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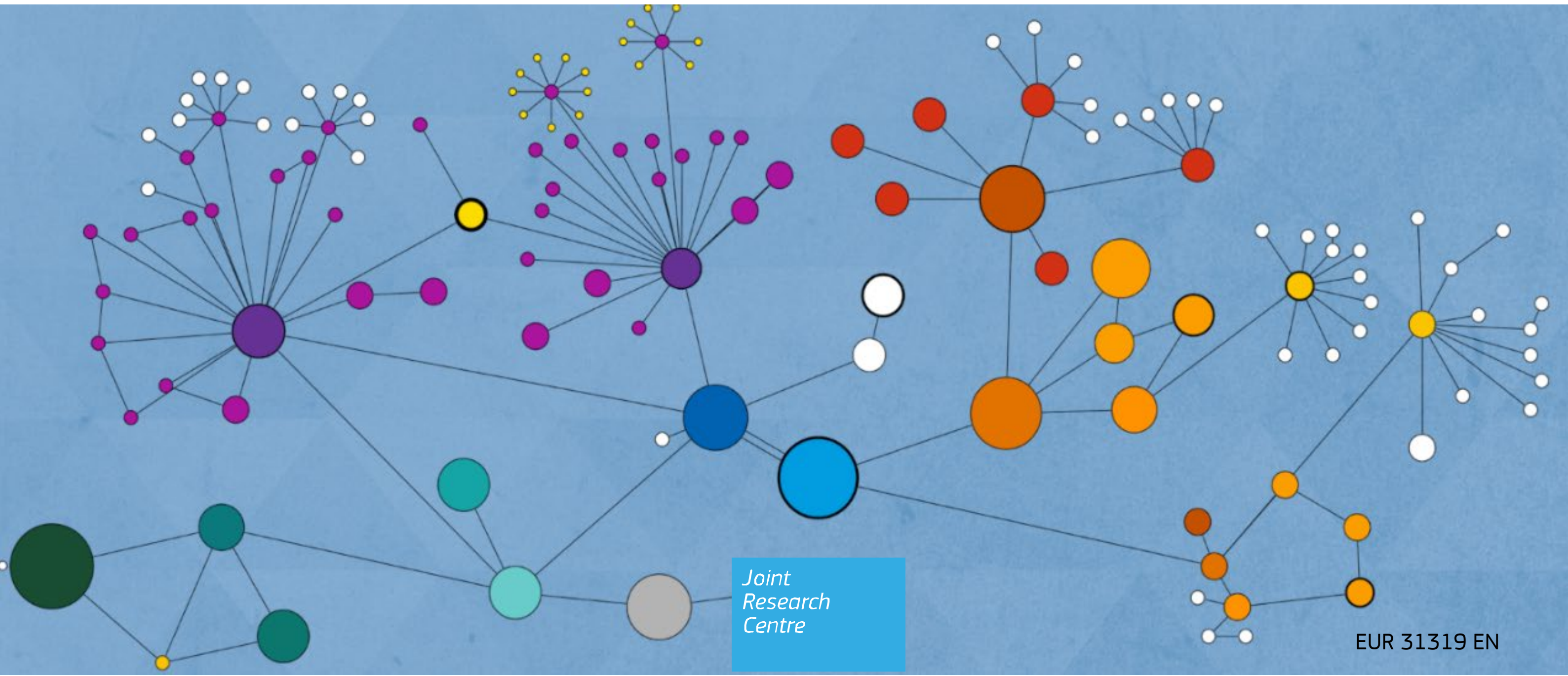
JRC TECHNICAL REPORT

A policy oriented analytical approach to map the digital ecosystem (DGTES)

Methodology and overview



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Contents

Abstract

This report describes the Digital Techno-Economic ecoSystem (DGTES), which is the application of the Techno-Economic ecoSystem (TES) analytical approach to the analysis of the digital ecosystem. It explains the steps leading to the construction of the DGTES digital ecosystem graph dataset and highlights the originality and the advantages of this approach. The report also offers an overview of a set of indicators that can be generated from the DGTES digital ecosystem dataset, in order to provide a global and comprehensive analysis of the digital ecosystem while keeping the policy perspective in mind.

This report reflects on how DGTES can be used to formulate policy-relevant recommendations. The results of DGTES can provide novel insights for a better discussion within the framework of main European Union's (EU) policy initiatives aiming at strengthening Europe's competitiveness and leadership, and inform policies fostering the development of the technological and industrial capabilities needed for a vibrant digital ecosystem in Europe.

The TES approach had already been applied to other techno-economic segments that are rapidly evolving and are expected to play a key role in the digital transformation, such as photonics, earth observations technologies, and artificial intelligence (AI)[1]. DGTES is the first example of a more comprehensive application of the TES analytical approach to the study of an industrial ecosystem.

([1]) See the JRC Technical Reports 'The AI Techno-Economic Segment Analysis' (De Prato et al. 2019), 'The techno-economic segment of Earth observation' (Pogorzelska et al. 2019), and 'Unveiling Latent Relations in the Photonics Techno-Economic Complex System' (Samoili et al. 2019).

Foreword

Digital transformation is one of the key phenomena our societies are experiencing. Digital technologies are deeply transforming the way we produce, consume, learn, work and enjoy life, having tremendous impact on our societies and economies. The way we approach this crucial transformation is key to ensure we will make it a successful one: it will have to elevate us, individually and collectively, by enabling a human-cantered, sustainable and more prosperous future.

There are plenty of aspects surrounding digital transformation that need to be taken into account: social consequences, economic effects, environmental impact, industrial changes among others. It is a multifaceted transition that, in order to be deeply understood, requires a holistic approach. In particular, it is extremely important to be able to systematically identify which are the relevant players driving this phenomenon, how they interact and engage, where their activities take place and around which technological domains. This is what we name a *digital ecosystem*.

The concept of digital ecosystem lies at the core of digital transformation. Understanding it, is therefore key for grasping and steering the digital transformation, and has various policy implications – including a new European industrial policy, European open strategic autonomy, the achievement of the Digital Decade goals or the identification of European champions in emerging digital technologies.

This report presents the application of the Techno-Economic ecoSystems (TES) methodology to the identification of the digital ecosystem, focusing on the methodological aspects. It will be the first report of a series of two, the latter presenting the details and results of the analysis. This work is part of our effort, at JRC, to identify and capture, in a forward looking and policy-relevant way, the effects and opportunities brought by digital transformation.

Mikel Landabaso Alvarez

Director, Growth and Innovation Directorate, European Commission Joint Research Centre (JRC)

Acknowledgements

This report has been prepared within the framework of the project IDITES (The Impact of Digital Transformation on the Economy and Society) implemented by the Digital Economy Unit of the European Commission's (EC) Joint Research Centre (JRC). By providing appropriate metrics to measure and monitor critical aspects of the digital transformation and of emerging digital technologies within their economic and technological ecosystems, and by investigating technology-driven innovation and change in a global perspective, the IDITES project contributes to analysing the impacts of the digital transformation on economies and societies. More specifically, the work presented in this report builds on the experience of the 'Prospective Insights on ICT R&D' (PREDICT) project, which aims at providing new methodologies and indicators to measure and analyse the digital transformation and the evolution of emerging technological domains that are likely to impact future economic trajectories.

This work continues the thread of research on the Techno-Economic ecoSystems (TES) methodological approach conducted within the framework of the PREDICT project. TES is a science-based analytical approach originally developed by the Digital Economy Unit of the JRC to target technology-based dynamic segments that play an important role in the digital transformation but tend to elude official statistics or standard classifications. The lack of indicators adequate to capture the pervasiveness and evolution of emerging technologies raises a call for new analytical instruments and metrics to better inform policies for a more sustainable, digital, resilient and globally competitive European economy. TES is thus a suitable tool to describe and analyse dynamic emerging technologies those pervasiveness and evolution are better assessed using metrics and indicators capable to account for their holistic nature and complex structure.

The authors would like to acknowledge the contributions from several colleagues. First of all, Josep Soler-Garrido, who contributed to the conceptualisation of the digital areas and the procedures to define the perimeter of the digital ecosystem. The authors are also deeply grateful to Carlos Torrecilla Salinas, Michael Lutz, Paul Desruelle, Emilia Gómez, Eva Martinez Rodriguez, and Juan Torrecillas Jodar for their comments and their support through the realisation of this work.

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Executive summary

Policy context

A period of uncertainty and fast-changing global scenarios is revealing the existence of disruptions and bottlenecks in supply chains, markets, and technology transfer, exposing the vulnerabilities of the European digital space as well as its dependencies on non-European technologies and players. This is posing **new challenges that call for urgent strategic policy initiatives to ensure Europe continue pursuing the twin transition**. In this regard, the European Union (EU) is realigning its economic, industrial, and technological ambitions. This requires the EU to assess and address any strategic dependencies, in order to reduce reliance on third countries in strategic segments and critical technologies, create a technologically autonomous and sovereign Europe, and increase competitiveness in digital and green technologies, to better prepare for the challenges and opportunities of the twin transition.

In this context, technological and digital leadership remains an essential driver of EU's competitiveness, as digital technologies are reshaping the horizon of technology development and their mastering can grant the EU a leading role in the future global technological landscape. The successful implementation of **the digital transformation represents the condition for EU's present and future digital and industrial leadership and sovereignty.**

Being the *locus* of digital transformation, **the digital ecosystem is at the centre of the EU's goals of EU's digital policies**. Digital technologies and the digital ecosystem have indeed gained a special position on current policy stage, lying at the intersection of major EU policy initiatives and programmes - such as the Digital Decade, the New Innovation Agenda, the New Industrial Strategy – that aim at positioning Europe as a global industrial and technological leader, making the EU more competitive globally, and enhancing its strategic autonomy. **Understanding and analysing the digital ecosystem,** alone as well as in its overlapping with other industrial ecosystems, **has become a necessary, urgent and policy-relevant exercise**. Monitoring its evolution is also key to leverage a successful twin transition in all industrial ecosystems, and also allows insights on the other ecosystems' evolution paths.

About the report: objectives and audience

This report proposes a way to explore and investigate the digital ecosystem from a policy-relevant perspective. More specifically, **the report describes the Digital Techno-Economic ecoSystem (DGTES)**, which is the application of the Techno-Economic ecoSystem (TES) analytical approach to the study of the digital ecosystem. In particular, the report:

- explains the DGTES analytical approach and the steps leading to the construction of the DGTES graph database;
- discusses the aims, originality, and advantages of this analytical approach for the study of emerging technologies in dynamic techno-economic ecosystems, such as the digital ecosystem;
- presents a set of metrics and indicators that can be generated from the DGTES digital ecosystem dataset in order to provide a global overview and an analysis of the digital ecosystem;
- reflects on how the results of DGTES can provide insights to policy initiatives aiming at strengthening EU's digital leadership and sovereignty, and at fostering the development of the technological and industrial capabilities needed for a vibrant digital ecosystem in Europe.

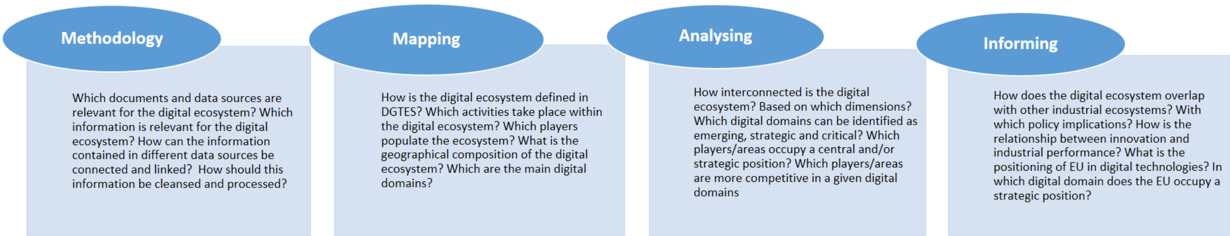
This report targets a broad audience, which includes that part of the scientific community engaging in policy-relevant research as well as decision- and policy-makers. The style and the content of the report try to be consistent with the aim of favouring its reading and understanding also by a non-technical audience, without sacrificing the complex nature and the scientific rigour that characterize the DGTES analytical approach.

About DGTES: justifications and steps

Segments of rapidly evolving and emerging technologies, such as digital technologies, are hardly captured by traditional metrics or classifications, which have a limited ability in detecting the complex structure and the web of interconnections and relationships that characterizes these dynamic technology-based environments. The lack of indicators adequate to capture the pervasiveness and evolution of emerging digital technologies raises a call for new analytical instruments to better understand the digital ecosystem and to inform policies for a more sustainable, digital, resilient and globally competitive European economy. Grounded on the TES methodology developed by EC JRC to map and explore dynamic and complex techno-economic segments, **DGTES represents an appropriate analytical approach to** responds to this call for an adequate tool to study, explore and **better understand the complex landscape of digital technologies, and to timely inform policy initiatives** of EU and Member States (MSs) for a technologically dynamic ecosystem such as the digital one.

DGTES is characterized by various steps (Figure Es.1). DGTES proposes a methodology to collect and converge multiple sources of microdata into a harmonized graph database, where the information contained in individual datasets is enriched and amplified by the possible connections across them. Giving access to a comprehensive set of relevant information on the digital ecosystem, this DGTES database enables the generation of a series of indicators and metrics that allow mapping and analysing the digital ecosystem by providing a compelling characterization of its main elements (i.e. actors, activities, interlinkages) and a better understanding of its features, structure and complexity. DGTES is a policy-relevant analytical instrument that can contribute to informing, assessing and ultimately improving the policies aiming at fostering digital transformation and leveraging a successful twin transition.

Figure ES 1. DGTES: main steps



Source: Authors' elaboration, Digital Economy Unit, JRC.

DGTES in a nutshell

The Digital Techno-Economic ecoSystem (DGTES) is the application of the TES analytical approach to the study of the digital ecosystem. **The main aim of DGTES is to map the digital ecosystem and to provide an analysis of its elements, structure and features from a holistic, multidimensional and policy-relevant perspective**. Considering the volume and variety of sources considered, and the amount of work needed to match through the data sources, DGTES represents one of the most accurate and comprehensive way to describe, map and analyse a dynamic and complex environment of emerging technologies such as the digital ecosystem.

Figure ES.2 and ES.3 offer a representation of the workflow and of the potential outcomes of the DGTES analytical approach described in the report. DGTES can be exemplified as a process unfolding along six phases – four describing the DGTES methodology (Figure ES.2) and two related to the analysis and how its results can serve to inform EU policies (Figure ES.3).

1. Setting the technological perimeter of the digital ecosystem, by identifying its main technological subdomains with the notion of *digital areas*

Digital areas correspond to informal, internally-coherent, techno-economic categories used to cluster digital technologies that relate to the same technological domain (e.g. "Artificial Intelligence") and/or to the same type of application or final use (e.g. eHealth solutions). The 15 digital areas considered by DGTES are complaint with the two criteria of being forward looking and policy relevant. Each digital area is also associated to a unique list of keywords, which are used to search into various repositories of textual documents (i.e. patents, journal articles, EU-funded projects), in order to identify those documents that are relevant for the definition of the digital ecosystem (see following points).

2. Detecting the *activities* that define the digital ecosystem, by collecting and pre-processing the textual information contained in relevant documents

DGTES considers as relevant those *activities* that contribute to the production and/or evolution of digital technologies – that is, that leave a 'digital footprint'. In practice, an activity is associated to a document that carries textual information about the activity itself and its attributes. The documents corresponding to relevant activities are detected by searching for given lists of keywords within specific repositories (see previous point). In DGTES, relevant activities can be of three types:

(a) *business activities,* derived from information on companies' core business and on the production, supply and/or exchange of goods and/or services, and/or on investments and funds financing industrial and business initiatives (i.e. venture capital deals);

(b) *innovation activities,* corresponding to outputs of Research & Development (R&D) activities in the form of patenting initiatives (i.e. filing of priority patents) and/or participation in innovative research projects (i.e. EU-funded projects H2020 and FP7);

(c) *research activities,* reflecting academic contributions of frontier research, such as publications and/or participation in high level international conferences.

3. Identifying *players* engaging in relevant activities, by cleansing and processing the textual information contained in relevant documents

In DGTES, the term *player* defines any economic (market and non-market) actor involved in digitally-relevant activities. More specifically, players engaging in the digital ecosystem are identified from the documents corresponding to the relevant activities (see previous point) after a multi-step process of data cleansing, which includes (among others) disambiguation, classification, and validation. Relevant players can be of three types:

(a) *companies and firm;*

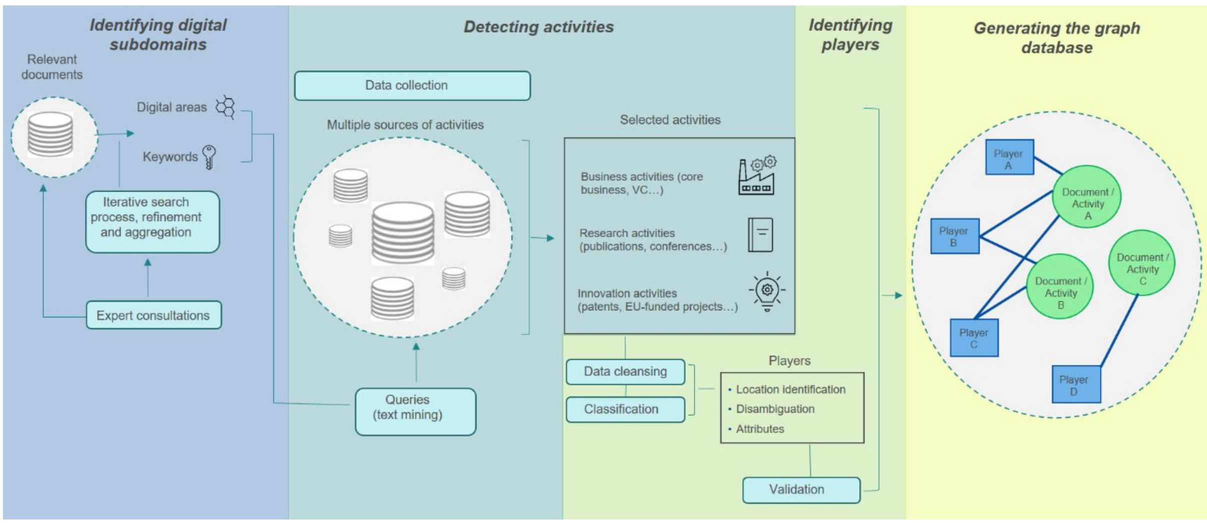
(b) *academic institutions and research centres;*

(c) *governmental authorities and bodies.*

4. Generating the *graph database* of the digital ecosystem, built on the interlinkages connecting activities and players

The analysis of the textual information in the relevant documents allows connecting activities and players, thus identifying how players relate to each other and are interlinked through their shared activities or other attributes (i.e. colocation). The DGTES database also contains information about the players participating in the detected activities and about their features and attributes (i.e. their organizational type and geographical location). The web of connections built on all these elements and information defines the structure of the DGTES graph database, which ultimately allows mapping the digital ecosystem.

Figure ES.2. DGTES workflow and methodology – Phases 1 to 4



Source: Authors' elaboration, Digital Economy Unit, JRC.

5. Calculating *indicators* to map and analyse the digital ecosystem

DGTES allows generating a series of *indicators* that can help disclose, investigate and better understand the digital ecosystem. These can be grouped in different sets according to their goals and to dimensions of analysis:

(a) indicators that provide an overview of the digital ecosystem global landscape, with its main elements and dimensions;

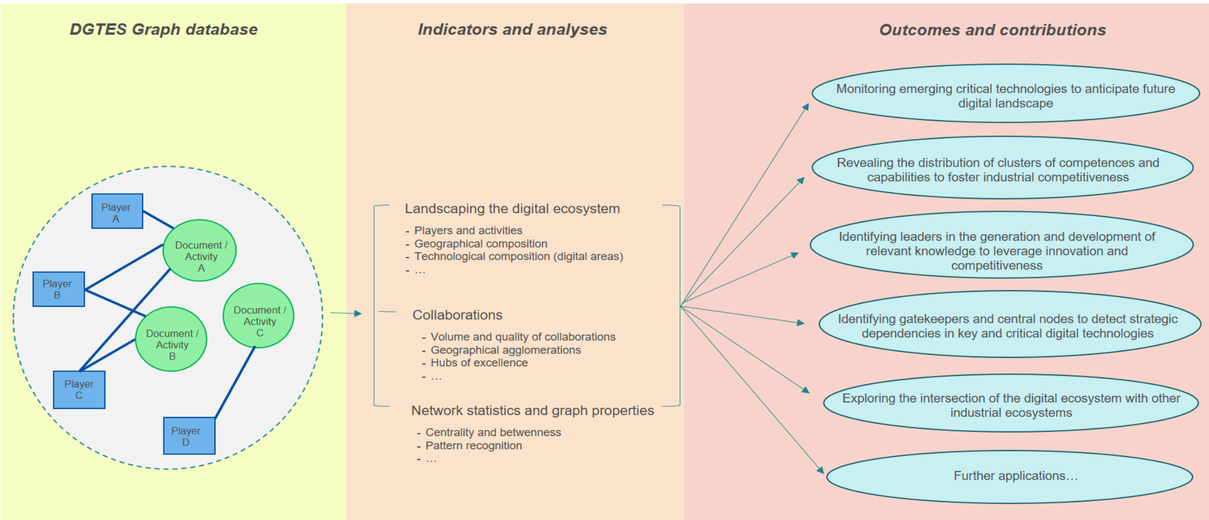
(b) indicators that describe and analyse the network nature of the digital ecosystem (i.e. collaboration metrics, network statistics, graph properties).

The high level of granularity is a crucial feature of the DGTES database, which allows grasping a finer picture of the elements of the ecosystem and of their attributes (i.e. focus on a specific organizational type, such as firms and companies). Moreover, most of the indicators can be calculated for each year in the covered period, thus allowing to add a longitudinal and time-varying perspective to the analysis of the digital ecosystem.

6. *Informing* policies for digital transformation and twin transition

Policies aiming at fostering the digital transition and reducing Europe's digital dependency need to be grounded on a better and more comprehensive understanding of the digital ecosystem. In this regard, DGTES can offer novel evidence on the positioning of the EU in terms of leadership and competitiveness in the domain of emerging and critical digital technologies, informing, assessing and informing policy initiatives fostering digital transformation and helping Europe successfully navigate towards a more sustainable, digital, resilient and globally competitive economy. The results of DGTES can even contribute to the formulation of concrete policy instruments, such as a toolbox of interventions to mitigate EU strategic dependencies in key industries and critical digital subdomains.

Figure ES 3. DGTES for EU policy priorities – Phases 5 to 6



Source: Authors' elaboration, Digital Economy Unit, JRC.

Next steps and future work

Future works using DGTES will enlarge the scope of the analysis to embrace more dimensions and aspects of the digital ecosystem, and beyond it. Just to mention few possible avenues of future research, these works could look at the technological features of the digital ecosystem with the application of Natural Language Processing (NLP) methods like topic modelling; explore the drivers of industrial competitiveness and see how certain features of the digital ecosystem are related to the industrial performance; analyse the intersections between the digital ecosystem and the other 13 industrial ecosystems identified by the Industrial Strategy.

1 Introduction

A new global economic and industrial landscape is emerging from the series of shocks that have shaken societies and economies during the past few years.

Openness to trade and investments has been a major source of growth for the EU (European Union), which still remains a major importer and exporter. However, the COVID-19 pandemic crisis has revealed the existence of economic and industrial strengths as well as of bottlenecks, as Europe has been severely tested by supply restrictions, border closures and fragmentations following the COVID-19 outbreak. The pandemic has indeed exposed the vulnerabilities of the European digital space and its dependencies on non-European technologies. The vulnerability of interdependent entities to disruptions in value chains, trade flows and technology transfer has become even more evident since the escalation of the armed conflict in Ukraine, whose severe consequences are reinforcing the urgency of prompt strategic policy changes to ensure the EU's peace, prosperity and security, today as well as in the future.

Europe is realigning its economic and industrial ambitions to take into account these new global circumstances. With the awareness that this calls for a better grip and understanding of where current and future strategic dependencies lie, Europe is redefining its competitive edge and its position as one main player on the global landscape. Going hand-in-hand with the need to steer recovery towards a more sustainable, digital, resilient and globally competitive industry and economy, current global contingencies require Europe to increase its competitiveness in digital and green technologies in order to better prepare for the challenges and opportunities of the twin transition.

In this context, technological leadership remains an essential driver of EU's competitiveness and innovation. Now more than ever the EU needs to leverage its position as global industrial and technological leader to reduce reliance on third countries in strategic segments and create a technologically autonomous and sovereign Europe. In particular, EU's ability to keep the pace with the emergence of dynamic technology-based segments plays a fundamental role in defining Europe's role in the technological and industrial scene and in shaping its current and future social and economic trajectories.

As a dynamic technological domain horizontally affecting the whole economy, digital technologies are attracting increasing attention as key drivers of economic growth, competitiveness, and economic resilience. The rapid evolution of digital technologies is catalysing the *digital transformation*, intended as the fundamental and deep transformation of market and non-market activities and processes by means of digital technologies, leading to fundamental changes in the way to operate, produce and deliver value. The digital transformation had already been leading to deep changes in the economy and the society. Still, the COVID19 pandemic crisis increased even more this interest for the impact of digital technologies on economic resilience and industrial recovery, and reinforced the perception of their crucial role, as these technologies have become an imperative for working, learning, entertaining, socialising, shopping, delivering services and accessing everything from health services to culture. This accelerated pace of digital transformation, triggered by an unprecedented demand for digital technologies, calls for a better understanding of its pervasiveness and benefits.

The successful implementation of the digital transformation is the condition for EU's present and future digital and industrial leadership. It is thus not surprising that the digital transformation has come to occupy a central place in EU's policy space. '*A Europe fit for the digital age*'[2] is one of the six European Commission's priorities for the period 2019-2024. It represents the EU's Digital Strategy and envisions Europe as a strong and sovereign digital player, placing the digital transformation at the centre of EU's future to make it work for people and businesses while helping to achieve the European Green Deal target of a climate-neutral Europe by 2050[3]. Following the footsteps of the Digital Strategy, in 2021 the Commission presented Europe's Digital Compass and the Policy Programme 'Path to the Digital Decade'[4] to translate EU digital vision into concrete targets and to ensure that Europe achieves a successful twin transition by 2030. This Policy Programme remarks Europe's ambition to make the following years '*the digital decade'*, by reinforcing its digital leadership in an open and interconnected world and by pursuing digital policies that foster EU digital

(2) See the webpage of 'A Europe fit for the digital age' (https://ec.europa.eu/info/strategy/priorities-2019-2024/europe-fit-digital-age_en) and the Commission's communication 'Shaping Europe's digital future' (COM (2020)67 final).

(3) See the Commission's communication 'The European Green Deal' (COM(2019) 640 final).

(4) See the Commission's communication '2030 Digital Compass: the European way for the Digital Decade' (COM (2021) 118 final) and the Decision of the European Parliament and of the Council to establish the 2030 Policy Program 'Path to the Digital Decade' (COM 2021) 574 final).

sovereignty while empowering people and businesses to seize a human-centred, sustainable, and more prosperous digital future. Consistently with this vision, the Recovery and Resilience Facility (RRF)[5] acknowledges that digital technologies are key factors for economic recovery and resilience. Aware that bouncing back from the COVID19 crisis represents an opportunity to accelerate digital transformation, this policy instrument promotes reforms and investments in digital technologies, digital skills, services and infrastructures to improve EU competitiveness.

Also the EU 2020 New Industrial Strategy and its updated version[6], launched in 2021 to take into account the implications of the COVID-19 crisis, are fully in line with the mentioned policy initiatives' visions and goals of EU digital sovereignty and global leadership. Pursuing an ambitious European industrial policy, the New Industrial Strategy lays out a plan to leverage Europe's position as a global industrial leader by supporting the twin transitions, making EU industry more competitive globally, and enhancing its strategic autonomy. In this regard, the Industrial Strategy makes clear that attaining EU's digital ambitions requires to assess and address any strategic weaknesses, vulnerabilities and strategic dependencies in key areas where Europe depends on its global competitors, such as in the domain of digital technologies related to online platforms, semiconductors, cloud computing, and in critical inputs necessary for the green and digital transitions. EU digital sovereignty and leadership need to be grounded on the achievement of strategic autonomy, both industrial and technological.

As well as focusing on technologies and strategic dependencies, the Industrial Strategy also promotes a new approach to think of economic activities in terms of industrial ecosystems. Industrial ecosystems can be defined as interdependent techno-economic spaces where activities take place in an interconnected way and with the participation of heterogeneous actors pursing different socioeconomic goals. 14 industrial ecosystems[7], covering a whole range of economic activities and purposes, have been identified based on their economic and technological relevance, and on their expected contribution to the decarbonisation, digitalisation and resilience of the EU economy.

Among these 14 ecosystems, the digital ecosystem presents its own peculiarities. It is where digital transformation takes place and shape: here the processes of creation, development and production of digital technologies are triggered and moulded by interactive and complex dynamics, but at the same time the structure of this ecosystem and the composition of its stakeholders are influenced by the evolution of digital technologies, in a feedback-loop mechanism. The digital ecosystem is, therefore, characterized by a dynamic technological change and particularly complex interlinkages. The digital ecosystem is also transversal and horizontal by nature. Digital technologies currently represent the substrate of any technical solution and have transversal applications in any activity, thus making the digital ecosystem horizontal to all other technological and industrial ecosystem. Moreover, the extreme permeability of all activities to digital technologies implies that the digital ecosystem is not simply intersecting but that it is also transforming the other industrial ecosystems from inside, by defining the current and future technological scope in which they operate. In this respect, the digital ecosystem is forward-looking, as it already incubates the technological trajectories that will shape the economy in the future. Analysing the digital ecosystem and monitoring its evolution is therefore key to leverage a successful twin transition in all industrial ecosystems, and also allows insights on the other ecosystems' evolution paths.

Being the *locus* of digital transformation, the digital ecosystem lies at the centre of the current policy stage, at the intersection of major EU policy initiatives and programmes, such as the Industrial Strategy and the Digital Decade. This report focuses on the digital ecosystem and on how this can be investigated from a policy-relevant perspective – that is, in a way that contributes to informing and assessing policies aiming at transforming Europe into a more sustainable, digital, resilient and globally competitive economy.

Understanding the elements and the features of the digital ecosystem, alone as well as in its overlapping with other industrial ecosystems, and analysing and monitoring its evolution, is indeed a necessary, urgent and

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([5]) The Recovery and Resilience Facility is the key instrument at the heart of NextGenerationEU to mitigate the impact of the COVID-19 pandemic crisis and help the EU emerge stronger and more resilient. For more information, see Commission's communication 'Europe's moment: Repair and Prepare for the Next Generation' (COM (2020) 456 final).

([6]) See the Commission's communications 'A new Industrial Strategy for Europe' (COM(2020) 102 final) and 'Updating the 2020 New Industrial Strategy: Building a stronger Single Market for Europe's recovery' (COM(2021) 350 final).

([7]) The 14 industrial ecosystems are: Aerospace & Defence, Agri-food, Construction, Cultural and Creative Industries, Digital, Electronics, Energy Intensive Industries, Energy-Renewables, Health, Mobility-Transport-Automotive, Proximity, Social Economy and Civil Security, Retail, Textiles, and Tourism. They represent approximately 70% of the EU economy and 80% of the business economy (as a share of value added) (COM(2020) 102 final).

policy-relevant exercise. Yet, the absence of standard classifications and of indicators that can adequately capture the features of such a dynamic and complex ecosystem prevents from measuring the pervasiveness and evolution of digital technologies. This lack raises a call for new indicators and analytical instruments to better understand the digital ecosystem and to properly support the implementation of policy initiatives accounting for its dynamics and complex interlinkages

The Techno-Economic ecoSystem (TES) approach represents an appropriate methodological choice to analyse the complex landscape of digital technologies. TES is a science-based analytical approach developed by the Digital Economy Unit of the European Commission's (EC) Joint Research Centre (JRC) to investigate integrated and technology-based dynamic segments that play an important role in the evolution of economies and societies but tend to elude available official statistics or classifications. The TES methodology can provide a comprehensive representation of the industrial ecosystems, with indicators that reflect their heterogeneous elements and interlinkages as well as their nature of holistic, complex systems. It also allows detecting emerging technological domains as well as knowledge flows and bottlenecks, offering timely policy-relevant insights. The TES approach is an ecosystem by design; this methodology can thus be applied to the analysis of any dynamic and rapidly evolving technological, techno-economic, and industrial ecosystem.

The Digital Techno-Economic ecoSystem (DGTES) is the application of the TES analytical approach to the study of the digital ecosystem. Providing a compelling characterisation of its key elements (i.e. actors, activities, interlinkages), features and structure, DGTES maps the digital ecosystem and contributes to its better description and comprehension, in Europe as well as worldwide, at regional as well as at country and local level. This analytical approach also allows looking at the characteristic of the networks resulting from shared activities, collaborations and co-location, and highlighting knowledge flows and gatekeepers, latent communities, hubs, and emerging clusters of excellence.

In this regard, DGTES represents a forward-looking approach: by exploring the network of knowledge and diffusion of digital technologies at global level as well as within the EU, it can reveal weak signals of emerging digital subdomains and monitor the evolution of the international industrial and research landscape, at the same time identifying opportunities and sources of competitiveness, and detecting vulnerabilities and obstacles that could compromise EU's leadership in the current and future global scenarios. Shedding light on the worldwide networks of stakeholders and technological subdomains, DGTES can offer novel evidence about the strategic positioning of EU and of individual Member States (MSs) in the realm of emerging digital technologies, and about how to foster the development of a vibrant digital ecosystem in Europe. Hence, DGTES responds to the call for an adequate tool to inform EU policy initiatives on the evolution and technical uptake in the very dynamic technological domain of digital technologies, and can significantly contribute to the debate on competitiveness and technological and industrial leadership of the EU in the perspective of the EU polices such as the Industrial Strategy and Digital Decade.

The goal of this report is to describe the application of JRC's TES methodology to the study of the digital ecosystem (DGTES) and to explain the steps leading to the construction of the DGTES digital ecosystem database while highlighting the originality and the advantages of this approach. The report also introduces some of the metrics and indicators that can be generated based on the DGTES digital ecosystem database in order to map the digital ecosystem and to analyse it from a policy-relevant perspective. In this regard, the report highlights how this methodology can help reveal emerging technological trajectories, latent knowledge flows and communities, gatekeepers and hubs within the ecosystem, by looking at the hierarchy of the network connections and interlinkages resulting from shared activities, locations and technological fields. Finally, the report reflects on how DGTES can provide policy-relevant insights.

The report is structured as follows. Section 2 presents the general aims of TES and discusses the motivations for choosing this analytical approach, highlighting the gap in the conventional methodologies and metrics in capturing and measuring the complexity, pervasiveness and evolution of dynamic techno-economic ecosystems. Section 3 describes the DGTES, which is the application of the TES methodological approach to the digital ecosystem. This section explains the processes of data collection and cleansing, and discusses the procedures used to identify the technological subdomains (digital areas) that determine the technological perimeter of the digital ecosystem, and to generate the final DGTES database. Section 4 introduces some of the indicators and measures that can be generated from the DGTES database, in order to provide a characterisation of the key elements and features as well as a worldwide overview of the digital ecosystem. This section also points out the future directions of analysis, stressing the potential of DGTES in exploring more dimensions and aspects of the digital ecosystem as well as beyond it. Section 5 concludes by discussing the policy-relevance of the DGTES approach and how it can be extended to the analysis of other ecosystems.

2 TES: grasping the complexity of dynamic Techno-Economic ecoSystems

This section introduces and discusses the Techno-Economic ecoSystems (TES) analytical approach designed by the Digital Economy Unit of the European Commission's (EC) Joint Research Centre (JRC) to map and explore complex techno-economic ecosystems of dynamic and emerging technologies. The first subsection presents the aims, features and scope of the TES methodology. It also justifies the choice of this approach for the analysis of segments of emerging technologies from a policy-relevant perspective. The second subsection discusses the limitations of the TES as analytical tool, highlighting what falls beyond its original aim and scope.

2.1 A new instrument to map Techno-Economic ecoSystems

The TES analytical approach was developed by EC JRC to map and explore dynamic and complex techno-economic segments and ecosystems of emerging technologies that are rapidly evolving and are expected to influence competitiveness and economic growth, but their evolution and pervasiveness are hardly analysed and assessed using available official statistics or standard classifications.

These techno-economic segments are dynamic environments characterized by being based on emerging technologies, accelerated technological change, and complex interlinkages. These technologies are reshaping the horizon of technology development and their mastering can grant the European Union (EU) a leading role in the future global technological landscape. Still, their complex structure is hardly captured by traditional metrics or classifications, which have a limited ability in detecting the relational dimensions of these technology-based environments, where one part can influence the behaviour of other actors and shape the whole structure. Conventional indicators not only fail to adequately detect the web of interconnections and relationships within these techno-economic segments, but also to track the dynamics of knowledge flows within and across geographical boundaries as well as within and across technological domains.

The shortcomings of traditional indicators are more evident in the case of segments of rapidly emerging technologies. The fast evolution of these technologies generates new sectors and revolutionize existing ones through the creation of new processes, new products, and new linkages within and across industrial activities. In such a dynamic techno-economic context, traditional industrial classifications based on sets of homogeneous activities (i.e. NACE) are exhausting their explanatory power: they are less suitable to describe, investigate and explore processes and products that are increasingly shaped by interconnections across sectors and by more technological content. This transformation of industrial production is due to the rise of transversal multi-purpose technologies like digital technologies, which are permeating all processes and operations, and whose industrial application is enforcing more and new connections across different production activities and actors, even across industrial sectors. This is leading to increasingly interconnected and interdependent chains of value creation in what have become multisector production processes.

In addition, the surge of *deep tech* innovations, resulting from the convergence between digital technologies and scientific fields, is strengthening the relationship between science, technological innovation and production, making research and innovation (R&I) more and more integrated into industrial activities. The increasing importance of *deep tech* as a new wave of innovation for Europe has been clearly remarked by the Commission's communication 'A New European Innovation Agenda' (COM (2022))332 final), considering its potential to thrive and deliver breakthrough solutions to address key societal challenges and to accelerate the transformation into a greener, knowledge-based, and resilient economy. This implies that factors that are now determining the future evolution of industrial activities - as it is the case of R&I-related factors - fall outside the traditional industrial and product classification, which was not designed to take into account these research-production linkages. This is further diminishing the suitability of traditional industrial classifications for forward-looking analytical purposes.

The 2020 New Industrial Strategy gave an important contribution to 'breaking the silos' of traditional industrial sectors, moving away from a narrow focus on industry defined as set of producers of homogeneous products towards a broader approach based on industrial ecosystems. These ecosystems can be defined as interdependent techno-economic spaces where all players are involved in the achievement of a certain socioeconomic goal and where activities take place in an interconnected way - from the smallest start-ups and the largest companies cooperating to satisfy a new market need, the research activities supporting industrial innovation in firms, the regulators steering economic activity through conducive policies, to the services providers and suppliers (COM(2020)102 final). The novelty of this approach is that it incorporates the systemic importance of all the horizontal and vertical links among economic actors, recognising the role of those activities often considered as ancillary to industry, such as R&I. The New Industrial Strategy calls for new indicators to monitor the competitiveness of the EU economy as a whole and as it emerges from the connections across industrial ecosystems (COM(2021) 350 final). The strategy also emphasizes the need of appropriate analytical tools to identify areas of strategic dependencies, in particular in sensitive ecosystems, which could threaten EU industrial and digital sovereignty.

It has thus become urgent to rethink how to analyse the industrial ecosystems in order to improve our understanding of industrial dynamics in a context characterized by increasing scientific, technological and productive interconnections and by the transversal application of and multi-purpose digital technologies. This need for indicators and analytical instruments to account for interlinkages and evolutions within and across industrial ecosystems is policy relevant: it responds to a call for more evidence-based insights to support policies shaping the industrial ecosystems, which can be done only through indicators that can properly grasp their complexity, dynamic and integration.

The TES analytical approach responds to this call for new instruments to map, analyse and understand the techno-economic ecosystems not otherwise systematically covered by available traditional statistics. TES does so by embracing a systemic perspective that can reveal the interlinkages and interactions across players as well as measure the digital transformation of the economy (Figure 1).

TES is '*ecosystem by design'*. TES is designed to reveal the complex structure of the interlinkages connecting its elements (i.e. actors and activities)[8], allowing to draw the ecosystems as they emerge from the collected information about: who the key players are, which different roles they play in the ecosystem, in which technologies they specialise, how they are geographically distributed, how they are connected to each other, how innovation spreads through the networks. TES is a methodology appropriate to describe and analyse techno-economic segments that function as a complex system. In this respect, it also allows looking at how players participate in implicit relations and tacit processes of learning and knowledge exchange. This methodological approach is thus particularly suitable for ecosystems where knowledge creation and diffusion take a network structure, such as in the case of ecosystems of multi-purpose and horizontal technologies like digital ones.

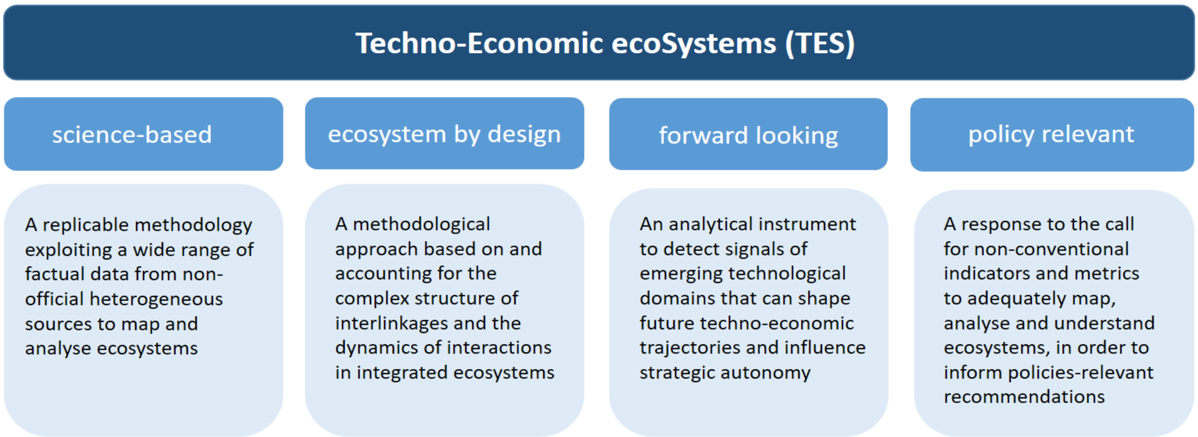
TES is a science-based analytical approach grounded on a micro-based perspective. It is conceived as a replicable methodology to map and analyse technology-driven ecosystems by exploiting a wide range of factual data from non-official heterogeneous sources, bridging the needs of describing, monitoring and benchmarking these ecosystems with quantitative analysis and scientific evidence. The TES methodology also allows for a certain flexibility in the scope of analysis: the fact that it relays on data collected at a micro-level makes it possible to exploit the high granularity of the data and to add more and finer levels of analysis - for instance, to explore different geographical levels (e.g., cities, countries, regions) or zoom on specific players (e.g. firms or research institutions)..

TES is a forward-looking approach. It allows detecting weak signals of emerging technological domains that are likely to shape the future trajectory of knowledge flows and production but whose technological and industrial application is still evolving. This characteristic of TES is particularly useful when mapping knowledge flows in order to detect the emerging thematic layers of technologies and to identify which actors occupy a strategic position and control the networks of knowledge flows and production in these technological domains. TES can be relevant from the perspective of European strategic autonomy, as it can contribute to the analysis and assessment of the risk of vulnerabilities arising from European economies' strategic dependencies.

Finally, TES is policy relevant. The TES analytical approach responds to the call for a policy-relevant methodology that can provide quantitative indicators and metrics adequate to map the geographic presence, technological development, impact, and evolution of complex and dynamic techno-economic ecosystems. Based on a rigorous scientific methodology, the results of the application of TES to an ecosystem can contribute to informing and shaping policy-relevant recommendations aiming at fostering EU's technological and industrial leadership.

(8) Section 3 "DGTES: applying the TES methodological approach to the digital ecosystem" provides a more precise definition of which are the actors and the activities in an ecosystem analysed with the TES methodology.

Figure 1. The TES analytical approach: specific features



Source: Authors' elaboration, Digital Economy Unit, JRC.

In sum, the TES analytical approach can provide a timely representation of integrated ecosystems of emerging technologies that play an important role in the evolution of economies and societies, offering a synthetic but analytical and policy-relevant overview of their elements, structure, and dynamics. TES is an appropriate instrument for the analysis of technologically dynamic environments that can be better described and assessed using metrics and indicators that account for their holistic nature and complex structure. Box 1 summarizes the main aspects and dimensions of techno-economic ecosystems that can be mapped and analysed using the TES approach.

Box 1. TES: mapping the landscape of dynamic techno-economic ecosystems from a policy-relevant perspective

The Techno-Economic ecoSystems (TES) analytical approach allows mapping the landscape characterizing a dynamic techno-economic ecosystem. More specifically, the application of TES can:

- Identify main stakeholders

Using several sources of microdata, both horizontal covering the whole economy and vertical to the analysed technological domain, TES generates a comprehensive database containing detailed information on activities and players, answering the questions: Who are the key players? Which activities do they engage in?

- Draw the competitive international scenario

Relying on information on individual players' location, TES allows looking at the geographical distribution of activities and players at different levels (worldwide, regional, local), addressing the following issues: Where are players and activities located and geographically distributed? How different are the geographical regions in terms of the 'critical mass' of players and activities they display? Which geographical regions are leading in terms of activities performed/players hosted? Which geographical regions are more active in sharing research and innovation activities? Which role does a geographical region play in the worldwide network, also with respect to brokering knowledge specific to sub-technologies?

- Detect key thematic areas and technological domains or subdomains

TES allows detecting the main thematic areas and technological domains and subdomains that characterize an ecosystem. By relating these with geographical distribution of players, TES allows defining the technological profile of the ecosystem at different levels (worldwide, regional, local hotspots), addressing the following issues: Which thematic areas dominate the ecosystem? In which areas, domains or subdomains do activities concentrate? In which areas, domains or subdomains is a certain geographical area more competitive and/or specialized? Which areas, domains or subdomains do emerging technologies cluster around?

- Describe industrial composition and capacity

TES can provide an overview on industrial capacity and composition in the ecosystem, by relating the information on firms' features (i.e. size, organizational type, main sector of activity, location, performance, technological domain of main activities) to answer the questions: How active are firms in the ecosystem? How is the profile of the firms engaging in the ecosystem?

- Reveal patterns of collaboration

TES reveals the networks of collaborations and relations across players in the ecosystem. By considering their geographical and technological dimensions, TES can describe this collaborative network and its characteristics, addressing the following issues: How are players connected to each other? Across which regions? How does innovation spread through the network? Which players are leading in terms of collaborative activities and where are they located? Who controls knowledge flows and production (gatekeepers) and where are they located? How were such knowledge flow evolving over time, what can be expected future trends?

The TES methodology has so far been applied to the study of segments of emerging technologies that are rapidly evolving and are expected to have a high impact on economies and societies, such as photonics (Samoili et al. 2019), earth observations technologies (Pogorzelska et al. 2019), and artificial intelligence (AI) (De Prato et al. 2019, Righi et al. 2021)[9]. In these studies, the TES approach proved its ability to map and analyse the features and functions of ecosystem of these dynamic emerging technologies, respecting their complex nature and taking into account their heterogeneous players and activities as well as their interlinkages and networks.

Being an ecosystem by design, the TES methodological approach can be applied to any dynamic techno-economic ecosystem. This is the case of the digital ecosystem, which is the techno-economic space where digital technologies take shape and evolve. Digital technologies are extremely policy relevant, since their evolution is catalysing the digital transformation. However, as in the case of other emerging and transversal technologies, the absence of adequate indicators challenges the possibility to measure and analyse the pervasiveness, evolution and impact of digital technologies. Better understanding the forces driving digital transformation has become an urgent imperative, as succeeding in Europe's digital and green twin transitions is one the main policy priority of the European Commission.

The application of the TES analytical approach to the digital ecosystem (DGTES) can serve the purpose of having methodologies and instruments suitable to describe and analyse the global landscape of digital technologies from a policy-relevant perspective, allowing to grasp both features of complexity and of technological dynamism of the digital ecosystem. In the perspective of the EU Industrial and Digital Strategies (discussed in the Introduction), DGTES can help deal with issues related to digital transformation and to the mitigation of strategic dependencies in critical industries, contributing to the formulation of policies fostering EU digital and industrial leadership in the current and emerging technological landscape.

2.2 Beyond the scope of the TES analytical approach

The TES analytical approach was developed to map and analyse complex techno-dynamic ecosystems of emerging technologies. Despite encompassing several dimensions and layers of analysis and comprehensively exploring various aspects of these ecosystems, the explanatory power of TES is constrained in the case of environments whose structure, composition and thematic outreach the ones of a techno-dynamic ecosystems. It is therefore useful to point out the cases falling out of the analytical scope of the TES methodological approach.

The TES approach is mostly based on codified knowledge (i.e. patents, publications, project funds, description of industrial activities) and relies on both proprietary and public information that is formalized and accessible. Although it allows drawing implicit or tacit networks of potential relations based on information on geographical or technological proximity (i.e. latent communities), the TES methodology has a limited explanatory power about the elements of an ecosystem that that cannot be explicitly observed, because they correspond, for example, to: knowledge protected by industrial secrets (thus, not publicly shared); type of transactions not reflected in accessible data; activities performed by very small enterprises, etc. Even if the list of sources can be extended further, both for what concerns with horizontal sources at global level and vertical sources specific to selected technologies, several financial transactions as well as technology transfer activities may take place without releasing adequate data allowing to reflect and monitor them. These data are, therefore, invisible to the TES methodology.

(9) See the JRC Technical Reports 'The AI Techno-Economic Segment Analysis' (De Prato et al. 2019), 'The techno-economic segment of Earth observation' (Pogorzelska et al. 2019), and 'Unveiling Latent Relations in the Photonics Techno-Economic Complex System' (Samoili et al. 2019).

The TES methodology defines the techno-economic ecosystems from a supply-side perspective. TES is designed to identify players engaging in industrial, research or innovation activities related to the production of knowledge, goods or services within a certain technological domain, whose ultimate outcome is to push further the technological frontier. Hence, by design the TES approach is not suitable to explore the demand-side and the micro-level mechanisms underlying technology adoption in a certain technological domain.

The TES methodology detects only a little part of the mechanism of financing and investments that take place within an ecosystem. For instance, in its current version, TES covers publicly funded research only at EU level, but it disregards public funding initiatives at national level. While TES captures as much as possible funding deals and investments (for example, it also relies on information on venture capital funds), this approach may miss other important sources of financial inputs and resources, which makes it unable to univocally associate the whole amounts invested in an ecosystem with its activities and outputs. TES is thus inadequate to be used as financial assessment tool for a whole ecosystem.

At this stage, the TES approach presents a limited explanatory power also on the series of industrial production linkages distributed along an entire value chain. Although some considerations about strategic control of the networks of production in a certain domain can be drawn from specific technological aspects, TES does not rely on information about the relative position of players within existing value chains, nor does it include information on products and their features (i.e. primary input, intermediate, final) or market structure. In this regard, TES is not suitable to directly capture market-dynamics or assess players' market shares.

Finally, complex techno-economic environments are also shaped through the dynamic interaction of their elements and features with what can be defined as the 'rules of the game' – that is, the convergence of institutions, regulations, culture, infrastructure that concur to shape the governance, functions and structure of an ecosystems. The TES analytical approach is not designed to directly look at and to account for these 'rules of the game', but acknowledges that these play a role in shaping the features, structure and functions of an ecosystem.

3 DGTES: applying the TES methodological approach to the digital ecosystem

The Digital Techno-Economic ecoSystem (DGTES) is the application of the Techno-Economic ecoSystem (TES) methodology to the analysis digital ecosystem. This section provides an overview of the DGTES workflow. The first subsection explains how the technological perimeter of the digital ecosystem has been delimited through the identification of a series of relevant techno-economic subdomains, defined as digital areas. The identification of these digital areas allows the construction of the list of keywords then used to build queries to generate the DGTES database of the digital ecosystem. The second subsection describes the phases of data collection and data processing leading to the generation of the DGTES database.

3.1 The technological boundaries of the digital ecosystem: digital areas

Setting the technological boundaries is a necessary exercise to define what belongs to and who participates in an ecosystem and, therefore, to provide an adequate overview. The TES methodology comes with a defined and reproducible approach to establish the boundaries of any techno-economic ecosystem.

In the specific case of the digital ecosystem, boundaries were identified in terms of main technological subdomains defined by a set of *digital areas*. *Digital areas* correspond to informal, techno-economic categories used to cluster digital technologies that relate to the same technological domain (e.g. “Artificial Intelligence” can be defined as a digital area, entailing various technological solutions based on the principles of artificial intelligence, such as Natural Language Processing (NLP), machine learning, etc.) and/or to the same type of application or final use (e.g. eHealth or eGovernment solutions). The digital areas considered by DGTES are complaint with the two criteria of being forward looking and policy relevant.

This section contains a short description about: (i) *why* the notion of digital area has been introduced; (ii) *what* are digital areas; (iii) *how* digital areas were identified; (iv) *how* digital areas serve, in practice, the implementation of DGTES.

3.1.1 *Why* the notion of digital area

Defining the scope of the term "digital" is challenging. Given the horizontal and transversal nature of digital technologies, the vastness of the technological applications that such a concept may include – even starting from a standard, conservative definition such as: electronic tools, systems, devices and resources that generate, store or process data - makes it difficult to set boundaries that are at the same time not too broad, entailing any activity involving some degree of ‘digital’, and not too restrictive, embracing only very specific digital solutions.

The notion of digital area has been introduced, at this level, to systematise the application of criteria to tighten the scope of the digital ecosystem, so to avoid the inclusion of devices and tools that are associated with more conventional and mature digital solutions now seen more as *commodities* (i.e. terms as *personal computer*, *printer*, *scanner* and the like), which would have brought the whole exercise out of its looked-for boundaries. Hence, the notion of digital area primarily responds to the need of “digital scoping” in order to set clear boundaries to the digital ecosystem. Digital areas are by construction mutually exclusive, in line with the aim of reducing as much as possible the rise of possible ambiguities and of minimising the return of false positive results (even within the same global technological domain).

At the same time, the notion of digital area allows restraining the perimeter of the digital ecosystem to technological subdomains of particular industrial and policy relevance. In fact, a first step to establish the digital areas was deciding to consider only forward looking and policy-relevant digital subdomains. In practice, these subdomains are the ones related to *digital transformation*, defined as the integration of digital technology into different market and non-market activities and processes, fundamentally changing the way to operate, produce and deliver value. Thus, in order to be identified as a digital area in DGTES, a digital subdomain should - in addition to displaying a certain degree of internal technological coherence - contribute to digital transformation, which becomes the guiding principle in setting the perimeter of the digital ecosystem. Examples of forward looking and policy relevant digital areas include subdomains having a direct impact on future infrastructure (“Electronics, Semiconductors, Power Electronics”, “Infrastructure, Cloud Computing, Digital Platform, IaaS (Infrastructure-as-a-Service), SaaS (Software-as-a-Service), PaaS

(Platform-as-a-Service), on-line platforms, Social Networks, Internet") as well as technologies undergoing a continuous development concurring to the launch of new market/non-market possibilities ("Quantum technologies") or the advance of relatively new ones ("Internet of Things")[10].

This approach arose from extended consultations with stakeholders and experts, and resulted in the application of a main general criteria to concentrate on the front-end part and most dynamic digital technologies, disregarding mature and consolidated manufacturing processes with relative low level of innovativeness.

3.1.2 *What* is a digital area

Digital area is an informal notion used to group keywords that are semantically relevant to the same technological domain in a theoretical taxonomy (e.g. "Artificial Intelligence" may be defined as the digital area including the following keywords: *Natural Language Processing*, *Decision Support Systems*, *Machine Learning*, *Deep Learning*, *Planning*, etc.[11]).

In order to better understand the definition of digital area, it may be useful to remark the distinction from the notion of keyword. A *keyword* corresponds to a technology, tool, process, or a characterising element, expressed as a word or phrase, identifying, or conceptually included in, one or more digital areas (e.g. the aforementioned *Natural Language Processing* is a keyword belonging to the digital area of "Artificial Intelligence"). Thus, in the presented methodology each digital area encompasses a set of related technologies that are associated to one or more keywords.

Although some of those technologies (keywords) could be better specified (e.g.: *Natural Language Processing* may include *Computational Linguistics*, *Machine Translation*, *Parsing*, etc.), the methodological assumption to maintain a 'flat taxonomy' composed by only two layers implies that all the items falling under "Artificial Intelligence" were kept (as keywords) at the same level (i.e., although *Parsing* would conceptually stay under *Natural Language Processing*, in our system *Parsing* and *Natural Language Processing* are two keywords at the same level).

3.1.3 *How* digital areas were identified

Digital areas were identified through a series of sequential and iterative phases and steps. These phases and steps were conducted with the goal of progressively refining results, in order to obtain a final number of internally coherent and techno-economically relevant digital areas, and to associate each of these digital areas with a specific list of unique keywords. It is useful to reiterate that the perimeter and scope that has been set for the identification of the digital areas is that of *digital transformation*, defined as the integration of digital technology into different market and non-market activities and processes, fundamentally changing the way to operate, produce and deliver value. Box 2 describes in brief these sequential phases and steps, clarifying how they led to the identification of 15 forward-looking and policy relevant digital areas.

This process of identification of the relevant digital areas involved the application of both manual and automated search on textual documents to progressively refine results and to reduce the number of digital areas. These iterative refinements were carried out until obtaining a final set of digital areas that both covers the highest number of digital subdomains falling within the digital ecosystem and allows to avoid redundant areas, by either redistributing keywords or grouping digital areas referring to the same (or a similar) digital domain. The final output of this whole procedure was a set of 15 digital areas (Table 1).

(10) The final list of digital areas is displayed in Table 2.

(11) In the following, digital areas will be expressed in quotation marks ("Artificial Intelligence") and keywords in italics (*Natural Language Processing*).

Box 2. Identifying the digital areas

This process of identification of the digital areas starts with a first detection of relevant digital areas through an initial search in selected relevant documents, such as reports or publications from different sources (including DG GROW repository, JRC repository, DG CNECT – Horizon Europe Research and Innovation repository, and other sources)[12]. All the documents that were analysed in this phase regard the design and implementation of sector-specific policies that deal with the definition of technologies (in terms of EU positioning vs. other macro-regions, current policies, design of future programmes, etc.), belonging to specific sectors (e.g., agriculture, energy, environment, health, etc.)

Once a first tentative set of digital areas has been identified, a more accurate manual search was performed. This manual search consisted of two steps:

1. Reading carefully the documents, starting from the abstract/introduction to check both the structure of the document and whether it was reasonable to assume it to contain issues of interest.

2. Searching for the identified digital areas and implementing a naïve (computational linguistics-oriented) interpretation of the mathematical notion of 'neighborhood'[13]. This procedure is likely to detect more keywords semantically related to that digital area by setting the 'search space' to a certain number of 'neighbouring' sentences (for example, 3 sentences) every time a phrase containing the term associated to a specific digital area (e.g., "Artificial Intelligence") is found in a text. This allowed to make a further check in order not to skip (possible) keywords to be assigned to a specific digital area.

After the implementation of these steps, a set of 50 digital areas was obtained. The aggregation of digital areas possibly referring to the same (or similar) digital domain allowed for a reduced 21 entry set (e.g. "3D Printing" and "Additive manufacturing", originally two separate digital areas, were merged into the digital area of "3D Printing, Additive manufacturing")[14].

Then, one further iteration was performed in order to further reduce the number of digital areas and to eliminate the eventual overlap of keywords across different digital areas. This iteration included the reassignment of keywords from one digital area to another and the removal of keywords considered too vague after a second analysis. The final output of this whole procedure was a set of 15 digital areas (Table 1).

Table 1. Digital areas in DGTES

1	"3D Printing, Additive manufacturing"
2	"5G and beyond, Autonomous Networks, Communications, Telecommunications and connectivity"
3	"Advanced Computing, High Performance Computing (HPC), edge computing"
4	"Artificial Intelligence"
5	"Autonomous Systems, Robotics"
6	"Blockchain, Distributed Ledger"
7	"Cybersecurity, Safety & Security, Digital Identity"
8	"Data, Dynamic Data"
9	"eBusiness, e-Commerce"
10	"Electronics, Semiconductors, Power Electronics"
11	"Extended Reality, Virtual Reality, Augmented reality"
12	"Infrastructure, Cloud Computing, Digital Platform, IaaS, SaaS, PaaS, on-line platforms, Social "Networks,

(12) See Appendix 1 for the list of considered documents.

(13) In topology, a neighbourhood is one of the basic concepts in a topological space. It is closely related to the concepts of open set and interior. Intuitively speaking, a *neighbourhood* of a point is a set of points containing that point where one can move some amount in any direction away from that point without leaving the set.

(14) At this stage, no curation was performed on the list of keywords associated to each identified digital area, except for the deletion of duplicates (including for keywords exactly matching the digital areas they belonged to).

	Internet"
13	"Internet of Things, AIDC (automatic identification and data capture)"
14	"Quantum Technologies"
15	"Verticals" (*)

(*) The "Verticals" area has been added in order to include keywords that refer to final applications rather than to technologies, and keywords that conceptually seem to belong more appropriately to other industrial ecosystems (e.g. Transportations, Healthcare, etc)., although still maintaining a link to the digital one. One example is the keyword health data sharing: despite obviously belonging to the healthcare ecosystem, it anyway maintains a strong link to the digital ecosystem (besides looking more like a class of final applications rather than a technology).

Source: Authors' elaboration, Digital Economy Unit, JRC.

3.1.4 *How* digital areas serve the implementation of DGTES

The procedure for the identification of the digital areas also allowed associating each of the 15 digital areas with a list of unique keywords. Digital areas have been indeed used both in a top-down and bottom-up way. First, during the manual keyword selection, digital areas facilitated the identification of more keywords through the search into better-specified domain literature and sources (e.g., by taking Artificial Intelligence-related sources and extract keywords only from selected publications). Then, by building specific queries, digital areas were used to minimize the level of ambiguity many keywords inherently have (e.g., in the query, by accompanying the keyword *common-sense reasoning* with the digital area "Artificial Intelligence", so to avoid results coming from, say, psychology or social sciences sources).

Hence, the described methodology allowed obtaining a comprehensive dictionary of keywords associated to the domain of digital technologies, focusing on their policy-relevant and forward-looking segments. The final list of keywords emerging from this iterative procedure was also functional to identify the digital areas defining the boundaries of the digital ecosystem. In fact, the identification of digital areas was driven by the progressive refinement of the associated list of keywords but, at the same time, it was also functional to the detection of relevant keywords, which allow mapping the digital ecosystem in a forward-looking and policy relevant perspective

The 15 digital areas are associated to the final, consolidated list of keywords[15] that constitutes the 'semantic space' characterizing the digital ecosystem. As described with more details in the next subsection (see Box 2), this list of keywords is used to build queries that are then launched on the database made up by specific repositories (patents, journals, business activities, EU funds, etc.), in order to generate the DGTES digital ecosystem database.

The currently applied list includes 466 keywords[16], each of which belongs to one of the identified 15 digital areas. These keywords allow to cover the many facets of the digital ecosystem in a forward-looking policy perspective, i.e. focusing on technologies and domains that are strictly related to the aforementioned notion of digital transformation. At the same time, these keywords allow to draw proper digital ecosystem's boundaries, in the sense of not allowing for the inclusion of trivial and too general keywords (e.g. *keyboard*, *computer science*) that would dramatically increase the number of false positive results, which are not relevant for the proposed analysis.

3.2 The DGTES ecosystem database

The application of the TES methodology to the digital ecosystem (DGTES) leads to the generation of the DGTES digital ecosystem database of players and activities engaging with digital technologies. Using the detailed information contained in the DGTES database, the activities and the players relevant for the definition of digital ecosystem can be identified and related, taking into consideration features and attributes such as organizational type, digital areas, geographical location, etc.. The connection of all these elements and information allows mapping the digital ecosystem.

(15) The complete list of keywords and queries is publicly available and accessible from the European Data Portal and from the JRC PREDICT website (https://joint-research-centre.ec.europa.eu/predict/digital-ecosystem-analysis-dgtes-2022/dgtes-keywords-list-2022_en).

(16) While the mentioned set of keywords has been used to define the DGTES environment and build the current database, activities are being carried on to extend it to a finer level of granularity, in accordance to the TES methodology, to ensure an even more precise capturing of relevant subdomains of the digital technologies.

The methodological approach employed to generate the DGTES database unfolds in three phases: (i) detecting relevant activities, (ii) identifying players involved in relevant activities, and (iii) connecting these elements to generate the DGTES graph database to map the digital ecosystem.

3.2.1 Detecting activities leaving a 'digital footprint'

The first phase of the DGTES methodological approach consists of the identification, collection and text pre-processing of the data associated with activities.

To be included in DGTES, an activity should correspond to an economic process leading to outputs contributing to the production, innovation and evolution of digital technologies - that is, increasing and expanding the availability of and/or the knowledge on these technologies. In other words, activities should leave a 'digital footprint' in one or more of the digital areas that define the digital ecosystem. These selected activities represent the first main element (or building block) of the DGTES analytical approach.

With the intention to establish a comprehensive digital landscape, the DGTES methodology targets three different types of activities, organized in three groups according to their nature and outputs (i.e. industrial or research). These constitute the 'three pillars' sustaining the structure of the digital ecosystem (see De Prato et al. 2019, Righi et al. 2020):

1. *business activities,* derived from information on companies' core business and on the production, supply and/or exchange of goods and/or services, and/or on investments and funds financing industrial and business initiatives (i.e. venture capital deals);
2. *innovation activities,* corresponding to outputs of Research & Development (R&D) activities in the form of patenting initiatives (i.e. filing of priority patents) and/or participation in innovative research projects (i.e. EU-funded projects H2020 and FP7);
3. *research activities,* reflecting academic contributions of frontier research, such as publications and/or participation in high level international conferences.

In practice, each activity is associated to a document that carries textual information about the activity itself (i.e. whether business, innovation or research) and its attributes. In order to discern which activities can be considered as having this 'digital footprint', the DGTES methodology uses a dictionary of selected keywords[17] to search through different sources of factual data, each source representing a repository of documents that carry textual information[18]. In the current version of DGTES, the list of factual data sources used includes: patent application records; databases of EU funded projects; business information; databases of scientific publications and participation in international conferences[19]. On this textual information a keyword extraction algorithm (using queries) is implemented in order to detect the documents associated to digitally-relevant activities. The version of the DGTES presented in this report uses 466 keywords and six horizontal data sources[20]. Box 3 clarifies how, in practice, the selected keywords were used to build the queries leading to the identification of relevant documents.

Box 3. Generating the final DGTES database: from keywords to queries

The keywords (identified through the process explained in subsection 3.1.3) represent the core of the queries to be used in the search exercise to build the DGTES digital ecosystem database.

(17) The construction of the keywords has been described in the previous subsection. The complete list of keywords and queries is publicly available and accessible from the European Data Portal and from the JRC PREDICT website (https://joint-research-centre.ec.europa.eu/predict/digital-ecosystem-analysis-dgtes-2022/dgtes-keywords-list-2022_en).

(18) The data sources can be of two types: i) horizontal, which entail non-technology specific data sources, but data potentially useful to detect all type of digitally-relevant activities (i.e. firm level information repositories containing data on any type of firms in all industrial sectors); ii) vertical, which correspond to technology specific data sources, such as information exclusively related to, in the current case, digital technologies (i.e. data collected by industrial association targeting a specific technological domain, or, for example lists of start-ups active in artificial intelligence, robotics, etc.).

(19) This list could be expanded in future versions of DGTES.

(20) Work is ongoing to include in the source list a set of vertical sources, specific to the digital domain and to the identified digital areas.

The construction of queries must follow some rules, especially aimed at avoiding as much as possible the return of false positive results that are not relevant for the purpose of this analysis. This effect is mainly due to the fact that many keywords, taken in isolation, maintain a high degree of ambiguity. For example, when taken in isolation, the term 5G may correspond to the "5th generation technology standard for broadband cellular networks" but also to the phrase "five grams"; *decision tree* may refer (among others) to psychology or project management or, within the digital ecosystem, to Artificial intelligence (AI).

The first step to build queries from the set of keywords, then, is establishing whether a keyword has some level of ambiguity or not. For instance, while it is difficult to imagine a context where *cybersecurity* refers to some context which is not inherently digital; the same cannot be said for *fraud*, or *grid*, or *inference*. So, as far as the actual construction of queries is concerned, if one keyword is labelled as unambiguous, then the query can be simply built with the keyword itself. One example is the query "chatbot", made up by just the keyword *chatbot*.

Digital areas may be used in order to minimise the noise (and false positive results) deriving from keywords' ambiguity. When one keyword is labelled as ambiguous, then the query can be built by putting the digital area and the keyword in an AND relation, like this: (digital area AND keyword). For instance, the keyword *fraud* will concur to the construction of the query (Blockchain, Distributed Ledger AND fraud); the keyword *grid* will concur to build the query (Advanced Computing, High Performance Computing, edge computing AND grid).

When digital areas are constituted by several elements, as the ones used in the examples above, real queries will use the OR operator in order to widen their search potentialities. So, the example above should actually be written as (("Advanced Computing" OR "High Performance Computing" OR "Edge computing") AND ("Grid")). Quotes (") are inserted for all the constituents of the query, especially in order to isolate phrases made up by more than one word.

Digital areas cannot always be used as they are. Most of them are composed by constituents made up by multiple words or phrases ("3D Printing, Additive manufacturing"). The first question to take into account is whether such constituents are ambiguous or unambiguous themselves (in the framework of the digital ecosystem). For instance, while "cybersecurity" may be considered unambiguous, the same cannot be said for "infrastructure".

In order to minimize the risk to return results from other semantic contexts, two basic rules should be applied:

1. In case a digital area contains more than one element, and those elements are totally unambiguous (e.g., "3D Printing, Additive manufacturing"), those elements can be simply put in OR;

2. In case a digital area contains one or more elements inherently ambiguous (e.g., "data", "electronics", "infrastructure"), then we may decide either to:

— merge (in AND) two or more elements belonging to the same digital area (e.g.: "5G" AND "communications"); or

— "specify" the element by completing it with one (or more) additional element that better specify it (e.g., "infrastructure" becoming "software infrastructure", or the like), paying attention that the added element is not ambiguous in its own.

The ambiguous/unambiguous labelling of keywords and the proper use of the AND/OR Boolean operators make it possible to build queries that allow at the same time a high representational power and the minimization of false positive results.

As the scope of the analysis is to obtain an updated picture of the digital ecosystem, the detected documents are filtered based on the year of reference and only documents issued between 2009 and 2022 are considered[21]. The inclusion of the latest years allows capturing the most recent evolution of digital technologies in a timely manner. The possibility to associate each document to a year is an important feature of the DGTES, as it allows analysing the evolution of the digital ecosystem over time and the emergence of subdomains of digital technologies.

([21]) For some documents - in particular those containing the description of a firm's activities and business - a date is possibly not available. When the data sources provide information about economic activities currently existing, the year of reference is taken depending on a systematic set of considerations to proxy the year/s in which relevant activities may have been performed, assuming that the information was valid at that time.

3.2.2 Identifying the players shaping the digital ecosystem

The second phase of the DGTES methodological approach consists of the identification of the players participating in the digital ecosystem.

Economic players represent the second main element (or building block) of the DGTES analytical approach. In DGTES, the term 'economic player' is used to define any economic (market and non-market) actor involved in digitally-relevant activities. These 'behaving entities' (Righi et al. 2020) play an active role in shaping the digital ecosystem and influencing its economic performance, development and future evolution.

Players can be:

1. *companies and firm*;
1. *academic institutions and research centres*;
2. *governmental authorities and bodies*.

This classification recalls the 'triple helix' model of innovation developed to describe the interactions between the main actors engaging in innovation activities and pursuing innovation outputs: university, government, and industry (Etzkowitz and Leydesdorff 1995; 2000). Although the three entities may perform innovation in response to different incentives and with different purposes (i.e. industry responds to market incentives and develops innovation to boost competitiveness, while university engages in research for non-market purposes), the 'triple helix' model contemplates a possible evolution towards more hybrid frameworks, where each component evolves to adopt some characteristics of the other institution. The fact that DGTES does not impose a univocal correspondence between the type of activity and the type of player – that is, each player can perform one or more business, innovation and/or research activities - makes this approach adequate to account for the possible hybrid nature of players.

The DGTES methodology identifies the players through the analysis of the textual information contained in the document associated to a digitally-relevant activity[22]. However, this requires the implementation of a multi-steps process of data cleansing before the database is ready and usable for the analysis of the digital ecosystem. Box 4 summaries this multi-step process.

Box 4. Generating the final DGTES database: from documents to players

A data cleansing process is performed on the selection of documents resulting from the analysis of their textual information, in order to improve precision for the identification of unambiguous, relevant players. This process consists of the following steps:

- Look for information on players and players' location

Only documents containing text information about players are considered. Where applicable, players' locations (at the city level) are corrected or completed based on information contained in the document, via web scraping, or from other sources.

- Disambiguation of players

Players' names need to be disambiguated, as the same player can be simultaneously detected by multiple factual data sources. The process of disambiguation allows identifying if the same player is involved in multiple activities and correcting for eventual duplications. This process is based on: (i) the geographical location of players (eliminating players with the same name that share the same location at city level); (ii) algorithms measuring similarity of names that identifies misspelled names and variations of the same name; (iii) algorithm working on network of similarities that identifies groups of potential duplicated agents. This implies that the information on each player can result from the combination of what collected from different sources. If the same economic institution is detected in multiple locations, these are considered as different, individual players, belonging, when applicable, to the same multi-site organisation (i.e. firms with an headquarter and several subsidiaries).

([22]) This implies that business activities that do not explicitly include the production, supply and/or exchange of digital technologies in the description of their core business are not considered. Nevertheless, they can be detected if they have filed a digitally-relevant patent or have a digitally-relevant publication (Righi et al. 2020) or having received venture capital (VC) funding for a digitally-relevant activity, and so on.

- Identify the organisational type

The organisational type of each player is identified, which can correspond to: academic institutions and research centres; governmental authorities and bodies; firms and companies. The focus is placed on the organisations, and not on individuals (i.e. the applicant organisation owning the invention in the case of patents, or affiliation instead of the individual authors in conference proceedings or publications).

3.2.3 Generating the graph database to map the digital ecosystem

The third phase of the DGTES methodological approach generates the graph database of the digital ecosystem, built on the interlinkages connecting activities and players.

The database obtained through the reiteration of keywords queries and the processes of data cleansing and disambiguation contains detailed information about the participation of each player in the detected activities and about their features and attributes. More specifically, the DGTES methodology uses on two sets of information to generate the graph database and map the digital ecosystem:

1. *information about the detected activity*, such as the description of the activity (e.g. from textual information in documents such as the description of companies' activity, abstract of articles or of patents), the date of the activity (publication date, patent application filing date…), and the digital area associated to the activity;
2. *information about the related players*, such as the organizational type (e.g. firm, government institution, research institution…), geographical location, industrial sector and financial information (when applicable).

The analysis of the textual information in the documents allows connecting activities and players, thus identifying how players relate to each other and are interlinked through their shared activities. The web of relationships built on the connections across activities and players constitute the structure of the DGTES digital ecosystem graph database.

The final graph database reflects a complex system made of players, activities and their respective attributes. This system is populated by interdependent agents whose (formal or informal) connections, interactions on joint activities, and behaviours reveal the emergence of a non-random structure (Newman 2011). The graph structure of the DGTES digital ecosystem database allows it to be explored as a network[23], whose nodes and edges correspond to players and activities.

The fact that the data are collected at a micro-level from a heterogeneous group of factual data sources allows enriching the scope of the mapping exercise with more and finer levels of analysis. The possibility to retrieve agents' locations at high granularity (e.g. city level) allows exploring the ecosystem at different geographic and administrative levels (e.g., cities, countries, regions). The spatial dimension is indeed a fundamental and original feature of the TES methodology: based on the information on their location, players belonging to the same geographical area can be grouped together to produce their geo-based networks and explore differences and their relative positioning at specific geographic levels as well as at global level. Following this same approach, DGTES can map the geographical space of production and diffusion of knowledge around digital technologies.

In addition, the information on digital areas allows relating individual players to digital subdomains. Besides offering useful insights on which players are contributing to the evolution of specific digital technologies, this allows looking at the composition of each digital subdomain in terms of the main attributes of players (i.e. organisational type, geographical location, etc.) and exploring the distribution of digital capabilities and technological competences in the ecosystem. This feature of DGTES is particularly powerful and useful to map knowledge flows based on interlinkages across players and colocation at local as well as at global level, and to investigate collaborations and the evolution of emerging domains in digital technologies.

Moreover, a further analysis of the textual information in the documents allows to identify in each document a specific set of technology-related terms. These terms can be pegged to the activity associated to the document and stored as its additional attributes. In this way, the connection of each activity with a set of terms constitute another layer of relations among activities – and, therefore, also among the related players – that enriches the complexity of the network underlying the digital ecosystem. This allows performing bottom

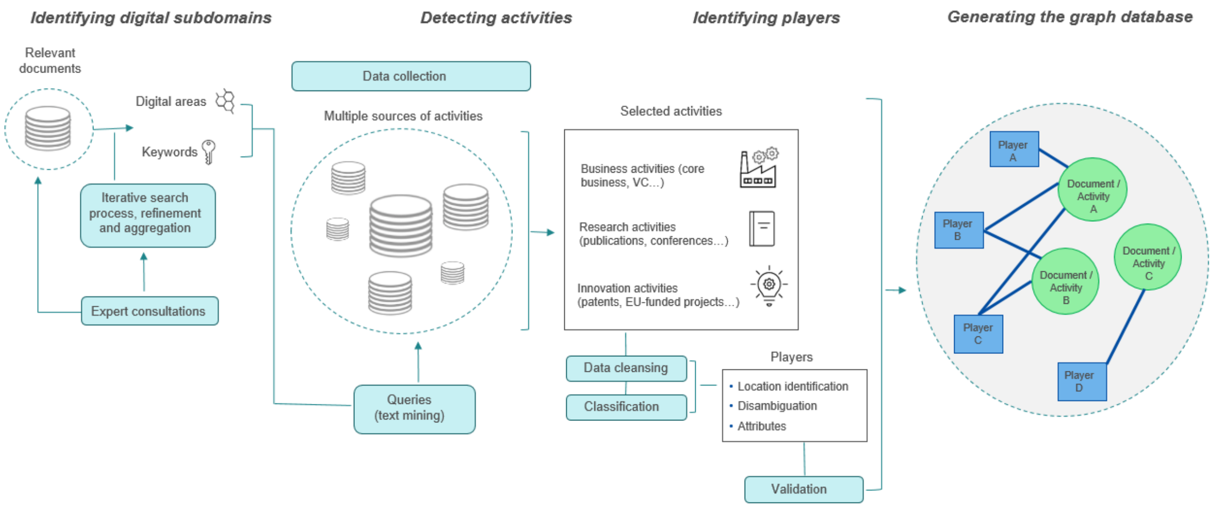
(23) See Righi et al. (2020) for more details on how the graph database can generate different types of networks.

up topic modelling of thematic areas, which increases the explanatory power of DGTES and its potential in revealing latent communities of players as well as relations across digital subdomains.

Considering the volume and variety of sources considered, and the amount of work needed to match through the data sources, the TES analytical approach provides one of the most accurate and comprehensive way to describe, map and analyse a dynamic and complex ecosystem of emerging technologies (De Prato et al. 2019; Pogorzelska et al. 2019; Samoili et al. 2019; Righi et al. 2020). The implementation of DGTES shows that this is the case also for digital technologies and the digital ecosystem.

To summarize, Figure 2 presents a schematic representation of the workflow of the DGTES analytical approach described in this section. It displays the main aspects of the DGTES methodology leading to a map of the digital ecosystems, going from the detection of the activities characterising the digital ecosystem (left part) to the procedures to cleanse the data, to the production of the final graph database (right part).

Figure 2. DGTES workflow and methodology



Source: Authors' elaboration, Digital Economy Unit, JRC.

4 DGTES at work: mapping and navigating through the digital ecosystem

This section provides an overview of the possible outcomes of the application of the Techno-Economic ecoSystems (TES) approach to the study of the digital ecosystem (DGTES). The first subsection suggests some paths of analysis that can be explored using the DGTES digital ecosystem database. The second subsection introduces some of the indicators and metrics that can be generated from the DGTES database and briefly discusses how these can provide a first overview of the digital ecosystem. The third subsection builds on the presented indicators to point out future directions of analysis, stressing the potential of DGTES in exploring further dimensions and aspects of the digital ecosystem, and beyond it.

4.1 An itinerary to explore the digital ecosystem

The aim of DGTES is to map the digital ecosystem and provide an analysis of its elements, structure and features from a holistic, multidimensional and policy-relevant perspective. In particular, this descriptive and analytical exercise can address three sets of research questions:

1. Which are the economic players participating in the supply, creation and evolution of digital technologies, by engaging in relevant research, innovation and business activities? Where are they located and how are they geographically distributed?
2. Which technological subdomains (digital areas) define the boundaries of the digital ecosystem? Which are the technological realm of the activities of the players in the digital ecosystem? Which digital areas represent emerging technological subdomains?
3. How do players interact in the digital ecosystem? Which network of collaborations and interlinkages results from their shared activities, locations and technological fields? Which type of collaborations are in place in the digital ecosystem? Which players are in the strategic position to control and shape the flows of knowledge and production?

These research questions can serve as research paths to navigate through the digital ecosystem with a clear analytical focus and to grasp a deeper and meaningful understanding of its elements, structure and features.

From a policy perspective, this research exercise can offer novel evidence on the positioning of the European Union (EU) in terms of attractiveness and excellence in research and innovation (R&I) and in terms of industrial leadership and competitiveness in the domain of emerging and critical digital technologies. This can contribute to the design of policies that help Europe successfully navigate the digital transition. By shedding light on the networks that characterize the global digital landscape, the results of this research can also contribute to the identification of opportunities, synergies, and obstacles that need to be addressed to foster the development of a vibrant digital ecosystem and to strengthen EU's digital and industrial leadership in current and future global scenarios.

4.2 DGTES indicators and metrics

Offering a quantitative response to the issue of measuring and assessing dynamic techno-economic ecosystems in the absence of adequate conventional statistics, the application of the TES methodological approach allows generating a series of indicators that can help disclose, investigate and better understand the digital ecosystem.

This subsection introduces and discusses some of the indicators and metrics that can be produced from the DGTES database. These can be grouped in different sets according to their goals and to dimensions of analysis: (i) indicators that provide an overview of the digital ecosystem global landscape, with its main elements and dimensions of analysis; (ii) indicators that describe and analyse the network nature of the digital ecosystem.

The results of the calculations of these indicators and metrics will be presented and discussed in an upcoming work based on the DGTES database obtained considering the period between 2009 and 2022. Most of the presented indicators can also be calculated for each year in the covered period, thus allowing to add a longitudinal and time-varying perspective to the analysis of the digital ecosystem. All these indicators and metrics represent a first step towards addressing the research questions presented in Section 4.1.

Building on the economic literature that describes the economy and economic activities as interconnected systems, the indicators produced with the DGTES analytical approach are inspired by theories of complex systems and apply techniques of network analysis. In this sense, DGETS also complements and push forward a line of research to which JRC is already contributing with different scopes and objectives, since earlier exercises aiming at identifying the European Poles of ICT Excellence, or analysing the worldwide innovation networks (De Prato and Nepelski 2013; De Prato and Nepelski 2012), to the current work on economic complexity (Pugliese and Tacchella 2021). However, this latter works aim at measuring the export and innovation capabilities necessary for a country or region to be competitive also relying on product data, whereas DGTES focuses more on analysing and understanding the dynamics, features and interactions within segments of emerging technologies such as digital ones. Moreover, thanks to the granularity of the underlying microdata, DGTES allows to apply a different geographical focus (i.e. global, country, regional) and even to zoom at the level of players and organizations.

4.2.1 An overview of the digital global landscape

Setting the stage: players and activities in the digital ecosystem

The analysis starts with the identification of the main elements that define the digital ecosystem. In this regard, DGTES can provide a snapshot of the *activities* (*business, innovation, research*) taking place within the perimeter of the digital ecosystem and of the related *players* (*firm, research institution, government*) (Table 2 Indicators 1.a).

The high level of granularity is a crucial feature of the DGTES database. Exploiting the full range of micro-data collected across different data sources, DGTES allows grasping a finer picture of the elements of the ecosystem and of their attributes. For example, it allows relating the organizational type of the players with their involvement in various types of activities (Table 2 Indicators 1.b). This implies that DGTES can 'zoom in' and focus on specific actors in the digital ecosystem, such as firms and companies (Table 2 Indicators 1.c.). By crossing the available information on firm's characteristics (i.e. size, main sector of activity), DGTES can offer an original and novel look on industrial capacity and composition in the digital ecosystem.

DGTES can also provide a dynamic overview of the digital ecosystem. The fact that the DGTES database is built on microdata collected over a time span of more than 10 years (2009-2022) makes it possible to generate the indicators at different points in time. Adding this longitudinal dimension allows picturing how the digital ecosystem has evolved over time, in terms of composition of both players and activities. Picturing the evolution of the digital ecosystem can help reveal weak signals of future technological trajectories, supporting policymakers with the identification of digital subdomains that can shape future digital leadership.

Table 2. Indicators 1: Players and activities in the digital ecosystem

Indicators 1	Questions	Indicators (*)
1.a	What happens in the digital ecosystem? Which activities are predominant? (i.e. business, innovation or research?) Who populates the digital ecosystem? Which type of players are more common? (i.e. firms, research institutions, government institutions?)	Total number of activities Share of activities by type (over total number of activities) Total number of players Share of players by organizational type (over total number of players)
1.b	How do the different players engage in the digital ecosystem? Which players do what? Are some players specialized in some activities?	Share of activity by type per each organizational type (over total number of activities performed by each organizational type)
1.c	Example: focus on firms How do firms engage in the digital ecosystem? Which activities do they perform more frequently?	Share of activities performed by firms by type (over total number of activities performed by all firms)

(*) The indicators can be calculated for each year in the considered period (2009-2022). The same applies to Table 4, 5 and 6.

Source: Authors' elaboration, Digital Economy Unit, JRC.

Adding a first layer to the analysis: geographical distribution of the digital ecosystem

The information on the location of players allows including the geographical dimension into the analysis of the digital ecosystem. DGTES can provide a picture of the geographical distribution and composition of the digital ecosystem, offering an overview of where the main players are located and how they participate in the ecosystem's activities (Table 3 Indicators 2.a).

The granularity of the DGTES database allows highlighting different geographical levels in the digital ecosystem (geographical area, country, regional, or city level). Based on this information, geographical agglomerations of players are generated by considering together all players sharing the same geographical area (even at different levels) (Table 3 Indicators 2.b). In this way DGTES can show the relative weight of different geographical areas (i.e. countries) in the digital ecosystem. This feature of DGTES is fundamental for the comprehension of the spatial dimension of the digital ecosystem.

By breaking down the geographical composition of the ecosystem also by type of player and activities, DGTES makes it possible to zoom in and look at the situation of specific actors in a specific geographical area (Table 3 Indicators 2.c). For instance, it can display which geographical area hosts the largest share of firms, or in which activities these firms are engaging in a given geographical area. Relying on the available information on firm characteristics, it can also look at the composition of firms' foreign ownership and relate this with the relative weight of the geographical areas of origin of the foreign owner, as it emerges from the analysis of the digital ecosystem (Table 3 Indicators 2.d).

By crossing the information on activities, players and their location, some indicators of the intensity of activities can be calculated for each geographical area. The number of activities per player allows for a first rough comparison of 'how productive' (in terms of activities performed per player) different areas are (Table 3 Indicators 2.e). In addition, for comparative purposes, the size of the countries' economies (proxied by GDP, measured in EUR billion purchasing power standards (PPS)[24]) can be used to get an idea of 'how productive' a geographical area is with respect to its economic weight. The number of players can also be related to the country GDP (Table 3 Indicators 2.f).

Calculating these indicators for different years over the period covered by the DGTES database (2009-2022) allows exploring how the geographical composition of the digital ecosystem has evolved over time. This shows how the relative weight of the different geographical areas has changed in terms of 'critical mass' of players and activities within the digital ecosystem, thus revealing which geographical areas have engaged more in the global digital landscape and/or which areas have been evolving faster.

Table 3. Indicators 2: Adding the geographical dimension to the digital ecosystem

Indicators 2	Questions	Indicators
2.a	Where are players located? Where do activities take place?	Total number of players by geographical area Total number of activities by geographical area
2.b	Which are the main geographical areas in terms of 'critical mass' of players and/or activities? Which type of players or activities are more frequent in a given geographical area?	Share of players by geographical area (over total number of players) Share of activities by geographical area (over total number of activities) Share of players by organizational type per each geographical area (over total number of players in each geographical area) Share of activities by type per each geographical area (over total number of

(24) The use of GDP values in purchasing power standards (PPS) allows to account for price differences across countries. For more information on this indicator, see Righi et al. (2020).

		activities in each geographical area) Percentile distribution of number of players in different geographical area
	Example: focus on firms	
2.c	Where are most firms located?	Share of firms by geographical area Total number of firms by geographical area
	How do firms engage in the digital ecosystem in each geographical area?	Total number of activities performed by firms by geographical area
2.d	To what extent are firms owned by or related to third—country actors?	Firms' location and foreign ownership
2.e	How 'productive' is the digital ecosystem in each geographical area?	Average number of activities per player in each geographical area Median number of activities per player in each geographical area
2.f	How 'productive' is the digital ecosystem in each geographical area with respect to the size of its economy?	Total number of activities over country GDP per each geographical area Total number of players over country GDP per each geographical area

Source: Authors' elaboration, Digital Economy Unit, JRC.

Adding a second layer to the analysis: digital areas and technological composition of the digital ecosystem

Digital areas correspond to the techno-economic subdomains that define the boundaries of the digital ecosystem from a forward-looking and policy relevant perspective (as described in Section 3.1). The information on the digital areas allows adding a stronger technological focus to the analysis of the digital ecosystem, which can, for example, help detect weak signals of emerging technological domains in the global digital landscape.

DGTES can offer an overview of how the digital areas are scattered through the ecosystem and what is their relative weight in the digital landscape (Table 4 Indicators 3.a). The number of different digital areas in which each player engage can give an idea of how specialized or diversified players are in terms of digital subdomains of their activities (Table 4Indicators 3.b). In addition, the information on the organizational type of the players can provide an even finer picture of the technological composition of the digital ecosystem, for instance by revealing how each type of player participates in the digital areas (Table 4 Indicators 3.c).

Crossing the information on players' location and digital areas allows looking at the geographical distribution and composition of the digital areas (Table 4 Indicators 3.d). This offers a first representation of the relative participation of each geographical area in the considered digital subdomains, giving an idea of the overall geographical distribution of technological competences and capabilities within the digital ecosystem. This information can be particularly interesting and policy-relevant in the case of digital areas associated to critical emerging digital subdomains. This feature of DGTES is important for a forward-looking assessment of the evolution of the global digital landscape.

In this regard, a useful indicator of the relative specialization in a certain digital area is the revealed comparative advantage (RCA) (Righi et al. 2021) (Table 4 Indicators 3.e). The RCA measures technological specialisation by comparing each geographical area's breakdown of activities in a certain digital area against all activities in that digital area worldwide (world average)[25].

([25]) The revealed comparative advantage (RCA) is calculated as the ratio of the share of activities of a geographical area in a certain digital area in the total amount of activities in that geographical area over the share of activities in that digital area worldwide in the total amount of activities worldwide. A RCA value of 1 represents the global average specialisation; thus, this value is taken as

The possibility to calculate these indicators for different years over the covered period (2009-2022) can provide a better understanding of the technological dynamics in the digital ecosystem. Changes in the relative distribution of the digital areas allows pointing out emerging technological trajectories, showing how some clusters of digital technologies have started arising and how some others have eventually become predominant over time, occupying a relatively larger weight within the digital ecosystem. Moreover, the analysis of the evolution of the types of activities within a digital area can reveal the existence of patterns of technological maturity (for instance, if in a digital area the majority of activities shifts from research to innovation or business over time).

The information on the geographical distribution of digital areas also allows relating the evolution of the geographical and technological dimensions of the digital ecosystem. By showing on how the relative involvement in digital subdomains of different geographical areas has changed over time, DGTES can offer novel insights on the episodes of technological 'catching up' or 'leapfrogging' eventually experienced by some geographical areas in correspondence to successful reductions of the technology gap (Lee and Malerba 2017). Being the technology gap one of the root causes of strategic dependencies, this exercise can help disclose relevant information on the global patterns of emerging technological and industrial leadership.

Table 4. Indicators 3: Adding the technological dimension to the digital ecosystem

Indicators 3	Questions	Indicators
3.a	Which are the main digital areas in the ecosystem?	Total number of activities by digital areas Share of activities by digital areas (over total number of activities) Total number of players by digital areas Share of players by digital areas (over total number of players)
3.b	How specialized are players in terms of digital areas?	Average number of different digital areas per player Median number of different digital areas per player
3.c	How do the different players (per organizational type) engage in digital areas? Do some type of players engage more in some digital areas?	Share of digital areas by players' organizational type Share of players' organizational type by digital area
3.d	What is the geographical distribution of the digital areas? To which geographical area corresponds the largest share of activities in each digital area?	Share of geographical areas by digital area Share of digital areas by geographical area
3.e	In which digital areas is each geographical area more competitive?	Revealed comparative advantage (RCA)

Source: Authors' elaboration, Digital Economy Unit, JRC.

4.2.2 A collaborative ecosystem

A complex system of relations by design

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the benchmark. A value of RCA above 1 for a geographical area in a certain digital area means that the proportion of activities in that digital area is higher than in the world average, and therefore reveals a comparative advantage of the considered geographical area in that digital area. For more details and examples about the use of this indicator, see Righi et al. (2021).

As discussed in Section 3.2, the web of connections across players based on their shared activities and locations constitutes the main structure of the DGTES digital ecosystem graph database. This can be explored as a network of interlinkages. Analysing this network with adequate indicators can reveal the features of collaborations and knowledge flows within the ecosystem, while keeping a geographical (worldwide, EU, regional) and technological (digital areas) perspective. This feature of DGTES is crucial for the comprehension of the complex structure of the digital ecosystem and of its characteristics in terms of production, development, exchange and control of relevant knowledge.

DGTES can provide a unique picture of the volume and the features of the collaborations that take place within the digital ecosystem[26]. It can shed light on how collaborative the digital ecosystem is by looking at the amount of shared (thus, collaborative) activities as well as at which activities are conducted by individual players (thus, players that operate in isolation from the rest of the ecosystem) (Table 5 Indicators 4.a). The granularity of the information on players and activities contained in the DGTES dataset allows to better describe the patterns of collaboration. For instance, it can give an idea of to what extent different organizational types are involved in the observed collaborations (i.e. firms with universities and/or research institutions), while the information on type of activities can reveal which activities tend to be more collaborative (Table 5 Indicators 4.b).

Geographical networks of collaborations can be generated by considering together all players from the same geographical area. This allows looking at spatial characteristics of these collaborations, such as how spread out collaborative players are, how collaborative a certain geographical area is, or what is the volume of internal (when players are located in the same geographical area) or external (when players do not share the same location) collaborations (Righi et al. 2020) (Table 5 Indicators 4.c). It is noteworthy that DGTES can also highlight 'latent' knowledge flows based on implicit relations and (hypothetical) tacit processes of knowledge exchange potentially driven by players' spatial proximity and co-location (Table 6 Indicators 4.d). This indicator can provide more insights on the nature and purpose of implicit collaboration patterns in the digital ecosystem, allowing to detect eventual 'latent communities' and tosee to what extent these overlap with formally observed communities, and even associate them to specific digital domains.

Additional indicators can be constructed using the information on the digital areas. These allow exploring to what extent collaborative players are more or less diversified in terms of the digital areas they engage in, or if non-collaborative players tend to specialize in some specific digital areas (Table 5 Indicators 4.e). This can provide an indication of possible emerging digital domains, whose knowledge is still unset and evolving, thus making players more reluctant to engage in collaborations.

DGTES fully exploits its explanatory power when it looks more in depth at the properties of the network. By revealing the presence of gatekeepers and hubs, indicators derived from network analysis (i.e. network statistics, such as weighted betweenness centrality (WBC)[27]) allow assessing the level of control exerted by different groups of players or geographical areas over the network (Righi et al. 2020) (Table 5 Indicators 4.f). These indicators allow introducing an additional analytical level to the study of the digital ecosystem: the identification of strategic positioning in emerging digital domains.

As information about time is available for research and innovation activities (i.e. patents, publications and conferences), these indicators can be computed on a yearly basis, considering only the set of collaborations occurring in each year at a time. When calculated at different points in time, network statistical indicators (such as WBC) describe how the control over the knowledge flow within the digital ecosystem has evolved over the considered period (2009-2022). This reveals how the relative positioning of the technological leaders within the network have changed over time and, at the same time, pointing out the presence of potential emerging leaders. This feature of DGTES is particularly relevant from the perspective of strategic autonomy emphasised in the EU Industrial Strategy, as it can contribute to a better understanding of the current and potential role of EU in the digital ecosystem as well as to detecting possible vulnerabilities and sources of strategic dependencies that could compromise EU's leadership in the current and future global digital landscape.

([26]) The exploration of collaborations within the digital ecosystem relies on research (i.e. journal publications, conferences) and innovation (i.e. patents) activities.

([27]) The betweenness centrality (BC) is a measure of centrality of a certain node (i.e. *v*) in the network. It is calculated as the ratio between the number of shortest paths between two other nodes (i.e. *s* and *t*) and the number of shortest paths between these two nodes (*s* and *t*) in which *v* lies. See Righi et al (2020) for more details on the computation of this network statistical indicator.

Table 5. Indicators 4: Exploiting the relational dimension of the digital ecosystem

Indicators 4	Question	Indicator
4.a	How collaborative is the digital ecosystem? How many activities are the result of collaborations across players in the digital ecosystem?	Number of collaborative [non-collaborative] activities (performed by more than one player) Share of collaborative [non-collaborative] activities (over total number of activities)
4.b	How collaborative are the different type of (research or innovation) activities? How collaborative are the different type of players? Which type of players tend to be more/less collaborative?	Share of collaborative [non-collaborative] activities by type of activity Share of collaborative [non-collaborative] activities by players' organizational type Share of collaborative activities performed by players with the same [different] organizational type (over total number of activities)
4.c	How spatially concentrated/spread out are collaborative players?	Average spatial distance across collaborative players (in general/within a certain geographical area)
	How collaborative is a geographical area?	Share of collaborative [non-collaborative] activities per geographical area
	Within which geographical areas do players collaborate more with players in the same geographical area (internally)? Within which geographical areas do players collaborate more with players in a different geographical area (externally)?	Share of internal collaborative activities per geographical area Share of external collaborative activities per geographical area
4.d	How spatially concentrated or spread out are players (independently of them directly collaborating) within a certain geographical area?	Average spatial distance across players within a certain geographical area Average spatial distance across players within a certain geographical area
4.e	How specialized are collaborative [non-collaborative] players in terms of digital areas?	Average number of different digital areas per collaborative [non-collaborative] player Median number of different digital areas per collaborative [non-collaborative] player
4.f	Which players or geographical area do occupy a strategic position in the network?	Weighted betweenness centrality (WBC)

Source: Authors' elaboration, Digital Economy Unit, JRC.

4.3 Further applications and extensions of the DGTES

The presented work describes the first application of the TES methodology to the digital ecosystem (DGTES). As first step in the process of mapping the digital ecosystem, a series of indicators originated from the DGTES database can be generated, with the aim of providing a comprehensive and policy-relevant overview of the global digital landscape.

However, the indicators and metrics presented above reflect just some of the aspects and dimensions that can be explored with DGTES. Certainly, there is room to extend the application of the DGTES analytical approach: future works investigating the digital ecosystem using DGTES will build on this report and enlarge the scope of the analysis to embrace more dimensions and aspects of the digital ecosystem, and beyond it. Some possible avenues of future research can be already pointed out. Their relevance to current EU policy developments makes these avenues of research particularly urgent to explore.

Using the information on digital areas, DGTES could look more in depth at the technological features of the knowledge generated and exchanged within the digital ecosystem. The application of Natural Language Processing (NLP) methods like topic modelling[28] would enable the clustering of all detected relevant documents (associated with relevant activities), allowing to explore the degree of thematic closeness across digital areas and to look at potential dynamics of proximity and distancing of technological subdomains over time. This would provide novel evidence about the relationship across digital technologies.

A deeper analysis of the collaborations that take place within each digital area could provide additional information on which digital subdomains are more active in producing knowledge, which ones in exchanging knowledge through collaborative activities, and whether being active in a certain digital subdomain makes it more likely for a player to be active also in another 'technologically contiguous' (proxied by closeness) digital area. This network of collaborations could be explored separately by each digital area, allowing to draw differences and similarities in the shape of these networks in the different digital subdomains, and to see whether and to what extent these networks overlap.

DGTES could also contribute to refining current understanding of how knowledge is used in the digital ecosystem. For instance, using additional information on how many years has a certain patent been renewed or the analysis of patent citations could reveal the purpose of filing that patent - whether it was to appropriate the return to innovation or, instead, with a more 'defensive purpose' to block or discourage other players from engaging in a certain digital technology or its application. Crossing these results with the information on digital areas can give an idea of which digital subdomain are emerging and are likely to become critical, as their mastering is expected to ensure technological leadership in the future global digital landscape.

DGTES could be employed to investigate aspects of the digital ecosystem related to EU industrial policies. DGTES could contribute to further exploring the drivers of industrial competitiveness, by looking at how certain features of the digital ecosystem (i.e. level of activity, location of players, specialization or diversification in different digital areas) can be related to the industrial performance of a given geographical area. Given the granularity of the used micro-data, DGTES allows conducting this analysis at different levels, both in terms of geographical levels (i.e. country, region, city) and player's characteristics. For instance, DGTES could focus on firms and use the available information on firms' characteristics (i.e. size, sector) to see how these interplay with the digital ecosystem.

In this regard, DGTES could provide novel insights on the participation of small and medium enterprises (SMEs) in the digital ecosystem. Accounting for over 99% of all European firms, small and medium enterprises (SMEs) are a vital part of European economy and society but they have been slow at taking up digital solutions, often due to lack of available skills, access to finance and markets (COM(2020) 102 final). SMEs are at the core of the Industrial Strategy, which sets out measures and actions to facilitate their engagement in the transition towards a more digital, clean, circular and globally competitive EU industry[29]. Depending on the available information, DGTES could target this specific type of actors and provide an original and useful picture of SMEs' role and positioning within the digital ecosystem.

DGTES could be used to explore and analyse the intersections between the digital ecosystem and the other 13 industrial ecosystems[30] identified by the Industrial Strategy (COM(2020) 102 final). Industrial ecosystems tend indeed to be linked to and overlap with each other, as some activities are by nature more horizontal and can be relevant for more than one ecosystem at the same time. This is clearly the case of the digital ecosystem: the extreme permeability of all industrial operations and processes to digitalization implies that

(28) See Righi et al. (2020) for a better discussion of the application of these data processing methods - more specifically, of the Latent Dirichlet Allocation (LDA) model - in the case of the techno-economic segment of Artificial Intelligence (AI TES). More information available on the AI Watch webpage (https://ai-watch.ec.europa.eu/index_en) and on the AI TES dedicated dashboard (https://web.jrc.ec.europa.eu/dashboard/AI_WATCH_LANDSCAPE/index.html?bookmark=overview).

(29) A dedicated strategy for SMEs is adopted in parallel with the New Industrial Strategy (see the Commission's Communication 'SME strategy for a sustainable and digital Europe' (COM (2020) 103 final)).

(30) The 14 industrial ecosystems are: Aerospace & Defence, Agri-food, Construction, Cultural and Creative Industries, Digital, Electronics, Energy Intensive Industries, Energy-Renewables, Health, Mobility-Transport-Automotive, Proximity, Social Economy and Civil Security, Retail, Textiles, and Tourism (see COM(2020) 102 final).

the digital ecosystem is intersecting with all other industrial ecosystems, transforming the way in which all other ecosystems perform their core activities, and defining the technological scope in which they operate. Thus, analysing and better understanding the digital ecosystem is key to leverage a successful twin transition in the whole economy. A cross-ecosystem analysis of the industrial landscape at global as well as at EU level could be one of the main and most policy-relevant contributions of the DGTES.

Finally, taking a step back from the specific focus on the digital ecosystem and looking at the whole economy, the TES methodological approach could be applied to any other industrial ecosystem, obtaining valuable knowledge about who does what, with whom, where and when. Focusing on the needs of players within diverse industrial ecosystems' value chains, the New Industrial Strategy seems to optimally match the possibilities offered by the TES analytical approach. The aggregated micro-data approach of TES, based on multiple integrated factual data sources, can be used to identify the boundaries of each industrial ecosystem and to provide insights about players, technologies, and processes within each ecosystem. A comprehensive picture of this 'system of ecosystems' can contribute to advising decision-makers with the design of better informed and more forward-looking policies aimed at filling actual and foreseeable gaps as well as at further strengthening areas of excellence of the European economy.

5 Conclusions: DGTES for a digital, sustainable, resilient and globally competitive EU economy

This section discusses and interprets how the application of the Techno-Economic ecosystem (TES) methodological approach to the analysis of the digital ecosystem (DGTES) can contribute to informing, assessing and ultimately improving the policies aiming at transforming the European Union (EU) into a more sustainable, digital, resilient and globally competitive economy. The first subsection briefly summarizes the main challenges and opportunities EU's digital and industrial policies face in the light of uncertain and fast-changing global circumstances. The second subsection reviews how DGTES can contribute to addressing current policy-relevant issues.

5.1 Fostering digital transformation in an changing global landscape: a renewed policy challenge for the EU

Digital technologies have been changing the face of societies, economies and industries for a few decades. During past years, the extent to which digital technologies permeate all aspects of economic and social activities has dramatically expanded, as these technologies have become an imperative for working and doing business, communication and social interactions, learning and entertaining, shopping and accessing a broad range of services from health to culture. Digital technologies are nowadays generating an ever-increasing amount of data, which can lead to a completely new means and levels of value creation, establish new business models, allow industry to be more productive and provide workers with new skills.

As powerful drivers of the green transition, digital solutions can also significantly contribute to the achievement of the European Green Deal goals by supporting circular economy with a fully integrated life-cycle approach - from design through sourcing of energy, raw materials and other inputs to final products until the end-of-life stage - , helping achieve carbon-neutrality in all sectors and reduce environmental footprints. This remarks how the digital transformation should go hand-in-hand with the green transition, pursuing the aim of not increasing any further the environmental burden of digital actives (i.e. in terms of total electricity use and emissions) but instead significantly contributing to the transition towards a climate neutral, circular, and resilient European economy and society.

The COVID-19 pandemic has reinforced the importance of digital transformation for the resilience of societies and economies, and accelerated its pace. At the same time, the pandemic crisis has exposed the vulnerabilities of the European digital space and its dependencies on non-European technologies and players. Driven by concerns about economic prosperity, competitiveness, and supply chains resilience that emerged during the COVID-19 crisis, EU policies such are the Digital Decade and the Industrial Strategy have remarked the importance of reinforcing Europe's industrial and strategic autonomy to enhance industrial capacity and digital transformation. Coupled with a period of uncertainty and fast changing global circumstances, this is posing new challenges for Europe as it sets off on the twin transition.

To be technologically and digitally sovereign in an interconnected world, Europe needs to assess and address strategic weaknesses, vulnerabilities and high-risk dependencies in the most critical and emerging digital technologies, which endanger the achievement of its digital and industrial ambitions. At the same time, strategic dependencies could also represent a window of opportunity for Europe's industry to develop its own products and services in critical areas, contributing to boosting competitiveness and industrial leadership. In this case, efforts and resources could be invested to retain existing strengths and gain position in digital domains where no global incumbents have yet emerged. Yet, all this requires Europe to develop and further strengthen its own technological capabilities and capacities in a way that enables people, societies and businesses to fully grasp the benefits of the digital transformation.

In these challenging times, Europe's aspiration to pursue digital transformation to seize a human centred, sustainable and more prosperous digital future is more relevant than ever. This calls for urgent, ambitious and coherent policy initiatives. As discussed in the Introduction, several existing EU policies and programmes are consistent in their visions and goals of digital sovereignty and leadership, and in line with the objectives of the European Green Deal. However, to avoid the risk of these remaining a too high-level agenda without clear references for the implementation of concrete plans, these policies need to be complemented and competed by sound science-based analyses to identify European strengths and weaknesses compared to other global leaders, as well as to monitor strategic control points and bottlenecks in critical technological domains. Thus, policies aiming at fostering the digital transition and reducing Europe's digital dependency need to be grounded on a better and more comprehensive understanding of the features and structure of the digital ecosystem, in isolation as well as in its intersections with the other industrial ecosystems. In this respect, DGTES represents a valid instrument to conduct the needed policy-oriented analyses.

5.2 A policy-oriented analytical instrument to steer digital transformation

DGTES is by design a policy relevant analytical instrument. As explained in the previous sections of this report, DGTES can provide quantitative indicators and metrics adequate to map the spatial distribution, technological development, and evolution of a complex and dynamic industrial ecosystem. Based on a rigorous scientific methodology to integrate multiple micro-data bases, the DGTES analytical approach allows to look with a minimum time delay at highly dynamic, integrated technological domains such as the digital ecosystem. This almost real-time possibility allows DGTES to play a key role in supporting the design and implementation of timely policy initiatives fostering digital transformation. Mostly important, the TES methodological approach at the ground of DGTES can potentially be applied to any techno-economic ecosystem.

The policy space related to the digital ecosystem lies at the intersection of major policy programmes for EU's resilience and competitiveness, such as the New Industrial Strategy, the Digital Decade, and the New Innovation Agenda. The application of DGTES can thus offer policy-relevant recommendations for achieving the goals of digital sovereignty and leadership pursued by these policies. DGTES can help deal with a series of issues that, if not timely addressed, could jeopardize the effective implementation of policy initiatives for a more digital, sustainable, resilient and globally competitive EU economy.

— Monitoring EU's role in shaping the evolution of emerging digital technologies

DGTES can provide insights on the patterns of evolution of digital technologies. It can identify which digital subdomains have expanded more over time and are expected to reveal particularly dynamic trajectories. At the same time, by relating this information with the geographical composition of the digital ecosystem, it can shed lights on which global players are driving and steering the observed technological dynamism. This allows monitoring EU's participation in shaping the evolution of the current and future global digital landscape. One example is the use of information derived from the analysis of patent data to generate DGTES indicators such as the specialisation in specific digital areas, which allows detecting possible gaps in strategic emerging digital subdomains and eventually intervening with the design of appropriate policies.

— Assessing features and properties of collaborative networks in the global digital ecosystem

By identifying global players in different digital subdomains, DGTES can describe and assess the distribution of competences and capabilities within the digital ecosystem, even at different levels of aggregation (i.e. regional, national or local). The micro-data foundation of the DGTES methodology allows drawing the networks of interlinkages and connections, which are at the same time the outcomes and drivers of these clusters of competences and capabilities. Furthermore, the analysis of explicit and implicit (or 'latent') communities spanning over multiple vertical topics allows to explore and make hypotheses on possible effects (in terms of strengths as well as possible weaknesses) on the whole system. This information is important for shaping targeted policy interventions aiming at strengthening the connection between research and market-oriented activities, in order to increase the leverage technological innovation as driver of competitiveness and productivity.

— Complementing the Industrial Strategy by highlighting the overlaps and interactions of the digital ecosystem with other industrial ecosystems

DGTES allows taking into account the transversal and horizontal nature of the digital ecosystem and exploring its intersections with other industrial ecosystems. The results of these cross-ecosystem analysis contribute to understanding the interactions within as well as across ecosystems, which is important for better informing policy initiatives supporting a stronger interaction and exchange across industrial ecosystems. For example, DGTES can reveal the presence and the spatial distribution of multi-ecosystem clusters of competences capabilities that could be targeted to leverage an effective allocation of policy initiatives fostering industrial competitiveness.

— Supporting the Innovation Agenda with original indicators and metrics

DGTES can support the implementation and assessment of the initiatives related to the Innovation Agenda to improve EU's innovation performance and foster the wave of *deep tech* innovation with original indicators and metrics. Besides offering a timely snapshot of EU's position in terms of leadership in scientific knowledge production and exchange with respect to other global competitors, DGTES allows relating EU's scientific capabilities in the realm of digital technologies with the Research and Innovation (R&I) activities conducted at firm level and with the performance of the industrial base. The possibility to investigate and explore the features of partnerships and collaborations between companies and research actors through EU programmes can contribute to a better understanding of their role in driving innovation across Europe. The geographical nuances of DGTES can also provide novel insights about how to measure the innovation divide across Member States (MSs) and European regions and to address internal cohesion.

— Detecting digital areas that are critical for EU's open strategic autonomy

DGTES allows for the exploitation of quantitative and qualitative indicators to gain knowledge through technology intelligence. Unlike standard statistical methodologies, DGTES can reveal hidden trends in data, anticipating strategic dependencies in key and critical digital technologies, and revealing patterns that draw attention to emerging vulnerabilities and potential bottlenecks. This information can provide relevant insights to design and assess policy initiatives aiming at strengthening EU digital leadership and sovereignty, such as the New Industrial Strategy and the European Chips Act[31]. Such an analysis would also allow to determine the extent to which individual MSs can rely on their own or intra-European resources as well as, on the other side, they remain dependant from other, extra-EU players.

The results of DGTES can contribute to the formulation of concrete policy instruments, such as a toolbox of interventions to mitigate EU strategic dependencies in key industries and critical digital subdomains. Table 6 suggests some examples of 'how DGTES could contribute' to informing, steering and improving EU policies related to digital transformation, technological sovereignty, and industrial leadership.

Figure 3 concludes by summarizing how the results of the analyses conducted using the DGTES approach can provide novel evidence-based insights to the debate on current EU policy priorities.

Table 6. How DGTES can contribute to policy-relevant issues

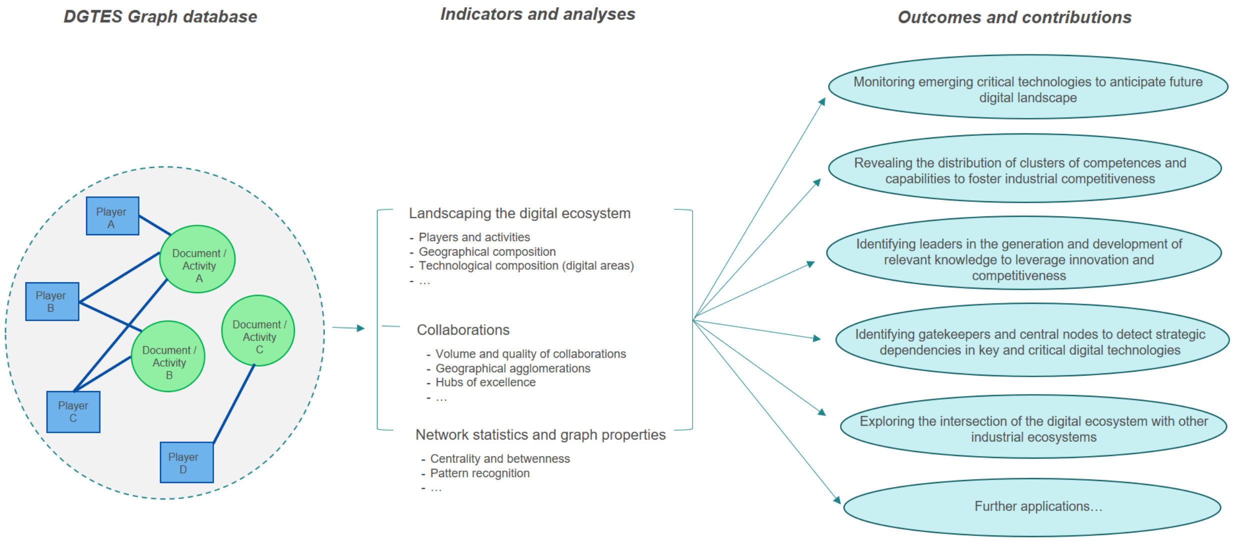
Policy-relevant issues	**DGTES potential contributions**
Industrial competitiveness	
What is the relationship between research, innovation and industrial performance in the digital ecosystem?	Reveal the interlace of industrial, innovation and research activities Describe industrial composition and capabilities of industrial players involved in the digital ecosystem
How do research and innovation outputs translate into industrial performance? In this respect, what is the situation of SMEs in the digital ecosystem?	Relate industrial player's performance with their characteristics and their level of involvement in the digital ecosystem Zooms on different dimensions and levels, with focus on SMEs
How do digital technologies influence other industrial ecosystems?	Identify activities and players that lay at the intersection of different industrial ecosystems
Emerging digital technologies	
Which are the technological boundaries of the digital ecosystem? Which are the most critical emerging technological subdomains in the digital ecosystem?	Describe the technological composition of the digital ecosystem by mapping the main digital subdomains identified by the digital areas (worldwide, EU, regional) Explore proximity and possible synergies across different digital subdomains (digital areas)
How is the technological frontier in digital technologies moving? Are there weak signals of	Identify weak signal of emerging digital subdomains digital (digital areas) that are pushing forward the digital

(31) See the Commission's communication 'A Chips Act for Europe' (COM(2022) 45 final).

emerging technological trajectories?	frontier
Digital leadership	
Where are the clusters of (research, technological, production/industrial) capabilities localized? How are these clusters of capabilities characterized?	Identify the stakeholders, players, and critical mass of capabilities by geographical area (worldwide, EU, regional) Describe and explore their features/properties
How is knowledge generated and shared in the digital ecosystem, within and across geographical areas? Which are the main players in the digital ecosystem in terms of knowledge generation and exchange? What is the position of the EU?	Analyse knowledge generation and exchange (as activities of research and innovation) across players and within (implicit and explicit) communities in the EU (worldwide, EU, regional) Describe and explore the features/properties of collaborative networks within the EU (in activities of research and innovation)
Digital sovereignty and strategic autonomy	
How does the EU participate in shaping and steering the evolution of digital technologies?	Identify the players shaping the evolution of digital subdomains (digital areas) in the digital ecosystem
Which actors have a strategic position and control the network in the digital ecosystem? What is the position of the EU?	Identify gatekeepers and central nodes in the ecosystem, to assess the presence of bottlenecks and potential vulnerabilities in terms of players involved (number and characteristics), types of knowledge, technological subdomains (digital areas)
In which digital areas is the EU stronger, more competitive? And in which digital areas is the EU weaker, less competitive? Where does the ecosystem present bottlenecks or vulnerabilities that could turn into strategic dependencies for the EU? How can we identify and monitor the technology gap at the root of strategic dependencies? In which has the EU more potential? (window of opportunity)	Measure the technology gap of the EU with respect to other global players

Source: Authors' elaboration, Digital Economy Unit, JRC.

Figure 3. DGTES for EU policy priorities



Source: Authors' elaboration, Digital Economy Unit, JRC.

References

COM(2019) 240 final, Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions (2019). *The European Green Deal.*

COM(2020) 67 final, Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions (2020). *Shaping Europe's digital future.*

COM(2020) 102 final, Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions (2020). *A New Industrial Strategy for Europe.*

COM(2020) 103 final, Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions (2020). *SME strategy for a sustainable and digital Europe.*

COM(2020) 456 final, Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions (2020). *Europe's moment: Repair and Prepare for the Next Generation.*

COM(2021) 118 final, Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions (2021). *2030 Digital Compass: the European way for the Digital Decade.*

COM(2021) 350 final, Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions (2021). *Updating the 2020 New Industrial Strategy: Building a stronger Single Market for Europe's recovery.*

COM(2021) 574 final, Decision of the European Parliament and of the Council establishing the 2030 Policy Program "Path to the Digital Decade".

COM(2022) 45 final, Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions (2022). *A Chips Act for Europe.*

COM(2022) 332 final, Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions (2022). *A New European Innovation Agenda.*

De Prato G., López Cobo., M., Samoili S., Righi R., Vázquez-Prada Baillet, M. and Cardona M., *The AI techno-economic segment analysis. Selected indicators*, EUR 29952 EN, Publications Office of the European Union, Luxembourg, 2019, ISBN 978-92-76-12584-6, doi:10.2760/576586, JRC118071.

De Prato G, Nepelski D. *Mapping the European ICT Poles of Excellence: The Atlas of ICT Activity in Europe*. EUR 26579. Luxembourg (Luxembourg): Publications Office of the European Union; 2013. JRC85353.

De Prato G, Nepelski D. *The Global R&D Network. A network analysis of international R&D centres*. EUR 25964. Luxembourg: European Commission; 2013. JRC79478

Etzkowitz, H., and Leydesdorff, L., *The Triple Helix -- University-Industry-Government Relations: A Laboratory for Knowledge Based Economic Development*. Rochester, 1995, NY. SSRN 2480085.

Etzkowitz, H. and Leydesdorff, L., *The dynamics of innovation: From national systems and "mode 2" to a triple helix of university–industry– government - relations*. Research Policy, 29(2), 2000, pp.109–123.

Lee, K. and Malerba, F., Catch-up cycles and changes in industrial leadership: Windows of opportunity and responses of firms and countries in the evolution of sectoral systems, *Research Policy*, Volume 46 (2), 2017, p. 338-351, ISSN 0048-7333, doi:10.1016/j.respol.2016.09.006.

Newman, M. E., *Complex systems: A survey,* 2011*,* arXiv preprint arXiv:1112.1440.

Pogorzelska, K., Righi, R., Cardona, M., Lopez Cobo, M., Ziemba, L., Vazquez-Prada Baillet, M., Samoili, S. and De Prato, G., *The techno-economic segment of Earth observation*, EUR 29946 EN, Publications office of the European Union, Luxembourg, 2019, ISBN 978-92-76-10384-4, doi:10.2760/538664, JRC118467.

Pugliese E., Tacchella A., *Economic Complexity Analytics: Country factsheets*, EUR 30711 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-37869-3, doi:10.2760/368138, JRC124939

Righi, R., Pineda León, C., Cardona, M., Soler Garrido, J., Papazoglou, M., Samoili, S. and Vázquez-Prada Baillet, M., *AI Watch Index*, López Cobo, M. and De Prato, G. editor(s), EUR 31039 EN, Publications Office of the European Union, Luxembourg, 2022, ISBN 978-92-76-51147-2, doi:10.2760/435020, JRC128744.

Righi, R., Lopez Cobo, M., Samoili, S., Cardona, M., Vazquez-Prada Baillet, M. and De Prato, G.*, EU in the global Artificial Intelligence landscape*, European Commission, 2021, JRC125613, URL: https://publications.jrc.ec.europa.eu/repository/handle/JRC125613.

Righi, R., Samoili, S., López Cobo, M., Vazquez-Prada Baillet, M., Cardona, M. and De Prato, G., The AI techno-economic complex System: Worldwide landscape, thematic subdomains and technological collaborations, *Telecommunications Policy*, Volume 44 (6), 2020, 101943, ISSN 0308-5961, doi:10.1016/j.telpol.2020.101943.

Samoili, S., Righi, R., Lopez-Cobo, M., Cardona, M. and De Prato, G. (2019), *Unveiling latent relations in the photonics techno-economic complex cystem.* In: Cagnoni, S., Mordonini, M., Pecori, R., Roli, A., Villani, M. (eds) Artificial Life and Evolutionary Computation. WIVACE 2018. Communications in Computer and Information Science, vol 900. Springer, Cham, 2019, doi:10.1007/978-3-030-21733-4_6.

List of abbreviations and definitions

AI	Artificial Intelligence
ATI	Advanced Technologies for Industry
BC	Betweenness centrality
EC	European Commission
EU	European Union
DESI	Digital Economy and Society Index
DGTES	Digital Techno-Economic ecoSystem
GDP	Gross Domestic Product
JRC	Joint Research Centre
IaaS	Infrastructure as a service
IDITES	Impact of Digital Transformation on the Economy and Society (project)
LDA	Latent Dirichlet Allocation
MS	Member State
NLP	Natural Language Processing
PaaS	Platform as a service
PPS	Purchasing Power Standards
PREDICT	Prospective Insights on ICT R&D (project)
RCA	Revealed comparative advantage
R&D	Research & Development
R&I	Research & Innovation
SaaS	Software as a service
SMEs	Small and medium enterprises
TES	Techno-Economic ecoSystem
WBC	Weighted betweenness centrality

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Annexes

Annex 1. Identification of digital areas

List of documents consulted for the initial identification of digital areas, by repository.

From JRC repository[32]

Digital Transformation in Transport, Construction, Energy, Government and Public Administration (https://publications.jrc.ec.europa.eu/repository/handle/JRC116179)
Global Value Chains and Innovation Networks in the Fourth Industrial Era (https://publications.jrc.ec.europa.eu/repository/handle/JRC124742)
Mobility Imaginaries: The Social & Ethical Issues of Connected and Automated Vehicles (https://publications.jrc.ec.europa.eu/repository/handle/JRC125412)

From DG GROW repository[33]

New technologies and digitisation: Opportunities and challenges for the social economy and social enterprises (EASME/COSME/2017/024), 06.10.2020 (https://c.europa.eu/growth/content/new-technologies-and-digitisation-opportunities-and-challenges-social-economy-and-social_en)
Definition of the digital building logbook – Report 1 of the study on the development of a European Union framework for buildings' digital logbook, 02.10.2020 (https://op.europa.eu/en/publication-detail/-/publication/cacf9ee6-06ba-11eb-a511-01aa75ed71a1/language-en)
Supporting digitalisation of the construction sector and SMEs. 31.10.2019 (https://ec.europa.eu/docsroom/documents/38281)

From DG CNECT – Horizon Europe Research and Innovation[34] repository

Shaping the digital (r)evolution in agriculture – EIP Agri (https://ec.europa.eu/eip/agriculture/sites/default/files/eip-agri_brochure_digital_revolution_2018_en_web.pdf)
EU auditors, not just lawmakers, recognise the potential of digital farming tools (https://www.euractiv.com/section/agriculture-food/news/eu-auditors-not-just-lawmakers-recognize-the-potential-of-digital-farming-tools/)
Digital Farming: Driving productivity and a more sustainable way of farming (https://www.euractiv.com/section/agriculture-food/video/digital-farming-driving-productivity-and-a-more-sustainable-way-of-farming/)
Internet of farms to reduce red tape and enable more transparency (https://www.euractiv.com/section/agriculture-food/news/internet-of-farms-to-reduce-red-tape-and-enable-more-transparency/)
Digitising European Industry (http://ec.europa.eu/newsroom/horizon2020/document.cfm?doc_id=40217)
The role of digital technologies in the EU agricultural research & innovation strategy (http://ec.europa.eu/newsroom/horizon2020/document.cfm?doc_id=40218)
DIGITIZING THE AGRI-FOOD SECTOR (http://ec.europa.eu/newsroom/horizon2020/document.cfm?doc_id=40220)
Research workshop on Digitising the Agri-food Sector: a research agenda for Horizon 2020 (http://ec.europa.eu/newsroom/horizon2020/document.cfm?doc_id=40233)
Flightpath 2050 Europe's Vision for Aviation (https://ec.europa.eu/transport/sites/default/files/modes/air/doc/flightpath2050.pdf)
EU project WATCH(es)-OVER people in transit (https://cordis.europa.eu/article/id/30895-eu-project-watchesover-people-in-transit)
Vision Inspired Driver Assistance Systems (https://cordis.europa.eu/project/id/690772)
COSAFE (Cooperative Connected Intelligent Vehicles for Safe and Efficient Road Transport) (https://cordis.europa.eu/project/id/824019/reporting)

[32] https://publications.jrc.ec.europa.eu/repository/handle/JRC126053

[33] https://ec.europa.eu/growth/publications_en

[34] https://ec.europa.eu/info/research-and-innovation/research-area_en

Digital technology improves safety at sea (https://ec.europa.eu/research-and-innovation/en/projects/success-stories/all/digital-technology-improves-safety-sea)
ZERO-EMISSION WATERBORNE TRANSPORT (https://www.waterborne.eu/images/documents/201021_SRIA_Zero_Emission_Waterborne_Transport_spread.pdf)
Rail 2030 – Research & Innovation Priorities (https://errac.org/wp-content/uploads/2019/09/errac_rail_2030_research_and_innovation_priorities.pdf)
Big data offers big gains for transport operators (https://ec.europa.eu/research-and-innovation/en/projects/success-stories/all/big-data-offers-big-gains-transport-operators)
European Project "SCORE" (https://cordis.europa.eu/project/id/784960/it)
European Project "FLORA ROBOTICA" (https://cordis.europa.eu/project/id/640959)
European Project "SubCULTron" (https://cordis.europa.eu/project/id/640967)
European project "COMPARE" (https://cordis.europa.eu/project/id/643476)
Knowledge Centre for Bioeconomy (https://knowledge4policy.ec.europa.eu/bioeconomy_en)
Deploying the bioeconomy in the EU (https://op.europa.eu/en/publication-detail/-/publication/2cf89630-e2bc-11eb-895a-01aa75ed71a1/)
European Project "BIGCLOUT" (https://cordis.europa.eu/project/id/723139)
European Proje ct "METAFLUIDICS" (https://cordis.europa.eu/project/id/685474)
European Project "COSY-BIO" (https://cordis.europa.eu/project/id/766840)
European Project "SYMBIOTIC" (https://cordis.europa.eu/project/id/637107)

From other repositories of the European Commission

Digital transformation scoreboard (2018) - EU businesses go digital: Opportunities, outcomes and uptake (https://op.europa.eu/en/publication-detail/-/publication/683fe365-408b-11e9-8d04-01aa75ed71a1)
The Digital Economy and Society Index (DESI) (https://ec.europa.eu/newsroom/dae/document.cfm?doc_id=67086)
2030 Digital Compass: the European way for the Digital Decade (https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX%3A52021DC0118)
Digital Europe Programme (https://digital-strategy.ec.europa.eu/en/activities/digital-programme)

From repositories of other organizations

OECD Report: a roadmap toward a common framework for measuring the digital economy (https://www.oecd.org/sti/roadmap-toward-a-common-framework-for-measuring-the-digital-economy.pdf)
ETSI Technology Radar (https://www.standict.eu/sites/default/files/2021-05/etsi_wp45_ETSI_technology_radar.pdf)
CEN/CENELEC Work Programme 2021 (https://www.cencenelec.eu/news-and-events/news/2021/publications/2021-01-25-cen-and-cenelec-work-programme-2021/?Sectors[]=6945)

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