF TECHNICAL COMPETENCIES OF DIHS SPECIALISING IN THE PUBLIC ADMINISTRATION AND DEFENCE SECTORS.
Source: JRC analysis.

There is a broad range of services provided by DIHs depending on their capacities and also on the level of maturity SMEs have reached in their process of digital transformation.

The types of services most commonly mentioned by DIHs that provide support to the public administration and defence sectors are the following (see Figure 5.4):

- Collaborative Research
- Ecosystem building, scouting, brokerage, networking
- Awareness creation
- Concept validation and prototyping
- Education and skills development

Frequency of services provided

Service	Frequency
Collaborative Research	71
Ecosystem building, scouting, brokerage, networking	70
Awareness creation	69
Concept validation and prototyping	64
Education and skills development	61
Testing and validation	59
Incubator/accelerator support	59
Mentoring	45
Visioning and Strategy Development for Businesses	45
Access to Funding and Investor Readiness Services	41
Digital Maturity Assessment	39
Market intelligence	35
Voice of the customer, product consortia	30
Pre-competitive series production	23
Commercial infrastructure	22
Other	18

FIGURE 5.4: FREQUENCY OF SERVICES PROVIDED BY DIHS SPECIALISING IN THE PUBLIC ADMINISTRATION AND DEFENCE SECTORS.
Source: JRC analysis.

Examples of digitalisation services in public administration and defence:

DIHs are already contributing to the digital transformation of stakeholders in the public administration and defence sectors in Europe and their role will be increasingly important in the future. The following are some examples of different digitisation services provided by DIHs to beneficiaries related to the public administration and defence sectors in different countries:

i) Luxembourg Institute of Science and Technology (LIST), Luxembourg[259]

   Service example: Measuring the performance of education systems depends on the reliable measurement of actable competencies. In a context where traditional paper-based instruments become more and more unadapted to the skills that need to be evaluated, nowadays Computer-Based Assessment represents one of the cornerstones of future Human Capital development. In close collaboration with the University of Luxembourg (psychology and educational measurement), the authors have developed an advanced Computer-Based Assessment Open-Source platform called TAO. This platform aims to provide value added artefacts to various types of stakeholders which range from the policy-making perspective, OECD (Pisa, Piaac) to other international institutions. Technological partnerships in the assessment fields have also been established with world-leaders such as Educational Testing Services (ETS), in the US, and the Australian Council of Educational Research (ACER), Australia. Today, TAO has been transferred to the spin-off OAT created in 2013 which now has 28 collaborators.

ii) TeraLab: Big Data Platform for Research, Education, and Innovation, France[260]

   Service example: Access to Research (eGovernement)

   Analysis of the use of the Gallica digital library (French Component of Europeana)

   Client profile: French National Library

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[259] http://s3platform.jrc.ec.europa.eu/digital-innovation-hubs-tool/-/dih/1061/view
[260] http://s3platform.jrc.ec.europa.eu/digital-innovation-hubs-tool/-/dih/1058/view

Client Needs: The BnF (*Bibliotèque nationale de France* – French national library) and Telecom ParisTech, and the Department of Economics and Social Sciences have been working together on qualitative analysis since 2013 (2014 observation of Gallica users, 2015: Study of the use of funds used by amateurs to digitize the Great War). In 2017, they needed to complete this initial research item with a digital, quantitative analysis: Log Mining = Logs of Gallica Website from the BnF on the behaviour of users of the BnF: 40 m visitors per day, 20 m lines of logs per day. They needed an infrastructure, security, and tools so that data scientist could access these logs.

Solution provided to meet the needs:

The contribution of Teralab was:

- Technical: Implementation of an ElasticSearch database, Easy recovery for treatments.
- Workspace security: the TeraLab team worked with the security officer of BnF in order to access the logs.
- Acceleration of research action by providing all tools, security, and pre-installed workspace to focus on Log Mining.
  Benefits for the BnF: Data security, Data stored in France.
  Benefits for Telecom ParisTech: Flexibility, adaptability (changing needs)
  Analyses produced:
- Simple statistics (popular documents, average times, entry point..).

- Analysis and optimization of the impact of mediation (blog, Facebook) on the Gallica audience.
- Characterization of uses: how Gallica users navigate the site[261].

iii) Algebra LAB, Croatia[262]

Service example: Labour Market Dynamics Monitoring using Big Data

Client profile: labour market stakeholders and policy makers

Client needs: to understand labour market dynamics

Solution provided: the system developed provides a profound insight into the supply and demand of skills in the labour market and the gap between the same with the main aim of supporting decision-making in employment policies and the education system. As part of the system, estimates of skills that will be required in the future in certain geographic areas are provided. The use of regional data enabled insight into all the specifics of the EU labour market, which was one of the main goals the solution needed to meet. In fact, data from tens of millions of job adverts from the European Centre for the Development of Vocational Education (CEDEFOP) was used. In addition to these advertisements, job advertisements published on the European Job Mobility Portal (EURES) were used as well as data from 4.7 million job seekers' curriculum vitaes[263].

5.3 | Impacts of Digital Transformation on Government and Public Administration

This section gives a general and non-exhaustive overview of problems, issues, and limitations encountered when assessing the impacts of DT on government and public administration. It includes several specific examples and conceptual approaches. Starting with the economic impacts, then moving on to the social impacts, following the structure of this report and adding a sub-section on the impact of cybercrime, justified by the enormous importance of these potential impacts on society. Economic and social impacts on many aspects have to be viewed as a whole as they influence each other. ICTs are linked to the emergence and evolution of new socio-technical systems

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261   More details: https://www.teralab-datascience.fr/fr/accueil/le-projet/utilisateurs/clients/la-bibliotheque-nationale-de-france
262   http://s3platform.jrc.ec.europa.eu/digital-innovation-hubs-tool/-/dih/2566/view
263   More details: https://www.linkedin.com/pulse/croatian-team-won-first-eu-big-data-hackathon-leo-mr%C5%A1i%C4%87-phd/

that bring data, services, technologies, and people from different sectors together so as to respond to changing societal needs, form new social partnerships, and develop innovative solutions. DT generates new relationships and dynamics involving actors and resources outside public organisations, and modifies the ways by which the value embedded in the services is produced.

Although the political impact of DT is substantial, it was not taken separately as it is implicit in many statements within all sections and so it could lead to repetitions. Impact evaluation, as part of a broader agenda of evidence-based policy making, is not specifically developed here. Digital transformation of government and public administration – digital government – have different impacts on institutions and their internal processes as well as on citizens, business, and stakeholders in all policy areas (economic, social, environmental, cultural impacts) – the governance of a State and throughout the various segments of society. A multiplicity of factors, contextual situations, and diversity of inter-related

> *Evaluation of the socio-economic impacts of DT is complex and requires multiple metrics. It is a multi-disciplinary exercise with inter-related factors, in different national and local contexts and time scales*

areas make impact evaluation a complex and multi-metrics exercise simultaneously involving quantitative and qualitative dimensions. Most attempts at impact assessment have not lead to conclusive, coherent, and comprehensive results. The social and economic impacts of governmental intervention are usually evaluated in a business case process and the qualitative and social values are often not considered. The central challenge in carrying out effective impact evaluations is to identify the causal relationship between the program or policy and the outcomes of interest (Gertler, P. et al, 2016).

5.3.1. Economic impacts

The economic impacts of digital transformation can be seen in the functioning and efficiency of the public sector (public services and public enterprises), including all its attributed roles. However, it is also relevant to consider the economic impact that digital government policy design and implementation have on other policy areas and on business. Examples of how countries are running their digital government strategies clearly illustrate this. As part of the

business and growth policy of the Danish Government, its Digital Strategy includes the following: "to create good framework conditions for commerce and industry and, thus, contribute to growth in Denmark through the promotion of digital solutions in Danish businesses, through promotion of entrepreneurship and through establishing the foundation for Danish businesses to be able to continue to compete in the global market. Efforts by the public sector must promote

> *Evidence of impacts of DT in governments and public administrations have to be considered across their functions, the political and policymaking context, the instruments available and the beneficiaries that governments and public administrations intend to address*

years have tried to quantify whether developments of eGovernment have any impact on growth. In particular, Srivastava et al. (2016) have shown that there are significant differences in antecedents and consequences of e-business and eGovernment development between developing and developed countries. In the same spirit, a simple analysis of EU Member States was performed, making a correlation to the E-Government Development Index (EGDI)[265] (United Nations, 2016) and GDP growth[266] for years 2008, 2010, 2012, 2014 and 2016. Countries were split into two classes: EU old Member States (AT, BE, CY, DK, FI, FR, DE, EL, IE, IT, LU, MT, NL, PT, ES, SE, UK) and countries that accessed the EU at later stage (BG, HR, CZ, EE, HU, LV, LT, PL, RO, SK, SI), in order to see if there is any difference between the two groups. By fixing the EGDI at the beginning of the sample (2004) one can see that in 2010 the correlation with GDP growth rates becomes positive and significant. If we then split the sample into newer Member States and older Member States we see that in the older Member States the highest correlation happens in 2012 (negligible for newer Member States) while in 2014 the countries which accessed the EU later start seeing the effects of E-government. These effects then vanish in 2016 (see Figure 5.5).

Digital government proceeds at different speeds and using diverse formulas in each country, although a certain regional identity has been verified. Countries do not necessarily follow the same steps.

Different speeds and paths also happen within a country and digital transformation is not happening equally in all administrative regions and at all levels of administration. Therefore, the economic (and social) impact of digital government differs between countries and the ranking between different levels of impact cannot have the same value across Europe. Most studies at country level do not cover the digital transformation across all roles and functions of government and public administration at all levels of governance and the impact of digital government in all economic aspects although they could be fundamental to monitoring and understanding what works well and what needs to be further elaborated or changed in the specific national or local context. The

digitisation in the private sector. Digitisation efforts should create strong framework conditions for businesses and support their digital transition."[264]

Although it is quite challenging to evaluate the impact of eGovernment on the economy, some studies in recent

[264]   A Stronger and more Secure Digital Denmark - The Digital Strategy 2016-2020, May 2016, https://digst.dk/media/16165/ds_singlepage_uk_web.pdf
[265]   https://publicadministration.un.org/egovkb/en-us/Data-Center EGDI incorporates the access characteristics such as the infrastructure and educational levels to reflect how a country is using information technologies to promote access and inclusion of its people. The EGDI is a composite measure of three important dimensions of e-government, namely: provision of online services, telecommunication connectivity, and human capacity. https://publicadministration.un.org/egovkb/en-us/about/overview/-e-government
[266]   Source Eurostat Real GDP growth rate – volume: tec00115

Correlation between EGDI 2004 and GDP growth rates 2008-2016

■ All EU MS ■ Old EU MS ■ New EU MS
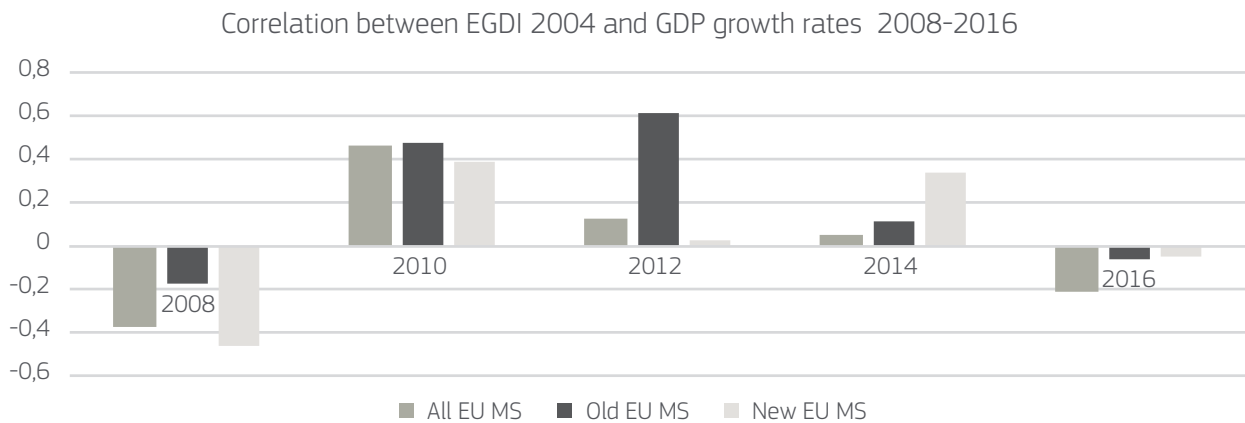
FIGURE 5.5: CORRELATION BETWEEN THE UN E-GOVERNMENT DEVELOPMENT INDEX (EGDI) AND GDP GROWTH.
Source: JRC analysis, based on United Nations and EUROSTAT data.

complexity of factors, areas of interest, and bodies involved make it at least very difficult to provide significant results at multi-country level. Simplifying the issue, a way of measuring the impact of a policy implementation that uses ICT is in the business case process, comparing the economic impact of this design in the specific National or local context with a design without this technology.

The reduction of administrative burden on public services and businesses and time savings are often quantified for specific areas (Arendsen, Rex, et al. 2014) as well the turnover derived from new business opportunities in a digital environment with open access to data. These studies showing a particular aspect of the full picture are relevant but cannot be extrapolated to represent the whole.

Galasso et al. (2016) carried out a Cost-Benefit analysis and an analysis of non-monetized benefits of a set of Open Government Services (OGS) initiatives with a view to assessing the value of OGS from a quantitative and qualitative point of view.

Sunstein, C. (2013) raises questions about the limits of cost/benefit calculations, sometimes deliberately weighing costs/benefits and government can alter regulated entities and citizens conduct by modifying incentives. Sunstein explains that based on insights from *behavioural economics*, individuals often act impulsively in ways that harm their own interests and this should lead to a cost-benefit analysis that reflects the lessons of behavioural

economics (Van Bavel, R., et al., 2013) and to consideration of whether "*nudges*"[267] provide the most appropriate regulatory response in many instances.

> " *DT occurs through different paths, and at different speeds, between countries and sectors. Even within a country, DT may not happen equally in all administrative regions and at all levels of administration* "

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[267]   Nudges are defined as "approaches that do not force anyone to do anything and maintain freedom of choice, but have the potential to make people healthier, wealthier, and happier." Richard H.Thaler and Cass R. Sunstein (2008) Nudge: Improving Decisions about Health, Wealth and Happiness.

5.3.2. Social impacts

Analysing the social impact of digital technology applied to government and the public sector is a complex and multi-faceted challenge, with many different national and local contexts, factors, time scales, and possible metrics. Empirical observations, perceptions, philosophies, or partial analysis cannot replace the gap on coherent and rigorous scientific approach conducted by interdisciplinary teams. A comprehensive overview of the social impact of DT should cover three distinct areas:

- the impact of technology used in society on the processes of governing, for example, social networks;
- the impact of technology on society that needs a policy intervention e.g. regulatory, information campaign;
- the impact on society of the use of digital technology within policy making, politics, and/or public administration.

It is hard to distinguish the effect of technology in the public sector from more general effects, strongly interacting in different dimensions. For example, societal changes are impacting the relationship between individuals and government in many ways. The shift of generations with different lifestyles and different perceptions in their expectations towards public services and decision makers –– the retirement wave of the "baby-boomer" generation (born after 1945) and the "millennials" growing up as a digital generation (born after the early 1980s) who have now come into adulthood are indicators of this change. It also affects the composition of the age cohorts of civil servants in public administration. Migration is another element that is influencing the age structure and the social composition of a city, region, or nation. Demographic change and migration lead to a shift in the demand for public services. Growing social inequality – inter alia driven by the future of work impacts – is another push factor driving social differentiation.

Social networks offer new forms of far-reaching information and communication as well as location independent networking. This provides a broader information base (including fake news and misinformation) about policy-making and public services as well as new relationships and new ways of influencing events. The UK Government Office for Science (2013) suggests that hyper-connectivity has the potential to increase the pace of change in people's identities, but it also raises awareness about multiplicity of identities and that they are culturally and contextually
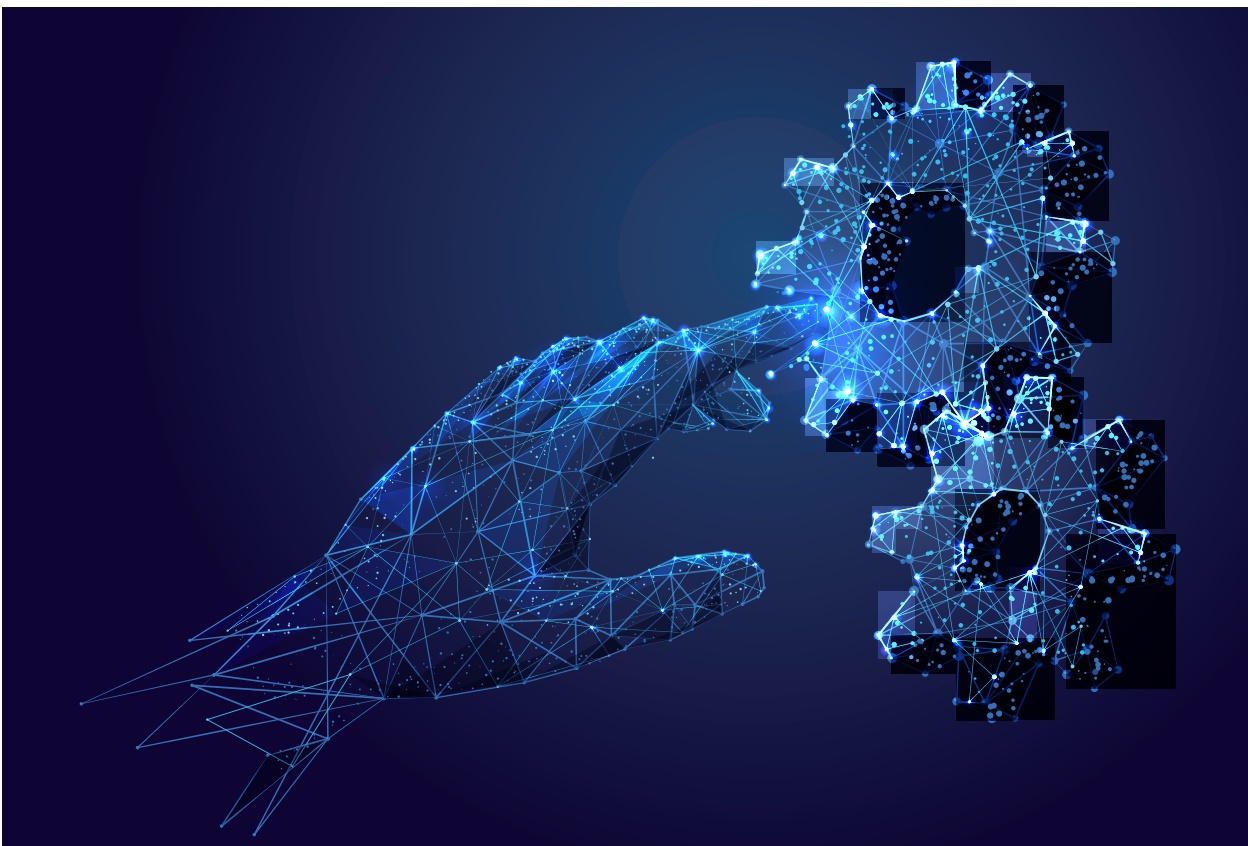
embedded. The connectedness to virtual or real social groups influences lifestyles and consumer behaviour, and changed citizens' expectations of how products and services are delivered. This raises expectations in individual's interactions with public institutions. Farrell and Goodman (2013) expect that rapid social change and technological innovation will continue to change citizens' expectations of government delivery. Some of the innovation opportunities in the public sector include better access to information, better interaction between citizens and the state, and new forms of public engagement (Caulier-Grice et al, 2012). ICT brings new ways for social innovation to take place and tends to reduce previously existing barriers. However, Millard (2015) believes that the use of ICT for citizen involvement in political decisions and public policy making, which democratic governments are widely adopting (such as e-consultation, e-deliberation, and similar online initiatives), is just a narrow view of how people can be involved. Furthermore, it is essential not to neglect both the "disconnected" and vulnerable groups.

The way government actions, whether analogue or digital, impact civic and democratic principles, the efficiency and effectiveness of administration, and the improvement of public value and the wellbeing of society is significant (Kelly et al, 2002). Millard (2015) suggests that all actors should engage in the activities of the government if the engagement creates public value and is open. Empowering beneficiaries and communities by informing and engaging them through online channels, social media platforms, smartphones, or in providing feedback on service content and quality has an as yet unmeasured social impact.

An example is that demand for public services from socio-economically disadvantaged groups (relating to poor health or a disability, limited education, technical skills, and financial means) can be significant, especially in times of economic uncertainty when there is significant pressure on government financial resources. However, these groups contain people who have been least likely to access government services online, and who tend to rely on single channels when accessing services, usually involving human agents. These people can find it difficult to articulate their complex needs to service providers, or to engage with the processes of providing evidence that they qualify to receive services. Simply directing socially excluded people to digital Government (swapping the human channel for

> *Empowering beneficiaries and communities by informing and engaging them through online channels, social media platforms, or by providing feedback on services' content and quality, has a socio-economic impact not yet measured*

an electronic channel) does not in itself guarantee that they will benefit from relevant services more effectively and efficiently. It is through a multi-channel approach and flexible availability of services, personalised, and configured around users' needs and preferences that sustainable services can be delivered. When a country applying the principle of multichannel service delivery chains involving a number of different stakeholders, such as the central and local public administrations, civil society/ third sector, Communities of Practices, and the citizens themselves (as in the case of horizontal subsidiarity[268]), it is very difficult to assess the socio-economic impact of digital transformation on each segment and stakeholders of the delivery chain at a certain point in time as these

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[268] http://www.icnl.org/research/journal/vol4iss4/art_3.htm

are intrinsically related. However, each EURO spent by the City Council to fight unemployment creates an impact not only on the economy at large but also on the fight against crime, drug addiction, and eventually on all the directly as well as indirectly related sectors (e.g. health, housing, job market, family, etc.) in terms of both savings and effective investment in social policies[269].

As multi-channel brings about a simultaneous combination of communication channels that enable a network service model to function effectively, it therefore means the organisational interactions which make up the network rather than only a collection of access routes for delivering services.

On the other hand, people, firms, interest groups and political organizations are using the Internet in their lives and business in a huge variety of ways, potentially with profound policy effects. Although these developments are much discussed as social and economic phenomena, the policy responses that they necessitate have not been less analysed as often (Margetts, H.Z., 2009). The governance of the Internet is a debated issue. It has implications for public policy regarding social, economic, and political changes across sectors and government, and may require a policy response.

Digital facilities in government should contribute to a rise in trust in political and social institutions and processes. It connects citizens to institutions and increases the legitimacy and efficiency of democratic governments (Mishler & Rose, 2001; Godefroidt et al, 2015) when properly used. It is often assumed that trust depends on the institutional performances, dealing with public needs, citizens freedoms, fighting corruption, etc. (Hutchinson and Johnston, 2011; Vesnic-Alujevic, 2016). The Tallinn declaration (Estonia Presidency of Council, 2017) assumed that digital transformation can foster trust in governments by increasing the transparency, responsiveness, reliability, and integrity of public governance.

Emerging technologies require governments and regulatory bodies to respect and protect citizens' rights, freedoms, and values. With the appearance of filter bubbles and fake news, the politics of algorithms and automation and understanding contemporary political processes are becoming relevant when they impact democratic

processes negatively due to misinformation and lack of trust in political institutions. Sunstein, C. (2017) contends that the fundamental problem with filtering is that communication technologies and social media are merely treating citizens in a democratic system as consumers in a communications market, although citizens do not think and act like consumers and "the choices people make as political participants can be systematically different from those they make as consumers". In Sunstein's view, *filtering and personalization*, characteristic of social media, disable users from implementing their democratic aspirations and drive them into making political decisions in their capacity as private consumers instead of as deliberative citizens.

Considering societal trends in the use of the Internet and their implications for policymaking, Margetts (2009) says there is a need to look at how these trends might affect each of the four 'tools' of government policy (nodality, authority, treasure, and organisational capacity) in terms of sustaining the operations of government and driving innovation, and asking which values it might bring to policy-making, considering that any public policy will involve some mixture of these four tools. As well as bringing changes to each of the 'tools' of government, the Internet might bring change to policymaking and to the norms, values, and ethics of public policy. For all four tools discussed above, Hood and Margetts (2007) noted a development towards digitally enabled '*group targeting* '. Group targeting can make public policy more targeted and more efficient, but it can also have less desirable effects such as increasing inequalities between those who are fast-tracked and those who are slow-tracked.

Digital transformation and artificial intelligence have repercussions on labour markets: some jobs will be replaced, other jobs will be created, and many jobs will be transformed. Even though the real impacts are impossible to estimate for the moment, it is clear that a digital transformation needs to be smooth and accompanied by public policies (European Commission 2017a). The authors could not find any literature on this subject, that is, stating that digital transformation in government and public sector produces unemployment, where laws regulating labour in the public administration may safeguard contractual situations.

According to the OECD's Well-being Research[270], societal progress is about improvements in the well-being of

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269   https://joinup.ec.europa.eu/document/mc-egov-study-multi-channel-delivery-strategies-and-sustainable-business-models-public-services
270   Measuring Well-being and Progress: Well-being Research http://www.oecd.org/statistics/measuring-well-being-and-progress.htm

people and households. Assessing such progress not only requires looking at the functioning of the economic system but also at the various experiences and living conditions of people. The OECD Framework for Measuring Well-Being and Progress is built around three distinct domains: material conditions, quality of life, and sustainability, each with their relevant dimensions". The OECD Better Life Initiative[271] focuses on developing statistics that can capture aspects of life that matter to people and that, taken together, help to shape the quality of their lives. This includes two elements, the How's Life? report (OECD, 2017e) published every two years, and the Better Life Index[272] which is an interactive web-based tool designed to involve people in the discussion on well-being.

5.3.3. The impact of Cybercrime

Cybersecurity is referred in the Introduction (1.3.3) of this report as a horizontal policy concern of digital transformation. In the case of governments and public administrations, cybercrime concerns are part of what is called the dark side of digital transformation. The digital transformation of public administrations and government services can result in greater cybersecurity risks. This is due to the "cyber" attack surface becoming larger as a result of the services enabled by digital technologies and the uptake of new technologies while at the same time the impacts of successful cyberattacks have a greater potential to disrupt society and essential government services. As a result of this, many threat agent groups might have strong motivations to carry out cyberattacks.

Cyber security is as much about people as it is about technology and tools (Noonan, K., 2017). Noonan asserts that a lot of security violations succeed through human engineering – by exploiting simple human vulnerabilities. Even the best security systems can be circumvented by leveraging the back-door exposures available to internal staff, suppliers, or users, not always due to simple errors and oversights but also increasingly due to what staff see as impractical procedures and governance. Krombholz, K. et al. (2014) provided a taxonomy and a comprehensive overview of advanced social engineering attacks.

The cyberattack against Estonia in 2017 is one of the best-known cases of a series of cyberattacks targeting public and governmental services. With its population of 1.3 million people, Estonia is known to be one of the most advanced digital societies in the world and a living example of digital transformation in public and governmental services. 99% of public services are available online. In 2005 it became the first country in the world to use e-voting in national elections and in 2014 it became the first country to offer e-Residency[273]. Estonia also pioneered the application of blockchain technology to enhance the trust and transparency of digital services[274]. In April 2007, Estonia suffered a series of coordinated cyberattacks that targeted governmental institutions and bodies, financial entities, telecommunication infrastructure, and newspapers. A series of waves of Distributed Denial of Service (DDoS) lasting several weeks disrupted institutional sites, national online public services, and communications impacting the normal functioning of the national government and society[275]. These attacks were not highly sophisticated, and due to their nature, did not create any lasting damage to Estonia's digital infrastructure. However, they provided a demonstration of how cyberattacks taking advantage of the digital transformation of governments and society can impact an entire country[276].

5.4 | Conclusions: the way forward for Policy and Research

Among other functions, governments and public bodies design policy, implement it, and provide administration, public services and infrastructures, and maintains social order and security. The impact of digital transformation

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[271] http://www.oecd.org/statistics/better-life-initiative.htm
[272] http://www.oecdbetterlifeindex.org/#/11111111111
[273] "e-Estonia guide". 2018. URL: https://e-estonia.com/wp-content/uploads/eestonia-guide-2018.pdf
[274] https://e-estonia.com/wp-content/uploads/2019sept-nochanges-faq-a4-v03-blockchain-1-1.pdf
[275] Schmidt, A. (2012). "The Estonian cyberattacks". The fierce domain–conflicts in cyberspace, 1986-2012
[276] NATO(2012) "Five years after Estonia's cyber attacks: lessons learned for NATO?". Research paper. URL: https://www.files.ethz.ch/isn/143191/rp_76.pdf

occurs within all these functions and their processes – generally called digital government. Therefore, to analyse the impact and the potentiality of ICT enabling these functions, or to identify which barriers need to be removed or risks managed, the roles and characteristics of government and public administration should be considered in the political and policy-making context.

Several aspects associated with making data available for reuse are still subject to further attention and research: discovering, securing, and accessing public sector data and private data of public interest, the value of data as a prime input in policy making and for innovative quality services and products, the meaning, conditions, and impact of sharing data and of open data, the role of data analytics in policy making and public administration, transparency about data processing and big data, and lastly, data to information for policy making and communication.

Enabling technologies do not work in isolation from infrastructures; they are selected as enablers of processes or instruments to serve policy goals, or in some cases they are themselves policy instruments. Exploring the best use of digitally enabled processes and services, and the role of disruptive technologies – Artificial Intelligence, Blockchain, APIs, digital platforms, and others – relates and depends on the type of policy instruments and use case where the

technology is to be implemented, applying the principle of digital by design.

Considerations about their usability and impact on different institutions and at different governance levels are necessary after testing and before implementation of the technology. Potential legal issues and accountability

> " *Making public data available for reuse requires measures for data discovery and security, and to safeguard privacy and transparency of data analytics* "

> *Digital technologies are selected as enablers of processes or as instruments to serve policy goals. In some cases, they are policy instruments in themselves, and do not work in isolation from the underlying infrastructure*

strategies for public servants and the whole population are matters that governments need to address by developing and applying appropriate policies, and research communities need to assist policy decisions. Research and policy involve deploying technological and other measures for understanding, monitoring, and managing the negative impacts of digital transformation on government and public administration, of which digital exclusion is one example, but there are others such as cybercrime, cyberterrorism, digital fraud, online addiction, online radicalization, mass social manipulation, and power concentration.

Choices on technologies impact on many stakeholders, including citizens and the non-public part of the society. To design digitally enabled services or to create new ones, users' needs are not the only factor that need to be considered. User needs are not homogeneous for the whole population and all economic sectors; the purpose of a public service may even not relate directly to a human, it may concern the environment, markets, infrastructure, and so on. The considerations that will lead to a certain state and the choices involved in digital government in a country at a certain moment in time include: the goals and priorities that governments need to achieve, the contextual situation at different administrative levels, national budgetary considerations, regional and local political, social, and economic differences, external offers by NGOs, and lastly opportunities that may lead to strategic partnerships. National or local contextual conditions at a certain moment in time that may justify what looks like insignificant progress may in fact be a fundament step in making faster and more significant overall progress to achieving digital government policy goals. Furthermore, regional or local conditions can make substantial differences in digital government inside a country, making comparisons between countries difficult and requiring correct interpretation and understanding of the impacts.

This situation leads to three remarks meriting further investigation: (i) what are the real drivers, issues, and benefits of the digital transformation on government and public administration in the context of administering legislation with multiple stakeholders, opposite to the concepts of user centricity?; (ii) what are the objectives to be attained, factors to consider, and boundary conditions of benchmarking digital government across states? Current measurement criteria evaluating country scores still do not catch the entire dimension of government and public administration and the impact in all areas of society. As

need to be revised before operationalisation. Experts on different digital technology developments should assist policy makers in selecting from multiple choices of technologies and standards according to functions to be covered, adoption of common interfaces, cybersecurity, and infrastructures across different public organisations. Here, there are concrete opportunities for a coherent research approach and strong potential for significant results. To further research and develop artificial intelligence as well as non-mature technologies such as distributed ledgers and blockchain in relation to specific use cases and conditions regarding the public sector is important, that is, moving from proof-of-concept or pilot projects to the real operational stage.

In order to avoid digital exclusion, reform of official basic education programmes, lifelong reskilling and upskilling

measuring and interpreting social, economic, legal, and political phenomena is the domain of social, economic, and political science in which changes are effected by applying technologies to a digital transformation, a multi-disciplinarily framework is necessary to set up a meaningful model for monitoring progress and evaluating impacts; (iii) incorporating in public policy making the results of behavioural sciences and knowledge of the cognitive process leading to choices and decisions, may assist the formulation of hypotheses of policy interventions and how to look for the evidences of the expected results on the ground with a scientific approach, before translating them into law. This is a way of creating a culture of evidence-based policy making. The multi-disciplinary and interdisciplinary approach that the JRC can offer may complement existing models and define several areas of research.

Digital government needs to be seen in the context of societal, economic, environmental, and political shifts. The new types of interaction between individuals and government and their effects may become the subject of study as they have already become important and now mark the society, indicating a transformation of future relations between individuals and government as well as relations between business and government, and it may lead to the development of new relationships between these actors. Research on the digital transformation of government needs to go beyond improvement of processes supporting the status quo but rather help to understand the new relationships between societal actors that generate public value and also understand the changing role of government in this ecosystem[277].

To summarise, several opportunities are open for researchers to embrace as a way of looking at research on digital government in line with the nature and characteristics of that sector, including clarity of terminology used, which will avoid multiple or contradicting interpretations of objectives. Better, scientifically-based advice needs to be given to policy makers.

> *New types of interactions between individuals, governments, businesses, and the third sector are part of DT and need to be thoroughly explored*

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[277] These statements are a metalevel analysis of the JRC Megatrends Hub. Source: JRC Competence centre on Foresight (2018): Megatrends Hub. URL: https://ec.europa.eu/knowledge4policy/foresight_en

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List of abbreviations and definitions for Part 5 – Digital Transformation in Government and Public Administration

ADS	Algorithmic Decision Systems
AI	Artificial Intelligence
API	Application Programming Interface
CEF	Connecting Europe Facility
COGI	Inter-Service Group on Geographic Information
DESI	Digital Economy and Society Index
DIH	Digital Innovation Hub
DSM	Digital Single Market
DT	Digital Transformation
EC	European Commission
EDPR	European Digital Progress Report
EFTA	European Free Trade Area
EGDI	E-Government Development Index
eID	Electronic Identification
eIDAS	Electronic Identification, Authentication and Trust Services
EIF	European Interoperability Framework
EP	European Parliament
EQI	EU Quality of Government
ESIF	European Structural and Investment Funds
EU	European Union
FP7	Seventh Framework Programme for Research
G2C	Government to Citizens
G2G	Government to Government
G2P	Government to Private
G20	Group of Twenty
GDP	Gross Domestic Product
GDPR	General Data Protection Regulation
GISCO	Geographical information system of the Commission
HPC	High-Performance Computing
ICT	Information and Communication Technologies
INSPIRE	Infrastructure for Spatial Information in Europe
IoT	Internet of Things
ISA2	Interoperability solutions for public administrations, businesses and citizens
JRC	Joint Research Centre
MS	Member State
NGO	Non-Governmental Organisation
NIFO	National Interoperability Framework Observatory
NIS	Network and Information Security
NPG	New Public Governance
NPM	New Public Management

OECD   Organisation of Economic Cooperation and Development

OGS   Open Government Services

OMC   Open Coordination Method

PSI   Public Sector Information

QoG   Quality of Government

S3P   Smart Specialisation Platform

SDG   Sustainable Development Goals

SME   Small and Medium Enterprise

SRSS   Structural Reform Support Service

UN   United Nations

UNDESA United Nations Department of Economic and Social Affairs

OVERALL CONCLUSIONS:
THE WAY FORWARD FOR POLICY
AND RESEARCH

Overall conclusions: the way forward for Policy and Research

Profound changes are taking place in the economy and society as a result of the uptake and integration of digital technologies in every aspect of human life. Digital technologies have become the foundation of all modern innovative economic and social systems and digital transformation (DT) is affecting all sectors of the economy and society. It is a cross-sector global transformation with both positive and negative effects.

Although we are still only at the beginning of this profound transformation, it is happening at increasing speed. There is therefore an urgent need to be able to identify and address the current and future challenges that DT raises for the economy and society, evaluating the impact and identifying areas requiring policy intervention.

The consequences of DT will affect almost all European policies. On the one hand, there are clearly DT-related "horizontal" policy aspects, such as, data sharing, privacy, cybersecurity, digital platforms, skills, research and innovation, etc., that are relevant to many sectors of economy and society. On the other hand, each "vertical" sector is also characterised by specific policy aspects related to DT. In order to address DT with a systematic approach, the report proposed a conceptual framework that includes four main sets of interacting components (EU values & objectives, policies, digital technologies, and socio-economic players). The intention in proposing this simple yet comprehensive framework is to show to policy makers the need to study the interactions between DT and the impacts on society and economy when new policy interventions are designed. This report provides examples of DT developments and impacts in three economic sectors and in government and public administration. Similar analysis would need to be extended in the future to other sectors such as, agri-food, health, etc.

It is clear from the analyses provided in this report that DT has a great disruptive potential in traditional sectors of the economy and in public services with many potential positive effects. DT has the potential to bring, for example, better, faster and more efficient services –including public services–; more convenience and power to users; more open markets; new business models; increased productivity; more safety; improved energy efficiency and increased sustainability; improved mobility and traffic flows; new types of occupations and jobs; etc.

Nevertheless, many technological, social and legislative barriers, and potential negative effects of DT need to be addressed. The report mentions for example, issues linked to data collection and re-use; related challenges such as privacy; cybersecurity issues; standardisation aspects; competition issues for example in the digital platforms ecosystem; liability aspects in the context of autonomous machines; legal aspects linked to new digital technologies (e.g., building codes, rules for autonomous vehicles, etc.); skills aspects with impact on education and training; the need to help smaller companies and public administrations; research and innovation challenges; and also issues linked with energy consumption of digital technology systems themselves; etc. These challenges and issues need to be addressed through appropriate policies.

DT is therefore expected to be a strategic European policy area for a number of years to come. Clearly, national polices will also be profoundly impacted, for example in education, to cite just one important domain. The challenge for regulators is to balance, on the one hand, technological progress and the many benefits DT can bring to the economy and society, and on the other one, addressing the negative impacts of DT and safeguarding fundamental rights and equality of the citizens according to EU fundamental values.

As indicated in the different sections of this report, the European Commission has already taken in recent years many concrete actions in order to ensure that European economy and society can benefit from the positive effects of DT, while mitigating the impacts of negative ones. The new von der Leyen Commission will continue these efforts and intends to develop a digital policy agenda on 'a Europe fit for the digital age' aiming to "ensure that Europe fully grasps the potential of the digital age and strengthens its industry and innovation capacity", while at the same time ensuring that "the European way is characterised by our human and ethical approach."[278]

Research, to observe and explore current and future DT developments and to analyse their impacts, is crucial in order to support evidence-based policy making. In line with its role as the European Commission's science and knowledge service, the Joint Research Centre will continue to contribute to this important domain.

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[278]   Mission letter of Commissioner Margrethe Vestager, Executive Vice President for a Europe fit for the Digital Age in the new Commission presided by Ms. Ursula von der Leyen, Brussels, 10 September 2019.

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Joint Research Centre

JRC Mission

As the science and knowledge service of the European Commission, the Joint Research Centre's mission is to support EU policies with indipendent evidence throughtout the whole policy cycle.

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