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Vision and Societal Challenges Working Group
Business Validation, Models, and Ecosystems Sub-Group

5G ecosystems

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Executive summary

Europe is investing significant resources in research and technology development of 5G networks through the 5G Private Public Partnership (5G PPP). In addition to various scientific and technological topics, the effort focuses on societal and business challenges creating value with 5G networks. This white paper discusses 5G ecosystems as a prerequisite for value creation for and by the engaged stakeholders and return of investment as a potential award for the engagement.

A clear identification of 5G stakeholders supports the creation and evolution of the 5G ecosystems by characterising the potential role that each actor can assume. The identified stakeholder groups include 5G industry and research organisations, vertical sectors' firms, complementor firms, as well as organisations and associations of providers and consumers active in the value network representing the interests of a larger collection of firms and organisations. Those stakeholder groups include both small and medium enterprises (SME) and larger companies, and whenever relevant academic institutions. In addition, standards organisations, open-source organisation and policy makers are an inherent part of the 5G ecosystems, as are governmental agencies at regional, national and European level that support the creation of value in the 5G ecosystems though funding or procurement of innovations.

In general, an **ecosystem** is a complex network of interacting cross-industry actors who work together and are dependent on each other to define, build and deliver value creating customer solutions. The depth and breadth of potential collaborations among actors defines the ecosystem with each actor delivering a piece of the solution or a contribution to the strength of the ecosystem. The power of the ecosystem comes from the fact that no single actor needs to own or operate all components of a solution, with the value of the ecosystem being greater than the combined value of each actor. **A 5G ecosystem** can be decomposed into two main aspects: (a) the network service provisioning aspect, and (b) the vertical sector service consumption aspect. The separation of aspects simplifies the discussion at each level by hiding the complexities inherent in each of the aspects. The involved actors, once concluded that it is attractive to engage in the ecosystem, must iteratively refine their strategies of positioning their firms for overall value creation, taking into account growth of the ecosystem. Hence, the evolved strategies of the involved actors should leave room for growing the ecosystem by making it attractive for additional actors to get involved.

In the 5G provisioning ecosystem, the needed services are mapped to roles that are expected to deliver these services. This allows a mapping of the roles to the actors seeking to create value. The roles in the 5G provisioning ecosystems have been developed by the 5G PPP Working Group on architecture, and are based on the model, that has been proposed by 3GPP. The model includes all necessary providers, operators and suppliers needed to deliver 5G services to the customers. The 5G provisioning ecosystem can be seen as a multi-actor platform ecosystem, as opposed to the single actor platform ecosystems by Amazon, Google; etc. The challenges in evolving from 4G into 5G and beyond, and further developing such a multi-stakeholder ecosystem platform, requires both technical and business coordination, development and interoperability between the involved stakeholders.

Similarly, the 5G vertical ecosystems are composed of other actors that assume roles necessary to adopt 5G services provided by the 5G provisioning ecosystem. In the context of 5G vertical enterprise customers, a large number of actors can assume complementor roles and are often competency specific to the vertical sector they act in.

A number of open questions remain at the interaction point of the 5G provisioning and 5G vertical ecosystems. The evolution of roles raises fears in firms of becoming obsolete, lose control over value generation, or lose market shares in their sector. These tensions, along with the uncertainty about revenue sharing must be managed in a way that creates comfort and reduces fear. Even if questions about the actual cost of deployment and operation remain, certain vertical sectors, such as Industry 4.0 or automotive, are emerging as early adopters, and are actively engaging in shaping the future of their ecosystem. Other vertical sectors are more cautious concerning early adoption. An often-heard question is "What can I do with 5G that I cannot do with 4G for my business?" In addition, there seems to be a general concern about the level of trust that 5G can induce, often in conjunction with the sensitivity of corporate and private data.

In any case the 5G ecosystems must ensure an environment which allows rapid evaluation of service concepts, technologies, system solutions and even business models, at a level that minimises risks related to introduction of commercial services and products. In the longer term, and with the evolution towards 6G, the challenges for functioning 5G/6G ecosystems can be mastered by the engaged actors that identify and grasp the opportunities and align value creation with the European and global sustainable development goals.

This White Paper concludes by emphasizing success factors under the control of the industry which makes it easy to innovate in and attractive for firms to join the 5G ecosystem. Among factors that ease the ecosystem moving forward are technological **openness** in the form of, e.g., open SW, APIs, and HW. **Standards** will continue to play a vital role for beyond 5G and 6G technologies. Openness in the form of **interoperability** based on pan-European, cross-border, cross domain business agreements are equally important, e.g., roaming agreements. Generally, to enable innovation it is necessary to **decrease knowledge barriers** by actively sharing and building knowledge among those experts who will apply 5G and beyond technologies.

Factors that can move the 5G ecosystem forward by making it more attractive to join are for stakeholders to decrease uncertainty by **signalling the intent** of building the market together with others and sharing roles and revenues. In an ecosystem, **self-regulation and sanctions** will play a role to balance the relationships between parties. To **implement use cases as show cases,** serve both to build and share knowledge in a quick way, as well as to demonstrate the parties' intent. Finally, adequate **regulation** is key to avoid unfortunate monopolies and potential hurdles to innovation and would also contribute to a stable environment and decrease uncertainty.

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Abbreviations

3GPP	3rd Generation Partnership Project
5G ACIA	5G Alliance for Connected Industries and Automation
5G IA	5G Infrastructure Association
5G PPP	5G Public Private Partnership
5GC	5G Core (network)
5GS	5G System
AI	Artificial Intelligence
AP	Application Provider
API	Application Programming Interface
B5G	Beyond 5G
BPL	Business Process Leader
BSS	Business Support System
BVME	Business Validation, Models, and Ecosystems (sub-group of the Vision and Societal Challenges Working Group)
CAM	Connected and Automated Mobility
CAPEX	Capital Expenditure
CDN	Content Delivery Network
CEF	Connecting Europe Facility
COTS	Commercially Off The Shelf
CSP	Communication Service Provider
DCSP	Data Centre Service Provider
DLT	Distributed Ledger Technology
DOI	Digital Object Identifier
DSP	Digital Service Provider
E2E	End to end

EC	European Commission
EDPB	European Data Protection Board
EN	European Norm
EPI	European Processor Initiative
ETP	European Technology Platform
ETSI	European Telecommunication Standards Institute
EU	European Union
FRMCS	Future Railway Mobile Communications System
GDP	Gross Domestic Product
GDPR	General Data Protection Regulation
GSM	Global System for Mobile Communications
GSMA	GSM Association
HEU	Horizon Europe
HW	Hardware
ICT	Information and Communication Technologies
IEEE	Institute of Electrical and Electronics Engineers
IMT	International Mobile Telecommunications
IoT	Internet of Things
IPR	Intellectual Property Rights
ISP	Internet Service Provider
IT	Information Technology
ITS	Intelligent Transport System
ITU	International Telecommunications Union
KPI	Key Performance Indicator
LTE	Long Term Evolution (mobile networks, i.e., 4G)
M2M	Machine-to-Machine

MCS	Mission Critical Services
MEC	Multi-Access Edge Computing
mIoT	massive Internet of Things
mMTC	massive Machine Type Communication
MNO	Mobile Network Operator
NGO	Non-Governmental Organisation
NO	Network Operator
NR	New Radio (5G)
NS	Network Slice
NSA	Non-Stand Alone (5G mode of operation)
NSaaS	Network Slice as a Service
OPEX	Operational Expenditure
OS	Open Source
OSS	Operation Support System
OT	Operation Technologies
PPA	Power Purchase Agreement
RAN	Radio Access Network
SA	Stand Alone (5G mode of operation)
SDG	Sustainable Development Goal
SDK	Software Development Kit
SDN	Software Defined Network
SG	Sub-Group
SLA	Service Level Agreements
SME	Small and Medium Enterprises
SNS	Smart Networks and Services
SP	Service Provider

SW	Software
TCO	Total Cost of Ownership
URLLC	Ultra-Reliable Low Latency Communication
VISP	Virtualisation Infrastructure Service Providers
VM	Virtual Machine
VNF	Virtual Network Function
VPC	Value Proposition Canvas

1 Introduction

The fifth generation (5G) of cellular communications is being successfully deployed worldwide at a fast pace. Instrumental to that success has been the joint efforts of several geographical-focused-with-worldwide-reach initiatives that, before the standardization work started, helped in creating an agreed-upon consensus of what 5G should be (e.g., which capabilities it should offer and which Key Performance Indicators (KPI) it should deliver). The EU established early in the previous decade a set of successful such initiatives, like the European Technology Platform Networld2020 [1] (which was transformed into NetworldEurope [2]) and the 5G Private Public Partnership (5G PPP) [3]. The private part of the latter, called the 5G Infrastructure Association (5G IA) [4], clustering the collective intelligence of academia, industry, research centres, and Small and Medium Enterprises (SME), has been very active in establishing focused work groups and in creating White Papers, workshops and other initiatives aiming at facilitating the convergence of telecommunications and verticals, so as to create a Europe-wide 5G ecosystem.

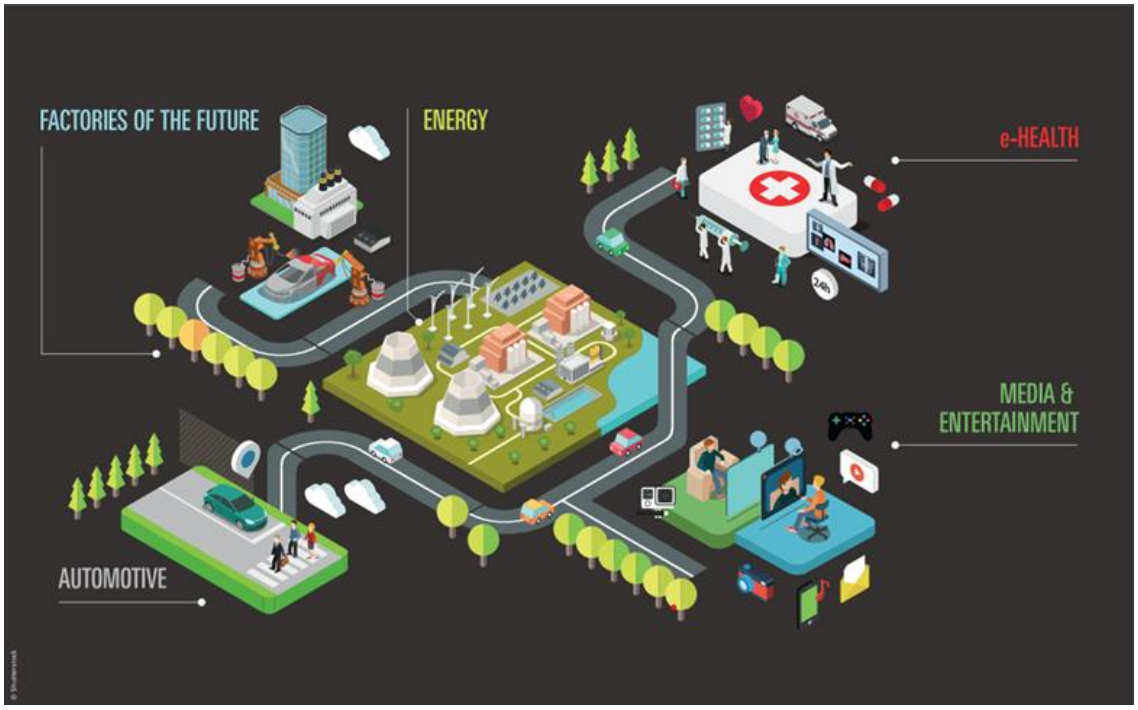

Figure 1 - Examples of 5G empowered verticals (adapted after [5])

Following the end of Horizon 2020 (the European Framework for Research and Innovation) in December 2020, and the start of the new Horizon Europe (HEU) program [6], spanning 2021-2027, 5G IA has started working, among others, on Beyond 5G (B5G) and 6G system definition, on the full digitization of the verticals via digital twins, and on enhancing and supporting the further evolution of the 5G ecosystem during the current decade.

The 3rd Generation Partnership Project (3GPP) has split the definition of 5G features in two phases: Phase 1 covered by 3GPP Rel. 15, and Phase 2 covered by 3GPP Rel. 16. 3GPP Rel. 17, once completed, will propose further 5G system enhancements. For the sake of defining a boundary between a 5G system enhancement and a B5G system we regard future 3GPP releases as those defining B5G and 6G systems, i.e. Rel.18 and beyond.

One of the key objectives of the 5G IA is to facilitate the convergence of telecommunications and verticals, so as to create a Europe-wide ecosystem. Why is the concept of *ecosystem* so important and at the centre of the ongoing further evolution of 5G with different verticals sectors moving towards 6G? This whitepaper addresses, among others, this question by defining the term ecosystem, explaining how we may understand 5G as an ecosystem. We elaborate on emerging examples of 5G ecosystems as well as on enabling and blocking forces.

Why do we discuss 5G ecosystems? Many stakeholders in the 5G market have observed the rapid growth in capital value of Internet scale businesses. In particular, the fascination has centred around global success stories such as Google, Facebook, and Amazon Web Services. These firms have new approaches to manage technological interfaces and partners' collaboration for innovation and market growth. What they are doing, falls into the concept of ecosystems. While technology and digitalization seem to enable the emergence of ecosystems, the ecosystem concept is foremost a way to understand the business dynamics in a market. Thus, to manage complex and systemic technologies as 5G, [7] it seems wise to have a closer look at ecosystems.

What is an ecosystem? In simple terms, *"an ecosystem encompasses a set of actors that contribute to the focal offer's user value proposition"[8]*; however, in an ecosystem a single firm, even if it plays the role of core actor or "keystone" [9], cannot decide *"the integration of upstream input into the focal offer"* and must instead mobilize other complementing firms to decide to join the value creation [8] [11]. All the other firms in the ecosystem ask a) if they should join; b) which pieces of a solution to provide, and; c) the profits from doing so [11]. The main motivation for why profit-seeking firms find the ecosystem concept beneficial, is that the growth of the whole market depends on the roles taken by other firms. Usually, a single firm hunts for a smaller market share in a big market, rather than a large share of a smaller one. **Thus, in emerging 5G ecosystems, driving firms' strategies must focus on how to mobilize other contributors to take part in value creation.**

In contrast to the ecosystem, the well-known value chain concept is originally used for a chain of internal activities carried out within a firm to produce a product [8] [10]. It is, however, frequently applied for the chain of activities between firms in a supply chain. When used across many firms, the value chain concept continues to regard relationships as linear and imply that a focal firm has more control over e.g., suppliers.

How to define *5G* ecosystems? This White Paper provides definitions and early examples of 5G ecosystems. We aim at equipping 5G stakeholders in telecommunication and vertical industry sectors with better understanding of ecosystem dynamics, the processes that take an ecosystem from birth to maturity, and the kind of strategies that are necessary to kick off its evolution (e.g., [12]). Not the least, we want to emphasize that an ecosystem does not evolve and reach volume without potential tensions between stakeholders, which call for the need of balancing strategies and interests, hurdles mitigation and consensus creation. This white paper elaborates on the 5G ecosystem from two perspectives: the provisioning 5G ecosystem, and the 5G vertical ecosystem.

When are ecosystem strategies appropriate? While an ***ecosystem*** is the *preferred* market configurations by some, the strategic actions and hurdles make it more *probable* [13] that eventually other market configurations, such as the ***value chain,*** will prevail. For some innovations, ecosystem-based strategies might indeed not be so relevant or challenging enough. When that occurs, a better choice is to adopt value-chain-based strategies, due to the fact that they allow a better control on the available resources so to better adhere to security or service requirements. A value chain strategy may also be a better choice in early phases where the only way to mobilize necessary firms, technologies and resources is to have direct control on them. In

this case, ecosystem strategies can become a suitable choice in later phases; e.g., Amazon Web Services evolved from Amazon's management of internal servers. Furthermore, to build ecosystems and to earn a profitable position is risky for all actors. Thus, when firms conclude that they depend on others to take on roles in an ecosystem, they have probably already failed to kick off market growth by applying value chain approaches.

The contributors of this White Paper are a mixed-skills set of people, some coming from ongoing EU-funded research projects, others are members of the 5G IA sub-work group *Business Validation, Models and Ecosystems (BVME)*. They are experts from the telecommunication and vertical industry sectors, who are currently exploring 5G market opportunities and business models. Insight and examples are drawn from some ongoing projects' experiences in an attempt to share some lessons learned, define best practices and recommendations, and enable more informed decisions when dealing with the 5G market and its evolution towards 6G.

The remainder of the White Paper is structured as follows: Section 2 introduces the ecosystem concept to frame our analyses of 5G market configurations. Section 3 explains how and why we distinguish between two 5G ecosystems: provisioning and verticals. Section 4 elaborates on examples of ecosystems that we currently find in the 5G provisioning domain, while 5G ecosystems emerging from use cases and verticals are presented in Section 5. Section 6 discusses evolving ecosystems and belonging challenges. Section 7 finally provides conclusions.

2 The ecosystem concept explained

Ecosystem strategies are relevant when firms alone are not capable of building enough market growth and size. Firms find they are interdependent on other firms to take a role in creating value and providing solutions to users and customers, and thus, are better off if they organize as an ecosystem. The embracement of interdependencies between firms and technologies position the ecosystem approach as systemic. The customer relationship, and the total design and implementation of the product, service, or solution, is not controlled by one actor in a value chain, or allocated between autonomous and independent firms in the market only by pricing ([8] – [12]) (see also definitions in Section 1).

When there is interdependency, to build a large market, other firms must be mobilized to innovate and invest by making it easy and attractive to join the accompanying ecosystem. Technological hurdles make it difficult and high perceived risks make it less attractive to join, Thus, they serve as obstacles to the growth of a market and an emergence of an ecosystem ([14] – [17].

5G promises to empower digitalization of many verticals, and for the sake of making it a success for all its stakeholders, applying ecosystem thinking can be a very powerful means. A communications service provider can supply a 5G service which co-exists with Information Technology / Operation Technologies (IT/OT) consultancy, system integration, software, and hosting in the markets for information and communication, and operation technologies (ICT, OT). When entering the industry verticals' domain, providers of 5G services could compete or collaborate with domain specific IT/OT providers. The collaboration-based approach is the ecosystem approach.

The most important objective when applying ecosystem strategies from a commercial point of view is to participate in the ecosystem and help create large markets together with other parties. However, large markets with critical and sustainable mass **evolved** from small ones [12]. In early phases of market growth there will be fewer firms (i.e., the core mass of the market) sharing the revenues. In later phases one would expect a high volume of firms (i.e., the sphere of contributing partners) which empower the market offer and share the total revenues. In ecosystems, there are strong network effects driving the growth (also called feedbacks and reinforcing effects). Ambitious and profit-seeking firms can take a deliberate choice to actively drive an ecosystem in a direction that is more beneficial for them, and to try to capture a more central role. When discussing ecosystem strategies, the perspective is usually from a focal firm. 5G providers have taken this perspective and see themselves as drivers of the 5G empowered ecosystem.

The more a firm has reached the conclusion that it is dependent on other partners to grow the demand for its own services, the more ecosystem strategies become relevant. **The objective of the ecosystem strategies is to enable and engage many other partners to take a role and build the market together**. Ecosystem strategies can be clustered into two main categories: easy-to-join, and attractiveness. The former concerns removing hurdles for developing and implementing technologies, by, e.g., available information, interfaces, guidelines, and support.

The latter concerns reducing perceived investment risks and increasing expectations to getting a share of revenues. A main obstacle to the ecosystem evolution is that all actors that do not drive the ecosystem growth are uncertain about the agenda of the firm(s) driving the ecosystem growth. In the 5G network context, the scepticism is directed towards mobile operators; in the computing part of 5G, there is scepticism towards the hyperscalers such as Microsoft Azure and Amazon Web Services (e.g., [18]).

There are situations where ecosystems strategies are not relevant and challenging. For some innovations, a value chain is the better choice because it is possible to control all resources in order to adhere to security or service requirements. A value chain strategy may also be a better choice in early phases of market growth where the only way to mobilize necessary firms, technologies and resources is to have direct control over them. In this case, ecosystem strategies can become a later choice. Furthermore, to build a common ecosystem and to earn a profitable position in it is risky for all actors.

In the next sub-sections, we elaborate how to recognize an emergent or existing ecosystem. First, we address structural aspects in early and late phases. Next, we elaborate on ecosystem strategies, and suggest that an actual implementation of ecosystem strategies would be an indicator of the existence of the ecosystem itself.

2.1 The structure and evolution of an ecosystem

A market which can be currently described as an ecosystem was at one point in time very small and immature. Nascent and mature ecosystems will have different characteristics regarding their size and structure [12], as described in Table 1. These structural characteristics are not enough to tell whether a specific market already is or could become an ecosystem. In order to further recognize a market as a potential ecosystem, we must first clarify how dependent actors are on others to drive market growth. Next, we must clarify if and how typical ecosystem strategies are used to achieve this growth. In the next sections, we discuss the strategies that are used in ecosystems to reach to build large markets.

Table 1 Ecosystem structural characteristics in different phases

Ecosystem phase	Nascent	Mature
Size (revenues)	Small	Large
Actors	Few	Many
Roles	Needed roles start to emerge	Roles settled
One central role	Not emerged or settled	Platform role A few central roles
Relationships	Sparsely connected network	Well-connected network
Perception of future	Uncertain	Settled

A systemic market like the ecosystem will be subject to many network effects (or feedbacks and reinforcing effects) affecting the dynamics between firms and technologies. Thus, the exact path of the ecosystem evolution from nascent to mature is uncertain. Network effects in systemic markets come from technological interfaces, learning effects, and increasing returns. Thus, such dynamics lead to markets with strong network externalities; when one technology (technology infrastructure solution/platform) or actor gets traction, it may evolve into a central and dominant position in the ecosystem. That is, we have “winner takes all” characteristics, and one central platform could emerge. Profit seeking and ambitious actors – large and small – find this position

attractive, however, this ambition could be counter-productive and creates an additional challenge in a context where it is necessary to mobilize others to invest and engage.

There is a lot of ongoing research about business ecosystem characteristics and ways of governing them in order to mobilize other firms (e.g., [14]). In short:

- **Make it easy:** enable easy recombination of technological components, e.g., by means of application programming interfaces (API) and belonging means for making recombination easy
- **Make it attractive:** mobilize other parties to take on a role in an ecosystem

2.2 Ecosystem relationships and strategies

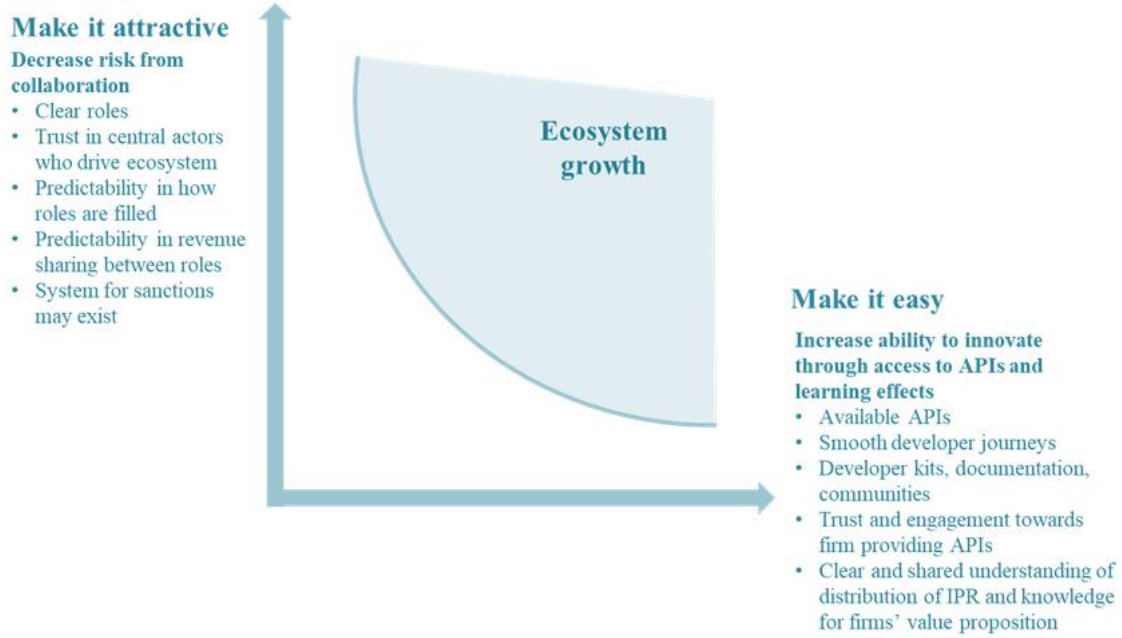

Figure 2 - Combination of ecosystem strategies for growth

2.2.1 Make it easy to access the ecosystem

Accessible and open interfaces (APIs, technological standards e.g., ETSI [19], and open-source software) between technological components is a necessary, however not sufficient prerequisite, to govern technologies in an ecosystem so that the market grows. Accessible and open means that interfaces are not only publicly available, but to make the process of accessing them easy for all members of the ecosystem. For instance, firms who co-create in the ecosystem should be invited into a smooth developer journey, have access to SW developer kits, documentation, developer communities, and hackathons. Reliable and solid technological enablement contributes to trust and engagement among stakeholders in an ecosystem. The APIs, technological standards, or open-source SW are important self-reinforcing factors in an ecosystem. Firstly, their easiness and wide distribution not only facilitate innovation by enabling recombination, but also serve as a push for using them. Secondly, when large user groups become familiar with a specific interface and can learn from each other, the threshold for choosing a different interface gets higher.

It should be noted that there is a tension between making technology easily available in order to grow the market and restricting access to a technology (i.e., to protect intellectual property rights (IPR)) in order to profit. The ecosystem approach recognizes that firms need to extract profits through IPR or knowledge, however, this must not stand in the way for the spread and use of technologies [15].

In summary, in a well-functioning ecosystem we would typically observe:

- Accessible APIs
- Smooth developer journeys
- Developer kits, documentation, communities
- Trust and engagement towards firms providing APIs
- Clear and shared understanding of distribution of IPR and knowledge as basis for firms' value proposition.

2.2.2 Make it attractive to join the ecosystem

Increasing the attractiveness to join an ecosystem is a necessary condition to build a large and growing ecosystem. Parties that are free-riding or a party that eventually tries to capture all revenues are perceived as risks. Markets' ability to develop into stable ecosystems despite such risks are described in collective action theories [16]. Such theories provide empirically based insight in how markets have handled the risk of contributing to building and maintaining a market (provisioning), when being uncertain about getting a fair share of it (appropriation) [17]. To make an ecosystem attractive implies to mitigate all such risks and convince other parties to innovate and invest in it.

A prerequisite for building an ecosystem is that the driving firms acknowledge their dependency on other firms to take on ecosystem roles to achieve growth. Then, a situation where parties trust each other must be established; to mobilize actors to create value in the ecosystem, their perceived risk of joining must be addressed. Clear roles for both driving firms and complementors in the future market must be indicated and formed through the identification of potential niches. Mutual benefit and profit are of paramount importance. Towards this direction, predictability in sharing of roles and revenues is important, and parties must over time demonstrate their willingness to leave parts of the market revenues to others. An actor can leverage on existing legitimacy as a key player in driving the ecosystem or must take the time and resources to earn other parties' trust. In markets with possible opportunism and free-riding, the ability to sanction is an accepted part of the governing mechanism. Moreover, to make it easy to innovate, to share APIs and knowledge, and enable experimentation both in technical and regulatory regime (through regulatory sandboxes) is also a way to signal willingness to take joint risk and create value together over time as well as to ensure symbiosis of competing entities. To attract and mobilize parties to build and run an ecosystem jointly is an act of balancing in the ecosystem [14] [17].

In summary, in a well-functioning ecosystem we would typically observe:

- Clear roles
- Trust in central actors who drives ecosystem
- Predictability in how roles are filled
- Predictability revenue sharing between roles
- System for sanctions may exist

3 5G stakeholders and ecosystems in focus

In Section 1 and 2 we discussed the ecosystem concept as a way to understand a 5G ecosystem. Section 3 has two main purposes. First, we open our perspective and reflect shortly on how 5G ecosystems are part of a larger societal and economic system. Second, we suggest a narrower definition of a 5G business ecosystem to carry out the analyses of the concept.

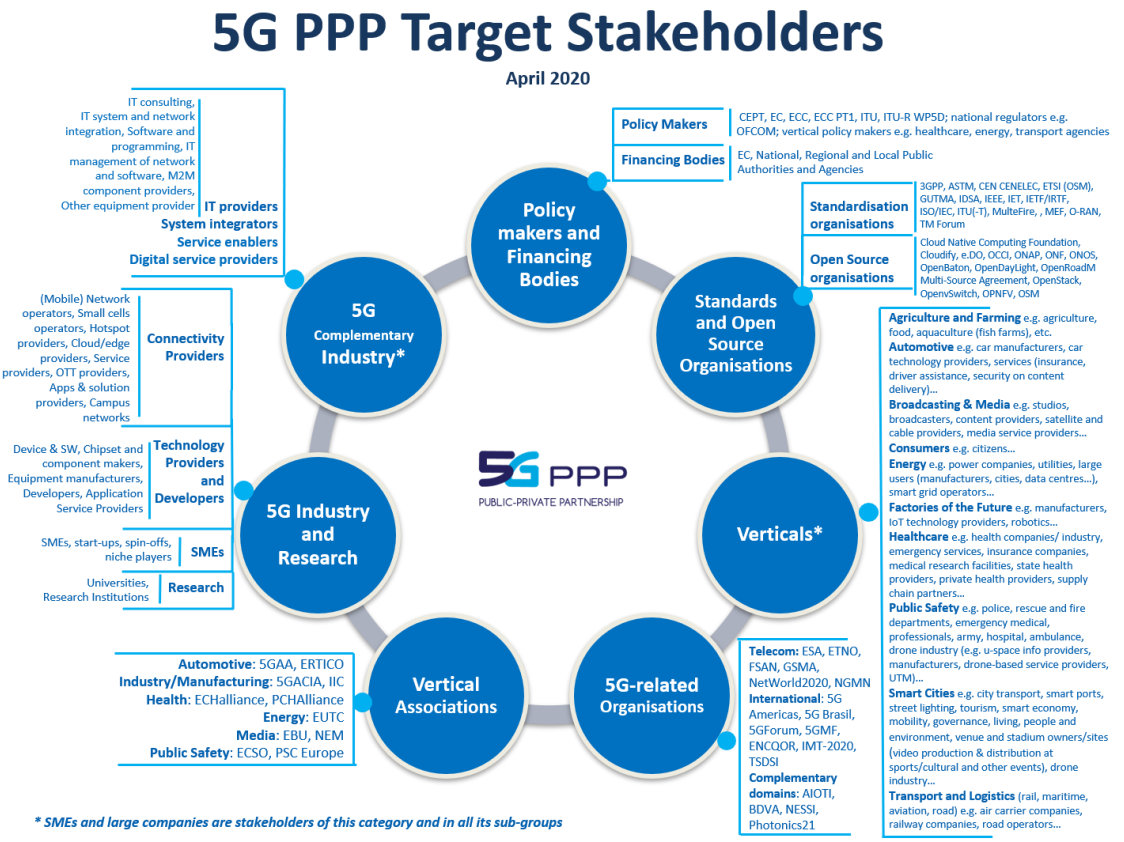

Figure 3 - 5G Stakeholders, from a 5G PPP [20]

As 5G evolves towards B5G, 5G IA work groups continuously identify new parties holding stakes in its evolution. The latest version of the document [20], summarizing 5G stakeholders identified, was released in April 2020 on the 5G PPP web site. Thus, Figure 3 illustrates all those roles and actors that hold stakes in the 5G markets, forming different clusters who would be active in 5G ecosystems. First, the stakeholders from the traditional 5G industry are those who provide connectivity solutions, equipment, SW, and research institutions. Second, policy makers and standard setting organizations have defined 5G as we know of it as of today. Third, tor the telecom community, it is a new approach to include parties whose interests and development also seem to depend on 5G evolution. Thus, the stakeholders form the IT industry that complements telecom has been emphasized in the 5G context. Fourth, verticals, such as the manufacturing and health industries, are important stakeholders. Finally, stakeholders are large and small sized entities, and it is recognized that especially SMEs will play an important role as innovators and risk-takers in 5G-evolution (Appendix 2).

3.1 Layers of 5G ecosystems

With the 5G stakeholders as a backdrop, we suggest that in real markets we cannot easily distinguish one 5G ecosystem. Instead, we will find several ecosystems in which stakeholders and technologies co-exist and co-evolve together. From the perspective of one focal technology, market, or user, there will be layers of influential stakeholders and governing mechanisms. In this context, analyses and discussions are dependent on both the holder of the analytic perspective and from which point of view the analysis is carried out. With this in mind, in Figure 4 we reuse the 5G PPP Figure 1 from Section 1 on how 5G empowers vertical industries [21] and suggest that analyses of the 5G ecosystem can be carried out in three layers of. First, the figure reflects how the 5G community sees itself in a central position, as providers of 5G technologies and services; this we will later refer to as the 5G provisioning ecosystem. Second, the vertical industries, such as health and manufacturing, profit from 5G services when improving current scenarios and enabling new disruptive ones; this we will later elaborate upon as 5G vertical ecosystems. Third, in addition to this, we add a layer of business environment which could either be seen as an integral part of the 5G ecosystem, or as external to it. The business environment will affect 5G provisioning and use through organizations such as research and education, governance, standardization, and finance. Indeed, these will establish compliance rules and governance policies, according to standards and regulations, for properly managing the whole 5G ecosystems from the provisioning of technology and services to their deployment and exploitation, moving toward a sustainable innovation as well. We do not further analyse the business environment in this White Paper.

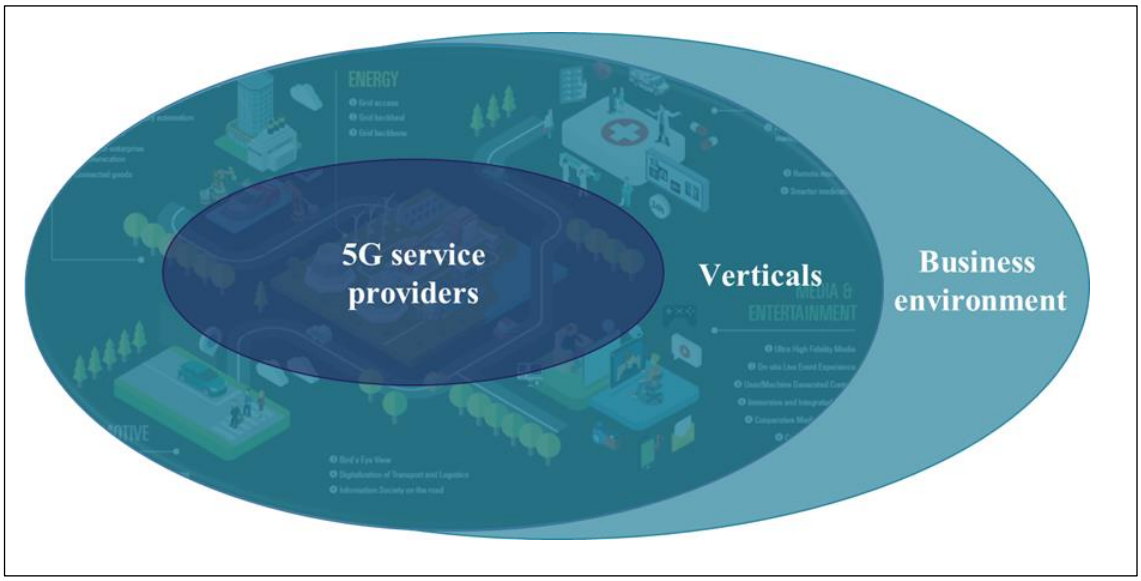

Figure 4 - Layers for analysing 5G ecosystems

3.2 Two 5G ecosystems for further analyses

The identification of all 5G stakeholders is important. However, to better analyse 5G ecosystems, the BVME team suggests to proceed with the analysis using two different points of view: the 5G provisioning ecosystem and the 5G vertical ecosystem, as depicted in Figure 5.

The distinction between these ecosystems serves two purposes. First, by reducing the total complexity focusing on a specific sub-part of the 5G ecosystem, it is possible to be more concrete when analysing and describing and assessing structure, relationships, and dynamics. Second, the distinction enables a discussion on how the different ecosystems are related regarding mutual dependency and potential competition. For instance, we capture how system integrators bridge the two ecosystems, having deep insight into the deployment of network slice instances in digital solutions, as well as connectivity requirements emerging from vertical enterprises and vertical application providers. System integrators who origin in the verticals' world operate private networks (e.g., large venue owners, engineering companies or transport operators) and may cross over to compete in the 5G provisioning ecosystem. The distinction also enables an analysis of whether and if a value chain approach after more appropriate than an ecosystem approach for the provisioning of 5G.

The 5G **provisioning ecosystem** encompasses those roles and actors who take part in developing, delivering, and providing 5G services (represented in the bottom left part of Figure 5). Traditionally, the telecom industry is seen as a value chain where network operators source the resources necessary to provide fixed and mobile telecommunication services. The notion of a 5G provisioning ecosystem acknowledges an increased dependency on other roles and actors to grow the 5G market. In the provisioning 5G ecosystem, roles and actors from verticals are black boxed (as illustrated in the top left part of Figure 5. The 5G provisioning ecosystem will be further elaborated upon in Section 4.

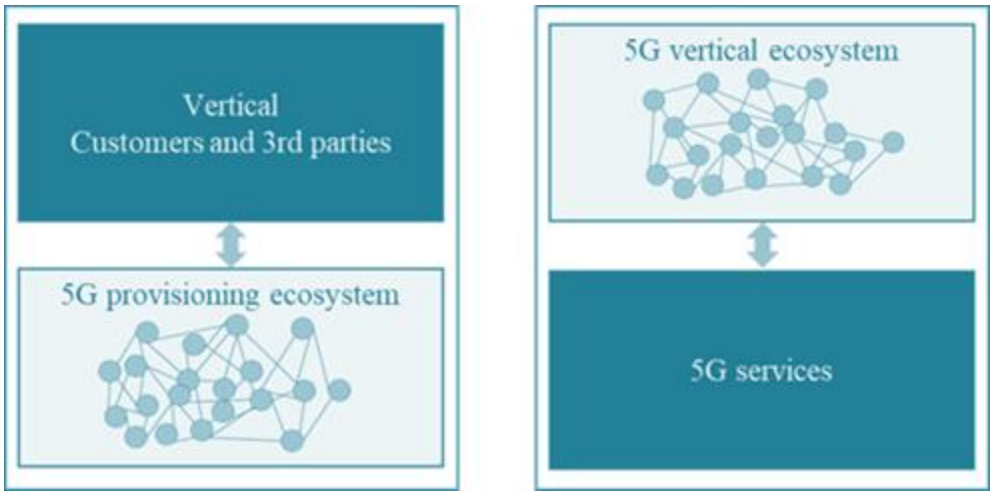

Figure 5 - Hiding and showing complexity in two 5G ecosystem points of view

The **5G vertical ecosystem** black boxes the 5G provisioning ecosystem and focuses on other actors who work closely together as part of vertical industries (see top part of Figure 5). While roles and actors from the telecommunication sector are still present in this ecosystem, the emphasis is on yet other roles which apply 5G services in their value creation and can be domain specific. Section 5further details the 5G vertical ecosystem. The split between these two ecosystems as an analytic approach is also successfully being applied in the market for electronic components, and is described in Appendix 4.

4 Development and Deployment of 5G provisioning ecosystem

The introduction of 4G was based on the business model of the network operators and was mainly driven by the need to enable a much higher capacity for data transfer over the mobile network. 4G also solved a number of scalability issues in the core network that resulted from the way data connection sessions were established. From the customer point of view 4G was just a faster network compared to 3G.

The introduction of 5G has been different because 5G represents a change of how the customers were involved in the definition of requirements and service capabilities. It represents a mind shift for the incumbent operators who have to align their own strategic plans for the evolution of their networks and services portfolio with customer expectations. This situation even being quite fruitful for the identification of needs and creation of opportunities for new entrants, is expected to create changes in the positioning of the existing actors in the 5G business environment as well as uncertainties about the investment and operational cost. These changes are observed by other existing and new actors in the ecosystem, who try to exploit the opportunities.

In general terms, it can be stated that, due to the relatively recent introduction of 5G, a full-fledged 5G market is not yet available. As a consequence, in this White Paper we can only make observations on a dynamically ramping up new market and elaborate some educated forecast. In fact, given that 5G technology and its commercial adoption are at their infancy, the development stages of the 5G business environment is still too much fluid and therefore cannot be easily determined. However, given the starting point of the telecommunication market and the targeted 5G business processes and roles, we can make observations related to the various pathways to be followed and the various business formulations to appear on top of future, fully fledged 5G deployments.

Current ICT business environment is well modelled in form of value chains for the provisioning of IT services determined by SW houses, and for the provisioning of network services by Internet Service Providers (ISPs) and Telecom operators. Latter stakeholders' activities focus on managing the complete value chains from deployment of vendors' equipment to providing a single customer interface to a large base of end-users and subscribers. These models along with the stakeholders' interests, visions and strategies have been comprehensively described in bibliography (e.g., [30] – [32]). From this point forward, the technology principles, the capabilities and the business potentials of 5G enable or -even necessitate- stronger involvement of a larger set of existing stakeholders and other parties as actors with new key roles in the provisioning of 5G services, thus driving the transformation of value chains into ecosystems.

This section touches on several key points of the 5G ecosystem: it provides an overview of the prerequisites of a 5G provisioning ecosystem; addresses why a 5G ecosystem can be functional and effective including the enablers, triggers and conditions underpinning the development of main and complementary 5G provisioning ecosystems; and finally identifies key challenges underlying these developments. Starting from the initial stages of 5G provisioning systems as continuation of the long-established Telecom Value Chains (indicatively as described in [30] – [33]), the driving forces leading to the opening of the 5G provisioning business to other parties and to the development of 5G provisioning ecosystems are presented. The potential formations of 5G provisioning ecosystems and their underlying business dynamics e.g., interests and roles of

potential stakeholders, cooperative and competitive interactions, are discussed. Finally, the main challenges in developing and deploying the 5G provisioning ecosystem are identified.

4.1 Overview of 5G Provisioning Roles

In general terms, 5G principles shift the Telecom industry from an equipment-based to platform-based foundation [28]; from silo network deployments (operated by a single party) to multi-domain, multi-tenant deployments with variously structured, multi-layer management and orchestration capabilities potentially operated by different parties (as collectively -non exhaustively- reported in [22]); from closed networks to open systems making network capabilities, such as data and network services, easily available for customers and partners ecosystems to innovate on, through network exposure, or service exposure within the network domain [29]. In other terms, 5G principles pave the way towards a dynamic, flexible way of "as a Service" provisioning of services and resources with more diversification in terms of types of services and performance. This shift is reflected in early (i.e., prior to commercial deployment) architectural approaches of fully fledged 5G networks, as well as in the early identification of process flows and business activities that are expected to appear in fully developed 5G provisioning systems. These activities as concrete roles are described briefly in the following.

In general, the 5G network architecture principles imply the introduction of new processes, activities and operations thus defining new roles. Listings of the technical processes, activities and the corresponding roles have been provided in a number of publications ([23] [24] [25] [26]). On this basis, the 5G PPP Architecture WG [22] has provided a representation of the processes and activities related to the 5G service provisioning, which have been grouped in coherent roles along with the relationships and interfacing options between them, as shown in Figure 6. These roles can be shared between one or more stakeholders of Figure 3, which will assume the management of relevant interfaces at business and technical level (an overview of which is provided in [22]).

A principal role in 5G provisioning is that of the Service Provider (SP), depicted as (1) in Figure 6, which directly interfaces the Service Customers and obtains and orchestrates resources from Network Operators (NO) (2), Virtualisation Infrastructure Service Providers (VISP) (3) and Data Centre Service Providers (DCSP) (4) (collectively referred to as Infrastructure Providers). The role of the SP comprises the roles of Communication Service Provider (CSP) (5), entailing the activities for offering traditional Telecom services, Digital Service Provider (DSP) (6), entailing the activities for offering digital services such as enhanced mobile broadband and IoT to various vertical industries, and Network Slice as a Service (NSaaS) Provider (7), entailing the activities for offering a network slice along with the services that it may support and configure [33].

These roles include, among others, the business communication and business services provisioning activities towards their interfacing roles, and are technically related to BSS/OSS systems interfacing the virtual or actual infrastructure resources, operated and maintained by the actor performing the Network Operator role. The Network Operator role is now shifting towards operating a programmable network infrastructure, spanning from the radio and/or fixed access to the edge, transport and core network, and is extended to include the operation of virtual resources leased by other Infrastructure Providers through appropriate APIs. To this end, a clearly distinct new role that needs to be filled in 5G provisioning is that of VISP (3), which offers virtualised network or cloud/edge computing resources available through APIs, and DCSP (4) which offers

raw computing resources. In the IT world, these roles correspond to cloud and data centre providers, respectively.

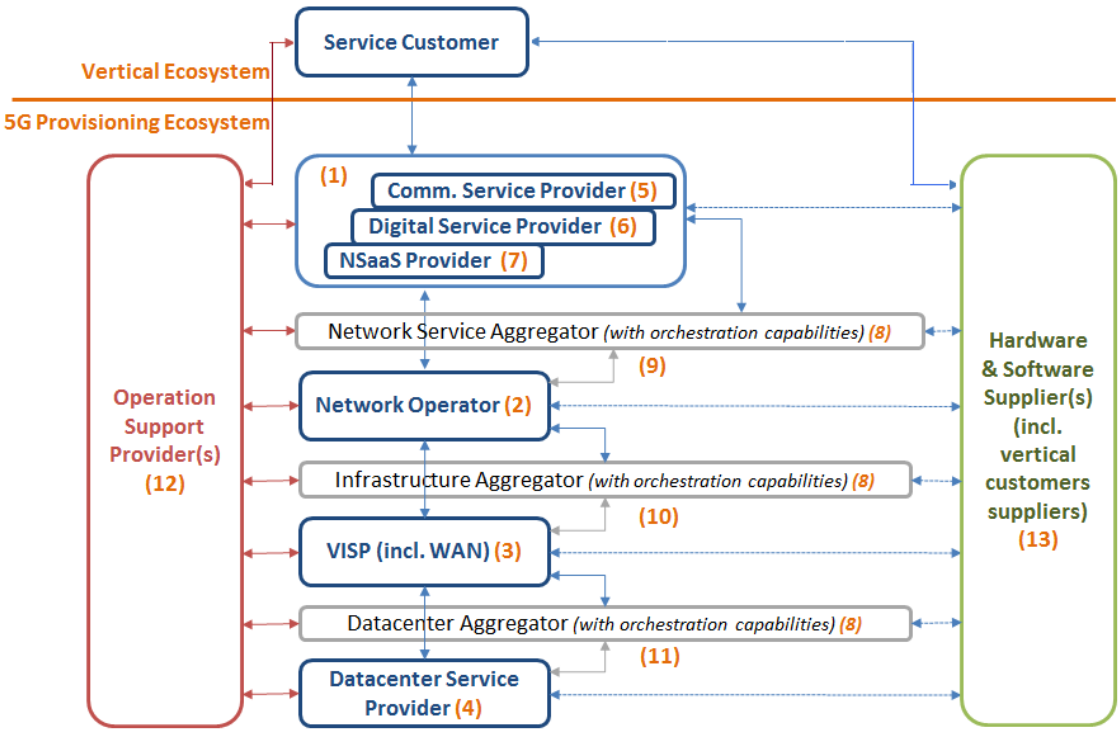

Figure 6 Roles in 5G provisioning systems (5GPPP) 60 [22]

Additional roles can be identified, such as the Service Aggregators at various layers, i.e., the Network Service Aggregator, the Infrastructure Aggregator and the Datacentre Aggregator (8) [22], or the Spectrum Aggregator, having business relationships with several spectrum license owners in order to share spectrum more cost efficiently and in a flexible way, etc. (see [25] for further details). The role of Network Service Aggregator can undertake the activities of service provisioning across multiple network operators required, e.g., in cross border, or in multiple private and public network environments.

It shall be noted that high interaction is expected between pure IT and Systems' roles, namely the roles of HW and SW suppliers (13) and operation support providers (12) and the roles of 5G resource provisioning, (1) to (11), as presented in Figure 6. This interaction reflects the aforementioned platform-based foundation of 5G systems. It is determined also by the fact that, ultimately, 5G resource provisioning will be performed on a per vertical application and service deployment basis, shifting from the traditional network resource provisioning based on generic QoS classes. In this context, the roles of Application Providers (AP) and System Providers to vertical customers (included in (12) and (13)) shall be added in 5G provisioning ecosystems.

Extending the 5G provisioning ecosystem definition, one should include policy makers and related regulations, and standard development organisations, as they have a very important role in enabling and fostering the growth of these ecosystems. However, these topics are not part of the current analysis, as mentioned in Section 3.1.

4.2 Initial Stages and Further Development of 5G Provisioning Environment

4.2.1 Initial Stages of 5G Provisioning Environment

At initial phases of 5G technology introduction (technically associated with 5G Non-Stand Alone (NSA) mode) to the telecom market, the established roles and value chain models used in 4G business modelling will still be capable of providing an adequate representation of the business environment. As 5G technology solutions mature towards fully fledged 5G deployments, business activities and operations will need to shift towards the afore-described set of roles. Given the fact that the 5G technology and commercial adoption is at infancy, the development stages of the 5G business environment cannot be strictly determined. However, given the starting point of the telecommunication market and the targeted 5G business activities and roles, we can make observations and forecasts related to the various pathways to be followed and the various business formulations to appear on top of future, fully fledged 5G deployments. The following paragraphs aim to provide observations on the mapping of roles to stakeholders through various stages of development of 5G business environment.

Considering the 5G business roles, the ones related to network and service provisioning are the SP (CSP, DSP, NSaaS Provider) and the Network Operator, as well as the Service Aggregators and Spectrum Aggregator - unless inhibited by the regional regulation and policies. In traditional telecom markets, the network and service provisioning roles have been performed by the Telecom Operators being those Mobile and/or Fixed-network Infrastructure Providers, obviously including a very different set of activities and relationships compared to the afore-listed 5G ones. At initial phases of 5G development, large, established Telecom Operators will continue to dominate in the provisioning of services, constituting the single customer interface towards the end-users, since this is the focal interest of their business activities, as can be indicated by Telecom Operators' being fast in deploying and promoting 5G (NSA) networks (indicatively Vodafone [37], Deutsche Telekom [38], Telefonica [39]).

At the same time, it can be identified the engagement of large Telecom Operators in empowering the digitization of European vertical industries, visible through their early involvement in the provisioning of integrated IT/cloud computing services along with the network ones to individuals and corporate customers / verticals (Telefonica [34] and [39], Vodafone [35], Deutsche Telekom [38]). Clearly in such cases, Telecom Operators undertake the role of Cloud/ Edge Providers -to evolve in the role of VISP and DCSP in 5G terms-, in addition to that of the Network Operator. Taking it a few steps forward, Telecom Operators can even undertake activities related to vertical application services provisioning ([41] [42]). This implies even greater shift of Telecom Operators to IT, SW and integration operations.

While acknowledging the role of established Telecom Operators as key actors in the 5G provisioning business at initial stages, the aforementioned assumption of the entire set of 5G provisioning roles solely by the Telecom Operator -determining completely the end-to-end (E2E) 5G provisioning- may not be followed throughout all stages of 5G business development due to numerous factors. At that point 5G provisioning ecosystems can emerge in various formulations, expectedly with the Telecom Operators maintaining the core actor position in them. In general, there will be cases where the 5G provisioning ecosystems will emerge as an evolution from the established network provisioning value chains, through the desirable, deliberate sharing of activities and roles traditionally held by established Telecom Operators with additional, possibly

new stakeholders. In other cases, 5G provisioning ecosystems will emerge as a total disruption to the existing market environment through the take-over of new, necessary roles (thus activities) by other than the established actors.

4.2.2 Key Driving Forces towards 5G Provisioning Ecosystems

The following can be listed as some of the key driving forces, leading to the opening of the 5G provisioning business to other stakeholders as first step needed to the development of an ecosystem. Apparently, these triggers and enablers are not emerging separately, but as parts of the complete picture of ICT evolution:

End-User- related

- The ever-growing service expectations of end-users, even included in recommendations, specifications and reports by standardisation organisations (indicatively in 3GPP specification series 22 - Service Aspects "Phase 1", ITU [41]), become very challenging to fulfil as they may require "the integration of lots of upstream inputs into the focal offer" [8], in very rough terms being the provision of (as also identified in [22] cumulatively from a wide number of research projects):
    - both network and IT services either as a complete, single service offering, or as a bundle of services offered through different interfaces
    - services tailored to the vertical-specific needs, moving from the traditional service provisioning based on generic service classes. This comes along with the need for several service aggregation activities, and a fine-grained management of end-user services from the provider(s).
    - high quality services, that implies the adoption of distributed architectures as supported by 5G, and further investments on infrastructure deployments, currently not at place.

Technical

- The intense 5G Network softwarisation (through Software Defined Networking and Network Function Virtualisation) enables shifting from closed technologies to platforms continuously evolved adopting DevOps practices (as mentioned in numerous posts, articles, books, etc. -as very indicatively in [45] – [48]). Apparently, this shift necessitates advanced IT competences, usually owned by the IT industry rather than by the Telecom industry parties.
- The 5G network virtualisation along with the orchestration capabilities at multiple layers and the deployment flexibility of 5G systems enable the seamless integration of multiple domains and resources potentially operated and offered by third parties, and the transformation of these domains into common unified frameworks at each aggregation layer (as indicatively mentioned in [48]). This transformation gives potential for active engagement of more stakeholders in 5G provisioning activities as first step to the creation of 5G provisioning ecosystems (The following two factors can be considered also as aspects of this transformation).
- Compared to legacy networks, network virtualisation in 5G is regarded as key in achieving cost-efficient deployments for similar use cases, since, in simple words, SW running on Commercial Off the Shelf (COTS) servers is good enough to operate a network and allows for light-weight core network solutions and at the same time gives a lot of potential for flexible network deployment options with regard to hosting of virtual

network functions (VNF), and automation capabilities; as indicatively mentioned in [27] [49]. These factors can boost significantly the deployment and operation of small-scale network deployments by stakeholders other than the traditional Telecom Operators.

- At the same time, on the one hand the simpler deployment, operation and integration of small cells (suitable for Hotspot networks) [50], as well as their cost-effectiveness - having comparable cost with Wi-Fi deployments (as clearly claimed in [51]), allow for the deployment of access networks, operated by stakeholders that are not primarily active in the field of telecommunications ([50] [52]). On the other hand, there is an increasing scarcity of available sites to deploy infrastructure and features, e.g., the 5G NR or MEC, that are necessary for demanding 5G use cases. Therefore, partnerships between these stakeholders and Telecom Operators can be key for the latter to extend their service provisioning (coverage) footprint ([52] [53]). Of course, this necessitates new skills also from those that are new to the telecommunication domain.

Economic and Business Environment-related

- During the latest years, the IT industry, including SW houses, open-source consortia, Data centre and Cloud Service Providers, have put through great expansions in infrastructure and services, investing in the associated skills and competencies. The latter are fundamental in 5G, and this opens the door to these ICT industry parties to engage at various stages of the service creation and, at some level, at the provisioning activities, as identified also in [20]. Indicatively, ICT industry parties can undertake roles related to cloud/edge infrastructure/resource operation and provisioning, platform operation and maintenance (such as Openstack/ Openshift/ Kubernetes/ ONAP/ other Virtualisation Infrastructure Orchestrators etc.), VNF and general-purpose re-usable SW component development and provisioning, etc. as in the case presented in [49].
- The new spectrum allocation and licensing policies in general may significantly influence the transformation of the market. As observed ([55] – [60] [75]), various spectrum allocation approaches are currently being considered for the 5G bands by the national regulators and policy makers ([55] [58] [75]) or industry alliances and suppliers ([57] [59]), ranging from exclusive licensing to regional and local licensing or license-exempt operations. At one point, approaches aim to put an end to closed contracts and oligopolies on this scarce and key resource, e.g., by allowing shorter / longer term spatially constrained allocations at low cost (this is also foreseen by EU Directives [75] towards fostering the deployment of short scale 5G networks). In other cases, policies may request high costs for large scale allocations and enforce that less densely populated areas, or less appealing deployments, are properly taken care of, thus pushing larger Telecom Operators to invest also in less profitable areas. It should be pointed out that even at this stage, huge pricing gaps between spectrum allocations to large Telecom Operators and those to vertical players may appear ([55] [60]).
- Establishing partnerships with stakeholders already possessing specific necessary infrastructure, skills, etc., can lead to lower Total Cost of Ownership for the Telecom Operator, compared to the case that the Telecom Operator undertakes all activities and roles, as mentioned in [49] [52] [53] [54].
- Lately the telecommunications sector has come across versatile disruptive business initiatives from industries not in direct competition with Telecom Operators (e.g., by service providers such as Apple, Samsung, Google, Amazon, and Netflix mentioned in [61] [64]) that go to the direction of more open, flexible, platforms and services provisioned on top of them. As indicated in numerous studies ([61] – [64]), various forms

of disruption is expected to be a huge trend in the upcoming years, and the transformation of the Telecom Operators' roles and activities shall definitely take this into account towards moving to the development of 5G provisioning ecosystems.

4.2.3 Formulations of 5G Provisioning Ecosystems

On the basis of the aforementioned technical factors and enablers, and the economic and business environment conditions, it comes out as a safe observation, that acknowledging these capabilities and mobilising stakeholders capable of contributing (technically) to the value creation and to the expansion of the service footprint, can be a strategic decision towards achieving growth both for Telcos and for other actors. Considering these key aspects, eventually, Telecom Operators - instead of developing in-house expertise- could be willing to pay especially for external support in IT competences and services, such as IT management services of network and SW, IT System and network integration services supporting the design and development of E2E orchestration platforms, at network and application level. For the same reasons, Telecom Operators could be willing to lease additional infrastructure resources from 3rd parties (new stakeholders becoming actors), practically outsourcing the operation of IT/Cloud/Edge infrastructure, particularly for localized/geo-fenced scenarios (as indicated in [53] [54]). They could also become more open to engage in continuously evolving SW projects (e.g., of VNFs, and general-purpose SW components) and adopt their solutions. In other words, in the context of the 5G provisioning ecosystem, Telecom Operators can maintain the Network Operators and Service Provider roles, while establishing collaborations with smaller/other Telecom Operators and verticals undertaking the role of (cooperating) Network Operator, as well with Cloud/Edge Providers as well as with the IT industry undertaking the roles of DCSP/ VISP an Service Aggregators of that layers.

In that landscape, collaborations may take the form of joint service provisioning, thus the customer interfacing activities can also be split into a number of sub-roles. In particular, the complete service provisioning may imply that the end-user maintains a set of interfaces to Telecom Operators (undertaking the roles of CSP, DSP, NSaaS Provider) and cloud/edge computing providers (undertaking the role of DSP and NSaaS for the compute resources), along with connections to independent or liaised large SW/Platform repositories. It shall be noted that there are initiatives that suggest a role for the individual Telecom Operator focused on Network Operator and Service Provider roles, leaving room for the development of an ecosystem at various layers of network deployment and roles. In this direction for instance, the GSMA and Telecom Operator driven suggestions envision a cross-operator mobile edge platform to meet the requirements of digital transformation of various vertical industries, featuring openness and inclusivity ([65] [66]). Depending on the business dynamics, the final openness of 5G network platforms, and the Telecom Operator strategy, the suggestions of mobile edge platform developments can evolve to a smaller or greater platform, based on which 5G provisioning ecosystems can evolve -from the business perspective (e.g., as indicated in [76] [65] [66]).

Considering the business potential in other cases, Application Service/ Content Providers or data centre/ cloud providers may undertake key activities as platform operators, thus parts of the Services Provider roles (NSaaS Provider or DSP role) in the 5G provisioning ecosystem, potentially determining the dynamics of it. Such cases can be seen also under the prism of telecom market disruption as indicated in ([61] – [64]).

Figure 7 provides an illustration of the main (alternative or coexisting) formulations of 5G provisioning ecosystems envisioned based on the observations of previous paragraphs.

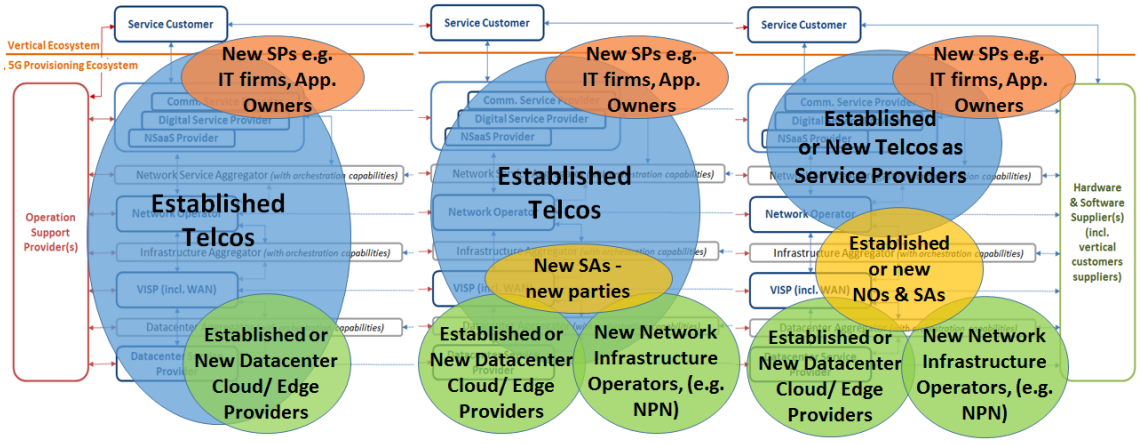

Figure 7 Potential formulations of 5G provisioning eco-systems

The level of cooperation between stakeholders, and how much actors fulfil completely or partially these roles in all the cases will be subject to the stakeholders' strategies and market dynamics per case, as well as to the regional regulation. It shall be noted that there can be cases where more than one formulation appears for the same actors in different areas/ local markets/ national markets. For instance, large Telecom Operators may undertake all roles in one 5G provisioning market, while deciding to adopt a more focused approach (e.g., SP or NO only) in others.

Watching these 5G-Provisioning formulations as time-extended developments, we see how well the ecosystems' growth theory is applicable. In early phases of 5G development (i.e. in the current 5G Non-Standalone provisioning systems, which lean on 4G systems and therefore reflecting 4G technical and business logic, there are few firms (i.e. the core mass of the market) contributing to the user' offer, while in late phases a high volume of firms will contribute to the value proposition to the end user. Initially, the central role is not settled, in the sense that although currently Telecom Operators hold this role, it is not clear how this will evolve in time, as well as in the sense that equilibrium in terms of roles sharing has not be settled (given the opportunities to appear with technology's advancements and the policies fostering the engagement of new stakeholders). At late stages the roles are clearly defined, well connected, and practically will be more associated with platform operation rather than with network/domain operation. Figure 8 illustrates how ecosystem growth principles are visible in the potential formulations of 5G provisioning ecosystems over time.

All considered, in this landscape, the boundaries are no longer that strict in terms of stakeholders and established business activities, one role can be assumed by or split between many stakeholders (as actors), and the classical categorisation and identification of actors in a linear value chain does not always reflect the stakeholder roles, activities, relationships and dynamics in the 5G environment. Therefore, introducing a new representation of stakeholders and relations in terms of ecosystem and applying ecosystem theory principles, is a much-needed exercise.

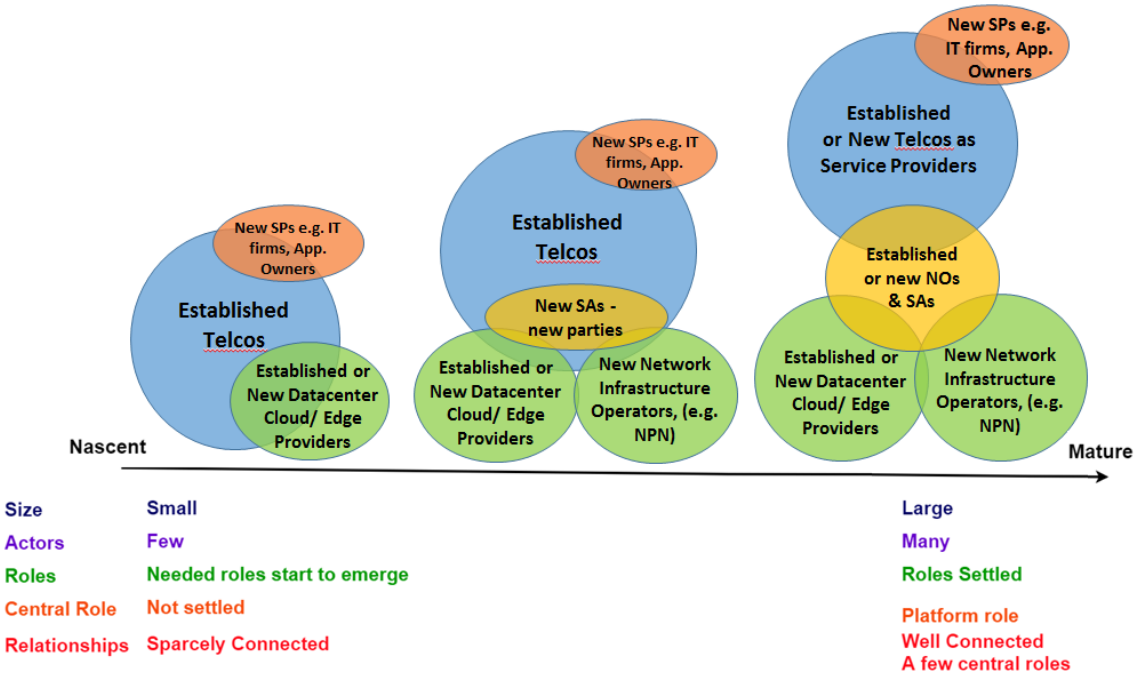

Figure 8 Application of ecosystem growth theory to 5G-provisioning ecosystems

4.3 Development of Complementary, Niche 5G Provisioning Ecosystems

Besides the development of large scale 5G provisioning ecosystems, the advent of 5G facilitates the evolution of complementary, small scale, niche 5G provisioning ecosystems, fostering the smaller Telecom Operator industry. 5G empowers actors far from the traditional industries or verticals (usually) with established experience in operating private networks (currently strictly for internal business operation) to engage into the 5G provisioning ecosystem by deploying or operating a 5G infrastructure, and by leasing resources or providing services to 3rd parties (initially such trend is reflected in [53] [58] [59]). Indicatively, such cases can be that of large venues (e.g., stadiums, festivals, large exhibition halls) owners, as well as the case of transport operators, especially railway operators, which may be interested in bridging the vision of Future Railway Mobile Communications System (FRMCS) (the future worldwide telecommunication standard and GSM-R successor) with the 5G hotspot operators' role (see Appendix 3 for more details).

Indicatively, considering the case of large venues, the media and entertainment industry constitutes a major sector in need of high-capacity network deployment at the owners' facilities. Currently ([72] [24]), telecom services are provided over multiple networks deployed and operated by different Telecom Operators and private networks for the venues' own needs. Following these practices, covering the extremely high traffic density only at specific timeframes implies high TCO for all stakeholders. The effectiveness and viability of these practices becomes further questioned with the increasing demand for data services, especially in view of the high-performance requirements of forthcoming services addressing this industry (e.g., Crowd-sourced applications, Audio-Visual, Augmented Reality/ Virtual Reality services). 5G network principles will enable the substitution of these infrastructures by a shared neutral one for the 5G service provisioning to multiple stakeholders, such as venue owners, Telecom Operators, Broadcasters, Content/ Multimedia Application Providers, large Content Data Networks, etc. ([72] [24]). The

key techno-economic drivers for this technical shift will be the lower TCO, along with the significant increase in network capacity and performance.

The distribution of 5G provisioning roles/activities between the various stakeholders will evolve as a trade-off between own interests and own needs of each stakeholder. To this end, in many cases, established Telecom Operators will undertake the role of 5G provisioning to end-users following established practices in infrastructure deployment and sites leasing from venue owners. Examples of early such deployments and partnerships developed on the aforementioned grounds are described in [67] – [71].

In other cases, business-wise, there can be also lack of interest from existing Telecom Operators to invest in high-capacity infrastructures that will be utilised only temporarily. This can potentially make room for other parties to engage in the 5G provisioning ecosystem; with these parties looking at the other side of the coin, that is, the considerably high market demand due to high -even if only temporarily- concentration of end users, and the high interest for service providers for such network deployments. Especially for venue owners, leading or engaging in niche 5G provisioning ecosystems may seem attractive, taking into account additional aspects such as their internal communication needs, the ownership of facilities and the decrease of TCO ([51]). In this landscape, venue owners may act as VISPs or may further undertake the role of NSaaS towards Telecom Operators (in the role of Service Customers in this case), and towards stakeholders with focal interest in the event industry (broadcasters, CDNs etc.), or/and undertake the role of CSP towards fans/venue guests ([23]). Apparently, depending on the final formation of relationships, various complementary niche 5G provisioning ecosystems can be built up, with multiple interfaces and multiple revenue streams. Of course, this implies a shift in roles and business activities on the basis of new business models for the key stakeholders.

For the stakeholders of these niche 5G provisioning ecosystems, swift implementation of new business models requires also handling of licensing and regulatory aspects. Considering the current common regulatory environment across EU ([75] [74] [76] – [79]), a set of licenses and agreements may be needed prior to initiation of business activities, such as: (a) licenses related to Telecommunication Service Provisioning; (b) commercial licences related to performing specific business activities; (c) special licences related to the provisioning of specific services, such as licenses to obtain specific range from the national numbering plan for telephony communications, licenses to offer broadcast content services; (d) spectrum licenses, depending on the wireless access network frequencies to be used (the grant of which is time-, market-, service-, and competition- specific), as mentioned in section 4.2.2.

The existence of such niche 5G provisioning ecosystems will complement rather than challenge the 5G provisioning landscape. On the one hand, this is mandated by the spatially restricted and temporal character of the service provisioning to end-users. This necessitates also the tight interaction of these niche 5G provisioning ecosystems with large 5G provisioning ecosystems for ensuring continuity for services that are not location restricted. Technically, this interaction may indicatively take any of the following forms: (a) the niche 5G provisioning ecosystems holding the role of VISPs interfacing Network Operators of the large scale 5G provisioning ecosystems, (b) the niche 5G provisioning ecosystems holding the role of Network Operator interfacing Network Service Aggregators of the large scale 5G provisioning ecosystems, (c) the niche 5G provisioning ecosystems holding the role of NSaaS provider interfacing CSPs of the large scale 5G provisioning ecosystems or, in other cases, d) the niche 5G provisioning ecosystems holding the role of CSPs interfacing AP/SPs of the large scale 5G provisioning ecosystems. On the other hand, from a macroscopic perspective, these niche 5G provisioning ecosystems may serve as

necessary service source platforms, on top of which other services can be built for other ecosystems. For instance, a niche 5G provisioning ecosystem of a stadium can provide the means for specific stakeholders to create special services on-site and distribute them or further build upon them other content services addressing end-users (not located in the stadium premises) of other 5G provisioning ecosystems.

4.4 Challenges in the Development of 5G Provisioning Ecosystems

Even though the development of 5G provisioning ecosystems is regarded as a necessity in order to kick off growth and enable 5G empowered innovation, a number of challenges may become visible at early stages of development only when applying ecosystem growth concepts and theory. In particular, considering the ecosystem theory, the flourishing of ecosystems is associated with strategies focusing on "making it easy" and "making it attractive" to engage, invest, participate and grow. From this perspective, challenges and barriers may be related to various aspects of 5G Provisioning, e.g., technical, economic and business, societal and end-user related, market and policies related, at various stages of its life-cycle. Acknowledging these challenges early is key in the development and sustainability of 5G Provisioning Ecosystems.

Technical

As mentioned in section 2.2.1 the need for easily accessible, known (even though not common) technical interfaces (e.g., APIs) is a challenge and at the same time key enabler of 5G provisioning ecosystems. This is mandatory so as to enable the engagement of actors in the ecosystem and for ensuring growth of the business related to these roles. Already acknowledged as a key challenge by the 5G industry ([84] – [86]), the requirement for easily accessible, known interfaces has led to the biannual Open API Adoption Assessment Reports from TM Forum that aim to measure the industry's progress in adoption of TM Forum Open APIs [87]. In practice, easily accessible, known interfaces are necessary on the one hand for integrating multiple technologies and multiple domains, and on the other hand for materialising the business activities and the business interfaces between the various roles – stakeholders – in the 5G provisioning ecosystem. Despite all efforts in standardisation of technologies, it always requires a lot of work to integrate equipment developed by different suppliers, and the situation gets even tougher in case of very complex systems like 5G (e.g., due to the multiple technologies and multiple domains in focus); EU-funded projects have put a lot of effort in this field, as reflected in the orchestration layers of [80] – [83]). Aligning business interactions (i.e., between the roles mentioned in Section 4.1) with technical interfaces can get even more complex, requiring a lot of tailor-made and technical aspects. Looking at the market readiness, the ability for actors to use APIs to easily interact with 5G systems is still in the making, even though the service-based foundation of the 5G architecture promises the necessary technical and business openness. To fuel the 5G market further as an ecosystem, APIs must be made available so that a 5G developer community can start to build and reinforce growth.

A number of technology (related to "making it easy") and business (related to "making it attractive") challenges that may appear are associated with the need for interoperability and service provisioning across 5G service provisioning ecosystems, mainly stemming from the end-user requirement for "ubiquitous service provisioning" and "mobility". This is translated into roaming (national or international) between networks for simple 5G network services, while for complex services it can be extended to service portability, Multi-access Edge Computing (MEC)

mobility (implying mobility of workloads across different edge computing-enabled sites, possibly operated by different VISPs/NOs), between networks, domains and platforms. A number of EU-funded projects put effort in this field, as reflected in the MEC mobility aspect addressed in [82], and transport network resource allocation under high mobility scenarios in [82] and [83]. In business terms however, ubiquitous 5G services provisioning requires collaboration between many SPs, NOs, and VISPs. To this end, current regulations aim to address the requirement for interoperability between operators as well as to avoid oligopolies of large Telecom Operators in the market -as core actors of the future ecosystems. The fact that interoperability between these service providers is governed by standards and industry associations ensures that "one platform" is expected to facilitate interaction of these ecosystems. This might appear as a contradiction to what we see in the cases of other ecosystems that have flourished as single platforms, such as large platform ecosystems of Amazon, Google; etc. however, it is worth noticing that the type of the provided services is different.

Last but not least, the process of orchestrating different sources at any of the aggregation layers, depicted in Figure 6, can be challenging, since at some point there will be the need to materialise specific agreements between the interacting actors in the ecosystem. At this point, technical implementations may need to reflect business agreements between multiple parties and balance even contradicting business requirements related to quality of service, prioritisation of interfaces, allocation of resources, etc., as those may be tightly associated with revenue streams.

Economic and Business

For each business sector, it is a huge step to rely on others to fill important roles, to open networks for others to apply, and form alliances instead of determining agreements with other stakeholders. This has been addressed, indicatively in [33], as a tension between the preferable ecosystem type of market, and a more probable actor-controlled type of market. At the same time, with representatives from the ICT sector being the main candidates to disrupt the telecommunications market, it is a critical decision for all stakeholders when, how and under which terms to ally or compete with each other, given that actors act according to self-interest. The competitive tensions between Telecom Operators - and all the other stakeholders that contribute to 5G services - is a characteristic of the market that has to be taken into account when discussing the emergence of a 5G ecosystem.

It can be a challenging task for all actors to develop the necessary competences and processes that fall outside of their established business. Staged investments will be needed, staffing can be critical, and business process re-engineering will be needed in all cases. Considering all roles and stakeholders in 5G provisioning, as far as the business planning is concerned, it can be very puzzling to position oneself to a future market environment, to address and appeal to a critical mass of a market, to quantify the willingness to adopt and the willingness to pay other actors, to estimate competition, etc. In many aspects, the actual business development can be challenging for existing and new parties; hence, solid business modelling and viable business cases are necessary for all stakeholders as a first step. At the same time, the market environment is not mature enough to allow safe market projections, business relationships between actors are not established, and uncertainties of any type may hinder business development for all stakeholders.

Societal/ End-user related

The prospects of any business development are determined at a certain grade by its capability to effectively address the needs and expectations of the end users, not only related to service and quality, but also to customer/business support and communication. Considering the 5G

provisioning ecosystem, building the necessary communication channels and interfacing the end-users can be key to the success of an ecosystem and shall be carefully shaped. Business support services shall run through all business interfaces, and SLAs towards the end-user shall be communicated and reflected across the complete net of stakeholders and roles. This can be considered as a challenge towards "making it attractive" to the user ecosystems to adopt and to the 5G provisioning ecosystems to grow.

Market / Policies related

The current regulatory environment of the ICT sector has been long established on the basis of principles of past technologies, where the E2E service provisioning industry is determined by a few parties, i.e., the Telecom Operators, in ownership and control of the resources (e.g., spectrum) and infrastructure. For long time, the focus has been to regulate the resource allocation, ensuring the viability of the companies investing in it, and to regulate the market to avoid oligopolies of large Telecom Operators', to avoid cartel policies in terms of pricing towards the customers, and to ensure nationwide population coverage. In the 5G provisioning context, regulation and policies shall be expanded to include the arrangement of relationships between actors in the ecosystem, to over-arch the sharing of liability between actors towards the customers, to facilitate the participation of stakeholders in the ecosystem, especially through simplifying the various licensing procedures and adopting a continuous licensing scheme. At the same time, having a stable regulatory environment is a precondition for the development of any business, for the cultivation of a trustful framework to urge companies to invest in, in other words to "make it attractive". At this early stage of the 5G provisioning systems, it is a very challenging task to plan and form ecosystem regulation, policies and strategies that can work for future environments. Apparently, regulation, policies and strategies will also go through several phases of addressing market aspects that are not foreseeable at this point in time.

To summarise, there are high ambitions for 5G regarding its capability to make growth at various domains, enable innovation, and involve many new parties in the flourishing 5G business environment. The Telecom business environment can hardly remain the same as it has been for a long time. End-user expectations, technology advancements, economic and business developments pave the way for new roles (and thus new actors) and drive the transformation from the traditional value chain to the 5G provisioning ecosystem. Based on 5G-PPP layered roles approach for 5G systems (discussed in Section 4.1), the 5G provisioning ecosystem, focuses on roles and actors taking part in developing, delivering and providing 5G services. The roles are, however, still in the forming. The 5G actors are still small in numbers. For sure there will emerge various formations of ecosystems, competing and complementary, large and niche-ones. The incumbent, i.e. the Telecom Operator, will probably maintain a central role; however, it is not yet evident how its role may transform in the forthcoming ecosystems.

Ecosystems that grow will evolve and improve gradually from one stage to the next, and parties may get involved at various stages. In the growing phase, tensions may occur between the desired overall growth of the ecosystem and any stakeholder's interest focusing on their own profits at first place. Fully exploiting the 5G system capabilities, and advancing the user's value proposition may require that more than one actor contribute substantially to delivering the users' focal offer, the picture to be completed with actors and institutions surrounding the ecosystem. To this end, interests need to be balanced.

A number of challenges are expected in this pathway, among which: technical and, business development challenges, tensions between parties in filling the roles and in formulating the appropriate relationships, societal and customer acceptance uncertainty, lack of existing, stable

ecosystem regulation and policies. Towards ensuring rapid development and growth and sustainability, many of these challenges may become visible at early stages of development only when applying ecosystem growth concepts and theory, and developing/ adopting ecosystems strategies at various levels. Such strategies focus on "making it easy" and "making it attractive" to engage, invest, participate and grow.

In the context of the BVME WG work, the Ecosystems' modelling approach has been applied to the 5G Provisioning business, and through this we have identified, elaborated on and illustrated:

- potential 5G provisioning ecosystem formulations (Roles mapped to Stakeholders)
- potential pathways of 5G provisioning ecosystems development
- key factors driving the 5G business towards adopting ecosystem strategies
- main challenges in making 5G provisioning ecosystems easy and attractive.

Focusing on the key learnings deriving from this work, through adopting the ecosystem approach, we can obtain a clearer understanding of existing business motivation and worries. This includes, early-identification of challenges that are not visible at initial business development phases, and early uptake of actions towards minimising risks and overcoming obstacles at various stages of the ecosystem development pathways.

Of course, the BVME WG – aggregating the views of experts from numerous R&I activities, from various EU countries/markets/etc. – has acknowledged the fundamental uncertainty related to the way the 5G ecosystems will evolve, as that will be determined by yet unknown business dynamics, business environment, the growth potential of each separate market (at national, local, and even regional level), and by the fact that, as always, as there will be the need of evolving the new ecosystem taking into consideration the incumbent players and the legacy systems.

5 The 5G vertical ecosystems

The introduction of 5G brought along an invite for verticals to engage with 5G, as 5G can enable new business opportunities. In this section we discuss how the concept of a 5G ecosystem can be understood when verticals are considered. Thus, we rest the discussion of how 5G can be developed and delivered by 5G Service Providers. Instead, we examine how composed technological solutions *in verticals* are delivered jointly by a different set of roles, where the 5G Service Provider delivers a 5G service as one important component. When 5G services are important parts of a technological solutions in verticals, we denote this as a 5G vertical ecosystem. Furthermore, we expect that there will be different 5G vertical ecosystems for different verticals, adjusting to specific market circumstances and dynamics.

Since 2015 5G PPP white papers have identified 5G verticals that can contribute to and are empowered by 5G, and those are: Automotive, Transportation, Media, Smart city, Healthcare, Factory of the future, Energy, Public safety, Ports-Airports, Tourism, and Agrifood [88]. Also, the Financial Times [89] elaborated on the same matter and provided a slightly different list of verticals that, outside of the ICT domain, can benefit from 5G: Agriculture, Forestry and Fishing; Manufacturing; Public services; Transport and storage; and Wholesale and Retail Sales. Within each vertical, there are specific processes that drive the evolution of the ecosystem. For instance, Automotive [90] and Manufacturing industries [91] have taken strong ownership and built alliances to define how 5G can be used and positively affect their businesses within their domains. Other sectors, e.g., Agriculture and Health, have not established such alliances but are still engaging in e.g., EU-funded research projects to explore new opportunities with 5G. In both cases, we expect that the same type of market dynamics must be addressed to kick off a 5G vertical ecosystem. Not the least, the success of a 5G provisioning market is founded on the demand from verticals and growth of the 5G vertical ecosystems.

The ecosystem approach is relevant when roles and actors are dependent on each other in delivering a composed solution and growth is affected by the roles' ability to share market and revenues. In the early days of a technology such as 5G, roles are not settled. In the cases of emerging 5G vertical ecosystems, traditional telecommunication operators see potential new roles and revenue opportunities. At the same time, they are dependent on mobilizing many other roles to innovate with and use 5G services. Thus, it is vital for all parties to understand the needs for collaboration and trust in ecosystems, and sources of tensions and inertia. It is not sufficient to address only the value proposition of the paying vertical customers, but also the benefits for all those other actors who take part in delivering the full solutions, are to be taken into consideration.

In the next sections, we first suggest basic roles in a 5G vertical ecosystem, so to better understand which type of roles and actors must be mobilized to engage in a 5G vertical ecosystem and kick off growth. Second, we present some of the challenges different parties perceive when engaging in 5G vertical ecosystems to understand how to approach these parties to increase their motivation to engage. Finally, we provide three examples of emerging 5G vertical ecosystems, which illustrate the opportunities with 5G services and the early and unresolved matters about roles and who could populate them.

5.1 Basic roles in 5G vertical ecosystems

The roles in a 5G vertical ecosystem are a disaggregation of the 5G Service Customer role in the 5G provisioning ecosystem (see Section 4.1). A first separation is between the role of the *5G Vertical enterprise customer* which purchases 5G services, and the role which support the vertical enterprise customer to create and operate a solution in the vertical domain. The 5G service provided by a 5G Service Provider is one component in such a solution. Thus, seen from the 5G Service Provider side, the supporting role complements a 5G service and the role may be referred to as a complementor [25] [118] [119]. Furthermore, this complementing role consists of many more specific roles and we therefore refer to the main role in plural – *5G Vertical complementors*. The roles in 5G vertical ecosystems are illustrated in Figure 9, including the relationship to the 5G provisioning ecosystem and the 5G Service Provider. It should be noted that the complementors are not only seen as providers of components in 5G empowered solutions; in an ecosystem context complementors are seen as critical holders and developers of knowledge which in turn is the basis for innovation in the vertical domain.

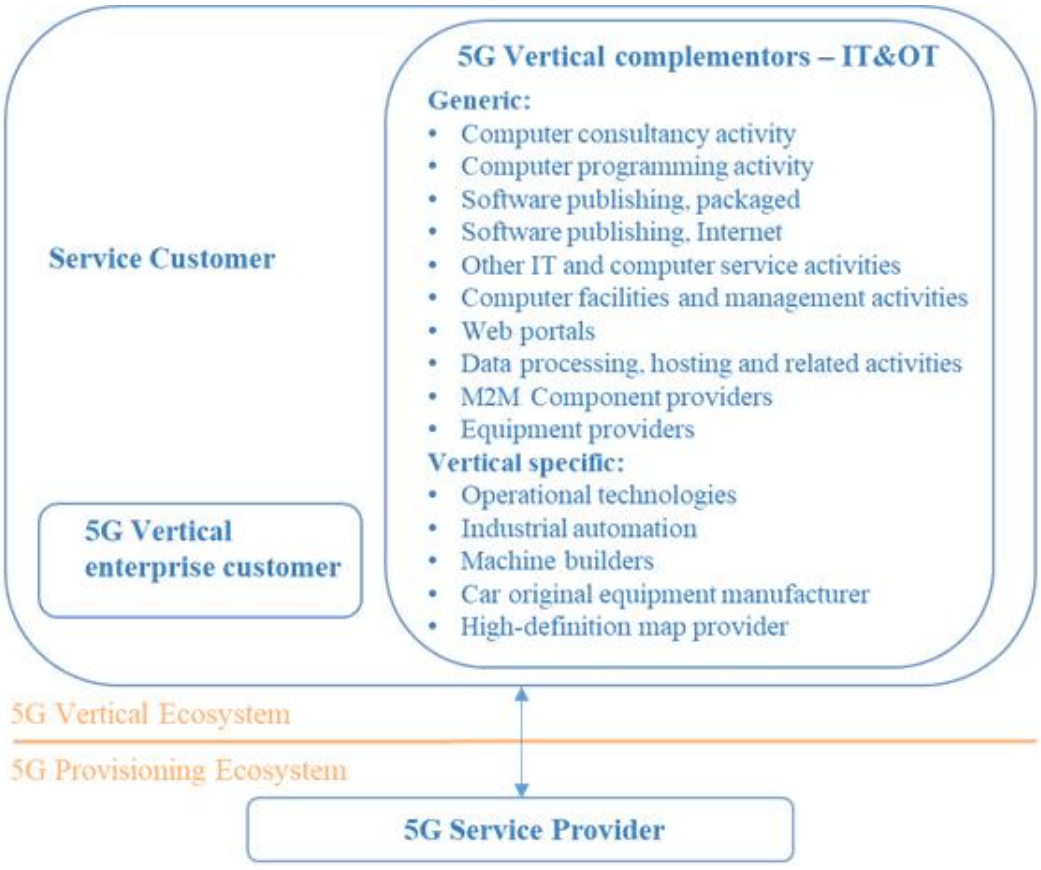

Figure 9 Roles in 5G vertical ecosystem (non-exhaustive list)

As of today, the roles in a 5G vertical ecosystem have not been subject to a detailed level of identification and description. Nevertheless, the ICT industry as such is thoroughly analysed and monitored. A good starting point is standardized classifications for public statistics [92], where the basic IT roles in the ICT industry are:

- Computer consultancy activity
- Computer programming activity

- Software publishing, packaged
- Software publishing, Internet
- Other IT and computer service activities
- Computer facilities and management activities
- Web portals
- Data processing, hosting and related activities

5G stakeholders have been further detailed in the previous section. The central role of equipment providers is even more evident from manufacturing point of view [93]. For instance, operational technologies (OT), industrial automation providers, and machine builders are important roles for manufacturers. Compared to the IT industry, the monitoring and size of the OT industry are not evident; it is hidden in industry statistical categories such as Installation of industrial machinery and equipment [92].

The above-mentioned basic roles have characteristics that affect how they play their part in a 5G vertical ecosystem. The IT and OT roles engage with a vertical enterprise customer with everything from ideation to actual operation, i.e., they are strategic consultants supporting ideation and design, or providing management of applications and computers/machines [25]. Drawing on ongoing projects such as DEDICAT 6G [92] we can provide an example of Computer consultancy activity, i.e., the role of the Business Process Leader (BPL) which (trans)forms the directives from complementors to concrete operations tailored to vision/mission of the company. The Business Systems Leader, under the computer programming activity category, will safeguard, for its part, that the various systems within a 5G context operate based on the provided processes. To ensure the total demand for 5G services, a 5G Service Provider must mobilize these complementing vertical roles in all phases.

In addition, these roles can be coloured by their vertical context or the holders of the roles.

First, some actors in the above roles serve vertical enterprises in a generic way, while others have specialized on specific verticals, for instance in Finance, Health, Manufacturing, or the Automotive sector. As an example of roles in the latter, we can list Car Original Equipment Manufacturer and High-Definition Map Provider [94].

Second, some vertical enterprise customers have internalized the complementing roles, e.g., some enterprises do not purchase consultancy services but carry out strategy, problem solving and ideation themselves. Other vertical enterprises carry out programming and manage their own communication networks. In this way, the vertical enterprise customer itself takes on a role in the 5G vertical ecosystem, in addition to being a customer. Another example is the interoperability facilitator: the role falls in the category of 5G Vertical complementors under Other IT and computer service activities but can be also assumed by the Vertical enterprise customer. This interoperability facilitator ensures effective collaboration between 5G services and existing IT infrastructure producing data (e.g., management information systems [25], enterprise resource planning), addressing trust and liability issues.

Third, some actors in these different roles are mostly local, while others are global. For instance, there are many local system integrators, while Microsoft is an example of both a global application and hosting provider.

Fourth and final observation is that some actors are large and well established in a role while others are SMEs, of which some are start-ups. Appendix 4 elaborate on challenges in a 5G markets specific to mobilizing SMEs, specifically when they are start-ups and potential growth firms.

A proper definition and enumeration of roles are indeed relevant when discussing dynamics and relationships in real ecosystems. However other aspects such as global presence, being an SME or a start-up oftentimes are also additional topics for thorough analysis of market dynamics.

These roles, in their many facets, already today serve vertical enterprise customers alongside telecommunication service providers and amount to huge markets. Hence, 5G vertical ecosystems are not a greenfield market for 5G Service Providers. The roles in the 5G vertical ecosystem are on the one hand, those that 5G is expected to empower when creating and providing new vertical solutions. On the other hand, there will be tensions between the 5G Service Provider and other roles of the 5G vertical ecosystem. Moreover, in the early days of 5G vertical ecosystems, there will be competition for revenues and, disruption of current roles and positions will take place.

In the following we elaborate on two observations which affects the potential evolution of 5G vertical ecosystems. First, the different parties that must be involved in creating value with 5G in verticals are sceptic and perceive challenges. Second, our examples of 5G vertical ecosystems are still sparsely populated with roles and the business relationships are not firmly set. These two observations indicate that 5G vertical ecosystems are still in their early nascent days and their evolution is uncertain. According to ecosystem strategies, a lot of work remains to be done, motivating and ensuring parties about why and how they should engage.

5.2 Main challenges of the 5G vertical ecosystem

There is a broad consensus that 5G services can be key to innovation and growth in verticals and the IT and telecommunication market [89] [95] [102]. The contributors to this White Paper (also known as BVME-SG experts) participate as experts in EU-funded research projects which investigate, chase, and promote opportunities with 5G in verticals and the ICT industry. Such group of experts on the one hand is very much positive on the huge set of opportunities that 5G can bring to the market; on the other hand, it has observed from all types of complementors in vertical that there are challenges and concerns when interacting with 5G as a concept for innovation. The most important concerns mentioned by those experts are clustered in Textbox 1. A major part focus on the risk of joining the 5G ecosystem without knowing what one gets in return, i.e., what is it that makes joining the 5G ecosystems attractive? Further, how liabilities are shared between parties is a concern turning up when the services provided are mission or business critical. Only a minor part involves the practicalities of how 5G functions and how to work with it, i.e., what is it that makes it easy to be part of the 5G ecosystem?

This overview is foremost a temperature check which, however, supports the challenges often encountered when kicking off new ecosystems. There are also thorough analyses of 5G markets that state that lack of trust and collaboration between parties can slow down innovation. Future systems must overcome this to fully unfold the innovation potential of 5G [95]. Thus, there is reason to believe that the examples in Textbox 1 are real concerns that 5G Service Providers will meet when working to mobilize complementors in 5G vertical ecosystems.

The type of worries described in Textbox 1 signals the immature state that 5G vertical ecosystems are in. It may be that actors populating different roles already have acknowledged the value of 5G and that roles are mutually dependent in delivering 5G empowered solutions to vertical enterprise customers. However, the exact roles necessary to provide 5G empowered solutions are not evident, neither which are actors who are going to fill them, or the sharing of revenues. The perceived risk for joining 5G ecosystem is still high.

Perceived uncertainty and risks of joining the 5G vertical ecosystem

- 5G is perceived as providing an important technology push, however, with unclear consequences both for incumbents and new players
- The added value of 5G may be understood, but the related cost is not clear. E.g., how will the proclaimed reduction in operational delays and waste turn out, in comparison with the 5G deployment/migration/operational cost? Will there be a need for new vertical personnel specialized in 5G administration?
- How can one profit? The flows of value (revenues) are opaque. It is not easy to understand how revenues are shared between players in short and long term.
- How will liability be shared between parties, e.g., who will be responsible for accidents and productions/processes errors as result of misconfigured 5G decision making? How can the integration of a third-party 5G system ensure the security of production processes?
- Which role will the incumbents take (5G service providers or vertical enterprises)?
- How will new approaches to joint value creation disrupt existing and well-known business models?
- How will joining an ecosystem affect firms' relationship to customers and users?
- Who will control data flows? (see also Section 6)

It is difficult to understand what 5G is, and how to work with it

- Full-fledged and mature 5G offerings are slowly getting broadly deployed
- Stepping into deployment of 5G is challenging – there is a need for guidelines
- Existing information and knowledge about 5G are not easily accessible

Textbox 1 Complementors' worries joining 5G ecosystems, as seen by BVME-SG experts

In the next sections we provide some examples, which shed light on roles that are forming, and opportunities and tensions that can arise. The first example from Industry 4.0 illustrates the market negotiations between an incumbent vertical actor – namely the manufacturer – and a future 5G Service Provider. The second example from Health sheds light on a large market where, however, connectivity for health equipment and services currently are implemented in a non-systematic way. New roles may emerge locally, nationally, and across national markets to deliver health services in a more standardized way while applying 5G capabilities. Furthermore, it is exemplified how providers of health equipment may integrate connectivity into their services and traditional mobile operators are driven to enter roles providing health specific solutions.

In Smart cities, the third example of a 5G vertical ecosystem we learn that it is already described as an ecosystem with well-defined roles and success factors. The existing Smart city seems to welcome 5G services, however, it is suggested that a new role as a neutral 5G host is needed to mitigate restricted access to 5G capabilities and lack of interoperability between different 5G Service Providers. Moreover, it is emphasized that citizens play an important role in the evolution of the 5G empowered Smart city, as do vertical service developers who use 5G platforms to develop and deliver customized services.

5.3 5G vertical ecosystem Example #1: Industry 4.0

Industry 4.0 refers to automation of the manufacturing sector using smart technology, and where connected UEs play a central role [96]. Between 2021 and 2025, Industry 4.0 technologies are expected to increase gross margins of production by up to 13 % [97]. An increase in output quality and a decrease in both wasteful output and downtime will lead to growing productivity [98] [99]. Essential technology enablers for those improvements are applications such as closed-loop process control, predictive maintenance, digital twins, augmented and virtual reality and automated guided vehicles – within the manufacturer location. For all these applications, deploying the right communications system for the different needs in the industry plays a decisive role. Such communication systems must be reliable, scalable, secure against external and internal malicious threats, able to transmit data in near real time, and sometimes decentralized [97].

The enhancement brought by 5G to the communication systems is expected to substantially reduce installation and maintenance costs while allowing to easily connect mobile or inaccessible devices. Thus, 5G technology is expected to meet demands of networked production systems and has great potential to accelerate the ongoing digital transformation [100].

Success in unleashing the estimated potential depends on a well-functioning relationship between manufacturer and 5G Service provider. For the manufacturer on the one hand, an initial baseline for investing is the revenue improvements caused by implementing 5G (e.g., scrap reduction by closed-loop process control). To exceed this baseline requires further qualitative justifications or an expectation to benefits from future use of the implemented 5G services. For the 5G Service provider on the other hand, the baseline are the costs for deploying and running the 5G system (e.g., HS cost, maintenance cost). This is the minimum price the 5G Service Provider must receive for a 5G implementation on a manufacturer's site. Both the manufacturer and 5G Service Provider are influenced by various cost and revenue factors.

For the manufacturer, one of the most decisive points is whether it is a green or a brown field factory. Furthermore, the size of the plant, as well as the number of applications of 5G services within the plant domain, play a deciding role. This goes hand in hand with the 5G Service Provider engagement options. Depending on the manufacturing plant size and the number of applications, it might be more beneficial to offer a: 1) dedicated, independent 5G campus network; 2) 5G campus network within the public network of an 5G Service Provider; 3) 5G campus network with local user plane and network elements within the public network of an MNO; or 4) combination of the above.

This one-to-one relationship between 5G Service Provider and a manufacturer may encounter challenges arriving from the ecosystem context in (at least) two situations. One example is when the manufacturer realizes there are huge cost, but also quality and revenue benefits by applying 5G technologies. However, the business case is only positive at a price point which the 5G Service Provider can offer from a 5G implementation which is shared between many paying customers. Thus, the manufacturer's business case gets dependent on mobilizing other firms to explore and identify 5G business opportunities and share with them the cost and motivate the 5G Service Provider to offer services in the same geographic area. Another example is, when the 5G Service Provider learns that the manufacturers' benefits from 5G is conditioned on seamless outdoor and indoor coverage, and thus, interoperability and roaming between any outdoor and indoor 5G Service Provider. The 5G Service Providers may find that full interoperability is possible to achieve only when the indoor role is catered to by firms that are different from those serving the outdoor market.

5.4 5G vertical ecosystem Example #2: Health

eHealth is the practise of supporting healthcare with electronic processes, communication and information management systems [101]. The health vertical is present in all societies, and its generally large share of the GDP reflects a large addressable market also for 5G [102].

Thus, the existing Health vertical is mature with a large market size, incumbent stakeholders, and set structures and relationships. Still, analyses of health markets and use cases suggest that some new roles may emerge (see Appendix 5) [103]. In the existing markets, medical technical solutions seem to be delivered in a somewhat disaggregated manner across different deployments. For instance, medical equipment in need of connectivity adhere to hospital's local networks or rely on own installed and proprietary network solutions. Currently, health markets are national, and even regional (e.g., there is a practise in Italy and Germany with regional decision capabilities) in the sense that purchaser are local and subject to national or local regulations. In future, medical equipment may be carried by E2E 5G services across nations, caused by both the characteristics of solution (e.g., it is virtualized) and because medical equipment providers want one aggregation point across networks and national markets. Thus, we could expect *new* ecosystem roles and new type of relationships, with providers of: indoor 5G coverage; management of health data; E2E health 5G enabled services across national markets; aggregators of 5G services across national markets [105].

In the context of new roles and opportunities, both firms from Health and adjacent sectors, such as data management, could position for new roles, or SMEs could grow into them. The provisioning of E2E and data management solutions could also take the form of 5G platform ecosystems; in such a case, we must foresee a voluminous set of SMEs addressing specific Health challenges, aligned with standardized interfaces and processes.

The potential competition between roles and actors in an emerging Health 5G vertical ecosystem can be substantial. For new E2E health solutions, the balance in the relationships between providers of medical equipment, applications, and connectivity could change. An example case from GSMA and STL illustrates the potential tensions [104]. In short, they advise mobile network operators to not only take on roles as pure 5G Service Providers, but to move towards *"higher-value solutions tailored for specific target industries"*. In vertical markets in general, the market share of "Specific vertical solutions and applications" and "Aggregation platforms for data, applications and enablement services" constitute 70% and 25%, respectively. "Network-as-a-service" is left with 5-10%. The same market split is predicted for the 5G enabled health market, and MNOs are advised to aim for more than the "bottom" 5% connectivity revenues of the market.

5G Service Provider perspective: There may be a lot of truth in market analyses and forecasts that marginalize the 5G Service Providers' future connectivity revenue opportunities; it is also true that market analysts need to be very clear and even provocative to get their message through and to mobilize operators to act. The point to make here is that all actors in Health are re-considering their future opportunities and roles, all are chasing higher revenues and profits.

Health equipment perspective: We should expect that large medical equipment providers (e.g. Philips, Toshiba, and Drägenwerk) are considering how they can provide large medical platforms where the networks is only an input resource, and which e.g., SMEs are mobilized to use.

SME perspective: SMEs are discussing how to get access to purchaser, how to bypass the existing providers with their new innovative solutions, or how to persuade these providers to open their interfaces and give access to resources.

5.5 5G vertical ecosystem Example #3: Smart cities

A *Smart city* is a framework, predominantly composed of ICT, to develop, deploy, and promote sustainable development practices to address growing urbanization challenges [105]. Since 2007, more than half of the world's population lives in cities, and that share is projected to rise to 60 per cent by 2030 [106]. Furthermore, cities contribute to about 60% of global gross domestic product, and about 70% of global carbon emissions and over 60% of resource use. Thus, there are increasing pressure for innovation, efficiency, and social innovation to handle the growing urban population and their growing demands for better living [106].

The ecosystem approach has been suitable to analyse the smart city phenomenon [107]. There are many roles, actors and goals, dependencies, and cities go through lifecycle phases. The overlapping challenge between smart cities and ecosystems are summarized in the question: "What do policy makers and managers in these ecosystems for smart cities need to do in order for their projects to be sustainable in the long run?" [109]. This is the arena which 5G and beyond providers enter and intend to be a part of.

The *smart city ecosystem* is comprised of people, organizations and businesses, policies, laws and processes integrated together to create the desired outcomes applying technology to accelerate, facilitate, and transform the ecosystem. Successful smart cities often include the following stakeholders: Government, Industry, Academia, Entrepreneurs/Start-ups, Creatives & Artists, Residents and Advocates & the Social Sector [108]. Involving and recruiting stakeholders to contribute to the smart city is challenging. In this context, those who represent the city are the enablers for the smart city, avoiding political bottlenecks, balance authority, having clear accountability, enhance synergy of city stakeholders, strengthen project foundation, and improve users' experience [109]. Industry analysts highlight that smart city development is just as much a society driven exercise, as a technology driven one. In this respect, social entrepreneurs are playing an important role as intermediaries which unleash a willingness among stakeholders to increasingly experiment with additional diverse democratic arrangements beyond the conventional private-public partnerships [109].

[107] has reported the need for appropriate leadership strategies in different phases of evolution of the smart city. Smart city government takes steps away from market governance, and instead overlaps with strategies suggested by the ecosystem approach. The focus of the strategies, however, shift throughout the lifecycle. In the smart city initiation phase, there is a need for internal relationship building and trust, transparency, commitment, and goal setting. In a growth phase, the focus turns to external relations, a more controlling leadership requires co-creation strategies, promotion, and performance measurement. In early and late phases, it is vital to manage expectations.

Overall, a city which adheres to the definition of a smart city is already a rather mature ecosystem with mutual trust, clear roles, and expectations to stakeholders.

In what follows, the work of some EU-funded research projects is taken as an example to dig down on the Smart City ecosystem analysis.

5.5.1 5GCITY

The project 5GCITY [112] merges the idea of the smart city and 5G ecosystems by enhancing the role of municipalities and introducing a platform architecture managed as a neutral host. The proposed neutral host and the proposed business model "turn a city into a distributed, third party,

multi-tenant edge infrastructure" [112]. The 5GCity neutral host infrastructure dashboard allows operators and interested parties to develop (and pay for) slices, using a set of virtualized resources according to their needs, which again could be provided to customers and users for different purposes. The smart city entity could also choose to create a slice instance to provide, free of charge, public services to citizens. Yet other commercial and public entities could create slice instances for purposes such as entertainment or health care. 5G-CITY [112] also identified obstacles to the emergence of a smart city 5G ecosystem where a 5G Service Provider serve as a neutral host. First, there is a general scepticism towards the traditional telecommunication operators to their ability to share data, traffic, or information with other roles. Second, interoperability is necessary to achieve the vision of a smart city, but experience tells us that it is challenging to achieve both technology and business wise across all networks, slice instances and services.

Thus, in the case of neutral host [112], smart cities are concerned about their knowledge and experience to operate the network and, frequently, they are thinking of outsourcing it to a private company. Moreover, a 5G Service Providers face the question of developing and providing 5G empowered services alone, or rather mobilize other complementors to take on additional roles. Clearly, there are costs, revenue streams, and local contexts that must be considered in the case of an existing smart city. If applying an ecosystem strategy, municipalities and 5G Service Providers would admit potential share of total revenues to other roles and seek to cover costs from multiple wholesale purchases and a standardized service portfolio. That is, the adaptation to local and vertical requirements would be left to other roles, i.e., other service providers, and enterprises.

5.5.2 5G-TOURS

The project 5G-TOURS [113] brings together within the context of a city three core economic value creation ecosystems; Touristic sector, Health Sector and Transport (Airport) sector. For each of these sectors that form part of the economic value creation of a modern city they stand as independent ecosystems of value creation but can also act in concert. Anchor use cases in each sector create a business case for the deployment of networking infrastructure and devices. However, the vertical and users of these systems can benefit from the continuity of user journey crossing from one vertical use case ecosystem that is centred around the airport and then taking on the role of a tourist in the touristic city.

Whilst each deployment model for infrastructure in their city context may well be financed and deployed using different principles, the objective is to provide a continuity of capability in the service layer of the network, in the case of 5G-TOURS using 5G-EVE infrastructure [115] such that use cases and service layer concepts are portable and employ virtualisation principles. In this way a network of networks concept can emerge from the smart city context, illustrating how ecosystems may evolve.

5.5.3 5G-SOLUTIONS

In the smart city ecosystem, citizens are one important stakeholder in the planning process, co-designing and co-creating urban interventions in cities, but also the process where local community decides how to allocate part of a municipal budget [110] [114]. The smart city is one vertical studied in project 5G-SOLUTIONS, with use cases such as smart parking, and smart building and campus. Furthermore, smart sustainable city co-creation is explored together with the Norwegian University of Technology and Science and their +CityxChange project [109].

5G-SOLUTIONS also created an open innovation framework that can be used by cities, solutions providers, and citizens to set joint targets, assess their progress and learn from each other. This framework combines knowledge and experience of the partners and local stakeholders, public and society. The significance of mobilizing citizens is underscored by how the initiators co-authored a 'Citizen Engagement Solution Booklet'. The booklet summarizes how the city can manage citizens' engagement with the aim of reducing the effort, speeding up the process, strengthening quality and confidence in outputs, aligning across disciplines, and generally preparing a city to engage the market to acquire a solution [5-28], thus, making it easy to take part in innovation.

Tools and platforms to make citizens central in the delivery of smart projects are also available [111] [115]. [116] supports the engagement from citizens and other stakeholders (academics, industry, NGO, etc.) to the success of urban development projects. However, the authors also advice that it is important to question who is participating and why and to determine their underlying motivation to ensure that others do not go unheard.

5.5.4 5GENESIS

The project 5GENESIS [121] aims at validating KPIs for various 5G use cases, using five '5G Platforms' provided and run by several project partners. Project activities related to business and ecosystem aspects are taken care of by a set of Innovation and Exploitation Workshops [122], which have provided interesting results on future 5G and beyond vertical ecosystems.

In what follows we report the outcome of the six workshops held for the Malaga Platform, as it focuses on the Smart-city vertical. The validated use cases are all related to Mission Critical Services (MCS), driven by project partners like Nemergent and the Malaga Police Department. The actors related to the Malaga Platform are: i) those who run the Platform and clarify what added value and new added functionalities are; ii) the potential Platform customers that plan to exploit its benefits and features, in order to finally deliver better services to their own customers.

The actors related to the Malaga Platform are: i) those who run the Platform and clarify what added value and new added functionalities are; ii) the potential Platform customers that plan to exploit its benefits and features, in order to finally deliver better services to their own customers.

At first the Malaga Platform was analysed in order to assess its business potential, which resulted in the creation of five *exploitable outcomes*; the most promising one (from the business point of view) among those was identified to be the '*Platform as a private network operator service*'. Then, the known Value Proposition Canvas (VPC) method was applied to identify how three potential customers could benefit from the enhanced city network based on the Platform, so to better perform its surveillance and patrolling services. These customers also indicate further important roles in a future 5G vertical ecosystem for smart cities, i.e.:

- 'Vertical Service Developer', e.g., potential customers like industry (Airbus) or SME (Nemergent) delivering customized services to a broad set of their own customers;
- 'Research Project' willing to exploit the platform services for research-oriented targets;
- 'Service Operator-Service Evaluator', e.g., the Malaga Police Department, which will benefit from the enhanced city network based on the Malaga Platform so to better perform its surveillance and patrolling services, for the final benefit of the whole community.

Further analysis identified the first one as the most promising customer from the point of view of potential revenues for the Malaga Platform. The VPC created during the last workshop held in Q2 2021 provided a comprehensive picture of the potential of the Platform under analysis (more details will be made available in Q4 2021 in [122]). In the VPC, the main features are listed of

the offered product (i.e., the Malaga Platform), features tuned to the needs of the one Customer in focus, i.e., a 'Vertical Service Provider' that uses the Platform to deliver its services to its own customers. Further, the planned Gains and relieve of Pains are listed in the VPC, seen from the customer point of view. One can see those items as a wish-list of services the Customer would expect from the Malaga Platform. Finally, the characteristics of the product that can properly address and exploit (Gains) or solve and minder (Pains) are items created by the Customer in focus. Each Pain and Gain is to be addressed by at least on Gain Creator or Pain Reliever. For instance, a 'Gain' for a 'Customer' is 'Shorter slice creation time - service creation time' and the related 'Gain Creator' for the 'Product' are: 'MCS vendors can test their virtual servers in different NFV schemes and get ready for different commercial deployment requirements' and 'MCS vendors can test their applications in available 5G UEs'. An exemplary 'Pain' for a 'Customer' is 'Unstable and not up-to-date NFV deployment platform (for testing cloud and edge VNF deployment schemes)'; the related 'Pain Reliever' for the 'Product' is 'Availability of local platform experts to support and help in the configuration and execution of tests'.

To elaborate on the Malaga Platform as an ecosystem, a next step is to consider the dependencies between the providing parties and the actors who co-create and offer solutions to end users. A crucial point is to make it easy to innovate with the platform, as one pain relivers captures: "Well-structured portal that exposes the main platform features in an easy way". The VPC does not report pains about decreasing uncertainty for future revenue sharing, however, such factors may still affect the success of the Malaga Platform if it turns out to have ecosystem characteristics.

5.6 How can 5G vertical ecosystems be encouraged

According to the ecosystem approach, in a market where actors are dependent on each other but without decision rights, a pure head-on competition for roles and revenues may be counter-productive for innovation and growth. We have described several emerging 5G vertical ecosystems, seemingly in their very early days; parties acknowledge they are dependent on each other in delivering value to customers and users, but roles are not settled. At the same time, we have reported perceived concerns among those parties that need to be mobilized. We have illustrated how tensions could play out regarding protecting existing and acquiring new roles, competing for new revenues in existing roles, getting easy access to 5G resources, and interoperability technologically and business wise.

The key insight we provide is how to approach markets which have characteristics of an ecosystem. To compete with those parties that you are dependent on may hinder the 5G market to start growing. To fuel 5G market growth further requires active mobilizing of other parties by making it easy to innovate, but also to establish a market which they perceive as attractive and with acceptable risk levels. When firms choose to enter roles where they do compete with those that are their collaborators – and this will happen – the division of roles should be demonstrated clearly, and trust earned through consistent communication and action.

6 New challenges for the 5G ecosystem

Our elaboration on the 5G ecosystem vision emphasized opportunities and challenges focusing on the 5G provisioning and 5G vertical ecosystems. Yet, new challenges are already emerging around energy consumption and sustainability, and data management and privacy. Thus, growing concerns may significantly affect the evolution of the 5G and future 6G ecosystems.

First, 5G technological breakthroughs have addressed the customization challenge and allowed end-users to express their needs and requirements, through 5G-related standardization processes (e.g., the 3GPP) or through consortia and forums in pre-standardization phases. Network architecture and configuration can now be shaped as a function of services requirements. It is thus highly probable that the race for energy efficiency, to fight against the climate crisis, and the fear of data leakage and cyber-criminality become new requirements for 5G users, as well as new drivers towards the development of new technologies.

Second, such concerns may further shape business relationships and lead to the emergence of new roles and new actors in the 5G and beyond ecosystem. In an initial phase, these concerns may be understood by some actors as a real burden for market growth, especially when it comes to setting new rules towards the protection of the environment or the protection of citizens' private data. Regulators at different levels, local, regional and international, are likely to play a pivotal role in shaping the evolution of the 5G ecosystems and in the future balancing of stakeholders. With time, these concerns may however be considered rather as new opportunities to offer services that better match users' sensibility. The need to guaranty sustainability and security of end-to-end 5G-enabled solutions, accounting for their whole life-cycle, may render roles and stakeholders even more dependent on each other in the delivery of such solutions.

In the following, we first introduce the issue of the ever-increasing demand for energy and resources from the ICT sector and discuss how 5G and beyond deployments and related regulations could impact achieving sustainability goals. Second, we elaborate on how the 5G and beyond visions may lead to a continuous data growth, especially boosted by ubiquitous IoT devices and distribution of ultra-high-quality content media. Technology progress is already taking care seriously of these concerns, however if not continuously monitored and addressed, both trends can be counterproductive to the benefits of 5G by creating rebound effects (including cyber threats and data breaches). This highlights the need to carefully navigate the efforts of the 5G ecosystem's stakeholders around such trends to maximise potentials and facilitate sustainable growth. For each section we discuss how governing and regulatory mechanisms might pose technical and non-technical challenges that have to be overcome and how these could impact future 5G ecosystem evolutions.

6.1 An evolution towards sustainability and energy savings?

5G high performance networks and their new features are seen as key drivers for digitalization. They are expected to be implemented globally and rapidly. With a massive 5G roll-out, the electricity consumption and consequently CO_2-emissions of communication networks are expected to substantially increase [123]. ICT is already responsible for 5% of the world's CO_2-emissions, a value most likely to grow quickly as the number of connected devices and data traffic increases [124].

Additionally, beyond increases in energy efficiency and growing importance of (local scale) sustainable energy sources, regulations of data traffic growth might be needed to achieve 'digital sobriety'. New policy regimes are emerging to tackle increasing energy demand. In December 2019, the European Commission presented the European Green Deal for a sustainable EU-economy. Three objectives are in focus: zero net greenhouse gas emissions by 2050, decoupling economic growth from resource use, and that no one, neither people nor region, is left behind. This European Green Deal is supposed to be the roadmap of a sustainable EU-economy while also having a major impact on ICT-industry [126]. In line with this, 5G-PPP declared energy savings as one out of seven key technological challenges to be addressed [3]. To achieve those political targets some EU-countries might adopt regulatory tools through a 'digital sobriety' approach and increase taxes on energy, control or regulate data traffic growth or introduce an obligation to measure energy efficiency.

6.1.1 5G technical breakthroughs: an opportunity or a threat for climate change?

As it happens for each newly introduced technology family [127], 5G novel mechanisms help overcome the inefficiencies of the current communication technologies, including the dimensioning of cells and their capacity to handle peak traffic hours. According to [125], LTE networks have shown that base station resources are generally unused 75-90% of the time, even in highly loaded networks. 5G is going to introduce different bands, cell sizes (e.g., macro, mid, and small cells), new protocols (e.g., reference signals) and antennas (e.g., beam-forming) for addressing specific needs of load capacity per km^2 and bandwidth efficiently. These allow 5G to bring higher spectral efficiency (from 2bps/Hz to 10bps/Hz and more), serve more devices (up to 100 times more), and enable reducing energy spent per bit transmission by 10 to 100 times with respect to LTE.

From another perspective, 5G can directly contribute to environmental sustainability in many important fields and boost deployments to enable various vertical markets, in line with the EU policy framework on energy. We have already mentioned the crucial role 5G may play in the transformation of the energy sector towards smart grids, smart metering and digitization of power plants. Other positive environmental impacts can be realised in the mobility sector by facilitating de-carbonized multi-modal and shared mobility as well as in production towards utilising highly efficient smart factory and Industry 4.0 concepts. Because of such potentials, highly environmentally conscious policies, if adopted, can boost and support the 5G business ecosystem (e.g. through funding, easy-to-grant deployment permits), especially considering 5G-enabled solutions with inherent environmental sustainability character.

However, a higher number of connected IoT devices and related data will likely result in higher traffic, and thus higher power consumptions, CO_2-emissions, and resources use. Furthermore, 5G could be driving the wide-spread use of energy intense applications without inherent benefit to sustainability (e.g. high-resolution video streaming). Use cases like cloud-based mobile gaming could lead to a disproportionate rise in energy consumption not fully compensated by more efficient mobile networks. This puts a lot of pressure on roles and actors in the 5G ecosystem and highlights the need for resource efficient solutions in all aspects of a 5G and beyond network to minimize negative environmental impact. Efficient solutions can be driven by regulatory policies as well as the market conditions. Thus, the current willingness to restrict energy consumption is an additional driving factor in 5G and beyond ecosystems and may introduce new dependencies, roles, and business relationships.

6.1.2 New business challenges around sustainability

An annual growth of global mobile data traffic of 50 to 60% has been observed in the past [128] and current business models mostly consider the continuity of this high data growth.

However, there are some uncertainties about it and about the traffic profile of future networks. So far, the mass market could be considered as one of the biggest data consumers / cellular service users, but this trend may change in the future. Some analysis forecasts a diminution of the pace of cellular traffic growth [128], which may be further sustained by the increasing citizens' awareness on climate change and willingness to limit their energy consumption. Growing concerns on the Electric and Magnetic Fields (EMF) exposure level might also imply a loss of trust among a part of the population. On the contrary, verticals are increasingly interested in the value brought by 5G-enabled use cases and there is growing demand for ubiquitous connectivity. Such change in the traffic profile may significantly impact future 5G and beyond ecosystems, as well as future regulatory frameworks.

Second, the increasing prices of electricity, sustainability and green policies, social acceptance, and diversity of energy sources might be incentives to invest in the usage of renewable (on-site) energy and increasing effort on the development of energy efficiency technology. Energy efficiency measures, first adopted by businesses that are more sensitive to electricity prices, have resulted in these being amongst the most energy efficient in the world [129]. At this point it shall be noted that for network providers, electricity typically accounts for 15% of the network OPEX from which 80% account for base stations energy consumption costs [130]. Thus, the cost of energy is a significant factor contributing to the business sustainability and fix cost savings. This potentially impacts the way of doing business, in particular due to the growing number of smaller energy producers or the possibility for vertical / 5G stakeholders to produce their own energy locally. Interconnections may emerge between the energy sector and the 5G ecosystem.

6.1.3 Open questions on resources shortage

For 5G stakeholders, it is very important to decouple the economic growth of ICT from CO_2-emissions and the exploitation of natural resources to follow a vision of green communication and compliance with the Sustainable Development Goals [131]. The solution is to design, implement and operate 5G high performance infrastructures as energy efficient, resource-saving and environmentally friendly as much as possible.

Yet, continuous shortage of resources (including energy) needed in every single phase of the 5G deployment and their services, highlights the need to enact more sustainable processes through regulation, recycling of materials and investments on developing new innovative renewable raw materials and sustainable technologies for the well-being of the society. In particular, 5G and beyond ecosystems should already consider and get prepared to accommodate the forthcoming shortage of semiconductors, and other key hardware components, in order to avoid any crisis which would be detrimental to the whole market.

6.2 Data management for 5G vertical ecosystems

For years, data and its processing were viewed as an expense by organizations, necessary to business operations, but not as an opportunity. Recently, new technologies, among which artificial intelligence (AI) and big data analytics, have shed light on the high potential value held by data, such as product-related data or customer data, and triggered the development of innovative smart

services. Nowadays, the business of numerous companies is solely based on data, being it is data collection, transmission, processing, storage, etc. However, the strong and disruptive 5G dynamics could go much further than silo data processes (i.e., operated by a single-party) and may lead to the emergence of new usages and new players, towards the sharing of data among authorized stakeholders and the creation of combined data sets, for even higher value-added services. Yet, sharing and combining data sets hold a number of technical, business and regulatory challenges, as well as new threats, such as private data leakage or cyber-attacks.

The question of trust should have a significant impact on the evolution of 5G ecosystems. For example, today, some very large industrial companies make the choice to massively invest in standalone non-public networks that are designed, deployed and operated internally. Indeed, this deployment scenario is perceived as less risky when it comes to network isolation and security, even if this may not be always true from a technical perspective. Building trust between stakeholders is thus absolutely necessary to allow multi-tenant 5G solutions, as well as a good sharing of costs and liabilities.

6.2.1 Smart data services for 5G verticals – Examples of impact on 5G ecosystems

Smart cities are facing today the question of sharing their traffic data with navigation service providers (like Waze) while in exchange, these service providers would provide access to their real-time traffic and road conditions, for improved mobility management and urban infrastructure development.

Healthcare is also largely concerned by the ongoing digitalization. In particular, the electronic health record should systematize the collection of patient's data and allow its sharing across health facilities or companies. In many aspects, the COVID19 pandemic could accelerate this trend, by the real-time monitoring of the situation across countries or by the sharing of sensitive data towards an internationally recognized health pass.

Industry would also benefit from data exchange. Today, the data generated by the production machinery and robots on a shop floor is generally isolated, confined to a given business process and available to the machinery owner only. But data could be shared in an automated and secured manner between other industrial processes and among authorized stakeholders, to provide valued information on similar machinery or on complementary domain for improved production, maintenance, and monitoring. For example, this would allow a manufacturer to fine-tune its production lines based on the data received directly from providers and related to the workpieces used on these production lines. Another example of such collaboration relates to logistics between suppliers and consumers, and intralogistics within a factory, on assembly lines. Indeed, delivering the right parts to the right place at the right time would significantly improve efficiency and productivity, while reducing stocks.

6.2.2 Standardization and regulatory challenges of data management

Data management holds a number of technical, business and regulatory challenges, as well as new threats, such as private data leakage or cyber-attacks. Before going into more details, these challenges can be summarized as follows:

- How to incorporate requirements specific to verticals into 5G standards?

- How to cope with the net neutrality regulation?
- How to adapt the GDPR regulation?
- How to deal with the heterogeneity of data and technologies?

First, significant effort has been made to improve the performance and security of services over 5G networks. Although the Internet, as we know it today, is largely characterized by supporting just a single traffic mode (aka. "Best-effort"), 5G does support adaptable network performance, for both private and public network, and slicing allows the creation of a virtual isolated E2E network, tailored to the customer's needs across the network operator domain, i.e. a private network can be emulated on a public network. For this purpose, 5G users (e.g. Industry players, car manufacturers, and stakeholders from the logistics and transportation vertical) can now fully participate in the 5G network configuration and monitor its performance, through new collaboration tools, API and practices. They can also share their needs and expectations by 5G standardization and regulation, either directly or through consortiums, like 5G ACIA [91] for Industry. For standards organizations, like the 3GPP, **accounting for those new requirements**, in all their diversity, is a real challenge. In particular, sharing a common vocabulary is essential to clearly define KPIs and their value (e.g. a 10ms maximum latency). Trade-offs have to be found to be able to tailor 5G networks to users' needs while avoiding creating one standard for each vertical or each use case. Thereby, the 5G standards may evolve depending on the 5G users which are the most involved in this standardization process. This may have significant impact on future 5G ecosystems. New consortiums or associations, dedicated to a particular set of 5G users or 5G-enabled use cases, are likely to be created to defend their specific needs and ensure they are taken into account in future standards. New synergies can be expected from such collaboration and the scope of activities of ICT and verticals, which have remained clearly distinct so far, may go overlapping, pushing verticals to gain expertise in 5G technologies and pushing ICT to master verticals' fields of expertise.

Second, 5G innovations supporting adaptable network performance will have to adapt to and consider the general broadband regulation, including **net neutrality regulation**. This will apply across the range of critical services, not only society and business operation critical but also consumer and citizen critical network slices. Furthermore, new 5G features, including new spectrum policies and network infrastructure sharing, make the difference between private and public networks quite fuzzy. There is a need of a solid regulatory platform that ensure a predictable and innovation-friendly environment, for all relevant stakeholders and actors. We can anticipate that the notion of "specialized service" (a key term in today's net neutrality) need further elaboration and separation into i) "*specialized connectivity service*" and ii) "*specialized application service*" where the latter is enabled by the prior.

Third, the EU data protection regulation no. 2016/679 (GDPR) [159] and the EU privacy framework are technologically neutral [133] and aims to provide an adaptable, flexible and legal framework regulating certain aspects of personal data processing. GDPR reinforces the role of the European Data Protection Board (EDPB), giving it the power to issue guidelines on several topics. In other words, GDPR was not designed to regulate a specific technological solution, but it is "neutral" since it can be applied to all the activities involving personal data processing, regardless to their technological nature and status. A few concrete examples of this approach related to 5G can be found considering the EDPB guidelines on processing of personal data in the context of connected car [134], or the EDPB open public consultation on virtual voice assistance [135]. For certain major technological developments, new regulations and innovative legal frameworks at EU level have been planned, as it is the case of AI [138], or even the new proposal

of ePrivacy Regulation which should supersede the ePrivacy Directive on electronic communications [136] (also relevant in the framework of 5G solutions). However, several key aspects around 5G-enabled smart services, in particular for IoT, are **still incompatible with current GDPR regulations**, as further detailed in [137]. Numerous rights (e.g., the right to rectification, to be forgotten, to restrict processing) and time units (e.g., the 72h time limit) hardly suit 5G high speed data rates, high density of devices and high volume of data from diverse sources. Identity management is also a real challenge and the principles of GDPR data protection do not apply to anonymous data, which are not related to an identified or identifiable natural person. Then, in a 5G security context, a key objective is to separate a user of a specific device. Yet, how to deal with data automatically generated by robots, machines or algorithms, which may hold significant value for companies? How to deal with infrastructure mutualisation (including RAN and CORE sharing and user plane / control plane separation), where the notion of equipment and resource ownership becomes unclear?

Finally, and in line with previous challenge, another core issue emerges from the heterogeneity of data to be processed or exchanged. Generally, this data comes from a mix of sources (e.g. citizens' metadata, IoT sensors, cars, traffic lights, robots…) and from a mix of stakeholders (e.g. private companies, different levels of public players, from local communities to national State, and potentially international stakeholders for cross-border services). In addition, it has a mix of properties (e.g. personal / private / public, free / shared / sold, real-time / past records / forecast...) and may be transmitted through a mix of technologies (e.g., 4G / 5G, Wi-Fi, satellite, fibre, copper cables...). Mechanisms have to be found to **align security and privacy standards** and to ensure the **interoperability** of 5G with other technologies, so that the E2E security and privacy of smart services does not reduce to their weakest element. The drone ecosystem can be given as an example. Indeed, airspace authorities, drones service providers, aeronautics industry, MNOs and telco manufacturers are currently looking for the right regulation to ensure the safety of national and international airspace, while the sky shall be shared by manned aircraft, including planes or balloons, leisure drones, professional drone for aerial inspection, delivery drones, tethered drones military drones, using Wi-Fi, cellular, satellite, ADS-B connection or even optical fibre in case of a tethered drone.

More than any other cellular technology, 5G is questioning current regulation on data management and privacy. Because it will be used also for critical or emergency use cases, where lives are at stake (e.g., eHealth, connected cars or airspace security), the roles of the different stakeholders within the 5G ecosystems are likely to evolve in a much tighter regulatory framework, with potentially higher transparency requirements and more constrained certification/validation processes. In addition, a new business sector may gain prominence: insurance. Indeed, when end-to-end services are going to be largely multi-tenant and to gather several market sectors, each with its own regulation, a good understanding and sharing of liabilities will be essential, in particular in case of failure.

6.2.3 Ensuring trust between stakeholders: a new role for 5G?

In any case, what should be born in mind is that the challenges raised by 5G deployment are also opportunities. Opportunities not only for legislators to stress already issued piece of legislation, but also to introduce better shaped and adaptable regulatory framework. In addition, due to the innovative field in which 5G will be deployed, a major role shall be played by market actors companies, which can have a primary role in pushing forward the legal design, applying in new innovative way of the principles of privacy by design and by default [132], but most importantly

by creating new technological development able to respect the fundamental rights of personal data protection and privacy [133].

As exemplified earlier, business for smart services increasingly involves data monetization, for exchange between stakeholders, combination, joint processing and reselling. However, data is not as any goods. It may rapidly become hard to control its use, once it has left its producer's data centre, and to ensure data will be properly consumed, by the right / authorized consumer. There is growing concern regarding privacy, data sovereignty and governance. Several issues have been raised, among which data confidentiality, loss of data ownership, bylaw conflicts, creation of shared environment, different objectives in terms of security among the actors involved, data governance, visibility, transfer of data, hacking and IoT privacy issues [134].

As a means of transmitting data from producers to consumers, 5G definitely has a role to play in ensuring trust between stakeholders [139]. The mastering of enriched and trusted connectivity is a promising opportunity to sustain the 5G momentum. Trust can take a variety of forms for the various parties involved in a digital ecosystem:

- Individuals or organizations which are the sources of the data are concerned whether organizations that process data, use the data as authorized;
- An organization that processes the data, is concerned about data provenance;
- Individuals care that data are used only for purposes that have been clearly stated;
- Organizations that use data output must rely on that the output it is correct and unbiased.

To establish trustworthy relationships between involved parties, the following elements are seen as key expectations to be fulfilled:

- Data use controls: Establish who can use, process and pass on data.
- Secure data journeys: Identifying participants, from data source to the point of use.
- Traceability: Being able to log/record all activities performed in a data journey.
- Certification: Legitimize the level of trust, security, reliability and interoperability.
- Immutability of compliance's proofs: Compliance proofs resistant to tampering.
- A common vocabulary: Compatibility and interoperability rely on common understanding

In order to apprehend and further study how the concepts of trust-intensive data management can be applied from a business view perspective in the context of 5G, a data-related "roles model" describing a smart data service should be defined and added to the 5G ecosystem (e.g., data, owner, producer, consumer, clearing house, identity provider) and linked with 5G architectural aspects and implementation solutions. Until now, in the architectures designed for data management, there is no explicit role for 5G connectivity providers, however new opportunities are emerging regarding the roles of:

- *Infrastructure provider*, providing a certified data sharing infrastructure to clients. 5G connectivity providers' involvement is conditioned by their ability to comply with the data governance and framework and to act as a trustee party in terms of security, liability, performance.
- *Connectivity service provider*, as an asset of data management which could guarantee protection and performance between players.
- *Data application provider*: designing applications in a certified infrastructure will not be trivial. From this standpoint, this is business incentive for 5G connectivity providers to provide such services.

- *Data service provider*: in addition to building services for client's data assets, 5G connectivity providers should also provide services based upon its own data assets.
- *Data management integrator*: deploying and managing integrated data management solutions for 5G connectivity providers' customers (including the provisioning and the hosting of connectors, supporting intermediary data management components such as a broker or a clearing house).
- *Testing and certifying actor*: validating that a data management infrastructure complies with the certification process in place.

7 Conclusion

5G, the latest generation of telecommunication networks, has become reality since a couple of years, and from that point on, its deployment and adoption in basically all areas of the world have been realized at very fast pace. As a matter of fact, 5G has currently been established as the new must-have access technology for every new mobile phone. For that reason, it is a good time to provide some insights into the status of the 5G ecosystem that has been built in the meantime, in different ways and in different areas of the world. This White Paper therefore aims to provide a 5G territory cartography seen from the perspective of business and ecosystem aspects. The topics touched so far are briefly summarized in the following.

After a short introduction provided in ***Section 1***, ***Section 2*** defines and clarifies the basic concepts behind the terminology used in the White Paper, encompassing the derivation of the 5G ecosystem from the business ecosystem concept and analysing in general terms the structural characteristics of an ecosystem, such as its main players and roles, and the main drivers for actors to join an ecosystem. ***Section 3*** elaborates on the main stakeholders of the 5G ecosystem, showing its interaction with larger societal and economic systems, and providing a more focused definition of the 5G ecosystem. ***Section 4*** dives deep into the concept of the 5G provisioning ecosystem, describing its main roles and the different stages it is composed of, while also touching on niche aspects, listing key factors driving the 5G business towards adopting some ecosystem strategies, and finally highlighting the main challenges in the development of the 5G provisioning ecosystem. ***Section 5*** starts by defining a 5G vertical ecosystem and its differences to a 5G provisioning ecosystem. Then, basic roles of the 5G vertical ecosystem are described, together with the main challenges different parties perceive when engaging with it. The section ends with providing three examples (related to the 5G verticals Industry 4.0, eHealth, and Smart cities) of emerging 5G vertical ecosystems, which are used to highlight the opportunities that novel 5G services can provide to business, as well as the early and unresolved matters about roles and eligible candidates to fill those. ***Section 6*** gives a glimpse on what is supposed to happen next, touching on the evolution of 5G networks (5G-and-beyond) and its impact on the related 5G-and-beyond ecosystem aspects. Some key topics are touched upon, for instance energy and resources consumption, linked to the UN sustainability goals, data management and the common data space issue, and finally the not least important problem of trust among the 5G ecosystem players and stakeholders (encompassing established- and forthcoming ones).

In this last Section, we want to touch upon some forward looking aspects related to the evolution of 5G from the non-technical point of view, and provide some recommendations that can bring value to the entire 5G-and-beyond ecosystem, as they hint at best practises and lessons learnt from the introduction of previous generations into the business ecosystem.

7.1 Catalysts of 5G-and-beyond ecosystems

Several activities are currently taking place to start elaborating what the next generation of communication and computation system could look like, a system which is called ***5G-and-beyond*** (in literature) or **5G-Advanced** (according to the latest 3GPP jargon) if the three-years' timeframe regarding market launch is thought of, or ***6G*** when thinking of a five-to-eight-years timeframe beyond the current developments.

Worldwide, several associations constituted of stakeholders and players in the current 5G systems, including the always growing number of 5G verticals, have started working on creating consensus on what 6G may look like, for instance the 5G-IA [4] and NetworldEurope [2] in the EU, the Next G Alliance [140] in the US and the IMT-2030 (6G) promotion group in China. Several works have started to appear on the 6G topic since early 2020, coming both from the work conducted by the mentioned associations, and from literature, in the form of White Papers, position papers, conference and journal articles. For instance, ITU-T[141], Smart Networks and Services (SNS) [142], NGMN [143], recently issued interesting visionary documents, describing what is going to happen in the next years from the perspective of new technology enablers paving the way towards 6G systems. Those documents focus on technical aspects, as it is indeed too early to elaborate on the forthcoming ecosystem around 5G-and-beyond or even 6G networks. To have proper and educated conversations on those topics, at least a young market needs to be analysed to draw some meaningful conclusions. It is worth noting that usually a commercial market cannot appear before standard bodies issue relevant specifications, and it is common consensus that standardization work on 6G topics will not start before 2025. In summary, lots of insight is currently being built in a pre-standardization arena, sketching what 5G-and-beyond and 6G systems will be, but no educated conversation can happen for the next few years on business and market related aspects.

Nevertheless, creating an environment where discussions can take place on the potential evolutions of the current 5G ecosystem as well as on the emergence of potential new markets, is very important. That opportunity is given in the EU by, for instance, the work of several streams of activities within the SNS partnership [142] (in preparation), more specifically under the workgroup BVME, which most of the authors of this White Paper are part of. Scope of this team is to constantly monitor the evolution of the market and of the 5G ecosystem, and to issue timely updates to the business situation, e.g., by issuing revised versions of the White Paper.

It is also very important to create and economically sustain the existing ecosystem, enabling it to grow in a very competitive market landscape. This is one of the reasons why the newly launched Horizon Europe programme [6] is considered vital for the evolution and the establishment of a strong European ecosystem on 5G-and-beyond related domains.

7.2 5G-and-beyond ecosystems roadmap

Thanks to the ongoing extensive roll-out of 5G, high economic and societal growth, associated with a consistent amount of new innovations, are expected in the areas of the world that will deploy 5G and its evolutions. If the players and the stakeholders of 5G are dependent on each other in delivering the value proposition to users, they should consider applying ecosystem strategies, for the sake of maximizing the synergies and minimizing undesired overlaps.

It is uncertain if an ecosystem will kick off and grow, or the path it will take. Hence, we suggest grasping the possibility of shaping the ecosystem by identifying the hurdles and addressing them, and by aiming to reinforce enabling factors. For 5G and beyond, both hurdles and enablers can arise on the global as well as the local level. Thus, the realization of 5G ecosystems may take different forms in different national markets and vertical industries. Furthermore, the sequence and timing of hurdles, how and when they are mitigated, affect the path in unknown ways.

In an ecosystem context, the critical success factors are under the control of industry and make it easy to innovate and provide an attractive environment for firms to join. This nevertheless will happen with the unavoidable creation of tensions, as firms will compete to gain market shares

and, at the same time, collaborate, e.g., to create standards forming their own products. Among the factors that can make it easy to innovate and affect acceptance and evolution of the ecosystem, one can mention:

- **Open-X paradigm**: an open an inclusive environment is to be looked after as much as possible, as it is supposed to guarantee the fastest and broadest possible adoption of new technologies, while it allows newcomers to find their place in a growing and evolving ecosystem. The availability of the following features is considered key building blocks for a flourishing European future market, which has innovation and growth opportunities as its targets:
    - ***open-SW*** (to avoid the need to write a piece of code for common functionalities from the scratch),
    - ***open-APIs*** (e.g., to facilitate the management of different implementations for underlying technologies across MNOs, details not needed to be exposed to final users or potential commercial partners),
    - ***open-platforms and open-testbeds*** (to provide all players, also SMEs and academia, which might not have the skills, the workforces or the economical capability of building their own testbeds),
    - ***open-HW*** (it is very important to mention the ongoing EC-driven activities like the European Processor Initiative (EPI) and GAIA-X to create a secure, common and agreed-upon open data space for European players),
- **Standards**: without an agreed-upon standard, the introduction of new products and technologies in any market is slowed down, if not hindered. It is therefore crucial that the whole European industry will play a pivotal role in the creation of forthcoming standards related to 5G-and-beyond, and even more so on 6G technologies. The SNS with its dedicated workgroup on Pre-Standardization work, is in an excellent position to provide the existing ecosystem with a playground to align and exchange ideas among all players of the 5G ecosystem.
- **Pan-European, cross-border and cross-domain interoperability**: in this respect, interoperability extends beyond what is possible today, e.g., based on roaming agreements that allow customers to use basic services (voice, data...) in two separate networks, namely towards:
    - ensuring interoperability between multiple 5G technology domains of various layers (datacentre, virtualised infrastructure, network operation, etc.) in order to allow for service aggregation on top of these layers as a technical and business activity (as mentioned in the case of the GSMA proposed MEC platform in section 4.2), and
    - allowing for interaction and service provisioning across 5G provisioning ecosystems (as mentioned in the case between niche and large 5G provisioning ecosystems in Section 4.3) at initial stages taking the form of roaming between public networks and NPN.

To this end, various vertical Industries expressed the requirement to ensure service continuity and interoperability of 5G services, starting from the main 5G corridors including motorways, railways, and inland waterways across the national borders of the EU member states. The CEF2 programme has identified the need for investments to boost 5G network coverage along the 5G corridors to enable innovative smart mobility services for passengers and goods. A primary motivation is the transition to connected and automated mobility (CAM), which extends to generally stimulate the competitiveness of the telecom and transport industries.

- **Decrease knowledge barriers:** even assuming that the mentioned open-X paradigm and relevant standards are in place, new technologies are accompanied by knowledge barriers for users and uses, thus decreasing the intended openness. Human experts, who are those who will study and deploy new technologies, will after all, meet limitations to their ability to absorb new knowledge and replace or complement the current one. Thus, it is important to relieve the burden for users when introducing new technologies, for instance, with software developer kits, by enabling sharing of knowledge between experts, or to arrange a platform developer journey which guides the developer, step by step. In this respect, experimental platforms and testbeds are means by themselves that serve to decrease knowledge barriers.

Among the factors that can make an ecosystem more attractive and affect its evolution and growth are:

- **Signalling intent**. The uncertainty of contributing to develop and build a market and not getting anything in return, is a major risk factor in an ecosystem. To mitigate this, the actors should signal the roles they foresee in the ecosystem, including the role they are capable to fill and they want to have, and where they see that they are dependent on other roles and actors. This clarifies the costs and revenues different parties have to carry, and thus indicates the potential profit opportunities both in the short and long run.
- **Self-regulation and sanction:** when different players with different scopes and skills have to play in the same arena, it is key to play by the same rules, so that there is single, clear, and agreed-upon way of dealing with inevitable clashes, overlaps of market shares, technologies, and products, that may occur in any new and growing ecosystem. Knowing that all players have to follow the same rules will give the smaller ones the feeling that their small dimension is not necessarily a drawback for them, and the bigger ones the guarantees that their peers may not easily take part of their market share by means of unfair actions or of non-permitted agreements between a small sets of players to their own advantage. In an ecosystem, approved sanctions can be applied for unwanted behaviour, which may also serve to deter such behaviour.
- **Implement use cases as show cases:** At the verge of a broad deployment of a new technology, not all stakeholders and players of the ecosystem have the same knowledge, skills, expertise and capabilities to properly interpret the new environment, which comes due to the new features, technologies, or applications that have been newly introduced into the market. Therefore, it would be of great help to have a set of exemplary use cases for the most common vertical sectors of the ecosystem, which for instance, can help players with minor capabilities to ramp up knowledge in a quick way, and to avoid repeating mistakes others already made.
- **Regulation:** the regulation of each new generation of the telecommunication system was established based on existing working rules of the previous generations, adapted and updated in order to take into account new major aspects introduced by the new adopted technologies. In general terms, Regulation is the key in order to avoid monopolies or oligopolies that could stop the growth of a new market and could hinder the creation of new companies, services and applications. As a matter of fact, having a stable regulatory environment is a precondition for the development of any new business, as well as for the nurturing of a trusted framework where companies and ecosystem stakeholder would feel comfortable to invest in. Finally, it is foreseeable that Regulation of a new ecosystem will proceed in steps, dynamically adapting to the evolution of the new markets, for the benefit of ultimately all the stakeholders and players.

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Appendix 1 Terminology

In the context of Business Validation, Models and Ecosystems there is a high risk of confusing and inconsistent terminology. This results from the fact that many different teams which are working to address the pertinent challenges are coming from different backgrounds. Relying on sources external to the 5G PPP community does not help, because literature diverge on the definition of terms like business model, business case etc. Often terms are used loosely and certainly are not formally defined. From a pool of available and used definitions we have made some choices that approximate the intended meaning in this White Paper or have found a minimum consensus among the members of the working group. The definitions are in line with the terminology adopted since the beginning of BVME works, presented in [144].

A stakeholder is a party that holds a business interest or concern in e.g., an ecosystem.

A (market) actor or player is used in this document as a cumulative term to define legal entities with focused business interest. An actor can be a stakeholder in the ecosystem, or not.

A business role is the expected function performed by an actor (which is a stakeholder) in the ecosystem. Therefore, a business role can be mapped onto one actor, whereas one actor can perform one or more business roles. It should be noted that 3GPP in TR 28.801 is using the term actor to denote a similar concept to our definition, and which elsewhere is denoted stakeholder.

A business relationship can be defined as the association between two business roles that is manifested through a contract, which in turn specifies the context and constrains for the business relationship. In the context of an ecosystem, a contract should also be understood as mutual expectations between roles that are interdependent, however, do not directly control the other party. It should be noted that 3GPP in TR 28.801 is using the term actor to denote a similar concept to stakeholder.

A Business model describes qualitatively how *one* organisation endeavours to create, capture, and deliver value in an economic or societal context. A business model is used both for the description of how entrepreneurs create growth opportunities, as well as how established organisations identify new commercial opportunities.

A Business case is the identification of a business need that can be satisfied by the introduction of new or adapted existing products and services. It provides a systematic reasoning and argumentation about the assumptions, target market situation, benefits and risks, needed investments, as well as projected cash flow when an organisation plans to satisfy the business need. It typically includes also the opportunity cost and mostly expressed in quantitative terms in e.g. an Excel Book.

An ecosystem is in this White Paper defined in the following way: *"an ecosystem encompasses a set of actors that contribute to the focal offer's user value proposition"* [8]; however, in an ecosystem a single firm, even if it plays the role of core actor or "keystone" [9], cannot decide *"the integration of upstream input into the focal offer"* and must instead mobilize other complementing firms to decide to join the value creation [8]. All the other firms in the ecosystem ask a) if they should join, b) which pieces of a solution to provide, and c) the profits from doing so [10]. (See also introduction in this document).

Business Environment (also surroundings) is a term used to denote the combination of internal and external factors that influence directly or indirectly the operating situation of the firms (undertaking business activities at a specific business domain). The business environment can include factors such as: customers and suppliers; business activities of competitors and partners;

technology advancements; regulation, laws and government activities; market, social and economic trends. In the context of this White Paper, the term is used to denote specifically the business environment related to the ICT business domain. The 5G business environment term is used to denote specifically the business environment related to 5G. Business environment (thus 5G business environment) goes through various stages of development determined by (significant) changes in any of the influencing factors (e.g. by the maturity of business activities of firms at a specific domain).

Interfaces in ecosystems refer to technological interfaces such as APIs, or business interfaces such as business contracts.

Network effects is the term used in economics when the value a user gets from a good or service depends on the number of users of compatible products, e.g., in social media and classic telephony where existing users become a strong attractor for new users or when technological components offer wide compatibility. "Network" refers to the systemic nature of the phenomenon; studying social phenomena as systems is common in social sciences and innovation studies, and network effects are often referred to as self-reinforcing or feedback effects.

The 5G Provisioning Ecosystem encompasses those roles and actors who take part in developing, delivering, and providing 5G services. Traditionally, the telecom industry is seen as a value chain where network operators source the resources necessary to provide fixed and mobile telecommunication services. The notion of a 5G provisioning ecosystem acknowledges an increased dependency on other roles and actors to grow the 5G market.

The 5G Vertical Ecosystem black boxes the 5G provisioning ecosystem and focuses on other actors who work closely together as part of vertical industries. While roles and actors from the telecommunication sector are still present in this ecosystem, the emphasis is on stakeholders which work domain specifically and have a more generic presence across all verticals.

Value Chain is a term initially used by Porter [10], to define a business model consisting of sequential relationships between value producing activities in control of one organisation. Since then, the value-chain concept has been extended beyond individual firms. It can apply to complete supply chains and distribution networks creating value towards the delivery of a mix of products (goods and services) to the end customer. The industry wide sequential activities and interactions of the individual firms' value chains create an extended value chain, sometimes global in extent. Porter defines this larger interconnected system of value chains as "value system". In the context of this White Paper the term value chain is sometimes used with its broader definition, and specifically in terms of the telecom services provisioning it includes all activities -performed by any actor- from the deployment of network infrastructure to the interfacing with the customer. Despite such common uses of the value chain term, for the purposes of analysis, we will emphasize that the ecosystem approach serves to capture something which the value chain does not. The value chain's analyse markets as if they have a linear character; in contrast, the ecosystem approach assumes that markets are non-linear, and thus, the complexity and uncertainty increase.

Appendix 2 Two ecosystem approaches in COREnect

While this White Paper was being drafted, the COREnect project [145] decided to apply the "two ecosystems approach" proposed in this White Paper to analyse stakeholders in 5G and Electronic Components and Systems communities. The idea was to see whether this would add value in the identification of COREnect stakeholders, that were therefore defined on the one hand as the "COREnect provisioning ecosystem" and on the other hand as the "COREnect use case ecosystem". In return, COREnect provided feedback to the BVME-SG, as expressed in this sub-section.

Although challenging at first, the exercise demonstrated that it was feasible and useful to assign the different stakeholders to separate ecosystems. It provided a clearer picture of a complex ecosystem, comprising not only the 5G ecosystem but also the ECS (electronic components and systems) ecosystem, from the perspective of the COREnect community in charge of developing technologies, and from the perspective of the users of the COREnect technologies.

COREnect is a 2-year Coordination and Support Action aiming at developing a high-level strategic roadmap of core technologies for future connectivity systems and components, targeting the next generation telecommunications networks and services. COREnect sourced stakeholders from the 5G PPP stakeholder picture and followed the preliminary recommendations from the BVME SG to split between a provisioning and a use-case ecosystem: "COREnect community", i.e., the provisioning ecosystem; and "Users of the CORenect technologies", i.e., the use-case ecosystem. This is, to our best knowledge, the first attempt at a representation of two separate but complementary 5G (and B5G) ecosystems, in the model recommended in this document.

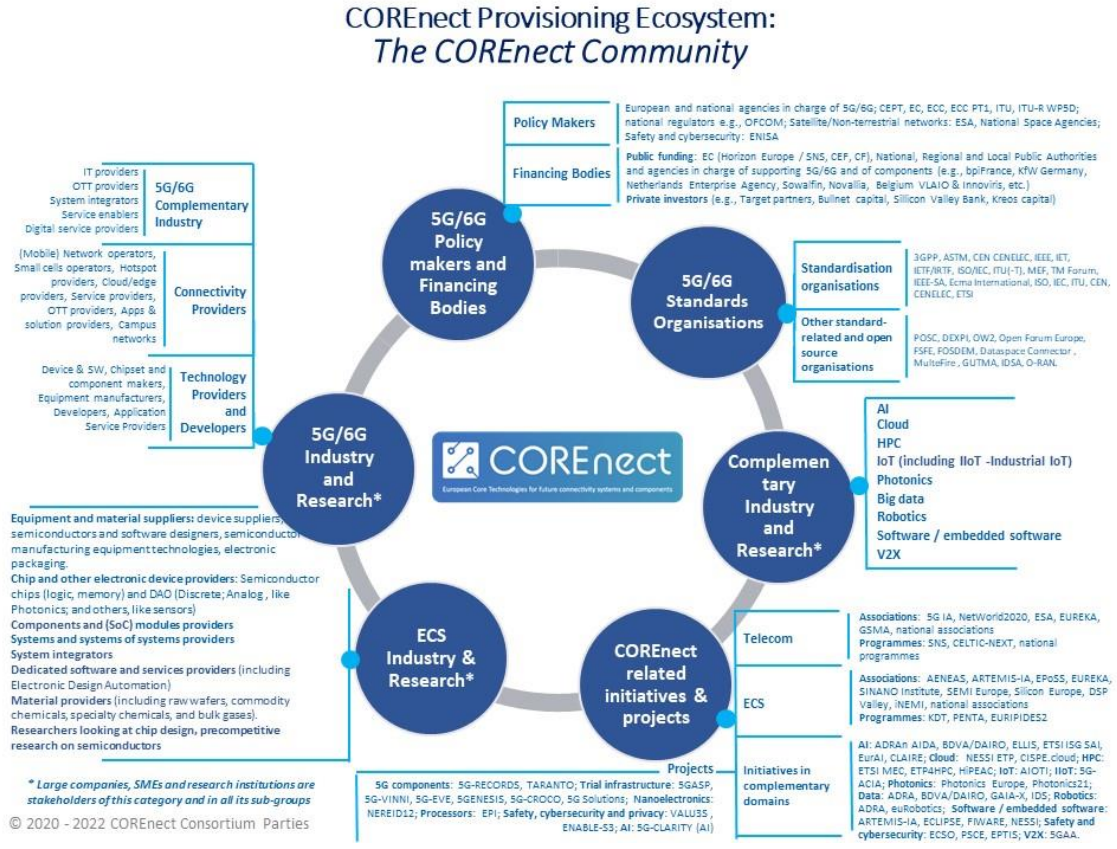

Figure 10 COREnect provisioning ecosystem: the COREnect community

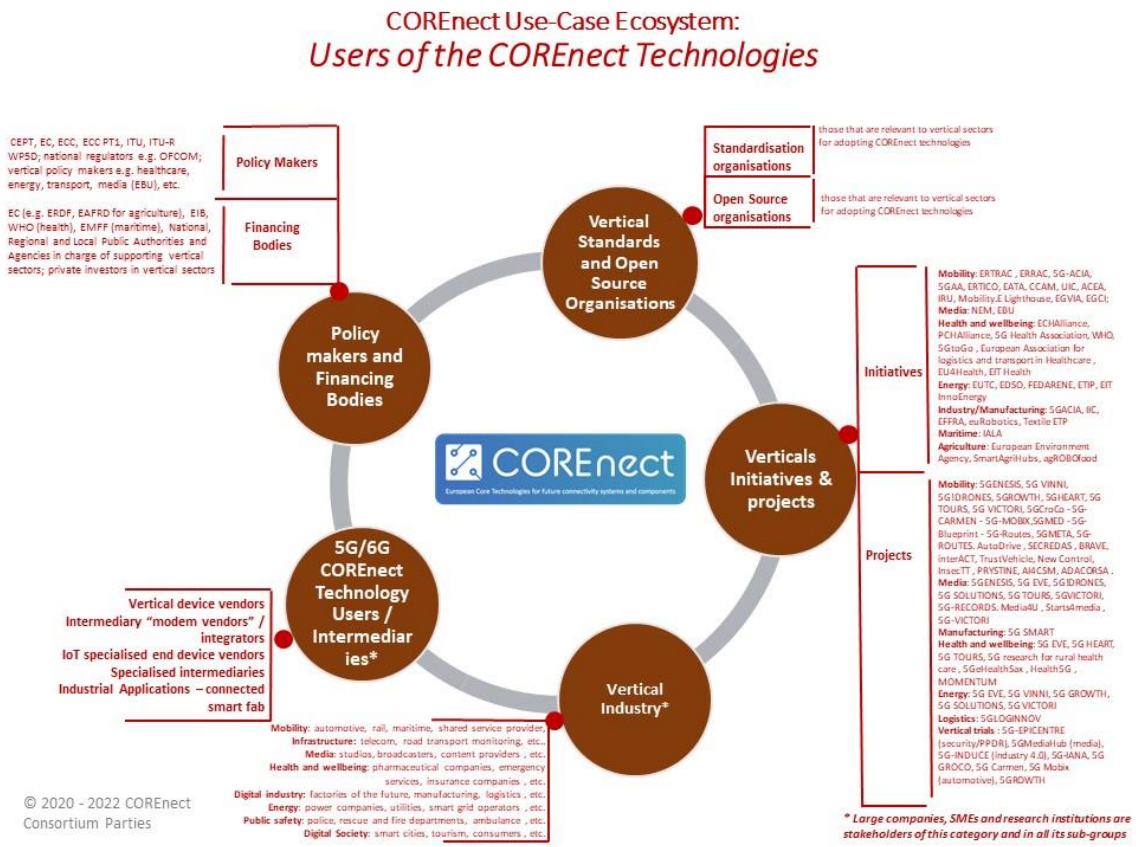

Figure 11 COREnect use-case ecosystem: users of the COREnect technologies

There does not seem to be any overlapping or replications in the completed stakeholder identification, as depicted in Figure 10 and

Figure 11. Therefore, the analysis performed by COREnect highlights there is indeed value in splitting the 5G ecosystem into two parts. COREnect performed already two stages of identification of the related stakeholders. Preliminary stakeholder pictures appeared in their "initial report on community building and outreach strategy" [146]. The two pictures below are the result of the 2nd stage of stakeholder identification, that will be included in COREnect's upcoming Deliverable 4.2 "interim report on community building and outreach strategy".

Appendix 3 Niche 5G Provisioning Ecosystems at Railway Environment

In modern railway transportation facilities, there is a demand for a broad range of novel on-board applications for passengers (advanced guiding services, real time information, infotainment services, etc.), referred to as "business services", along with train control, railway emergency voice communication services etc., denoted as "critical services", as well as train telemetry and maintenance services, non-critical real-time video (e.g. surveillance) services etc., referred to as "performance services" ([147] [148] [149]). Currently, the provisioning of the aforementioned services entails versatile technologies and network deployments supplied and operated by different stakeholders as providers (e.g., "business services" by public telecom service providers, "critical services" as mainly train automation related services by private GSM-R networks, etc.). These practices are pushing existing networks deployed in the railway environment to their limits, and make it difficult to guarantee extensive coverage for all services along the railway tracks, extending over thousands of kilometres. They are also leading to slow service deployment, low performance for premium services, and high TCO for all stakeholders (as described indicatively in [150]). In business terms, it gets very challenging and possibly risky for existing telecom operators to invest in infrastructures along the railway tracks ([150]), potentially making room for other players to undertake this activity.

Technically, the telecommunications system(s) that can address the current networks' inefficiencies and meet the requirements of the aforementioned services is commonly denoted as Future Railway Mobile Communication System (FRMCS), i.e., the future worldwide telecommunication standard and GSM-R successor ([149] [151] [152] [153]). FRMCS is as well seen as a key enabler for rail transport digitisation. It reflects the technology neutrality and network service logic of the 5G standard, tailored to the specific service requirements and deployment challenges of the railway environment ([148] [155]). Business-wise, while acknowledging that there will be cases where established Telecom Operators will seek to undertake the role of 5G provisioning at railway environment, as an extension of their nationwide 5G provisioning activities, it is not expected that 5G provisioning at railway environment will be a highly competitive business field [150]. As declared by several railway operators across Europe [154] railway operators (and/or other firms activated in the railways' industry) are expected to have high interest in investing in these infrastructures towards the digitisation of their own business activities exploiting the lack of high competition. At the same time, ownership of facilities is a significant asset for railway operators, considering the site acquisition costs necessary in any infrastructure deployment. An expansion of these activities and exploitation of these investments by opening them up to passenger services and to other DCSPs, CSPs, Network Service Aggregators can generate new revenue streams, and at the same time will position these stakeholders as core actors of the niche 5G provisioning ecosystem. In this context, the role to be undertaken would be that of VISP, or of Network Operator, or of NSaaS provider, or of CSP, depending on the business interest of the firm, on the interfacing agreements with other stakeholders, and on the business environment in general.

Appendix 4 SMEs challenges engaging in 5G ecosystems

Many discussions have happened within the NetworldEurope SME Working Group [156] about specific challenges facing SMEs when engaging in 5G ecosystems. Their concerns also centre around the need for large incumbents to acknowledge dependence on and mobilize SMEs for value creation and capturing. Furthermore, 5G is still not easily available as a technology for experimentation, innovation and testing.

- Partnerships between technological SMEs and verticals SMEs should be promoted and encouraged by both public authorities and private investors, in order to unleash innovation in 5G-related solutions and applications deployed in vertical sectors. Partnerships between SMEs and larger organisations should also be promoted and encouraged, maybe even more with larger organisations from the targeted vertical sectors i.e., those who will be part of the use-case ecosystem.
- Opening up the whole European 5G market, that is rather Member State-oriented at the moment (i.e., most policies are still decided at national level), and strengthening SMEs in reaching international markets, should be key to the support SMEs should get, both at national and European level.
- Large-scale trials with 5G infrastructure should be made fully available to SMEs. This has been described in detail in the SNS Partnership Proposal document [157].

In short, although it is essential, it is not enough to support research and innovation in EU projects to mobilize SMEs. It is also essential that the capacity of European SMEs can experiment with and deploy their solutions in commercial settings as they emerge. Among the main opportunities for SMEs are the technology knowledge they possess of given vertical sectors, where they already have expertise and customers. A different angle on the opportunities, is the great number of SMEs already involved in vertical sectors, but with no knowledge of 5G. Moreover, SMEs, thanks to their agile and flexible structure, may be better positioned to bring innovation and disruption in vertical sectors' business models. This applies both to technological and vertical SMEs – maybe even more if they work together.

Thus, the SMEs constitute a group which must be mobilized, both to meet the vision of Europe economic growth and because their competence is needed to build the 5G market. On the other hand, the potentially disruptive challenge they present to incumbents must be handled in the emerging 5G ecosystem.

Appendix 5 Example of new roles in health vertical

Following a use case in 5G-HEART [158], there are at least five relevant stakeholder groups in a health market, the beneficiary, executer, customer, provider, and regulator. The **beneficiary** is the patient and relatives. The **executer** is any person in the health sector who uses 5G enabled health solutions. The **customer** are managers of health operations, also the purchaser role. This role also includes the entity, which finances the 5G enabled health solutions. In UK and Scandinavia, such solutions are tax funded with one purchaser; in, for instance, the Netherlands, it is a social insurance model with multiple paying roles. The **providers** elaborated in the 5G-HEART example is the provider of medial technical equipment and the 5G provider (MNO). Other relevant provider entities mentioned in 5G-HEART are providers of monitoring patch solutions and specially designed cameras with form factors of a consumable pill. Important enabling providers are, for instance, those of advanced video conferencing solutions. Finally, domain specific **regulators** play a role in the health sector, as well as generic regulators of privacy.