CHAPTER 6

Emerging Trends and Possible Futures of the Telecommunication Networks in Italy

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Emerging Trends and Possible Futures of the Telecommunication Networks in Italy*

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Abstract. This chapter explores the possible futures for the telecommunication ecosystem in Italy, by focusing on a medium- and long-term perspective through the application of Strategic Foresight techniques. Our goal is identifying the most promising new directions and policies for driving the ecosystem evolution towards the preferable scenario, by working on different dimensions: market/economic models, technical advancement, regulatory frameworks, and users' expectations/perspectives. Regarding the first aspect, we analyze the emerging opportunities for companies in terms of enabling technologies and digital services that can be built on top of connectivity services, by also discussing the status of the network infrastructures in Italy. Then, the chapter examines the technical dimension, assessing the potential impact of technologies such as low-orbit satellites and aerial networks, the edge expansion, new materials and devices for reducing the carbon footprint of networks, artificial intelligence and programmability of networks, as well as the development of novel communication services based on immersive applications. Moreover, the research also analyzes the regulatory landscape, assessing the influence of policies on the evolution of telecommunication networks. It evaluates existing regulations and recommends reforms to stimulate innovation and greater industry participation. Finally, innovative requirements on the user side are presented. All these aspects are then projected

* This chapter presents results from the RESTART Net4Future project.

into four strategic scenarios, that have been developed by identifying key forces that could impact development trajectories, categorizing them as "predetermined" (i.e., with a clear trend) or "variables" (i.e., subject to unpredictable outcomes). In particular, we considered the combinations of high-impact extreme outcomes along the identified axes (namely, a unified European role: yes/no; level of urbanization: high/low) in scenarios entitled United States of Europe, City-States 2.0, Distributed States of Europe, and Digital Feudalism, for imaging the impact on the future telecommunication ecosystem.

1 Introduction

In the last years, and especially after the pandemic emergency due to COVID-19, it has clearly emerged the fundamental role of telecommunication infrastructures for interconnecting the human, the digital, and the physical world, thus enabling applications and services in several vertical domains (from healthcare, education, industry, agriculture, transportation, energy, to public administration, commerce, entertainment, and finance) able to guarantee a better usage of natural resources and a more inclusive access for users. Telecommunication networks have emerged as the backbone of the so-called digital ecosystem, a network of interconnected entities, including businesses, consumers, governments, and various service providers, that interact and collaborate through digital platforms to facilitate data collection and the provision of digital services.

Despite of this centrality, the telecommunication sector is currently experiencing a critical situation worldwide, due to the complex interplay between several factors, among which the need for investments for completing the roll-out of innovative technologies, and the obstacles in the deployment of innovative services and business models while current infrastructures are under the pressure of increasing performance demand.

In this chapter, we specifically refer to the Italian context, which is characterized by delays in the pervasive deployment of ultra-broadband fixed and mobile connections, e.g., optical fiber, FWA, and 5G cellular solutions, and by a fragmented infrastructure with significant regional disparities. This is due to economic and investment challenges for market players and the everlasting drop of revenues for operators, as well as the difficulties in introducing innovative services while the infrastructure investments have not been completed. The Italian perspective is framed in the context of general technological trends It is worth considering also the complex landscape of regulation, and even the scarce appeal of telecommunication master programs, which is leading to the lack of specialized human resources. As for regulation, a comparison to other similar European countries is made, as well as a reference to EU regulation.

On the basis of the outlined scenario, the survival of traditional telecommunications will be related not only to the investments necessary for the modernization of its networks but also to the ability to seize emerging opportunities in other areas of the digital market, where progress is essentially explained by the explosion of more innovative products and services. To survive the market dynamics, telecommunications operators will have to make significant efforts and try to adopt new business models that take into account the opportunities arising from other segments of the digital supply chain.

In the rest of the chapter, we present an analysis of the emerging digital eco-system under market, technical, regulatory, and user dimensions, carried out within the project Net4Future. We conclude by adding a socio-political dimension and by analyzing four different potential scenarios resulting from the combination of the most uncertain evolution drivers: the presence or absence of a strong unitary European regulation and policy on telecommunications, and the territorial configuration of connectivity demand, spanning continued urban concentration on the one hand and the recovery and revitalization of rural and peripheral areas on the other.

2 Market Dimension

The analysis of the three-year period 2023-2025 reveals an Italian telecommunications market that has moved beyond a phase of quantitative expansion to enter a complex phase of qualitative and technological recomposition. We are no longer witnessing a growth in the customer base, now essentially saturated, but rather a radical transformation of consumption models and the underlying infrastructure. This section analyzes the three fundamental dynamics defining the landscape: the pervasive technological substitution in infrastructure (technology swap); the radical change in data traffic consumption patterns and services; the growing systemic challenge linked to the economic sustainability of the sector.

2.1 A Structural Transition

The Italian telecommunications sector is undergoing a structural transformation.

In the fixed-line segment, traditional technologies, including voice-only lines, ADSL and hybrid fiber–copper solutions, are steadily declining, while growth is concentrated in Fiber to the Home (FTTH) and, to a lesser extent, Fixed Wireless Access (FWA). FTTH is progressively consolidating its role as the reference architecture for future fixed connectivity, while FWA is assuming a complementary structural function in areas where fiber deployment is economically inefficient.

The market has entered a phase of structural maturity in which competition is no longer centered on customer acquisition, but on the technological upgrading of existing users. Fiber to the Cabinet (FTTC) plays a paradoxical role. Initially deployed as a transitional technology to accelerate broadband diffusion, it now slows the transition to full fiber, as its performance is often perceived as sufficient by users, reducing the incentive to migrate. In parallel, a residual base of voice-only users persists, highlighting a digital divide that is increasingly cultural and demographic rather than infrastructural. For operators, the migration to FTTH offers opportunities for service differentiation and technological upselling, particularly when combined with fixed–mobile convergence strategies aimed at improving customer retention. At the same time, the sustainability of fiber investments remains uncertain due to high capital expenditures and strong price competition. Future developments will therefore be driven less by spontaneous demand than by supply-side decisions, including the progressive decommissioning of copper networks to reduce operating costs. As FTTH penetration increases, value creation is expected to shift from basic connectivity toward the digital services enabled by ultra-broadband networks.

In parallel, also the mobile sector is experiencing a partial starvation. Indeed, although the total number of active SIM cards continues to grow, this expansion is driven almost exclusively by Machine-to-Machine (M2M) connections. The human consumer market has reached saturation, and mobile connectivity for individuals has become a commodity service. Competition is largely based on price and customer churn through number portability, resulting in limited value creation and persistent margin pressure. By contrast, the growth of M2M connectivity represents a structural shift in the role of mobile networks, which are increasingly functioning as the digital nervous system for connected objects, infrastructures and industrial processes. This segment is characterized by greater contractual stability and long-term relationships, particularly within embedded-connectivity and B2B2C models. However, the rapid increase in M2M volumes is accompanied by very low unit revenues, raising concerns about investment sustainability and the risk of operators being relegated to the role of low-margin infrastructure providers.

The full maturation of the mobile ecosystem will depend on the deployment of 5G Standalone architectures, which are essential for managing massive device density and enabling vertical, sector-specific solutions. In this evolving landscape, operators are expected to move beyond the provision of connectivity alone, offering integrated service platforms that combine network access with embedded connectivity and data-driven services.

2.2 Evolution of Data Traffic and Services

Recent years are also characterized by important changes in data volumes. Total download traffic grew by 21.8% , from 23.46 to 28.35 Exabytes. However, the most striking data is that relating to upload traffic, which recorded a 46% surge, from 2.72 to 3.98 Exabytes. This phenomenon is confirmed by the analysis of unit consumption: average traffic per single line grew by 23% over the same period, indicating a radical and structural change in individual user behavior. The explosion in upload traffic, growing twice as fast as download traffic, demonstrates the shift of users behavios, from passive consumers to active content creators who produce and send large amounts of data to the internet. This dynamic makes asymmetric network architectures (such as ADSL and FTTC) technologically obsolete. The increase in unit consumption puts strain on network engineering, especially in shared-capacity architectures like GPON, risking degrading the quality of service (QoE) for all connected users. This situation generates a profound economic crisis, which we can describe with the metaphor of " Digital Inflation." Given a fixed monthly fee, a 23% increase in consumption per line erodes the operator's margins. The network's "purchasing power" (available capacity) is eroded by increased consumption. If a user pays €25 in 2023 and €25 in 2025 but consumes 23% more, the real value they are extracting from the operator has increased, while the value the operator receives in return has effectively devalued. This decoupling between (rising) data transport costs and (flat) revenues makes the "flat" business model economically unsustainable in the long term.

To handle the new volumes and increasingly bidirectional nature of traffic, networks will need to evolve from simple "pipes" to intelligent, distributed systems. In line with the international evolution, also in Italy, the telecommunication sector is expanding, from providing basic connectivity services by means of pervasive network infrastructures to integrating additional functionalities such as cloud/edge computing, data storage, security primitives, IoT, and AI.

As shown in 1, it turns out that the overall value chain is given by three different interacting components, which add *enabling services* and *digital services* on top of the connectivity services.

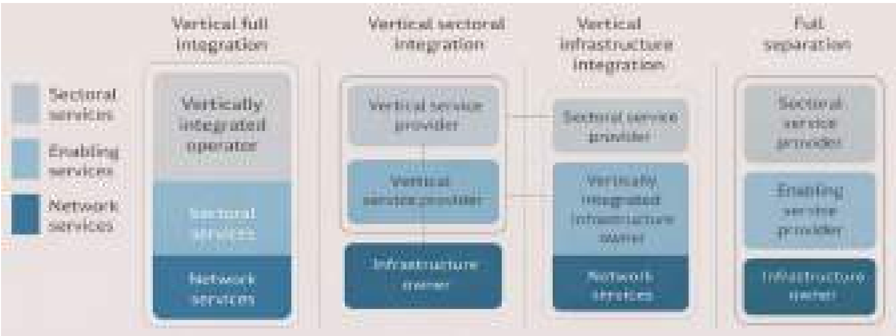

Fig. 1. The competitive alternatives for telcos

According to the actors dealing with the provisioning of these services, we can span from the so-called vertical integrated operator (managing all services built on top of connectivity) to the full separation scenario, where connectivity providers are independent of digital services providers and act rather as enabling element of the digital service value chain.

The Italian situation has been traditionally characterized by the presence of vertically integrated operators. These companies are not restricted to the provision of traditional connectivity services, but they also offer a wide range of value-added services like cloud/ edge computing, IoT and AI, and security solutions. Some of these operators have very advanced portfolios of services, providing IaaS, PaaS, and SaaS solutions to enterprises and public institutions. Services range from private, public, and hybrid cloud environments to disaster recovery and data storage solutions. Moreover, they have demonstrated to leverage their global scale for successfully developing and offering IoT platforms or cybersecurity solutions able to respond to local heterogeneous needs. The situation is now evolving towards a more fragmented scenario. The recent split of TIM into different companies and the case of an important player like Open Fiber (focusing purely on deploying and managing fiber optic infrastructure) demonstrate the presence of wholesale-only providers in Italy. In addition to vertical integration and full separation, Italy also has examples of hybrid models, where partnerships between operators and third-party providers (with high levels of specialization in different sectors) are common. This collaborative approach allows telcos to maintain control over connectivity while outsourcing or co-developing specific digital services.

According to the last annual report by Anitec-Assinform, the increasing success of digital services, developed on the last level of the telecommunication value chain, is enabling strong progress on digital transformation in Italy.

Financial Services represent one of the most successful ones. Banks and insurance companies are leading the digital shift, with AI and blockchain technologies playing a fundamental role in service definition, customer experience reform, and risk management. The digital transformation in these sectors is accompanied by a decline in physical branches and a shift to omni-channel service models.

A similar deep transformation involves the *Manufacturing and Energy* sectors: these industries are focusing on the digital monitoring and control of their traditional assets (either in terms of production systems or distribution energy grids) for supporting improved decision systems and predictive maintenance. The services are enabled by IoT and AI solutions, as well as cybersecurity primitives devised to prevent unauthorized access to physical resources.

Digital services are also affecting the *Public Administration services*. Initiatives such as SPID, AppIO, and PagoPA reflect the growing importance of digital identity platforms and a Mobile First approach, aimed at making public services more accessible and efficient for citizens.

Finally, another important sector worth mentioning is the *Healthcare* sector, which is growing thanks to the exploitation of telemedicine and AI for improving patient care, cybersecurity for safeguarding sensitive health data, and cloud services for data management and sharing.

Digital services based on the so-called *platforms*, devised to facilitate interactions between multiple user groups, are also transforming significantly the relevant markets. Indeed, these types of services are based on the creation of a digital intermediary between some providers of facilities in the real world and the users. Digital intermediation allows the reduction of transaction costs and support of service optimizations enabled by data-driven algorithms. Moreover, it creates a multi-sided market, where two groups of users (the facility providers and the facility consumers) multiply the opportunities for increasing the service value as the population of each group grows. In such a context, traditional industries are increasingly displaced from their coordinating role and many Italian companies (especially small and medium sizes) struggle to compete. As a result, there is a growing push for digital transformation across industries, as well as new challenges for regulatory bodies and policymakers.

2.3 Convergence, Net Neutrality and Sustainability

We described how the Italian telecommunications system is undergoing an irreversible metamorphosis: after a long phase of expansion and a subsequent phase of technological substitution, the sector is now entering an era of integration. The central challenge is no longer the relative dominance of one access technology over another, but the ability to seamlessly combine heterogeneous infrastructures into a unified user experience.

Convergence has therefore evolved from a commercial strategy based on bundled offerings into an industrial requirement. Fixed and mobile networks are no longer independent layers, but complementary components of a single system. The development of 5G, for instance, is intrinsically dependent on the availability of dense and high-capacity fiber backhaul, while fiber networks increasingly rely on wireless solutions to ensure ubiquitous coverage and flexibility. In this integrated paradigm, the objective is to provide an “always best connected” experience, in which the network dynamically selects the most appropriate access technology without perceptible discontinuity for the user.

This structural convergence, however, unfolds under severe economic constraints. The sector faces a growing imbalance between rising industrial investments in fiber, 5G, edge computing, and traffic transport, and revenues compressed by intense competition and flat-rate pricing models. At the same time, there is a tangible risk of value destruction if convergence is used primarily as a pricing tool, whereby one service is discounted to promote another. Such practices risk further eroding margins, weakening stand-alone operators, and accelerating consolidation pressures.

Within this evolving landscape, net neutrality emerges as a central regulatory and strategic aspect. The principle of equal treatment of traffic has historically played a fundamental role in preserving openness, competition, and innovation in digital markets. However, empirical evidence on traffic dynamics shows increasing heterogeneity in application requirements, with latency-sensitive, bandwidth-intensive, and mission-critical services coexisting on the same infrastructures. This raises questions about the sustainability of a strictly uniform treatment of traffic in an environment characterized by exponential growth, sharp peaks associated with major events, and rising quality-of-experience expectations. From this perspective, the key policy issue is not whether traffic differentiation should exist, but how it can be implemented in a transparent, proportional, and non-discriminatory manner. Measurement-driven approaches to traffic analysis and forecasting provide an objective basis for this debate, enabling the identification of normal operating regimes, exceptional events, and stress conditions.

Summarizing, the future of the Italian telecommunications sector lies in reconciling three objectives: infrastructure integration, economic sustainability, and the preservation of an open and competitive digital ecosystem.

3 Tecnological Dimension

3.1 Towards programmable and open networks

Traditionally, telecommunication networks have relied on very specialized hardware and closed software, implementing specific data and control operations with a monolithic design. Interoperability between network elements was achieved by following strict industry standards. Network services were offered as an integral part of the equipment. Conversely, the concept of network programmability refers to the possibility of deploying and connecting general-purpose equipment, which can change behavior and implement different operations on data by simply loading and executing a "program" decided by a centralized remote controller. Programs are built by composing instructions, which are supported by the equipment according to its internal (closed) design and exposed as open interfaces to network operators and third parties.

Although the concept of network programmability and control/data plane separation has its roots in the 1960s and 1970s, when the telephone network started its transition to digital, the trend has progressively emerged in the last twenty years, with increasing success in various network segments. Indeed, there are different aspects in which networks are becoming programmable:

1. the data forwarding operations between nodes, where OpenFlow represents the first successful programming model, based on the match/action abstraction, able to radically change the design of switches and routers;
2. the flow controlling operations, including firewalls, inspection, and load balancing functions, which rely on software programming models to be executed on standard servers;
3. the baseband operations of radio BSs, which can be centralized and migrated to datacenters, by exploiting innovative disaggregated architectures and interfaces for the RAN;
4. the scalable provisioning of network resources, which is decoupled by the physical availability of the hardware, thanks to the concept of network virtualization and slicing.

Note that different abstractions of network functions and elements, leading to different programming models, have emerged so far according to the required trade-offs between flexibility and execution efficiency of the programs, as well as vendors' needs for closed platforms. Usually, programmability has a cost in terms of performance; hardware acceleration abstractions (i.e. AALs) are needed for efficiently supporting the set of instructions exposed in the open interface.

SDN is undoubtedly a paradigm-breaking trend that is making obsolete the idea of protocols and changing the role of standards toward the definition of network programming interfaces and operating systems. This trend, consolidated in the wired domain, is now involving the wireless domain as well, with the emergence of O-RAN. O-RAN has the goal to open the RAN components, which are currently provided by a limited number of vendors and seen by the operators as black boxes. The idea is to expose disaggregated software-based components for supporting RAN operations and connecting these modules through open standardized interfaces. Open interfaces allow operators to onboard different equipment vendors, thus opening the RAN ecosystem to smaller players, and integrating intelligent, data-driven control schemes. O-RAN principles have the potential to drastically change the design, deployment, and operations of the next generations of cellular networks. Moreover, they enable new approaches to network security. Indeed, the possibility of overcoming the vendor's lock-in, improving the visibility of RAN performance, or running control programs for security analysis and threat identification, can make future networks more robust, resilient, and trustworthy.

3.2 Edge expansion

While the initial concept of the Internet targeted a distributed control network, the two last decades have witnessed the inception and growth of the cloud, aiming at stacking huge amounts of storage and computing resources under centralized control in data centers, so as to provide flexibility and on-demand elasticity for a wide variety of applications. The pendulum has moved back again in the last few years, especially in the framework of deployment of 5G and evolution towards 6G, entailing edge computing as a central element of new networking paradigms. The key idea is shifting substantial storage and computational power close to final users, especially in the context of mobile networks, thus providing high performance, energy saving on battery-dependent devices, and extra computational power for specific operations. The edge computing paradigm stems from the well-established content-delivery network evolution. Since the rise of widespread multimedia streaming services, providers have strived to sustain an adequate QoS on the Internet for their final users, moving the most popular content in each area close to final users. The content replication facilities are provided by several companies, providing small-scale data centers scattered in the access networks. Edge computing leverages this approach, broadening the range of applications and services with respect to mere multimedia streaming. Few examples are the support of IoE, integrating technologies as AI, blockchain, and microservices, for massive connectivity of devices [31], remotely controlled personalized healthcare [12], support to Intelligent Transportation System services and automated driving [23], industrial automation [51].

The advent and expansion of edge computing are boosted by the coupling with AI-supported applications, from natural language processing functions to personalized services, to image processing and generation, to automated driving, to mention but a few examples. Distributing AI across the network and bringing it close to final users opens up the opportunity for massive AI-based applications and data-driven approaches in a pervasive perspective [15,16]. AI-supported applications may require massive computational power and storage and are not necessarily suited for running on-board mobile devices. An interesting multi-objective optimization can be searched for to trade off energy consumption, delay, and accuracy of application output.

Europe is lagging behind other actors (e.g., USA and China) in the edge computing market, with a market value sized in several tens of millions USD in 2023, but expected to grow up to hundred million USD by early 2030's [7]. A braking factor in the development of these technological paradigms lies with the highly fragmented company scenario in Europe for network operators, as well as the lack of strong and large over-the-top players based in Europe. Most developments of AI-based applications and technology are driven by big non-EU companies. Other relevant concerns, which are carefully considered by EU institutions, have to do with security and privacy, which have special profiles when meeting with edge computing technology [37]. However, edge expansion could also open up opportunities for new actors in the telecommunications and service market. If properly driven by regulation, the development of edge-based technology revamps the importance of local communities, socio-economic local organizations, and small-medium enterprises well rooted in their own neighborhood.

3.3 New Frontiers of communication media

Communications media on which current networking technology is built are well-established: copper wire and radio since the XIX century and optical fiber since 70's of the XX century. The quest for larger bandwidth, more reliability, and new deployment environments and applications is however relentless. Optical networks are by now an established reality, grounded on powerful DWDM systems and a vast array of optical components [45]. More recent trends are towards wireless optical systems and the application of reconfigurable optical networks to the design of new generation data centers [56]. The fundamental advantage of optical networking is the ability to carry huge amounts of data through analog wavelength multiplexing and switching, thus escaping the electronics bottleneck as clock rates grow. Optical networks are also preferable from a sustainability and security point of view. This is a well-established technology that has been extended beyond the core Internet to the access network through PON. Still, optical technology finds new areas of application, e.g., underwater network [24]. This is yet another increasingly emerging trend, namely the extension of networking coverage to extreme and hostile environments, such as in underwater communications [27] and ad-hoc networks of moving objects, e.g., UAVs, robots, vehicles, or massive constellations of satellites [4,36].

Radio communications are dominating the networking scenario in the access network, as well as in specialized applications, such as the already mentioned satellite networks, but also for maritime and aerial communications, down to body area networks. A frontier of radio communications is the extension of usable frequencies to extremely large values, starting off with a 5G boost towards bandwidth above 6 GHz, e.g., with mmWave communications. This trend is pushing towards the so-called THz communications paradigm [48]. The twelve decades of usage of radio waves for communications have witnessed an unstoppable growth of used frequencies, motivated mainly by the quest for larger bandwidth and unallocated spectrum portions for new services. The Newfoundland of radio communications is the THz bandwidth. Besides offering very large bandwidths, due to the very small wavelength, THz technology is rejoining two mainstreams that used to march closely but are quite separated between them: communications and remote sensing [11,28,33]. Yet another rising technology for empowering wireless communication is based on RISs [22]. New materials are being studied whose reflectivity properties can be controlled and changed according to the desired directivity of the radio beam. Although this technology implies deploying such active material panels in the propagation environment, it is shown to boost communication performance, at least over local range distances. As a matter of example, an application to visible light communications is reported in Aboagye et al. [3].

Public institutions are part of this progress in that spectrum usage is regulated in most advanced countries. Given the geo-political fragmentation of the EU, it is critical that spectrum usage be faced in a consistent way in different countries, in a holistic socio-economic European perspective. Also, the role of unlicensed spectrum should be carefully evaluated. Although not specifically tied to a specific communication medium, it is worth mentioning the rise of the quantum Internet paradigm. Quantum key establishment protocols have been investigated and experimented long since over the last two decades. More recently, quantum computing is getting closer to becoming a practical reality. The convergence of quantum technology for communications and computing is pointing at a full-blown networking infrastructure exploiting quantum physics as its cornerstone [32,58]. The implications of such directions are hard to predict as of now. Most probably, the dawn of a quantum Internet, if it exits research labs to turn into an industrial reality, will not replace the "traditional" Internet, at least from a short-medium perspective.

3.4 Improving network sustainability

Telecommunication networks are experiencing a dramatic increment in the energy consumption and overall carbon footprint, due to the increasing traffic volumes and pervasiveness of the access infrastructures. Currently, it is estimated that the industry accounts for 3% to 4% of global CO_2 emissions, about twice that of civil aviation. With the current trends of growth in traffic volumes, fiber optic networks, and cellular sites, the industry's share will further increase unless investments in energy efficiency and more sustainable technologies can offset this trend [35]. Emissions derive mostly from purchasing energy and heat for the infrastructure (with the so-called scope 2 emissions), as well as from downstream and upstream activities connected to the telecommunication industry, which account for the energy consumption of suppliers and service providers. In the past few years, most telecommunication companies have declared that they should assume responsibility for their Scope 3 emissions, for example by demanding transparency into their suppliers' footprint [17]. In this scenario, there are several levels at which technological advances can improve network sustainability: from the device/sub-system level to the network integration level, up to the end-to-end service level.

At the device level, the usage of innovative semiconductor technologies, such as Gallium Nitride (GaN) and SiC, allows the design of energy-efficient components. Development of more efficient hardware involves many different components, from analog/digital converters, optical converters, and mixers, to graphene-based photo-detectors, low-noise and low-power amplifiers, and, in general, low-energy front-end transceivers able to work at the emerging mm waves or optical bands. Moreover, another interesting trend is the integration of small-scale energy harvesting technologies (like solar cells or piezoelectric generators) or wireless charging systems for developing battery-less devices able to work as end devices in heterogeneous applications.

At a sub-system integration level, innovative and efficient elements for future networks include programmable antenna systems able to exploit signal backscattering and reflective intelligent surfaces, ultra-low-power nodes, equipped with a wake-up radio interface for managing the sleeping states in a trigger-based logic, energy-efficient channel coders specialized for ultra-reliable and low-latency communications, all-optical processing solutions. Moreover, it is important to integrate probes for measuring energy consumption in different sub-systems, together with the other usual performance metrics.

At a network level, several research works consider the problem of designing more efficient RANs. Indeed, an approach based on powering cellular sites using energy harvested from renewable energy sources such as wind, solar, fuel cells, or a combination of these energy sources significantly contributes to the improvement of wireless network efficiency. Moreover, dynamically controlling the activation/de-activation of the BS can further improve the overall efficiency. Apart from the RAN, AI-driven network orchestration can be extended for dealing with energy optimization, by steering opportunistically the network traffic, or by selecting different security and network functions. More flexible and efficient network management is improving the network adaptability, without specialized hardware, by also reducing hardware obsolescence and reuse. Another emerging direction is based on the exploitation of edge computing for processing data closer to the source to reduce the energy required for long-distance data transmission. Sustainable data learning models. Finally, improving coexistence between multiple technologies and service providers by means of infrastructure sharing can improve circularity and reduce e-waste.

3.5 Towards intelligent networking and networking for intelligence

AI is prominently driving the development of new features and applications in many disparate fields, thanks to its apparent ability to extract meaning out of the wealth of data produced by humans and machines (e.g., in the framework of the Internet of Things). AI offers a valuable tool to tame the complexity associated with new societal living models, including smart cities, intelligent transportation, smart grids, and industrial automation. AI is a broad cap, covering several different specialized areas, ranging from knowledge representation to probabilistic reasoning, semantics, and machine learning. As of today, ML stands out as the most relevant of these areas for telecommunications. ML is already having a big impact in enabling machines to learn from data, with or without the supervision of humans. An astonishing improvement in ML capabilities has come in the last decade from the inception of deep neural network algorithms. The amazing achievements of ML tools have raised a huge hype of interest and expectations on their potential to improve information and communication technologies.

ML and AI in general are already affecting deeply the way technical problems are addressed, specifically those concerning communications and networking, e.g., in the design of 5G/6G networks [29,39]. As a matter of example, effective network slicing calls for very sophisticated mechanisms to configure and orchestrate network resources (e.g., virtual machines, network interfaces) where and when they are needed. The increasing level of complexity of networked systems management pushes towards increasingly automated solutions to cope with the volume of data and resources to be dealt with. The aim is to guarantee a high level of resource exploitation and to keep network management costs within affordable bounds. Here AI and ML can play a significant role [43]. All network architecture layers offer examples of fruitful applications of ML algorithms as well. To mention some areas where ML-based approaches have been proposed for networks, we refer to beamforming, dynamic spectrum sharing, multiple access control, routing, resource allocation, congestion control, proactive caching, and security. Also, the reverse is true since there is an active field of research and experimentation on what networks can do to assist and empower ML algorithms, e.g., with reference to real-time data collection, support of learning in the edge cloud, and distributed/federated learning.

AI, and specifically Machine Learning, is expected to play a major role in all of those areas, especially in cases where there is a model deficit, i.e., it is not known how to state an optimization model, or model statement leads to an unfeasibly complex problem (e.g., because of many involved parameters). As pointed out in Zappone et al. [57], coexistence can be expected between modelbased and data-driven approaches. Maintaining a hybrid approach allows us to leverage decades of model-based know-how accrued in the communications and networking fields, while at the same time keeping the door open to getting benefit from powerful data-driven deep learning algorithms in those cases where enough data can be collected cheaply.

Within the early developments of Shannon's seminal works, Shannon and Weaver identified three levels of communication [50]:

1. transmission of symbols (the technical problem);
2. semantic exchange of transmitted symbols (the semantic problem);
3. effect of semantic information exchange (the effectiveness problem).

Shannon deliberately focused on the technical problem in his seminal paper [49]. This enabled him to derive a rigorous mathematical theory of communication based on probabilistic models, which has insofar underpinned the whole development of information and communications technology. AI and ML offer the opportunity to move forward towards the semantic and effectiveness levels, as drivers in the design of new communications and networking systems [9]. This will require full integration of knowledge representation systems, ML, and goal-oriented communications, leading to what is often referred to as the semantic communication paradigm [10,21,53]. Communication and network systems could be tailored to exactly what is the relevant information that needs to be transmitted. to fulfill the desired goal, with the desired level of effectiveness. Under this respect, a critical open issue arises considering the tremendous impact of standardization as a cornerstone of technological evolution, interoperability, and open market enabler. Designing systems in a modular way, and putting them together to build complex networks appears to clash against goal-oriented semantic communications, which is inspired by a holistic approach, where the whole system design revolves around a specific goal and is carefully carved to fit that goal. How to exploit the potential of semantic communications enabled by deep learning algorithms (in general, by AI), while preserving the flexibility and modularity of networks is a big open issue in our view.

3.6 Integrated 3D networks

Wireless communications have traditionally ensured global coverage worldwide thanks to the integration of two complementary systems: ground networks and satellite networks. Ground networks, characterized by low access delays and cost-effectiveness, provide robust connectivity in urban and suburban areas but are inherently vulnerable to disasters, infrastructure damages, and installation limitations (e.g. in mountain regions or oceans where back-hauling links and BSs are difficult to deploy). Conversely, satellite networks extend coverage to remote and underserved areas, offering broadband connectivity where ground networks falter, with higher costs and limited performance.

A recent trend in these integrated wireless networks is represented by the introduction of a further intermediate level, in which aerial nodes (UAVs, aircraft, balloons, etc.) are deployed between satellited and terrestrial BSs, thus creating an integrated space-air-ground architecture [34]. The idea is to use the air segment to enhance the capacity in terrestrial areas with high service demands for disaster recovery, or for providing broadband coverage in rural areas at low cost, by means of HAPs & LAPs. Although several recent projects have focused on the deployment of integrated systems, such as the Global Information Grid [26], or aerial systems such as Loon [30], many design aspects still need to be fully investigated. Indeed, the time-variability of the network architecture, the heterogeneity of physical layer technologies, the limitations of each infrastructure layer, together with non-technical factors such as consumer readiness and regulatory aspects, require to be properly addressed. These networks also require a high level of self-organization capabilities, together with specific solutions for resource allocations, mobility management, multi-cast routing, and inter-layer optimizations.

A very innovative aspect of these systems is represented by the deployment and integration of UAV-based nodes, which on one side can significantly enhance cellular networks with aerial BSs, but on the other side require reliable connectivity for coordination and control. The former aspect, pioneered by academia, advocates the usage of UAV-based BSs for disaster assistance, border surveillance, or hotspot events, given that UAVs carrying a radio access node can be promptly dispatched, cheaply maintained, and easily maneuvered. The second aspect, strongly considered by the standardization fora (NR Rel. 17 [1], NR Rel. 18 [2]), triggered a parallel stream of research that aims at supporting UAV-based end-devices through cellular networks. Guaranteeing good coverage to these end devices is currently a challenge, as ground cellular BSs are typically down-tilted, with a limited 3D coverage on the height dimension. In other words, UAVs are only reached by upper antenna sidelobes and experience sharp signal fluctuations. Moreover, flying above buildings, UAVs receive and transmit LoS signals potentially interfering with a plurality of cells [20].

In such a scenario, innovative solutions for spectrum monitoring and allocations can be envisioned for improving spectrum utilization, especially on the third (novel) dimension. Challenged include both the space-air and the air-ground segments, where different frequencies and technologies are currently used. Apart from the integration of multiple-band systems, it is important to exploit navigation data and routing information of mobile infrastructure nodes to achieve optimal spectrum utilization [52]. Ultimately, spectrum sharing and innovative coexisting schemes between aerial, space networks, and ground networks will be necessary. In this scenario, cognitive radio technology, extensively studied in the past, but with scarce adoption in real networks, can play a role in dealing with a more dynamic spectrum allocation. Since aerial network nodes are far from the ground, spatial isolation can facilitate spectrum reuse; however, the absence of obstacles in the air links can extend the interfering area with other aerial nodes. This requires to exploit methods for controlling the transmitter power and beam angle, as well as for pervasive monitoring of the spectrum utilization along three dimensions [55] with innovative infrastructures.

3.7 Defining the Modern Telecommunications Testbed

With the increasing complexity of telecommunications systems, particularly 5G and 6G, the possibility of integrating various solutions into a reference platform acquires relevance since it allows researchers and practitioners to experiment with foundational aspects of future networks—such as spectrum, latency, security, and interoperability—and to cultivate new data-driven services. The function of a telecommunications testbed is exactly to provide a controlled, experimental environment essential for developing, testing, and validating the next generation of technologies. However, to view them just as mere technical sandboxes is an underestimation of their strategic importance. Testbeds are no longer optional R&D facilities but have become indispensable strategic assets, acting as the primary mechanism through which academia and enterprises will generate innovation in the next wave of digital transformation. Testbeds provide the necessary infrastructure to experiment with and integrate a range of foundational digital tools, such as 5G and 6G networks, Cloud computing, Artificial Intelligence, and Internet of Things, accelerating technological progress. They are multifaceted ecosystems that fundamentally shape market-level economic models, influence the evolution of regulatory frameworks, and set the pace of technological adoption across industries. In the next few paragraphs, we will explore the core dimensions through which testbed-driven innovation is redefining the future of digital services.

In the current scenario, the strategic value of telecommunications testbeds extends far beyond pure technological validation. If designed and managed strategically, they have the potential of becoming a powerful flywheel for progress, providing input not just technological advances but also generating an impact that permeates the economic, regulatory, and social fabric of the sector. To understand their comprehensive role, it is essential to understand the three core dimensions through which they drive the evolution of networks: Market and Economic Models, Regulatory Frameworks, and Technical Advancements.

Reshaping Market and Economic Models Testbeds function as powerful economic catalysts, enabling the creation of new business models and revenue streams founded on data-driven services. By simulating complex network conditions—such as 5G deployments, IoT connectivity, or edge computing—testbeds allow stakeholders to validate performance, security, and scalability. This approach ensures that investments are based on proven outcomes rather than assumptions, fostering smarter decision-making and more sustainable growth in the sector.

Due to the fast-evolving nature of telecommunications, the principle of *test before invest* is crucial for reducing risk and accelerating innovation. A network of testbed infrastructures can offer, as a service, a secure and predictable platform providing key technological enablers, such as a 5G and 6G testing infrastructure, where to experiment and validate new solutions, significantly reducing the financial and operational uncertainties associated with bringing a new solution or product to market. This reduction in market entry costs lowers barriers not only for emerging startups but also for well established operators, fostering a more dynamic and competitive commercial landscape.

Testbeds in the Regulatory Frameworks and Stakeholder Collaboration Testbeds can play a role also in aligning technological innovation with regulatory frameworks as well as involving stakeholders for a broader collaborative process. The testbed unique controlled environment for experimentation, allow regulators, industry players, and research institutions to jointly evaluate compliance, safety, and interoperability before large-scale deployment. This collaborative approach reduces uncertainty and miscommunication while ensuring that emerging telecoms solutions meet policy requirements and stakeholders concerns. This approach valuable builds trust among diverse stakeholders. Finally, testbeds act as a bridge between innovation and governance, enabling transparent dialogue and shared responsibility in shaping the future of telecommunications.

Testbeds have the capacity of acting as neutral grounds where new regulatory approaches can be explored and refined, thus serving as a sandbox for policy innovation. They facilitate the practical development of frameworks for data-driven services, addressing complex issues like data protection, data governance, data quality, and data interoperability.

Finally, testbeds serve as platforms for collaboration among diverse stakeholders, bringing together and engaging the key actors including regulators, industry, academia, and civil society in constructive dialogue and cooperative development. This collaborative function ensures that regulatory evolution is informed by practical insights and that new policies are both effective and widely supported.

Accelerating Technical Advancements and Aligning with User Expectations By directly involving end-users in the co-creation and evaluation of new services, testbeds can serve as realistic environments to ensure that innovation is aligned with genuine needs, preferences, and feedback. Using an user-centric approach guarantees that new solutions are not only technically sound but also valuable and readily adopted by their intended audience.

The Testbed as a Strategic Asset for Future Networks The interplay between testbed's economic, regulatory, and technical dimensions is not merely theoretical; it can actively shape outcomes in vertical markets and accelerate emerging technologies. Telecommunications testbeds are far more than technical facilities for experimentation. They are indispensable strategic assets that drive economic growth, shape responsive regulatory policy, and accelerate the creation of user-centric services. From enabling new data-driven business models to fostering collaboration across sectors and refining foundational technologies like VR/AR and edge computing, testbeds are the engines of progress in the modern digital landscape. As the telecommunications sector moves toward 6G and beyond, the role of these innovation ecosystems will only become more critical. Consequently, a strategic and sustained investment in testbed ecosystems is the non-negotiable price of admission for any entity aiming to lead—rather than follow—in the next era of digital innovation.

4 User Dimension

Promoting advanced connectivity services is challenging because often the users do not perceive tangible benefits from the enhanced technical capabilities or improved network performance. The users perception of technology and services is tied not only to connectivity performance, but also to experience, trust, and usability. Therefore, the user dimension of communications and media services spans over several aspects ranging from service adoption to accountability mechanisms. for managing disputes between users and service operators.

This section addresses the user dimension through multidisciplinary contributions, spanning from service adoption to accountability mechanisms. It first examines immersive XR services as a paradigmatic case in which network performance and system design directly shape user experience and service acceptance.

It also explores how XR services contribute to user empowerment in inclusive and assistive applications. The section then focuses on user empowerment by integrating legal compliance and accuracy with clarity and accessibility of legal communication related to service provisioning. Finally, the section sketches a next generation institutional interface between users and service operators for dispute management, aimed at improving trust, awareness, dispute prevention, and accountability in telecommunications services.

4.1 Drivers of User Acceptance in Advanced Communication Services

User acceptance of advanced communication services is strongly influenced by the perceived quality of experience, making XR technologies a particularly relevant case for analysis.

Assessing the quality of experience in eXtended Reality (XR) applications is a complex challenge involving technological, psychological, and sociological aspects. XR applications, which include Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR), use synthetic or mixed content with real elements, enabling applications in areas such as education, entertainment, healthcare, and cultural heritage. This diversity makes it difficult to define unambiguous metrics, as user perception depends on heterogeneous factors such as content fidelity, network performance, interface ergonomics, subjective characteristics, and experience intent.

Quality in XR services is determined by the behavior of the multimedia content, network performance, and the interface's ability to foster natural interaction. On the one hand, XR content involves complex representations such as point clouds, meshes, or 3D objects, which require high throughput and low latency. On the other hand, user experience also depends on device responsiveness, fluidity of interaction, and the ability to generate a sense of presence [40]. The field presents numerous open challenges: efficient 3D data compression, distributed rendering, low-latency transmission, network scalability, and protocols that ensure content consistency and synchrony. Numerous recent studies have explored edge computing techniques, adaptive caching, content prediction, and intelligent network resource management to support real-time XR applications.

XR quality of experience (QoE) is not limited to technical measures such as throughput or latency, but encompasses aspects such as immersion, engagement, usability, presence, and comfort. The literature highlights how individual variables influence the experience: gender, age, technological familiarity, and sensitivity to headset-related discomfort (such as cybersickness). For example, experienced users are more sensitive to even minimal variations in delay, while inexperienced users may be put off by the complexity of new interfaces.

Inclusivity is a crucial component. Different generations have different levels of acceptance and ability to use technology: older people often encounter difficulties related to poor digital literacy or the perception of limited usefulness. At the same time, XR could become a fundamental tool for cognitive support, autonomy, socialization, and health monitoring, provided it is designed with attention to accessibility, ease of use, and transparency. The integration of IoT and XR represents a strategic opportunity in supporting people with disabilities or motor and cognitive difficulties. Wearable sensors, biomedical devices, environmental sensors, or motion detection systems can provide real-time information to be represented or processed in XR environments to facilitate monitoring, navigation, rehabilitation, and interaction with space. Innovative XR applications for inclusion have been proposed also for learning applications. In this case, users interact with digital representations of objects and environments in immersive and multimodal ways, supporting personalized learning paths and enhancing engagement, particularly for students with special educational needs or limited access to traditional learning contexts [44].

Three main IoT-XR service architectures have been identified:

Patient-centric: Wearable sensors monitor vital signs or movement and present them in XR to caregivers and clinicians, enabling rapid interventions.

Indoor environmental XR: Smart-home and AR-based home environments assist users with orientation, accident prevention, and daily interactions.

Outdoor environmental XR: XR supported by urban sensors and mobile technologies guides users with visual or motor difficulties through AR, audio, or haptic signals.

The technological maturity of these systems requires reliable infrastructure, energy-efficient devices, and rapid transmission protocols. A key element is the Age of Information (AoI), a metric that quantifies the freshness of real-time data, crucial in highly dynamic IoT environments. Recent studies show how update frequency, network traffic, and sensor power limitations significantly influence AoI and therefore the usefulness of XR services.

The adoption of XR technologies requires an approach guided by acceptance models such as the Technology Acceptance Model (TAM), according to which perceived usefulness and ease of use are key determinants. The literature confirms that age, technological familiarity, and sociocultural conditions influence usage intention. In the healthcare context, recent research shows that perceived usefulness and enjoyment are determining factors for both operators and patients. However, the complexity of interfaces, poor interoperability with existing technologies, and a lack of trust in data management represent significant obstacles.

IoT-XR applications collect highly sensitive data: biometric, medical, behavioral, and environmental. This introduces significant legal responsibilities regarding security, transparency in data management, user rights, and regulatory compliance (such as GDPR). Users should be aware of how their data is being processed and provided with tools to control it. Transparent incentives and contractual models can improve users' willingness to share data securely.

Besides analyzing potential architecture with high outreach, the study addressed the issue of evaluating the XR experience through integrated tools. Traditional tools (UEQ, SUS, AttrakDiff) do not adequately capture aspects such as immersion, realism, or agency, while presence questionnaires (PQ, IPQ, ITC-

SOPI) are too long or difficult to integrate. To fill this gap, the X-UEQ was developed, a 12-item module that extends the UEQ while maintaining formal and syntactic compatibility. The six identified dimensions, inspired by the structure of the Presence Questionnaire, are: perceived realism, agency, sensory engagement, interface quality, active exploration, and performance evaluation [38]. The module was built through qualitative analysis of interviews with XR users. A validation study ($N = 40$, two apps: Anne Frank House VR and Cubism) showed good reliability for all scales ($\alpha = .73$˘.87, total $\alpha = .91$) and convergent validity with the Presence Questionnaire ($r = .48$˘.71, $p < .01$). The tool discriminated between apps on five out of six dimensions.

To sum up, quality assessment in XR services requires a multidisciplinary approach, capable of integrating technical and psychological aspects. Integration with the IoT opens up significant opportunities for inclusive and disability-supportive applications, but also introduces technical, social, and legal challenges. The X-UEQ questionnaire represents a validated contribution to more coherent and compact metrics for user experience in XR, offering a tool sensitive to the complexity of immersive interaction and suitable for iterative design cycles.

4.2 Transparency, Trust, and User Empowerment in Digital Telco Services

Transparency and trust are foundational conditions for user empowerment in digital telecommunications services, and consumer protection in the TELCO sector is a preventive process that begins at the moment of contract formation.

In digital and highly litigated B2C markets such as the TELCO sector, consumer protection increasingly relies on preventive safeguards operating at the moment of contract formation (Dir. (EU) 2018/1972; Italian Consumer Code; AGCOM Regulation on end-user contract protection, Res. No. 307/23/CONS, Annex B).

Especially when consumer contracts are concluded at a distance and through online channels, effective awareness of rights and obligations becomes structurally fragile, making contract transparency not merely a formal (legal) requirement but a substantive condition for effective consent, market trust, and, prospectively, dispute reduction. Ensuring contract clarity and comprehensibility therefore demands more than plain language: it requires a rethinking of the contract's ergonomics, including the structure of documents, the layout of subscription modules, and the interaction design of digital contracting environments.

In this perspective, legal design provides an interdisciplinary framework capable of integrating legal compliance and accuracy with linguistic clarity, cognitive accessibility, and user-centred legal communication (pre-contractual and contractual information). Research shows that visual organisation, interaction cues, and simplified conceptual models substantially enhance comprehension and support preventive protection [18][41][25][47][6].

Reimagined in this way, the contract becomes not only a repository of rights and obligations but a functional instrument of awareness that does more than correct informational asymmetries; it actively prevents conflict before it arises and contributes to a more trustworthy, transparent, and resilient digital marketplace [42].

The needs analysis conducted on this matter combined multiple levels of investigation. These included: (i) direct engagement with consumers representatives (Naples,19 December 2024) and the CNCU consultation via an open-ended questionnaire (paralleled by a roundtable with the legal departments of major market operators); (ii) the analysis of market data and litigation trends drawn from AGCOM's official monitoring reports; and (iii) a technical examination of current contractual practices, both from a legal and linguistic standpoint, involving the reconstruction and comparison of the general terms and subscription modules used by leading national operators, assessed in light of the European and domestic regulatory framework on contract transparency and consumer rights.

The evidence delineate a clear picture: consumer perceptions converge on the low intelligibility of contractual texts, particularly concerning complex and technically dense clauses such as unilateral modification clauses (*jus variandi*) and price indexation mechanisms. These concerns are corroborated by litigation data, which reveal a significant incidence of disputes plausibly linked to contractual opacity; the same data indeed identify, as particularly problematic and litigation-generating, clauses governing price adjustments and the presence of ancillary services bundled with offers. According to consumers, these criticalities become even more pronounced in the digital environment - now a primary contracting channel - where users report opaque informational pathways, poor accessibility for vulnerable consumers, and interface design elements capable of steering choices in non-transparent ways.

From this empirical record emerge four priorities for intervention: radically simplifying contractual language; standardising essential information; ensuring clear, dark patterns-free digital pathways; and fully including vulnerable users through dedicated solutions. The analysis of current contracting practices and the protections envisaged by recent European and national regulatory instruments further confirms the need to intervene primarily on the transparency and accessibility of the general terms of service in use.

On this basis, the contract redesign phase was developed around coordinated interventions on language, textual organisation, and the graphic and interactive design of contractual materials. Linguistic measurement and clarification involved the combined use of multiple LLMs, guided by a common prompt framework and anchored in international standards and domestic soft-law principles on plain legal language. Automated outputs were subjected to extensive manual revision to preserve legal consistency and the functional operation of the clauses. The work addressed both lexicon and syntax, aiming for short sentences, linear structures, reduction of unnecessary technicalities, and explicit definition of key terms.

In parallel, the reorganisation of content was designed to produce a text with a predictable logical structure, clearly labelled sections, and an immediate distinction between the rights and obligations of the parties. This semantic architecture was complemented by a systematic study of layout and graphic solutions: the use of icons and high-contrast colours to label semantic areas through a legend; the visual highlighting of potentially unfair terms to increase their salience; and the introduction of interactive summaries and guided reading pathways.

From an accessibility and usability perspective, interactive elements such as explanatory pop-ups were developed, alongside multichannel solutions including audio-reading with synchronised transcript and AI-generated video explaining complex clauses through concrete examples and plain language.

The result is a contract model that combines textual clarity, ergonomic structure, and digital accessibility, serving as the foundation for subsequent empirical testing aimed at defining innovative benchmarks for contractual transparency. Beyond their contribution as research outputs and potential references for future regulatory considerations in the field of effective consumer protection, such benchmarks will support the development of AI systems capable of assisting operators in drafting clear and accessible contractual documents [19]providing tools that can leverage perceived trust and thereby offer a meaningful competitive advantage.

4.3 Designing Accountability Mechanisms in User–Operator Relations

In line with the objective of designing accountability mechanisms in user–operator relations, we examined the redesign of a web based platform for the management of disputes between users and telecommunications operators, focusing on the Conciliaweb ODR platform interface. A further research line examined the redesign of a web platform for the management of disputes between users and telecom operators, namely the Conciliaweb ODR platform interface, applying Legal Design principles to strengthen its effectiveness and usability in B2C settings [13].

Evidence gathered through discussion panels with consumer associations and Telco operators, supported by a questionnaire, confirmed the need for clearer linguistic structures, more accessible interaction pathways, and tools capable of supporting vulnerable users. These findings pointed toward a broader objective: improving access to justice while reducing procedural delays and litigation costs.

The redesign followed a structured sequence. The initial phase centred on understanding the operational context and user needs through an in-depth analysis of the current platform and of comparable systems, complemented by interviews and panel discussions. Once needs had been identified, the work progressed to the design phase, defining the information architecture and developing wireframes and visual solutions. Particular attention was devoted to accessibility, integrating assistive functionalities such as video support, voice-based cursors, dedicated chatbots, and AI-enabled dictation for users with visual, cognitive, or motor impairments. The subsequent phase concerned the development and testing of an interactive, responsive prototype capable of functioning smoothly across devices. The final phase introduced an iterative evaluation cycle aimed at monitoring performance, identifying emerging needs, and supporting progressive optimisation of the platform.

The resulting prototype rests on three coordinated pillars: the systematic application of Legal Design; a language architecture aligned with ISO 24495-2 on communication and legal drafting; and a text architecture consistent with the European Accessibility Act (Directive 2019/883) and Legislative Decree 82/2022 (effective June 2025). Plain language is supplemented by visual elements and infographics, while interactive video tutorials guide users throughout the procedure. The virtual assistant ConcilIA provides continuous support, including automatic dictation, thereby facilitating access for users with visual, motor, or cognitive limitations.

The platform implements dedicated solutions for each category of disability:

Type of Disability	Accessibility Solutions Implemented
Visual	*High contrast, screen reader, automatic dictation*
Hearing	*Subtitles, keyboard navigation, automatic dictation*
Motor	*Voice commands, simple interfaces, automatic dictation*
Cognitive and Neurological	*Simple language, clear layout, automatic dictation*
Temporary or Situational	*Adaptive design, resilient interfaces, automatic dictation*

Fig. 2. Various types of accessibility solutions to be considered

Further components include an admissibility algorithm, a system for assessing platform adequacy, and a predictive conciliation model. The convergence between conversational AI (ConcilIA) and immersive XR technologies expands the horizon of digital justice, enabling simulated negotiation environments, institutional avatars guiding users, three-dimensional dashboards for case management, and integrated predictive metrics.

Overall, the section highlights how user centric considerations extend beyond technical performance to encompass empowerment, transparency, and accountability across the entire service lifecycle. Accessible services, clear legal communication, and institutional mechanisms for dispute management can make user empowerment a structural component of next generation telecommunications ecosystems.

5 Regulation perspective

5.1 Digital Equality and the Future of Telecom Regulation: Rebalancing Rights, Competition, and Infrastructure Power

The legal framework governing the digital ecosystem must confront a foundational question: how to safeguard digital equality in access to technology, conceived as a good that enables the exercise of fundamental rights. In this sense, competition law also plays an instrumental role in protecting fundamental rights, as it helps rebalance structural asymmetries that influence individuals' concrete ability to access and use essential digital services without economic barriers. At the same time, it is increasingly evident that an overly rigid regulatory apparatus may undermine the sector's competitiveness, discouraging innovation and imposing disproportionate burdens on market actors.

Technological and market transformations demand a shift away from the proceduralist orientation that has characterized digital constitutionalism to date, relying primarily on transparency, accountability, and due process as safeguards against concentrated power, especially of dominant digital platforms [14].

Correcting the imbalances between individuals, Telcos, and other digital businesses requires moving from soft-law initiatives to tangible, enforceable obligations capable of addressing the structural dynamics that generate dependency and concentration. This also entails forms of democratization within Telco and tech companies: enhanced transparency, meaningful user involvement, and governance mechanisms that distribute decision-making power and responsibility.

The objective is to reposition the center of gravity of digital regulation—moving from a reassuring yet often ineffective proceduralism toward a substantive constitutionalism that redistributes power and resources across the technological value chain. The primacy of fundamental rights remains the guiding criterion; however, it must translate into reasonable rules capable of protecting digital equality without imposing unjustified burdens that weaken the competitiveness of the very enterprises sustaining the digital infrastructure. This underlying tension frames the analysis that follows.

The evolution of the European telecommunications markets is emblematic of the increasing interplay between technological innovation, structural transformations, and regulatory interventions[12].

The transition from a monopolistic model to a competitive one has not produced a full rebalancing of market conditions, while the progressive functional convergence between telecommunications operators (Telcos) and large digital platforms (Gatekeepers, GKs) has introduced new frictions and regulatory misalignments. In this context, the definition of a unified and coherent framework constitutes one of the main challenges of European communications policy.

The present state of the art and open issues need to be analysed in light of the factual and regulatory evolution of telecommunications in the European Union (EU). In the beginning, the overcoming of the public monopoly led to the establishment of asymmetric regulation designed to compensate for the structural advantage of the former monopolist, still owning the network and at the same time active in retail services. This ex ante–oriented framework aimed to simulate conditions of effective competition through access obligations, non-discrimination, and constraints on the incumbent's negotiating autonomy. Antitrust rules, by

[12] For a deeper reflection on these topics, see G. De Minico, Regole o libertà per le telecomunicazioni del futuro? In G. De Minico - M. Orofino (eds.), La regolazione delle telecomunicazioni e dei dati nella società digitale (Jovene : Napoli), forthcoming.

contrast, operated ex post with a repressive function. The two regulatory systems were thus in an inverse proportionality relationship: the less competitive the market, the more intense the preventive regulation. The 2002 and 2009 packages and the Electronic Communications Code modified this structure, shifting to the National Regulatory Authorities (NRAs) the task of assessing, through a three-criteria test, when and in what forms to apply corrective remedies.

However, the progressive layering of directives, recommendations, and enforcement practices has rigidified the system. The generalized adoption of purely behavioural remedies has shown its insufficiency: despite formal compliance with the rules, vertically integrated operators continued to exercise substantial competitive advantages, highlighting the difficulty of restoring market equilibrium through mere conduct obligations.

One especially controversial point is the enduring difference between the regulatory burdens imposed on Telcos and GKs. Digitalization has increasingly blurred the distinction between services traditionally provided by the former and the latter, such as communication, intermediation, and the management of information flows. The service provided to the end user becomes functionally equivalent, regardless of the technical means employed. Yet a strong disparity remains: while Telcos are subject to network access obligations and strict regulatory oversight, GKs operate under a much lighter regime despite relying on the same connectivity infrastructure. The Digital Markets Act (DMA) seeks to fill this gap but does so through a paradigm profoundly different from Telco regulation. The designation of a GK results from exceeding quantitative thresholds, without a precise factual assessment of dominance or contestability in the relevant markets. The obligations imposed under Articles 5 and 6 of the DMA apply indiscriminately, with no explicit reference to the principle of proportionality and with an evident risk of redundancy vis-à-vis antitrust rules. At the same time, a content-based imbalance persists: while Telcos face access obligations, GKs are not subject to corresponding equal access obligations to their platforms. This disparity lacks justification in the nature of the infrastructures, both of which are functional to the provision of the final service and therefore both susceptible to being qualified as hybrid goods, straddling public and private law.

The regulatory divergence also emerges in the nature of the assets: physical networks for Telcos, data for GKs. User-generated data, once processed, constitute a qualitatively new asset, irreducible to the sum of individual contributions. Consequently, traditional remedies—particularly monetary sanctions—are inadequate to restore competitive balance in highly dynamic markets. In this research, we propose strengthening structural remedies: partial or full data sharing, interoperability obligations, advanced portability, tailored commitments. Similarly, on the Telco side, the possibility of a structural separation of the network cannot be excluded in principle, as the network constitutes an essential facility for market access. In both situations, the goal is to increase market contestability and reduce technological barriers, favouring solutions calibrated to the characteristics of the infringement and the different levels of vertical integration.

Another crucial point lies in the differing contributions to infrastructure costs that generate a significant economic imbalance. GKs absorb the largest share of data traffic yet contribute minimally to the costs of building and maintaining networks. This situation may justify a fair share mechanism, grounded in at least two reasons. The first is the need to redistribute investments necessary to achieve European connectivity objectives. The second is the need to reduce inefficient traffic consumption, which currently lacks real incentives for rationalization. The Draghi Report also emphasizes this point, noting that the current distribution of costs is not sustainable in a market now characterized by deep technological convergence.

As a matter of fact, regulatory overload—stemming from both EU rules and national gold-plating phenomena—has made the Telco sector less competitive than global digital operators. Selective, not general, deregulation is therefore necessary: removing superfluous rules in already competitive markets while preserving those needed where entrenched positions persist. The Italian case concerning the separation of the TIM network highlights the complexity of this approach. The sale of the network to FiberCop, accompanied by long-term exclusivity agreements, led AGCOM to consider suspending some regulatory obligations; however, the AGCM opened an investigation to assess whether these agreements generate new forms of competitive advantage. This episode shows that regulatory easing must be tailored case by case, avoiding uniform solutions.

Looking at future perspectives, the European Commission is preparing to replace the current code with the Digital Networks Act (DNA), intended to govern the new connectivity ecosystem. The DNA addresses essential areas: copper switch-off, spectrum harmonization, 5G network security, protection of submarine cables, dispute resolution mechanisms, and new contribution models. One of the central issues concerns governance. The choice between a decentralized model, centered on NRAs, and a centralized one, empowering the Commission, is not merely organizational. In a context dominated by large technological powers, a fragmented Europe risks strategic irrelevance. The argument for centralization is therefore also geopolitical: only a supranational authority can coordinate a single market and ensure homogeneous rules along the vertical and horizontal axes of equality.

Drawing from the above reflections, we can conclude that the interplay between Telcos and GKs shows that European regulation now stands at a crossroads: preserve a framework inherited from an outdated technological context or adapt it to an integrated ecosystem in which networks and platforms participate in the same value chain. Technology constitutes an extraordinary opportunity only if oriented toward reducing inequalities and spreading power; if used to consolidate pre-existing positions, it becomes, instead, a multiplier of imbalances. The future direction will depend on the Union's ability to adopt a unified, coherent regulatory strategy calibrated to the actual structure of contemporary digital markets.

5.2 Regulation of data between circulation and personal data protection: the current state of European regulation

In recent years, data has taken on a central role not only in economic processes and technological innovation, but also in the very architecture of fundamental rights in digital societies. Data is no longer merely a technical element or a production factor: it constitutes a precondition for the effective exercise of individual and social rights. This transformation marks a conceptual shift from the original paradigm of European data regulation, historically focused on the protection of personal privacy as a defensive barrier against undue interference.

The contemporary perspective, instead, ties the protection of data to their regulated circulation: the ability of data to move, to be accessible, interoperable, and reusable becomes a necessary – and not alternative – condition for the effective guarantee of rights such as the right to health, education, mobility, work, and even democratic participation itself. What emerges is a new constitutional grammar, in which data governance is understood as an enabling infrastructure of digital citizenship.

In this context, data regulation responds not only to logics of competition and innovation, but also serves as a tool for implementing the values of the European Union: dignity, autonomy, substantive equality, and solidarity. The protection of personal data, far from being superseded, remains a central element, but is articulated within a regulatory ecosystem aimed at promoting the safe and responsible circulation of data rather than hindering it.

The turning point in European regulation is represented by Regulation (EU) 2016/679 (GDPR), which marks the shift from a model based on consent and proprietary logic – typical of Directive 95/46/EC –to a framework grounded in accountability, transparency, and control over processing. The GDPR, based on both Article 114 and Article 16 TFEU, reflects a dual nature: on the one hand, it protects the fundamental right to personal data protection; on the other, it ensures the free flow of data as a cornerstone of the digital single market.

Alongside the GDPR, Directive 2002/58/EC (the e-Privacy Directive) survives as a special rule in the field of electronic communications. This directive, however, is now in a peculiar position: born as the lex specialis of Directive 95/46/EC, it continues to produce its effects with respect to the GDPR, creating a phenomenon of "inverse specialty" that requires complex interpretative efforts and coordination mechanisms between national sources and a directly applicable European regulation.

The e-Privacy Directive regulates crucial aspects such as: the confidentiality of electronic communications, the protection of traffic and location personal data, and access to users' devices through cookies and similar tracking tools. However, technological evolution has made it increasingly clear that the directive – and the national laws transposing it – struggle to operate in a profoundly different context, resulting in gray areas and overlapping regulatory provisions.

Over the last five years, the European Union has launched a new legislative phase that goes beyond the purely protective dimension of data and aims to enhance it as a strategic resource. The shift does not consist in weakening protection, but in acknowledging that protection is not incompatible with circulation; rather, it requires circulation as a prerequisite.

Among the most significant acts are: the Data Governance Act (DGA) that: introduces trust-based models for data sharing, access infrastructures, data intermediaries, and data altruism, shaping new safe spaces for the reuse of public data; the Data Act (DA) that recognises users' rights to access, obtain and share data generated by connected devices, overcoming proprietary logics and promoting the accessibility and interoperability of data, including personal data; the European Health Data Space (EHDS) which creates a regulatory environment that enables primary and secondary use of health data without making consent the sole basis for lawful processing, marking a significant evolution compared to Article 9 GDPR; finally the AI Act that adopts a risk-based approach and imposes obligations on quality, traceability, and accessibility of datasets for high-risk systems, implicitly acknowledging that without data there can be no reliable artificial intelligence.

The whole analysis of the post-GDPR regulatory landscape shows a proliferation of acts affecting the processing of personal data in vertical sectors, introducing exceptions and derogations to the general framework. This marks the shift from a horizontal, unitary, and coherent model to a mosaic of sector-specific regulations.

On the one hand, this enables rapid and targeted legislative responses to specific needs of the digital economy; on the other, it creates risks: legal uncertainty, inconsistent application, excessive reliance on national supervisory authorities, and – above all – a gradual weakening of the systemic clarity of the GDPR.

The evolution of European data law now seems headed toward a new phase, in which the central issue is no longer merely the search for a balance between protection and circulation, but the definition of a coherent and uniform regulatory architecture capable of overcoming the current asymmetries between actors operating in the same digital market.

The first element likely to shape the future of regulation is the alignment of obligations between traditional network operators (telco) – strictly bound by e-Privacy rules – and over-the-top (OTT) digital service providers. The current regulatory framework still distinguishes between those who provide public communication infrastructures and those who offer digital services built on those networks, imposing stricter obligations on the former on the basis of an outdated conception of electronic communications. This situation distorts the level playing field and is inconsistent with today's digital services economy, in which networks, platforms, and applications compete and replace each other in the functions offered to users.

In this regard, the recent decision of the European Commission to withdraw the proposal for an e-Privacy Regulation, after eight years of fruitless negotiations, is significant: it does not represent an abandonment of reform, but the opening of a new legislative phase aimed at definitively overcoming the telco–OTT dichotomy.

The second key element concerns the simplification of the digital regulatory landscape, which is currently excessively layered, fragmented, and marked by overlaps between general and sector-specific rules. This need has already been reflected in the legislative proposals recently presented by the Commission: a) the "GDPR Omnibus" Regulation Proposal, aimed at easing and rationalising certain GDPR compliance obligations to make them more sustainable, especially for SMEs; b) the "Digital Omnibus" Regulation Proposal, intended to directly amend provisions of the e-Privacy Directive by reducing its scope and integrating a new cookie rule into the GDPR, thus moving beyond the distinction between public networks and digital services; c) the consultation for the upcoming Digital Networks Act, designed to comprehensively rewrite the rules on electronic communications, address national fragmentation in the sector, and lay the foundation for a single market for digital networks.

The future of European data regulation therefore rests on three strategic axes.

The first concerns the principle of technological neutrality and the adoption of horizontal rules. This means establishing uniform requirements for all providers, regardless of the nature of the service they offer. Such an approach prevents certain categories of operators from being unfairly advantaged or disadvantaged, ensuring a level playing field and a coherent regulatory environment.

The second direction involves legislative harmonisation. At present, the European regulatory landscape is fragmented—both between Member States and between the telecommunications sector and the broader digital ecosystem. Overcoming these discrepancies is essential for building a truly integrated single market, one capable of fostering innovation, competitiveness, and long-term investment.

Finally, the third strategic axis focuses on the functional integration between data protection and data circulation. These two dimensions should no longer be perceived as opposing forces, but rather as complementary aspects that shape digital citizenship. The challenge is to develop a system in which data can move freely and securely, enabling new services and economic opportunities while safeguarding fundamental rights.

If these directions are confirmed, the European Union may complete the paradigm shift already underway: from a defensive privacy model to a constitutional model of data governance, in which the protection of individuals and market development are no longer conceived as opposing interests, but as structural components of the same digital architecture.

6 Future Scenarios

6.1 Strategic Scenarios for the Future of Telecommunications Infrastructures in Italy (2050).

Taking into account the overall picture described in the previous sections, University of Bologna and -skopìa Anticipation Services worked through strategic interviews and scenario building [46] [5] on the definition of four strategic scenarios for the future of Telecommunications Infrastructures in Italy in 2050. The scenarios have been developed from the perspective of the Italian government and with Italy as the primary reference context. The scenarios are not predictions but structured explorations of a “space of possible futures”, in line with futures studies and the Shell method [8] [54]. They extend insights from strategic interviews with Italian experts on the 2040 horizon, which highlighted persistent issues such as regulatory fragmentation, investment gaps, territorial disparities, geopolitical tensions, cyber-security vulnerabilities and weaknesses in European research and innovation. These concerns informed the scenario-building workshop held in November 2024, where a wide set of social, technological, economic, political and ecological forces was organised into predetermined trends and highly uncertain variables.

Two uncertainties emerged as particularly decisive for the evolution of telecommunications in Italy: the future strength of the European Union and the trajectory of urbanisation versus de-urbanisation. Their combination defines a four-scenario space: a strong EU with high urbanisation (“United States of Europe”), a weak EU with high urbanisation (“City State 2.0”), a strong EU with de-urbanisation (“Distributed States of Europe”), and a weak EU with de-urbanisation (“Digital Feudalism”). Each scenario is presented as a distinct socio-technical configuration, examining assumptions, infrastructure architectures, governance arrangements, stakeholder dynamics, risks and opportunities, and key indicators to track. Together, they serve as stress tests for current assumptions in policy and industry, and connect to broader themes raised in the deliverable, such as: inequalities, skills, privacy, the role of operators, rural development and climate resilience. This section concludes with a synthesis comparing the scenarios and outlining implications for anticipatory governance and long-term strategic planning in Italy and Europe.

Scenario 1 – United States of Europe “United States of Europe” lies in the quadrant of a strong, cohesive European Union combined with marked urbanisation by 2050. From the perspective of the Italian government, European integration has deepened politically and economically, producing a genuinely unified digital single market. A few large pan-European operators dominate telecommunications, and cities concentrate population, economic activity and innovation. The scenario responds directly to interview concerns about regulatory fragmentation, weak competitiveness and dependence on extra-European ICT supply chains.

Telecommunications infrastructures are centralised, integrated and largely European-owned. A small number of pan-European operators run convergent fixed-mobile-satellite networks, guaranteeing high-capacity connectivity in dense urban areas and satellite-supported coverage in rural regions. A European cloud and AI stack, supported by specialised hubs in artificial intelligence and robotics and by a European satellite constellation, underpins smart cities and the machine economy. Urban environments are saturated with digital services for mobility, energy, waste and public administration, but they depend heavily on large, centralised core infrastructures.

Governance is multi-level but strongly EU-centred. European institutions set strategy, standards and regulatory frameworks; national governments implement within this common frame; cities act as key implementation arenas for smart and green policies. Power is concentrated in alliances between EU institutions, a few pan-European telecom operators, the European ICT supply chain, multi-utilities and strategic sectors such as health, bio-medical industries and energy. Populist forces and actors concerned with local autonomy contest this centralisation and the dominance of large corporate players, especially where territorial imbalances persist.

The scenario offers major opportunities: it delivers the integrated single market and technological sovereignty sought in the interviews, enabling Europe and Italy to reduce dependence on non-European cloud, AI and telecom providers, exploit economies of scale in infrastructure deployment and develop advanced smart-city services. At the same time, strong centralisation creates systemic cyber-vulnerabilities and may deepen divides between dynamic metropolitan areas and more fragile rural or peripheral territories. Climate risks are concentrated in large urban agglomerations, and dense urbanisation may fuel social tensions and radicalisation. Italian policy and industry strategies, therefore, must couple support for European integration with active policies on territorial cohesion, resilience and inclusive access to advanced services.

Key indicators pointing towards this scenario include the degree of market consolidation (number of operators and share of pan-European, multi-sector players), the level of regulatory and standards harmonisation, and the extent of fixed and mobile coverage, including fibre-to-the-home penetration. The volume and nature of new European ICT technologies and applications signal technological autonomy. Demographic data on urban population, together with measures of the digitisation of citizen services, indicate the strength of the urban-centric, smart-city model.

Within the overall scenario set, "United States of Europe" represents the maximal combination of European integration, market concentration and urbanisation. It highlights core trade-offs between efficiency and resilience (centralised infrastructures vs exposure to systemic shocks), between sovereignty and diversity (European ICT stacks vs room for smaller actors), and between global competitiveness and territorial cohesion (smart, prosperous cities vs potentially neglected peripheries. In the later synthesis, it will serve as the reference case for a highly integrated, centralised and urban-centric future against which more fragmented or decentralised trajectories can be contrasted.

Scenario 2 – City State 2.0 "City State 2.0" reflects a weak and fragmented European Union combined with continued urbanisation by 2050. The absence of a unified EU policy leaves space for large metropolitan areas to act as autonomous centres of power. Some cities prosper and attract investment, while others struggle to maintain essential services. This scenario extends concerns highlighted in the interviews, regulatory divergence, lack of a digital single market and Europe's technological dependence, showing their consequences in a strongly urban but politically disjointed context.

Telecommunications are fully privatised, fragmented and uneven. Local and metropolitan operators dominate, often with limited investment capacity. A few wealthy city-states achieve advanced smart-city infrastructures through direct agreements with global players, relying on imported technologies and foreign cloud and AI services. Rural and peripheral areas face severe connectivity deficits, deepening the digital divide. Network architectures vary widely in quality, and the absence of a coordinated European space or ICT strategy removes Europe from technological leadership. Overall, telecom infrastructures mirror and reinforce territorial disparities.

Governance becomes centrifugal. Metropolitan authorities negotiate directly with international actors, while national and European institutions lose influence. Municipal companies, regional operators and some local authorities defend their autonomy but remain vulnerable to acquisitions by foreign firms. Citizens increasingly form virtual communities, weakening local ties and complicating collective governance. Stakeholder alignments are fragmented, with international corporations gaining significant leverage in the absence of shared regulation or European strategic direction.

Opportunities exist only in a few competitive city-states, where deregulation enables experimentation and attractive digital services. Yet the wider system faces severe risks: an extreme digital divide, chronic underinvestment outside major metropolitan areas, loss of technological sovereignty, uneven cybersecurity, and fragmented responses to climatic or social emergencies. For Italy, the scenario challenges any aim of universal service provision and reduces the ability to plan long-term infrastructure strategies. Fragmentation also increases polarisation, as citizens excluded from advanced services turn to virtual communities for identity and belonging.

Key indicators include rising population flows into major cities, proliferation but fragility of small operators, declining European patents, and low development of autonomous European technologies. Territorial indicators-coverage gaps, fibre-to-the-home disparities, uneven network take-up-signal widening inequalities. Social metrics such as fear-of-foreigners data, crime perceptions and growing reliance on virtual interactions reflect polarisation and weakened cohesion.

City State 2.0 shows what high urbanisation looks like without European coordination. It highlights trade-offs between metropolitan autonomy and shared strategic capacity, and between unregulated competition and universal access. As part of the overall scenario set, it represents a fragmented, city-driven trajectory in which telecommunications cease to be an integrating infrastructure and instead magnify territorial and social divides.

Scenario 3 – Distributed States of Europe "Distributed States of Europe" combines a strong and cohesive European Union with marked de-urbanisation by 2050. From the Italian government's viewpoint, Europe provides a stable political and regulatory framework, while Italy pursues a distributed development model based on the repopulation of rural and inland areas, supported by a capillary digital network and common European minimum standards.

Telecommunications infrastructures are pervasive and territorially balanced. Fixed, mobile and satellite systems ensure high-quality connectivity across cities, small towns and rural areas, with smart-territory solutions (sensors, edge computing, local data centres) enabling telemedicine, e-learning and local services. European AI hubs and ICT supply chains exist, but value is diffused through networks of SMEs and local technology companies linked to specific territories and zero-kilometre applications.

Governance is multilevel: regional governments enjoy greater autonomy yet act in coordination with European institutions, which set strategic directions and standards and retain a role in key companies. Allies include European operators and supply chains, networks of SMEs, energy communities, cooperatives, third-sector organisations and local governments. The main structural risk is a drift towards provincialism, if strong local identities are not continuously connected to wider European projects.

The scenario opens major opportunities for reducing the digital divide and rebalancing development. Telecommunications become a core enabler of smart territories, remote work, telemedicine and local innovation, aligning with energy communities and zero-kilometre production to support sustainability and climate resilience. At the same time, managing a complex mosaic of local realities may generate new inequalities between more and less dynamic territories and higher logistics costs for dispersed populations. For Italian telecom policy, this implies sustained investment in inclusive infrastructures, support for SME networks and cross-sector partnerships, and robust coordination mechanisms to keep decentralisation aligned with European standards, security and cohesion.

Key indicators include the number of operators and of multi-country or multi-sector operators, the evolution and enforcement of European standards, and coverage and take-up of networks across all territories, particularly fibre-to-the-home in small towns and rural areas. Demographic trends (share of population in cities vs small centres, growth of repopulating areas), diffusion of new European technologies and applications, levels of zero-kilometre production, numbers of mutual-help associations and changes in CO_2 emissions together reveal whether a distributed, sustainable and cohesive model is effectively consolidating.

Within the scenario set, “Distributed States of Europe” represents the “strong EU-de-urbanisation” trajectory. It contrasts with the urban-centralised path of Scenario 1 and with the fragmented configurations of Scenarios 2 and 4, showing that European integration can underpin territorial decentralisation rather than metropolitan concentration. In the overall synthesis, it will highlight trade-offs between efficiency and territorial justice, and between centralised and distributed resilience, and will illustrate how telecommunications can sustain a model in which local communities are empowered without weakening European coherence.

Scenario 4 – Digital Feudalism "Digital Feudalism" occupies the quadrant of a weak, fragmented European Union combined with marked de-urbanisation by 2050. From the vantage point of the Italian government, the collapse of a coherent EU policy leaves Europe geopolitically marginal, while Italian and other local territories reorganise around autonomous, largely rural or small-town communities. Large cities still exist but play a secondary role compared to localities that rely on their own resources, institutions and infrastructures.

Telecommunications infrastructures are highly decentralised and locally managed. Local TLC operators, often with a multi-utility profile, provide basic connectivity, while additional services are delivered through shared infrastructures and extensive use of network slicing. Architectures are distributed and tailored to community needs, supporting local platforms, open-source solutions and zero-kilometre economic circuits. However, technological development lags behind other scenarios: Europe no longer plays a leading role in the space economy or advanced ICT, and many cutting-edge technologies are imported and adapted rather than developed in Italy or Europe.

Governance is bottom-up and community-centred, with strong local institutions, cooperatives and energy communities acting as primary decision-makers and infrastructure owners. Local TLC operators, municipalities and open-source communities manage digital resources in a quasi-federal patchwork; logistics giants connect dispersed territories but also become critical gatekeepers. Allies include cooperatives, energy communities, local governments, small and medium-sized enterprises and local open-source projects. In contrast, large international technology companies that control key technologies are perceived as structural "enemies", as is any attempt to re-centralise control over data and infrastructures. Power is thus fragmented, with relatively weak national and European steering capacity.

The scenario offers significant opportunities in terms of social cohesion, quality of life and environmental sustainability. Local production and consumption, strong social ties and community-based innovation can support climate resilience and reduce long-distance mobility. At the same time, the combination of weak European coordination and technological lag exposes Italy to risks of dependency on external technology providers, uneven service quality and infrastructural fragmentation. Cyber security benefits from proximity and contextual knowledge but requires specialised expertise in each community and may suffer from limited resources and coordination. For Italian telecom policy, this scenario would imply rethinking regulation around local ownership, multi-utility logics and open-source ecosystems, while addressing vulnerabilities in logistics, advanced R&D and national security that cannot be managed at community scale alone.

Monitoring this scenario involves tracking the density and vitality of local socio-technical ecosystems: the number of cooperatives, community organisations and local TLC operators; the diffusion and continuity of local open-source projects; and the volume and distribution of network users and traffic. Together, these variables indicate whether autonomous communities are able to sustain and upgrade their infrastructures, whether zero-kilometre production and energy communities are consolidating, and whether the balance between local resilience and technological backwardness is moving towards stability or increasing vulnerability.

"Digital Feudalism" represents the "weak EU–de-urbanisation" configuration and forms the most radical counterpoint to the centralised, strong-EU path of Scenario 1. Compared to Scenario 3, it shows what happens when territorial decentralisation is not backed by European coordination, leading to stronger local cohesion but weaker technological capability and geopolitical influence. In the synthesis, it will highlight trade-offs between autonomy and scale, local quality of life and innovation capacity, and between community-based resilience and systemic vulnerabilities in a fragmented European environment.

7 Conclusions

In this chapter we presented the complex interplay between several factors affecting the evolution of telecommunication networks, from a multi-dimensional perspective. Building on this analysis, we identified some forces driving the evolution of the telecommunication eco-system and finally added a socio-political dimension, in terms of urbanization dynamics and the degree of European policy coordination.

The four scenarios offer a structured picture of how Italy's telecommunications infrastructure could evolve by 2050 under different combinations of EU strength and territorial development. Together, they show telecommunications as a strategic enabler of economic, social and spatial change, with outcomes shaped by long-term decisions on integration, investment, regulation and the balance between centralised and local approaches. The scenarios also act as a stress test for today's policies and business models, highlighting persistent vulnerabilities, digital divides, cyber-security threats, technological dependence, and signalling where anticipatory governance is most needed, from skills and sustainability to privacy and rural inclusion.

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