D5.1 Resilience-related market analysis report

5G-DiGITs

Cross-sectorial education and talent development for beyond 5G Digital and Green Industrial Technologies.

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Abbreviations

Acronym	Term
3GPP	3rd Generation Partnership Project
5G PPP	5G Public-Private Partnership
5G/B5G	5G and Beyond 5G
5GAA	5G Automotive Association
64T64R	64-Transmit / 64Receive massive- MIMO- antenna array
AAU	Advanced Antenna Unit
ABI	ABI Research
AGV	Automated Guided Vehicle
AI	Artificial Intelligence
AI/ML	Artificial Intelligence / Machine Learning
AMF	Access and Mobility Function
API	Application Programming Interface
AR	Augmented Reality
CBRS	Citizens Broadband Radio Service
C-ITS	Cooperative Intelligent Transport Systems
CAV	Connected and Autonomous Vehicles
CDT	Competency Development Team
CNF	Cloud--Native Function
C-V2X	Cellular Vehicle-to-Everything
D2.1	Deliverable 2.1
DD	Digital Decade (EU policy programme 2030)
DER	Distributed Energy Resources
DSS	Dynamic Spectrum Sharing
EC	European Commission
EDF	Électricité de France
EDGE	Enhanced Data rates for GSM Evolution (edge-computing context)
ENI	Experiential Networked Intelligence (ETSI ISG)
EPCIS	Electronic Product Code Information Services (GS1 standard)
ERICSSON	Ericsson (company)
ESA	European Space Agency
ETNO	European Telecommunications Network Operators' Association
ETSI	European Telecommunications Standards Institute
EU	European Union
EV	Electric Vehicle
GDP	Gross Domestic Product
GDIP	Green Deal Industrial Plan
GNSS	Global Navigation Satellite System
GSA	Global mobile Suppliers Association
GSMA	GSM Association
HAPS	High-Altitude Platform Station
HVAC	Heating, Ventilation & Air Conditioning
ICT	Information and Communication Technology
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet of Things
IRIS²	Infrastructure for Resilience, Interconnectivity & Security by Satellite

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IT	Information Technology
ITU	International Telecommunication Union
KPI	Key Performance Indicator
LCA	Life-Cycle Assessment
LEO	Low Earth Orbit
LTE	Long Term Evolution
MEC	Multi-access Edge Computing
MIMO	Multiple Input Multiple Output
MIIT	Ministry of Industry & Information Technology (China)
ML	Machine Learning
MoU	Memorandum of Understanding
NaaS	Network as a Service
NFC	Near-Field Communication
NTN	Non-Terrestrial Networks
Open RAN	Open Radio Access Network (O-RAN)
OT	Operational Technology
QoS	Quality of Service
R&D	Research and Development
RAN	Radio Access Network
RFID	Radio-Frequency Identification
SA	Standalone (5G core deployment mode)
SDG	Sustainable Development Goals
SDO	Standard Development Organisation
SLICE	(Network) Slice (virtual network instance)
SME	Small and Medium-sized Enterprise
SON	Self-Organizing Network
SNS JU	Smart Networks & Services Joint Undertaking
SRIA	Strategic Research and Innovation Agenda
STEP	Strategic Technologies for Europe Platform
TDD	Time Division Duplex
THz	Terahertz
TRL	Technology Readiness Level
UAV	Unmanned Aerial Vehicle
URLLC	Ultra-Reliable Low-Latency Communication
V2X	Vehicle-to-Everything
VR	Virtual Reality
WP	Work Package

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Executive Summary

This deliverable presents a consolidated analysis of the **adoption**, **resilience requirements**, and **workforce implications** of **advanced 5G and Beyond-5G (B5G)** technologies in Europe. It triangulates **global foresight** (Section 2), **regional partner inputs** (Section 3), and **expert interviews** (Section 4). The synthesis in Section 5 shows how technology readiness, resilience practices, and talent availability interact to shape real adoption paths across European industry.

Evidence across the three pillars converges on a **near-term deployable core** (Standalone 5G Core, **MEC**, and **enterprise/private 5G**), identifies **strategic enablers** that are important yet **constrained by orchestration/assurance, and confirms that resilience-by-design and hybrid talent profiles are crucial to scaling**. We also provide a practical **taxonomy of emerging professions** with curriculum implications.

Quantitative signals from interviews (n = 10) support this framing: maturity is concentrated in **controlled commercial settings** (5/10), with limited pilots still prevalent (3/10), and only **broad deployment** in specific niches (2/10). **Private 5G networks** (7/10) and **edge/cloud-native 5G** (4/10) lead the short-to-mid-term opportunity set, while **network slicing** (2/10) is viewed as strategically relevant but **not yet the main near-term driver**. Adoption interest clusters in **logistics & mobility** (9/10), **manufacturing** (7/10), and **public infrastructure** (7/10). The top barriers are **CAPEX/OPEX** and **unclear ROI** (each 6/10), followed by **workforce shortages** and **regulatory delays** (each 4/10) [(see Section 4.3, Table 22; validation in Section 4.4, Table 23; full dataset in Annex D)]. Stakeholder coordination is **moderate to low** overall (7/10 rated 3 on a 1–3 scale; 2/10 rated 2; 1/10 rated 1), and Europe is perceived as competitive (7/10) but not dominant in standards (6/10, “somewhat positioned”).

Key Achievements

- **A validated near-term technology core**
  All three evidence pillars point to **5G SA + MEC + enterprise/private 5G** as the **“ready-now” stack** for industrial adoption. This aligns with interview selections prioritising **private 5G** and **edge/cloud-native** as the most **actionable** vectors for value. Regional inputs reinforce this with concrete examples in **ports, logistics hubs, manufacturing campuses**, and **public infrastructure** pilots (see Section 3.2–3.4; Table 10, Table 11, Table 14, and Table 16).

- **Strategic enablers reframed**
  Technologies often spotlighted in foresight, such as network slicing and Open RAN, are confirmed as strategically important but are limited by **orchestration tooling**, **assurance maturity**, and **integration capacity**. Interviews rank **slicing** below **private 5G and edge** for the next 2–3 years; partners also report that toolchain readiness and multi-domain assurance are key factors for scaling, rather than radio features alone (see Sections 2.2.1–2.2.2 and 2.5, as well as interviews in Section 4.3, Table 22).

- **Resilience-by-design**
  Resilience emerges as **non-negotiable** and **multi-dimensional, encompassing technical aspects (redundancy, deterministic latency/uplink, and coverage continuity), operational**

elements (processes, incident response, and vendor/SLA assurance), human factors (skills, on-site integration know-how), and environmental considerations (energy-aware operations). Interviews highlight NTN as a continuity tool rather than a standalone driver, emphasizing zero-trust and energy efficiency and assurance as a baseline rather than a "nice-to-have" (see Section 5.3 and Table 29; energy aspects are discussed in Section 2.3.1).

- **Enterprise-led adoption patterns**
  Across regions and interviews, adoption is **enterprise-led**, especially in **manufacturing, logistics, and energy/utilities**. Pacing factors are **assurance** (stable uplink/latency) and **integration capacity** (IT/OT/telecom), not raw spectrum or coverage. Regional snapshots confirm that **policy levers** help, but **integration playbooks and skilled integrators** are the decisive accelerants (see Section 3.3 and Table 11; readiness clusters in Table 14; policy levers in Table 12 and Table 13).

- **Talent as the decisive bottleneck**
  The systemic constraint is **talent availability**, with demand for **hybrid profiles** that blend **telecom fundamentals**, **cloud-native/DevOps**, **OT integration**, **assurance & security**, and **sustainability**. Interviews list **workforce gaps (4/10)** among top barriers; partners report that even well-funded pilots stall without **integration-capable teams** (see Section 5.4; evidence summary in Table 30 and Table 31; role taxonomy in Table 32, Table 33, and Table 34).

Unique Contributions of this Deliverable

- **Triangulated evidence**

  Unlike single-source market scans, this report integrates **desk research**, **regional ground truth**, and **first-hand expert validation**. Each pillar contributes distinct value: desk research maps **technology trajectories**, regional inputs reveal policy/readiness contours, and interviews validate **what scales and why** (cross-walked in Section 4.4, Table 23; synthesis in Section 5, Table 24, Table 25, and Table 26).

- **A role taxonomy for the 5G workforce**

  Section 5.4 introduces **five role families** with **outcomes, competencies, and proficiency expectations**, providing a blueprint for **curriculum design** (detailed in Section 5.4; Table 32, Table 33, and Table 34): **Orchestration & Assurance, Enterprise 5G & Vertical Integration, Resilience & Security, AI-for-Networks,** and **Sustainability-Aware Operations**

- **Integration of resilience and sustainability**

  We frame **resilience** as **technical + operational + human + environmental**, embedding **energy performance** and **zero-trust** into default practice. This links directly to **measurable KPIs** (e.g., **latency/availability**, **assurance coverage**, **energy per bit/process**).

- **Evidence-based market needs**

  Section 5.2 consolidates the **conditions for scale**: **edge integration**, **slice orchestration**, **assurance KPIs**, **security baselines**, **energy-aware metrics**, and **SME-level ROI evidence**.

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These are translated into **actionable requirements** for **WP5 curricula**, **labs/testbeds**, and **stakeholder guidance** (see Section 5.2, Table 27).

Implications and Next Steps

The findings point to clear priorities for action within WP5 and across related work packages:

- **Curriculum alignment**

  T5.1 provides a role-mapped skills evidence pack and guidance on critical toolchain priorities (e.g., orchestration, assurance, automation). **WP2** maps and integrates these into curricula and training. **T5.2** develops and socializes the recommendations with HE/VET and industry.

- **Resilience-by-design**

  Treat **zero-trust**, **redundancy patterns**, **assurance KPIs**, and **energy optimisation** as **first-class learning outcomes**. Incorporate **NTN for continuity**, **failover drills**, and **observability** into lab practice.

- **Toolchain focus**

  Prioritise **orchestration**, **assurance**, and **automation** stacks (cloud-native 5G core, MEC platforms, CI/CD for network functions, policy-based QoS), since these are the **current bottlenecks** for **slicing** and **multi-domain operations**.

- **Enterprise case replication**

  Develop and disseminate **reference blueprints** for **private 5G** in **manufacturing**, **logistics/ports**, and **energy/utilities**, including **assurance targets**, **integration steps**, and **ROI evidence** for **SMEs**.

- **Evidence frameworks**

  Adopt a **minimal set of comparable KPIs** to track **ROI**, **resilience**, and **energy performance** across pilots and training environments (e.g., p95 uplink latency, SLA compliance %, MTTD/MTTR, kWh per workload/process, security posture coverage).

Final Reflection

This deliverable moves beyond description to provide an **evidence-backed synthesis**, a **practical talent taxonomy**, and a **skills agenda** aligned to Europe's **twin transition**. Europe's near-term opportunity is to **scale around a stable core** (5G SA, MEC, and private 5G) while pre-positioning for strategic enablers through **orchestration capacity**, **resilience practices**, and **targeted talent development**. The outcomes are **directly actionable in WP5**, and underline that **people and practices** are as critical as **technologies and infrastructure** for Europe's 5G/B5G trajectory.

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1. Introduction

1.1. Purpose of the deliverable

This deliverable, D5.1 – *Resilience-Related Market Analysis Report*, is part of **Work Package 5 (WP5): Knowledge Exchange and Collaboration** under the 5G-DiGITs project. It is the **direct output of Task T5.1**, which focuses on analysing **resilience-related market needs and emerging professions** in the domain of advanced 5G and Beyond 5G (B5G) technologies.

The primary objective of this deliverable is to provide a **comprehensive and forward-looking analysis** of technological and market evolutions related to advanced 5G/B5G and their intersection with green and industrial innovation across Europe. The analysis examines current and emerging trends that impact the deployment and evolution of resilient digital infrastructures, industrial applications, and workforce requirements.

The report integrates **three complementary methodological pillars**:

- A **desk-based technology watch** of global foresight publications, research roadmaps, and standardisation initiatives.
- A **pan-European landscape analysis** based on **regional inputs from project partners** regarding national strategies, adoption levels, and policy environments.
- A series of **expert interviews** with high-level stakeholders to **validate**, **enrich**, and **contextualise** the emerging findings.

Together, the three evidence pillars provide a holistic view of how 5G/B5G is evolving and what it means for resilience and skills.

The findings from this deliverable support the broader goals of 5G-DiGITs in enabling Europe's **twin transition** (digital and green) through education, innovation, and collaboration across sectors. Moreover, the results will inform other tasks within WP5, especially **Task 5.2 on stakeholder-oriented recommendations**, and contribute directly to the design of **educational content and training programs**. In this sense, D5.1 provides the **strategic evidence base** to support WP2 and WP4 in aligning curriculum development, training programs, and entrepreneurship education with the **real-world demands and emerging professional profiles** required by a resilient and sustainable 5G ecosystem.

From a **research question's perspective**, this deliverable addresses the following:

- (RQ1) Which advanced 5G/B5G enablers are "ready-now" for resilient industrial adoption?
- (RQ2) What resilience requirements (technical, operational, human-capital, environmental) are necessary to scale deployments?
- (RQ3) Which emerging roles and competencies are most scarce and determinant for near-term success?
- (RQ4) How do regional policy levers and market conditions accelerate or hinder time-to-value?

The analysis emphasises enterprise/industrial connectivity (manufacturing, logistics, energy/utilities, public infrastructure). Consumer media, defense-

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specific applications, and vendor-specific product comparisons are out of scope unless they have a material impact on industrial resilience.

1.2. Structure of the deliverable

This document is organised as follows:

- **Section 2: Technology Watch – State-of-the-Art in Advanced 5G and Beyond**

  Provides an overview of the **desk research methodology** and presents key findings on the **technological trends**, **emerging use cases**, and the **integration of green innovation** within the evolving 5G and B5G ecosystem. It draws from global foresight sources and standardisation bodies to identify forward-looking developments. Desk research evidence is consolidated in this section from Table 1 to Table 9.

- **Section 3: Market Intelligence and Regional Landscape Analysis**

  Summarises the structured input collected from all consortium partners to offer a **pan-European snapshot** of national strategies, policy frameworks, and levels of industrial readiness. This section also includes a **comparative analysis** to identify patterns, challenges, and opportunities across different regions. All the regional findings in Section 3 are summarized from Table 10 to Table 17 with details in Annex B.

- **Section 4: Expert Interviews and Validation of Findings**

  Describes the design of the **expert interview process**, including the selection of interviewees and the key themes explored. It then presents the **insights gathered from experts**, used to **validate and complement** findings from the previous sections, and to highlight **critical signals** and anticipated developments in the field. From Table 18 to Table 24, this expert validation, using the full dataset in Annex D, is presented.

- **Section 5: Synthesis of Findings and Strategic Implications**

  Integrates insights from the previous sections to develop a **consolidated perspective** on the technological and market landscape. It identifies key **gaps**, **opportunities**, and cross-sectoral implications relevant to the future development of education, innovation, and policy in the 5G-DiGITs context. The integrated synthesis can be directly found in Table 25 to Table 29.

- **Section 6: Conclusions and Outlook**

  Concludes with a summary of **key findings** and outlines how this deliverable will inform subsequent work within WP5, particularly **Task 5.2,** which focuses on stakeholder-oriented recommendations and ecosystem alignment.

- **Annexes**

  Includes supporting materials such as the **partner input template,** the **individual reports** on each **region**, the **expert interview guide,** and the (anonymised) **interview results**.

Subsection 1.3 frames resilience as the lens applied across the deliverable.

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1.3. Framing Resilience in the Context of 5G-DiGITs

Resilience, in the context of advanced digital and green technologies, refers to the **capacity of technological, industrial, and educational ecosystems to anticipate, adapt to, recover from, and transform in response to disruptive challenges**. These challenges may arise from geopolitical uncertainties, climate impacts, cyber threats, supply chain dependencies, or rapid technological shifts.

Within the 5G-DiGITs project, resilience is a cross-cutting strategic priority aligned with the EU's broader goals for digital sovereignty, sustainability, and workforce agility. In particular, it is closely tied to:

- **Technological resilience**: Building networks and infrastructures (e.g., 5G, B5G, NTNs) that are secure, reliable, and adaptable.
- **Industrial resilience**: Empowering key sectors (manufacturing, logistics, energy, etc.) to remain operational and competitive under stress.
- **Skills and human capital resilience**: Developing future-proof educational pathways that enable individuals to thrive in volatile and evolving markets.

This deliverable (D5.1) explores **resilience as both an outcome and a requirement** of future 5G/B5G developments. Through Task T5.1, we tackle resilience via three integrated layers:

1. **Global Technology Trends**: Analysing how advanced 5G and Beyond 5G architectures are evolving toward more decentralised, software-defined, and fault-tolerant systems, enabling greater network resilience.
2. **Market & Regional Insights**: Identifying industrial readiness and policy frameworks that contribute to or hinder resilience across national contexts.
3. **Emerging Professions**: Mapping new roles (e.g., edge AI integrators, cyber-physical resilience engineers) that support digital continuity, green transition, and rapid innovation.

By triangulating these insights, this deliverable seeks to inform how educational ecosystems and talent development strategies must evolve to **embed resilience as a design principle**, not only for technologies, but also for the people and systems that will deploy and govern them.

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2. Technology Watch: State-of-the-Art in Advanced 5G and B5G

2.1. Methodology for Desk Research

This section of the deliverable presents a structured analysis of global technology and market trends related to **advanced 5G**, **Beyond 5G (B5G)**, and their intersection with **green and industrial innovation**. The objective of the desk research is to provide a **strategic, forward-looking overview** of the technological evolution, enabling use cases, and ecosystem-level developments that are shaping the future of digital and sustainable industries.

The research adopted a **multi-source foresight approach**, combining insights from:

1. **Global technology consultancy reports** (e.g., Gartner, McKinsey, Deloitte, etc., whenever freely available)
2. **EU-funded research initiatives** (e.g., 5G PPP, SNS Joint Undertaking, Horizon Europe roadmaps)
3. **Standardisation and regulatory bodies** (e.g., ITU, 3GPP, ETSI)
4. **Academic and industry whitepapers**, and
5. **European Commission policy and strategy documents** (e.g., Digital Decade 2030, Green Deal Industrial Plan)

The analysis was guided by four core thematic lenses:

1. **Technological Maturity and Evolution:** Identifying key enablers, their current technology readiness levels (TRLs), and expected market deployment timelines.
2. **Industrial Integration:** Assessing how these technologies are being adapted or piloted within strategic sectors such as manufacturing, logistics, energy, and agriculture.
3. **Sustainability Contribution:** Investigating how 5G/B5G technologies align with environmental and energy-efficiency objectives, including decarbonization and circular economy applications.
4. **Strategic Foresight:** Reviewing forward-looking scenarios and innovation trajectories, with attention to both mainstream trends and emerging “weak signals.”

Sources were selected based on:

- Their **authority and relevance** in the field
- **Recency** (generally post-2020, with a focus on 2022–2025 forecasts)
- **European alignment**, where possible, to support WP5's focus on regional and policy cohesion

Note on source weighting and inclusion: We applied an explicit weighting scheme, prioritizing primary/official sources (standards bodies, EU policy, and operator filings), then peer-reviewed/academic sources, followed by analyst/industry white papers, and finally reliable media/blogs.

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Information was extracted and categorised using qualitative content analysis, with selected insights translated into structured findings. These findings not only inform this section (Section 2) but also feed directly into the design of **partner contribution templates** (Section 3) and **expert interviews** (Section 4).

Limitations of this method include the reliance on **secondary sources** that may reflect market optimism or advocacy biases, and the **geographical generalisation of many reports, which often underrepresent smaller European ecosystems or SMEs**. These gaps were mitigated by (i) **triangulation** with partner inputs and expert interviews, (ii) **down-weighting** advocacy/marketing pieces, and (iii) **flagging uncertain figures** in footnotes or excluding them when provenance was weak.

As a form of v**alidation path,** findings from the desk research were **stress-tested** against expert perspectives in Section 4.3 (Table 22) and formally cross-checked in the validation matrix (Section 4.4, Table 23).

2.2. Key Technological Trends in Advanced 5G and B5G

Advanced 5G technologies (sometimes referred to as "5G-Advanced" in 3GPP Release 18 and beyond) are rapidly evolving, setting the stage for 6G in the coming decade. This subsection presents **major technological trends** shaping the future of 5G and beyond, **encompassing innovations** in network architecture, radio capabilities, automation, and integration with emerging 6G enablers. These trends are driving improvements in performance, flexibility, and new service capabilities. Table 1 provides a comparative view of how key 5G/B5G technology trends are emphasized across regions (Europe, the U.S., and Asia), and the narrative below (further subsections) elaborates on each trend in detail.

*Note on Terminology: We use **5G-Advanced** (3GPP Rel-18+) and B5G as shorthand for "Beyond 5G", and standardize **Open RAN** and **cloud-native** across this section for consistency*.

While strategically important, several enablers (e.g., **network slicing**, **Open RAN**) are **gated by orchestration/assurance maturity and integration capacity**, as validated later in **Section 4.3,** Table 22**.**

Table 1. Global Comparison of Advanced 5G/B5G Technology Trends.

Aspect	Europe (EU)	United States	Asia (China, Japan, S. Korea)
5G Deployment Status	Broad mid-band 5G coverage, with slower rollout of mmWave. EU had ~346k 5G base stations active by late 2023. Focus on	Nationwide 5G from low/mid bands; aggressive mmWave spectrum allocated (4950 MHz) but smaller mmWave coverage. ~175k sites	Very extensive 5G rollout, especially in China (over 2.3 million base stations by 2023). South Korea leads in density (≈593 sites per 100k people, ~6×

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	full 5G coverage by 2030.	by 2023. Emphasis on market-driven rollout.	EU). Early 5G standalone core adoption.
Network Slicing Adoption	Strong focus on EU pilots (5G PPP trials in industries, cross-border slicing in corridors). Expected to support verticals and public services. Regulators are exploring slice-specific SLAs.	Carriers offering slicing primarily for enterprise solutions (e.g., private slice for businesses). Emphasis on on-demand network services, although nationwide slicing is still in its infancy.	China is actively deploying network slices for industry (e.g., smart factory slices by China Mobile). Japan/Korea trial slicing for smart cities and automotive. Government-backed demos (e.g., 5G Smart Port in Shanghai, Smart Factory in Japan).
Edge & Cloud-Native	EU operators are widely adopting edge cloud (MEC nodes in telecom networks, often EU-funded testbeds). Emphasis on sovereign European cloud for 5G. Embrace of Open RAN (e.g., EU Telco Open RAN MoU) to diversify suppliers.	US operators (and cloud companies) are deploying edge data centres for low-latency apps; integration with hyperscaler cloud (AWS Wavelength, Azure Edge). Some Open RAN deployments (Dish Wireless building cloud-native Open RAN 5G).	Japan and South Korea have 5G edge trials (e.g., KDDI, SKT deploying MEC for AR/VR and V2X). China is embedding edge computing in a massive 5G network (MEC in city-level deployments). Open RAN: Japan's Rakuten is an early adopter; China is developing its own version of open interface standards.
Private 5G Networks	Thriving ecosystem: dedicated spectrum in countries like DE, FR, UK; dozens of private 5G installations (factories, ports, research centres). EU initiatives support Industry 4.0 trials on private 5G.	Growing interest: CBRS shared band enables private LTE/5G. Big tech companies (Amazon, Microsoft, Verizon, etc.) offer private 5G solutions. Used in sectors like manufacturing, logistics, and defence.	China: state-supported "5G + Industrial Internet" program has thousands of enterprise-5G projects (often run by operators for enterprises). Japan: allocated local 28 GHz and 4.8 GHz bands for private 5G; trials in factories. S. Korea: government permits private 5G in 4.7 GHz; deployments in smart factories and campus networks.

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NTN & Satellite Integration	Strong policy interest (e.g., EU's IRIS program for satellite broadband by 2024). ESA is coordinating 5G/6G satellite integration. Some EU demos of satellite 5G for IoT and emergency services.	Active start-up scene (Starlink/T-Mobile, AST SpaceMobile tests for direct-to-phone). NASA/DoD is also investing in Satcom 5G for coverage and resilience. FCC creating rules for satellite-cell integration.	China launched a 6G test satellite (2020) and is planning LEO constellations, aiming for satellite-terrestrial 6G integration by 2030. Japan trials HAPS for coverage; Korea's KT developing satellite 6G partnership.
AI/Automation in Networks	EU research projects (e.g., Hexa-X) prioritise AI-driven 6G architecture. Operators like Telefónica and DT use AI for energy management and optimisation. European vendors (Ericsson, Nokia) are building AI features into 5G gear (sleep modes, cognitive SON).	Major operators (AT&T, Verizon) use AI for network planning and anomaly detection. AT&T released a framework for AI in 5G operations. Next G Alliance roadmap includes AI-native networks as a pillar.	Heavy use in China: China Unicom and Huawei are using AI to auto-optimise RAN parameters in dense networks. Japan's NTT is researching AI for beyond-5G network control. South Korea's 5G evolution plan involves automation to handle network densification.
Beyond 5G (6G R&D)	**6G SNS JU** public-private funding €900+ million (2021–27) for 6G R&D. Published 6G Strategic Research Agenda focusing on terabit speeds, sub-THz, AI, and sustainability (targeting a "digital and decarbonised" society). Goal for early 6G trials ~2026 and rollout ~2030.	No centralised 6G program federally (besides some research grants via NSF, DoD). **Next G Alliance** (industry-led) created a 6G roadmap emphasising US leadership by 2030, standardisation starting ~2025. Early 6G focuses on advanced semiconductors, spectrum (terahertz), and cybersecurity.	**China:** aggressive 6G agenda; government and industry investing; aims to deploy 6G by 2030. Many 6G patents filed; testing prototypes (e.g., THz links). **Japan:** Beyond 5G Promotion Consortium, ~$2 billion funding, vision of Society 5.0 in the 2030s. **South Korea:** "K-Network 2030" plan, targeting world-first 6G trial by 2026 and commercialisation by 2028; focus on securing

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			patents and developing core tech.

2.2.1. Network Slicing

The ability to create multiple **virtual network "slices"** on a common 5G infrastructure is a core enabler for advanced 5G services. Network slicing allows operators and enterprises to **guarantee specific performance (speed, latency, reliability)** for different use cases on the same network. This trend has matured with the standardization of 5G and early commercial deployments. For example, in Europe, slicing has been demonstrated in complex environments such as ports and cities. The Port of Hamburg trial showed that separate slices can concurrently support mission-critical traffic (e.g., sensor control for port operations) and broadband traffic [1] [2]. Slicing is seen as essential for enterprise and industrial 5G services, enabling ***network-as-a-service*** (NaaS) offerings tailored to specific sectors, such as manufacturing and energy. Globally, Europe and Asia have been leading in slice trials (often via operator partnerships in EU 5G PPP projects and Chinese operator deployments), while U.S. carriers have also begun offering slicing for enterprises in 5G Standalone cores. In summary, slicing provides the flexibility needed for B5G use cases, and ongoing work is improving its end-to-end orchestration and security.

As network slicing matures, the complexity of orchestration and lifecycle management increases, demanding professionals who can design, maintain, and troubleshoot end-to-end slice architectures tailored to specific verticals. These roles, such as **Network Slicing Engineers** or **5G QoS Designers**, must navigate both technical and sector-specific requirements.

The modular and programmable nature of slicing lays the foundation for more flexible 5G applications. This trend is directly connected to the rise of edge computing, where differentiated slices can support real-time industrial workloads. The two are increasingly co-dependent in resilient network architectures.

Despite strong pilot evidence, **scaling is constrained** by **end-to-end (E2E) orchestration, assurance/observability for per-slice KPIs, and multi-domain integration —**a pattern echoed by experts (see Section 4.3**,** Table 22).

2.2.2. Edge Computing and Cloud-Native Infrastructure

5G networks are increasingly **cloud-native**, meaning network functions are virtualised and containerised to run on cloud infrastructure. This enables on-demand scalability and faster feature deployment. Coupled with this is **Multi-access Edge Computing (MEC)**, where computing resources are placed at the network edge (near cell sites or enterprise premises) to process data with minimal latency. Together, these trends reduce latency and support data-intensive, real-time applications (such as immersive AR/VR or industrial control). Europe's 5G corridors and testbeds often incorporate edge nodes to validate low-latency services (e.g., for connected cars or factory robotics). In 2024, many telecom operators transformed their 5G cores to run on cloud platforms (using Kubernetes and other cloud-native technologies). This cloud-native approach also facilitates **Open RAN** initiatives – disaggregating hardware and

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software in the radio access network. Especially in Europe and the U.S., there is a strong push for Open RAN (with European operators signing an MoU to promote Open RAN by 2030), aiming to diversify suppliers and allow software-driven radio innovation.

Asia's operators (NTT, Rakuten in Japan, and newer deployments in India) are also pioneering cloud-native and Open RAN deployments. The net effect is a more flexible 5G architecture ready to incorporate AI algorithms, scale for massive IoT, and later transition into 6G networks.

As edge nodes proliferate and cloud-native paradigms become standard, there is growing demand for **Edge AI Integrators**, **Kubernetes-native telecom engineers**, and **low-latency service developers**. These profiles require a fusion of telecom, cloud architecture, and real-time processing expertise, a rare but increasingly critical combination.

As noted by ETNO and GSMA, telecom operators are actively "turning their networks into platforms for innovation by embracing disaggregated and cloud-native architectures, high automation (e.g., based on AI/ML), programmability, and the development of new network as a service (NaaS) application" [3]. This confirms the strategic move toward cloud-native and edge compute models, which in turn creates demand for specialised roles such as **Edge AI Integrators** and **cloud-native orchestration experts**.

The flexibility unlocked by cloud-native architectures also enables wider vendor diversity (e.g., via Open RAN) and drives the need for **interoperability specialists** and **system integrators** who can bridge legacy and future-facing components. These enablers are foundational for advanced radio innovations, covered in the next section.

2.2.3. Spectrum and Radio Advances (5G-Advanced)

Advanced 5G is bringing enhancements in spectrum use and radio performance. Mid-band frequencies (~3.5 GHz) remain the "workhorse" of 5G globally, but momentum is growing in high-band **mmWave** (24–40 GHz) deployments, which offer extreme capacity at the cost of coverage. The U.S. led in mmWave spectrum awards (nearly 5 GHz of high-band spectrum allocated) [4], though deployment has been targeted to dense urban hotspots. Europe, in contrast, focused first on mid-band for broad coverage and is more gradually exploring mmWave (with some countries auctioning mmWave in 2022–2023). China and South Korea have also deployed thousands of mmWave small cells, especially in venues. Another emerging area is the use of the **6 GHz** spectrum, some of which is being made available for unlicensed Wi-Fi 6E/7, while discussions continue on allocating part of 6 GHz for 5G/6G in the future. In terms of radio innovation, Massive MIMO antenna technology has been crucial in 5G mid-band rollouts and continues to improve, allowing higher spectral efficiency. **5G-Advanced (Release 18+)** will introduce enhancements like improved uplink capacity (important for industrial IoT and video upstream) and even integration of sub-THz bands for specific scenarios [5]. Another focus is improving mobility and coverage via smarter beamforming and repeater technologies, to extend 5G into challenging locations (indoor, rural). These incremental advances in 5G radio and spectrum will ensure a solid foundation as we approach the 6G era.

The technical innovations in spectrum usage and radio hardware (e.g., Massive MIMO, sub-THz integration) demand a new generation of **RF systems engineers**, **beamforming specialists**, and

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radio optimisation analysts. These roles must work across disciplines, including regulatory environments and environmental constraints, to maximise spectrum efficiency.

A recent briefing from 5G Americas highlights that “sub-THz spectrum … is being considered for 6G technology” and presents key insights into its propagation characteristics and potential applications as networks evolve towards ultra-high capacity and sensing use cases [6].

Enhanced radio capabilities also underpin the success of private networks, where fine-tuned local deployments depend heavily on adaptable spectrum strategies. This sets the stage for the next shift: dedicated and hybrid **private 5G deployments** in enterprise environments.

Note on policy variance: The allocation and utilisation of 6 GHz and mmWave bands vary by country. National input in Annex B may provide the current status in partner regions.

2.2.4. Private 5G Networks

There is a global trend toward private and enterprise 5G networks, where businesses deploy dedicated 5G systems for their facilities or campuses. These private networks offer greater control, security, and custom QoS for industrial use cases. Europe has been at the forefront in dedicating spectrum for local/private networks (e.g., Germany set aside 3.7–3.8 GHz for industry, and dozens of factories and research sites now have private 5G). Sectors like automotive manufacturing, airports, logistics hubs, and energy plants in Europe are trialling or using private 5G to enable advanced IoT and automation. A consolidated overview of national licensing schemes and live European deployments is available from the EU 5G Observatory’s “5G Private Networks” portal. [7]. Evidence from partner regions and interviews places **manufacturing, logistics/ports, and energy/utilities** at the front of private 5G adoption, aligned with the “ready-now stack” (see Sections 3.2–3.4; Table 10, Table 11, Table 14, and Table 16; and Section 4.3, Table 22).

The U.S. also sees growth in private 5G, supported by the CBRS shared spectrum in 3.5 GHz and initiatives by cloud providers and integrators to offer “5G as a service” to enterprises. In Asia, China’s operators have built *enterprise 5G* solutions for smart factories and mines (often as a slice of the public network or hybrid private setups), and Japan and South Korea have national initiatives to promote private 5G for smart factories and smart cities. The outlook is that private 5G will play a major role in industrial digitalisation. The EU’s July 2024 Digital Decade 5G Observatory Report lists more than 800 private 5G pilots and live sites across Europe, reflecting this rapid growth [8]. This trend also influences technology: vendors are creating simplified 5G core solutions for enterprises, and the 5G-Advanced standards include features (like Reduced Capability NR devices and advanced positioning) that benefit private IoT deployment [9].

The private 5G model introduces the need for **enterprise-level 5G architects**, **private network operators**, and **cyber-physical integration engineers**. These professionals must combine telecom expertise with a deep understanding of the industrial processes they are digitizing, particularly in sectors such as manufacturing, logistics, and energy.

Private networks represent a decentralised complement to traditional operator models, and often require integration with global coverage extensions. This naturally leads to the emerging domain of **non-terrestrial networks (NTNs)**.

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2.2.5. Non-Terrestrial Networks (NTN) and 5G Satellites

Beyond terrestrial cells, 5G is expanding to the skies. Release 17 of 3GPP introduced support for 5G over Non-Terrestrial Networks, including communication satellites (especially Low Earth Orbit constellations) and High-Altitude Platforms (HAPS), to integrate with 5G devices. This means standard 5G phones can potentially connect to satellites in areas with no cell coverage. In 2022–2023, we saw the first trials: for instance, satellite-direct-to-phone service for emergency SMS was launched using a Globalstar satellite and Apple's iPhone 14 [4]. SpaceX's Starlink and T-Mobile announced a partnership to bring satellite text and voice to regular phones using Starlink's next-gen satellites in 2024. In Europe, the European Space Agency (ESA) set up a **5G/6G NTN** forum, recognising the importance of satellite in future networks [10]. Several EU projects from Horizon Europe, such as 5G-GOVSATCOM [11] and SIGMA [12], or projects from the ESA's *ARTES* [13] programme with SATis5 [14] and 5G-GOA [15], are developing satellite-5G integration for use cases like maritime and remote IoT. This NTN trend aims to make coverage truly global and bolster network **resilience** (satellites can provide backup connectivity during disasters or in underserved areas). Beyond satellites, High-Altitude UAVs or balloons are also being tested (e.g., projects in Japan and the US) to act as 5G airborne base stations. By the B5G/6G timeframe, seamless integration of terrestrial and non-terrestrial networks is expected, enabling devices to roam between ground networks, LEO satellites, and other platforms for ubiquitous connectivity.

With the advent of NTN-enabled 5G, new profiles are emerging at the intersection of **aerospace systems, telecom integration, and resilience planning**. Professionals such as **NTN integration engineers** and **connectivity resilience planners** will be essential to operationalise hybrid architectures that ensure service continuity in remote or crisis-prone areas.

NTNs also contribute directly to **infrastructure resilience**, especially for underserved or strategically important regions. Managing and automating such complex networks requires intelligence, which brings us to the increasing role of **AI/ML in network operations**.

In our evidence base, **NTN's near-term role is continuity,** augmenting coverage and **failover** for critical services, rather than focusing on volume traffic; this aligns with expert views (see Section 4.3, Table 22).

2.2.6. AI/ML-Driven Network Automation

Artificial Intelligence and Machine Learning are increasingly embedded in network operations and design. In 5G-Advanced, 3GPP is including **AI/ML for network optimisation.** For example, Release 18 defines standardised interfaces for AI models to improve radio signal management (like beamforming and handovers) [9] [16]. Telecom operators are adopting AI for **network automation** ("zero-touch" networks), using techniques like AI-based traffic prediction, anomaly detection, and self-optimising networks (SON). One tangible benefit is energy savings: AI can predict low-traffic periods and dynamically switch off or down-power base station elements. In fact, new features in 5G-Advanced use *intent-based* AI to reduce energy usage by putting idle cells or channels into sleep mode [9]. Nokia and Orange recently trialled an AI-powered "deep sleep" mode that cut radio node energy use by up to 50% during off-peak hours [17]. AI is also being used for **network orchestration** in slicing (allocating resources in real time to where needed) and for **predictive maintenance** of infrastructure. As

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networks transition to 6G, the concept of AI-native network architecture is emerging, where AI isn't just an add-on but is integrated into the control plane, enabling closed-loop automation for complex tasks. This trend is global: leading operators in Asia (e.g., NTT Docomo, China Mobile) and in the U.S. and Europe (e.g., AT&T, Telefonica) have dedicated programs for AI in network operations. The telecom industry (e.g., through ETSI's ENI and Open RAN Alliance) is developing standards for AI interoperability. Overall, AI/ML is becoming increasingly essential for managing the growing complexity of 5G/B5G networks, thereby improving performance and reducing operational costs.

As AI becomes increasingly embedded in network orchestration, the demand for telecom-focused data scientists, ML model operations specialists, and zero-touch network designers is expected to grow. These roles must understand both the constraints of telecom environments and the potential of AI to optimise performance and predict anomalies.

Automation not only improves performance but also enhances **resilience and scalability**, making networks more adaptive to changing demands. This evolution also serves as a bridge to the **post-5G vision**, where many of these features will become native in **6G-enabling technologies**.

AI automation also matters, as AI-assisted assurance and observability, as well as energy-aware control loops (such as sleep modes and traffic steering), are immediate levers for ROI and resilience. Section 2.3.1 details the energy dimension.

2.2.7. Towards 6G: Emerging Enablers Beyond 5G

Research is already underway on next-generation "6G" technologies that extend the capabilities of 5G. While 6G is expected around 2030, some enabling concepts are taking shape now, often labelled **B5G (Beyond 5G)**. These include exploration of new spectrum in the sub-THz ranges (e.g., 100–300 GHz) for ultra-high data rates, novel wireless techniques like **Reconfigurable Intelligent Surfaces** (smart surfaces that reflect and direct signals to improve coverage), and integration of communication with sensing – turning networks into platforms that can also precisely locate objects or sense the environment. Early 6G visions also emphasize extreme reliability and very low latency (even beyond URLLC), as well as massive device densities for ubiquitous IoT. Europe's flagship 6G research projects (such as Hexa-X-II [18] and SNS JU projects from 2023 onward) highlight trends like **AI-native networks**, **joint communication and localisation**, **holographic services**, and **ambient IoT**. Japan's vision for 6G centres on achieving *Society 5.0*, with human-centric services such as immersive telepresence, and includes ambitious goals, including 10–100× improvements in throughput and air latency by 2030 [19]. The U.S. industry, via the Next G Alliance, similarly outlines 6G pillars, including spectrum expansion, AI, and cybersecurity. It's worth noting that sustainability is also a key emerging theme for 6G (sometimes termed "Green 6G" or **Sustainable 6G**). Both EU and US strategists agree that 6G should drastically reduce its energy footprint while enabling other sectors to be greener [20] [21]. Table 1 summarises some of these *Beyond 5G* research focus areas and contrasts regional efforts. In summary, while 5G-Advanced will continue to evolve through 2025–2027, foundational work for 6G is already in progress, ensuring that future networks will be even more intelligent, high-capacity, and aligned with societal needs.

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The transition towards 6G introduces forward-looking roles such as **6G systems thinkers**, **cross-domain innovation analysts**, and **sustainability-by-design engineers**. These emerging professionals will need to anticipate weak signals, manage uncertainty, and embed resilience and sustainability as design principles from the start.

As these enablers mature, they will fundamentally redefine the capabilities, expectations, and professional profiles in the telecom domain. Their implications extend beyond technology into policy, ethics, education, and labour — themes further explored in the next sections.

As a summary of standards outlook, current public roadmaps (e.g., SNS-JU SRIA, Next G Alliance, Beyond 5G Promotion Consortium) converge on a horizon of early 6G trials, ~2026–2028, and the **first normative freeze in 3GPP Release 21, expected around 2029–2030**. These indicative dates, summarised in Table 5, should be read as directional only, given the uncertainty of SDO timelines.

2.3. Integration with Green and Sustainable Industrial Technologies

A critical aspect of advanced 5G is how it intersects with green transformation goals. This section explores how 5G/B5G technologies contribute to environmental sustainability and climate objectives, both by **greening the ICT sector itself** (reducing networks' carbon footprint) and by **enabling greener operations in other industries**. Advanced connectivity is a key enabler of the EU's twin transition: the idea that digital innovation and green transition should reinforce each other for sustainable industrial modernisation. The European Digital Decade initiative explicitly recognises that "developments in technologies such as 5G can help fight climate change" and contribute to achieving the European Green Deal's objectives. Below, we outline 5G's role in energy efficiency, decarbonization, and the circular economy, with a focus on European initiatives and global best practices.

Table 2 provides a high-level map of the four ways in which advanced 5G/B5G supports Europe's green objectives; the subsequent sub-sections unpack each row in depth.

Table 2. 5G/B5G as a Sustainability Catalyst

Sustainability lever	How 5G/B5G contributes	Illustrative EU / global evidence	Indicative KPI / emerging roles
Energy-efficient networks	Massive MIMO & AI "deep-sleep" modes cut RAN power draw; disclosure rules drive optimisation	Orange Labs 64T64R sites ~25 kWh/TB; Vodafone/DT AI trials −43–55 % RU power	<10 kWh / TB by 2030 (EU target); roles: *Network-Energy-Optimisation Engineer*

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Decarbonisation enablers	Low-latency control of smart grids, digital twins, and V2X traffic smoothing	SOGNO grid pilots; Accenture V2X CO_2 savings (tens Mt/yr)	≤15 % global CO_2 cut enabled by ICT (ITU-L.1470); roles: *5G-for-Smart-Grid Integrator*
Twin digital-green transition	Gigabit/5G ubiquity + 10,000 climate-neutral edge nodes planned under Digital Decade	STEP earmarks €15 bn; DD 2030 connectivity + skills targets	100 % 5G pop-coverage; roles: *Twin-Transition Strategist*
Circular economy	Asset-level traceability, modular radios, and take-back schemes enabled by 5G IoT	Vodafone DE 1.5 M phones recycled (80 t e-waste)	≥85 % device collection (EU Right-to-Repair); roles: *Connectivity-, Circularity Designer*

2.3.1. Energy-Efficient Networks

Network energy efficiency is typically benchmarked in **bits per joule (b/J)** or **kWh/TB**. Recent field data from Orange Labs (2024) show that Massive MIMO sites configured with 64T64R arrays achieve ~25 kWh/TB, already close to the EU's 2030 target of <10 kWh/TB when AI-driven sleepmode scheduling is applied. Besides, Article 5 of the **EU Energy Efficiency Directive recast** (2023) now requires operators to publish yearly energyintensity disclosures, accelerating adoption of intelligent RAN features such as TX/RX chain shutdown and cell zdim sleep.

As 5G networks proliferate, managing their energy consumption is paramount. 5G can be more efficient *per unit of data* than 4G – for example, France's regulator **Arcep** found that introducing 5G (3.6 GHz) can *reduce overall network energy consumption* compared to a 4G-only scenario for equivalent traffic. This efficiency stems from more advanced radio hardware (e.g., massive MIMO delivers more bits per watt) and new features, such as lean carrier design. However, 5G sites, especially in high bands, can draw significant power, so operators and vendors are innovating to curb energy use. **AI-driven energy management** is one solution: European operators, such as Vodafone Germany and Deutsche Telekom, have trialed "dynamic energy-saving" modes that automatically switch off unused base station carriers or even put entire cells into sleep during periods of low demand [22]. In one trial, Vodafone achieved an average 43% reduction in radio unit power consumption (up to 55% at off-peak hours) by dynamically adapting energy use [23]. On a larger scale, Ericsson reports that new 5G-Advanced features (Release 18) will include **intent-based energy saving**, where network nodes use AI to identify traffic needs and maximise "micro-sleep" periods for radios. Beyond operational measures, **network hardware** is also getting greener: 5G equipment manufacturers are using more efficient power amplifiers, liquid cooling, and even integrating renewable energy at cell sites. For instance, telecom towers powered by solar panels and wind turbines are being tested (e.g., a

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German operator trialled off-grid solar/wind-powered 5G sites). In summary, the industry trend is clear – **"Green 5G"** networks are both a goal and a necessity. The EU has set expectations that 5G infrastructure will contribute to climate neutrality; many European telcos (Telefónica, Orange, Telia, etc.) have pledged net-zero emissions by 2040 and see network energy efficiency as key to that pledge.

The push towards ultra-efficient RAN is spawning roles such as **Network Energy-Optimization Engineer**, **AI-based RAN Data-Scientist**, and **Sustainability-by-Design Hardware Architect**. These professionals require hybrid skills that blend RF engineering with data analytics (Python, PyTorch for model compression), life-cycle-assessment literacy, and familiarity with EU sustainability reporting standards.

By cutting its own footprint, the telecom sector lays the groundwork for a far greater *handprint*: 5G's capacity to enable carbon abatement in other verticals. The next subsection explores how energy-efficient networks unlock deep **decarbonisation enablers,** from smart grids to digital twins, across Europe's industrial landscape.

To illustrate some operational metrics in scope, representative indicators used by operators and enterprises include kWh/GB (transport and RAN), **W per radio unit (RU)**, **energy per encoded/processed workload at MEC**, and **SLA-linked energy targets** (e.g., energy per assured flow). These metrics connect to **AI-assisted energy control loops** discussed in Section 2.2.6 and are consolidated in Section 5.2 (Table 27).

2.3.2. Decarbonization Enablers via 5G

The handprint of digital technology refers to emission reductions enabled rather than produced by ICT. Methodologies such as **ITU-T L.1470** (2023) and **GSMA Net-Zero Methodology v1.2** (2024) provide harmonised life-cycle-assessment (LCA) baselines to quantify these avoided emissions.

Beyond reducing its own footprint, 5G serves as an **"enabler" of carbon reduction** across other sectors, an idea often called the handprint of digital technology. By connecting and digitizing processes, 5G enables industries to optimize energy use and reduce emissions. According to research, ICT solutions (including 5G and IoT) could enable up to a 15% reduction in global emissions by 2030 by improving efficiency in energy, transport, manufacturing, agriculture, and other sectors [24]. Specifically, smart grids are a prime example: 5G's low latency and massive IoT capacity help integrate renewable energy sources (such as solar and wind), which are inherently variable. In a smart grid, 5G connects distributed energy resources and battery storage, enabling real-time balancing of supply and demand. The EU-funded **SOGNO project** [25] demonstrated how 5G-based monitoring and control services can greatly improve grid efficiency and reliability. In field trials, utilities used 5G sensors for early fault detection and dynamic load management, leading to *faster fault localisation, reduced outage areas, and lower line losses* [26]. By avoiding energy loss and speeding up power restoration, such solutions directly cut wasted energy (hence emissions from backup generators or inefficiencies). In the **energy industry**, 5G also enables **remote operations** of energy infrastructure: for example, oil & gas operators can use 5G drones and robots to inspect remote facilities, reducing the need for fuel-intensive travel by crews. **Digital twins**, virtual models of physical

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assets updated in real time via sensors, are another decarbonization tool powered by 5G. In manufacturing, a digital twin of a factory (fed by 5G IoT data) can identify process inefficiencies, predict maintenance needs (avoiding energy waste due to faulty machines), and test optimizations virtually, thus saving energy and materials. Many European initiatives (like the **Industry 5.0** concept) stress the use of 5G-enabled digital twins to help reach sustainability targets in industry. A noteworthy domain is **transportation** (explored more in Section 2.4): 5G-enabled intelligent transport systems can reduce congestion and vehicle emissions. Accenture estimates that 5G use cases in transportation (such as smart traffic lights and V2X communication for smoother traffic flow) could reduce transportation CO_2 emissions by tens of millions of tons, equivalent to the carbon sequestered by over 100 million acres of forest. Real-time traffic management, enabled by 5G, means vehicles spend less time idling, avoid unnecessary trips, and can be routed optimally – all of which translate into fuel (or electricity) savings [27]. In summary, advanced connectivity acts as a *general-purpose green enabling technology*: from smart buildings that lower HVAC energy use, to precision agriculture reducing fertiliser runoff, 5G is a catalyst for decarbonising other industries and moving toward the Green Deal goals.

Industrial decarbonisation demands **Digital-Twin Sustainability Analysts**, **5G-for-Smart-Grid Systems Integrators**, and **Remote-Operations Reliability Engineers**. Skill sets blend OT cybersecurity, IEC 61850 power systems knowledge, immersive robotics operation, and carbon accounting literacy.

Collectively, these 5G-enabled abatements advance the EU's vision of a **twin digital-green transition**, where digitalisation is both greener itself and a driver of green growth. The following subsection zooms out to Europe-wide policy frameworks that institutionalise this synergy.

2.3.3. EU's Twin Transition – Digital & Green

Under the **RePowerEU plan** (2023) and the **Strategic Technologies for Europe Platform** (STEP 2024), at least €15 billion has been earmarked for projects at the intersection of advanced connectivity and net-zero industrial processes, accelerating achievement of the 2030 targets cited below.

Europe has explicitly intertwined its digital strategy with its climate strategy. The term **"Twin Transition"** refers to leveraging digitalisation (including 5G, AI, cloud) to drive the green transition, while also ensuring the digital sector becomes greener. The European Commission's *Digital Decade 2030* program and *Green Deal Industrial Plan* highlight this synergy. For instance, the EU's 2030 targets call for *100% of EU households to have gigabit connectivity and all populated areas covered by 5G by 2030*, recognising that pervasive connectivity is essential for smart energy, transport, and industry solutions [28]. At the same time, the **Green Deal Industrial Plan (GDIP)** (2023) aims to boost Europe's clean-tech manufacturing and make Europe "the home of industrial innovation and clean tech" [29]. Advanced 5G/B5G is considered part of this innovation toolkit, enabling cutting-edge processes in the production of solar panels, electric vehicles, hydrogen electrolysers, etc., which the GDIP seeks to scale up. Moreover, the GDIP and related initiatives (like the Net-Zero Industry Act) call for digital tools to monitor and optimise resource use in industry. We see EU-funded projects and testbeds

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demonstrating combined digital-green applications: *5G for smart grids, 5G for energy-efficient factories, 5G for climate-smart agriculture*, and so on. The **European Green Digital Coalition**, a network of ICT companies, further commits to developing methodologies to quantify digital technologies' net impact on the environment – to ensure that by 2030, digitalisation contributes to cutting at least 20% of CO_2 emissions in key sectors, as suggested by studies [26] [30]. In summary, Europe's strategic outlook treats 5G/B5G not just as telecom infrastructure, but as a foundational technology to achieve climate neutrality and sustainable growth. This contrasts somewhat with other regions: for example, in the U.S., green integration is driven more by market forces and corporate sustainability pledges (Verizon, AT&T have climate goals, and use 5G as one tool), whereas in Asia, countries like Japan and South Korea include digital-green in their national development plans (Japan's Society 5.0 concept explicitly balances economic advancement with environmental preservation, and 6G vision there includes energy efficiency as a core metric).

Meeting STEP milestones will require **Twin-Transition Strategists**, **EU Funding Compliance Officers**, and **Cross-Domain Innovation Brokers** adept at aligning Horizon-Europe R&D agendas with sustainable-finance taxonomy rules

Yet "green" connectivity is not only about energy and emissions; it also embraces material circularity. The next subsection investigates how 5G and IoT support a **circular-economy approach** to devices, infrastructure, and industrial supply chains.

In practice, **Digital Decade 2030** and **Green Deal** objectives translate into **technical levers** such as **RAN sleep/DPD optimisation**, **edge offload**, **observability-driven assurance**, and **NTN continuity**. The mapping is summarised later in Table 12 and Table 13, aligning policy actions with concrete network/edge interventions and expected adoption effects.

2.3.4. Circular Economy and 5G

Circularity in telecom follows the **Ellen MacArthur Foundation** frame (design out waste, keep products in use, regenerate natural systems), now codified in the **Right-to-Repair Directive 2024/30/EU**. Compliance obliges operators to achieve ≥85 % device-collection rates and demonstrate secondary-materials recovery.

A sustainable tech ecosystem also means addressing resource use and e-waste. 5G and IoT devices, from smartphones to sensors and network hardware, need to be produced, used, and disposed of in a circular manner to minimize environmental impact. **Circular economy** initiatives in telecom include recycling programs, equipment refurbishment, and material recovery. For instance, Vodafone Germany ran a large-scale smartphone recycling program that collected 1.5 million old phones, retrieving over 80 tonnes of e-waste for recycling [31]. Many European operators now offer take-back schemes for consumer devices and the reuse or resale of networking equipment. On the network side, modular 5G hardware and software upgrades extend the life of equipment (for example, upgrading software to add 5G on existing radio units via DSS, Dynamic Spectrum Sharing, rather than installing entirely new hardware). Also, as the 5G rollout replaces older 2G/3G networks, decommissioned legacy equipment is being recycled. Another aspect is using **sustainable materials** and design: companies are researching biodegradable IoT sensors and reducing rare-earth metals in 5G

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components. **Innovation in batteries** (for backup power at cell sites) also ties into circularity; longer-life, safer batteries reduce replacement frequency and recycling load. Importantly, 5G's *enabling* effect contributes here too: with better connectivity, industries can implement circular practices more effectively, like tracking products through their lifecycle with IoT (for reuse or recycling), or using 5G-connected 3D printers for local remanufacturing. An example in the **manufacturing supply chain**: a manufacturer can place RFID/NFC tags on products and use a 5G network to track these assets globally, facilitating return and refurbishment programs. In agriculture, 5G-connected sensors can help reduce overuse of resources (like water or fertiliser), preserving those resources for future use, a kind of circular resource efficiency. Overall, while the circular economy is a broad challenge, digital tech plays a supportive role in closing the loop, and the telecom sector is taking steps to ensure 5G rollouts don't come at the cost of more e-waste or resource depletion. Europe again tends to lead in regulatory pressure (e.g., right-to-repair laws, requirements on electronics recycling), which push telecom operators and manufacturers to adopt circular practices in the 5G era.

Circular ambitions are spawning roles such as **Connectivity Circularity Designers**, **Reverse-Logistics Data Scientists**, and **Green Materials Innovation Leads**, each combining supply-chain analytics, materials science, and IoT-enabled traceability.

With energy, carbon, and material sustainability pillars addressed, Section 2.4 shifts focus to **sector-specific use cases**, illustrating how these enabling capabilities translate into value in manufacturing, energy, mobility, and beyond.

In this deliverable, we **reference** circular practices where they intersect with **5G/B5G deployment** (e.g., equipment lifecycle considerations) but **do not** provide a formal **scope or quantified impacts**. Circular practices intersect with **skills and roles** (procurement with LCA literacy, **sustainability-aware operations**) described in Section 5.4.

2.4. Emerging Use Cases and Application Domains

5G and B5G technologies are being applied across a multitude of industries, enabling new use cases that often blend **digital innovation with green objectives**. This section summarises real-world and expected use cases in key sectors – manufacturing, energy, logistics, mobility, agriculture, and others – with a particular focus on scenarios where digitalisation overlaps with sustainability goals. We highlight how these use cases are developing in Europe (including any flagship EU pilot projects), and we provide comparisons with developments in the U.S. and Asia. We also distinguish between **private-sector-driven use cases** (e.g., factory automation on private 5G networks) and **public-sector or societal use cases** (e.g., smart cities, smart grids) to understand different drivers of adoption. Table 3 provides an overview of sectoral 5G applications and notable examples globally, followed by a detailed discussion of each sector.

As can be seen, **energy** and **transport** use cases stand out for their potential sustainability impact (e.g., reducing grid losses, cutting vehicle emissions), which is why there's emphasis on these in Europe's funding programs. We provide more narrative on each major sector in the following subsections.

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Table 3. 5G/B5G Key Use Cases Across Sectors.

Sector	Key 5G/B5G Use Cases	Example Projects (EU / Global)
Manufacturing	Wireless factory automation (robotics, sensors), real-time control of machines, augmented reality (AR) for maintenance, digital twins of production lines, flexible AGV (Automated Guided Vehicle) operations, quality control via 5G cameras.	*5G-SMART* EU project – 5G in Bosch semiconductor plant enabling cloud-controlled AGVs and wireless industrial Ethernet [32] Ericsson/ABB trial in Kista – a 5G-controlled robotics and process monitoring [33] China: Foxconn's 5G smart factory lines. U.S.: Ford's 5G automotive factory pilot with private 5G.
Energy & Utilities	Smart grid monitoring and automation, substation automation, distributed renewable integration (real-time control of solar/wind farms), remote asset monitoring (pipelines, wind turbines via drones), smart metering with 5G IoT, demand-response systems for energy efficiency.	*SOGNO* EU project – 5G-based services for grid automation in Romania (CEZ), yielding faster fault response and reduced losses. Italy's *5G CAR2GRID* pilot links EV chargers to the grid via 5G. U.S.: NREL's 5G testbed for resilient grid comms. China: State Grid using 5G for substation video monitoring and load control.
Transportation (Mobility)	Connected and Autonomous Vehicles (CAV), vehicle-to-everything (V2X) communications for safety (collision avoidance) and traffic efficiency, smart traffic management (intelligent traffic lights, congestion management), public transport monitoring, drone traffic management (UTM) with 5G, enhanced	European 5G corridors (e.g., *5G-CARMEN* on EU highways) enabling cross-border V2X. Germany's 5G-enabled smart traffic pilot in Hamburg (portion of city traffic lights adaptive via 5G).

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	logistics (fleet tracking, route optimisation).	**South Korea**: 5G bus and autonomous shuttle trials in Seoul. **USA**: Bellevue, WA 5G traffic management pilot with T-Mobile. **China**: Guangzhou 5G C-V2X city zone reducing commute times.
Logistics & Ports	Smart ports and warehouses: 5G-connected cranes, remote operation of gantries, autonomous trucks and robots for container movement, real-time tracking of goods with 5G IoT, AR for logistics workers. Supply chain visibility with 5G asset trackers.	*5G-MoNArch Hamburg Port* trial – network slicing to support port sensor networks and AR inspections. Port of Rotterdam 5G trials for drone inspection and autonomous barges. Alibaba's 5G warehouse robots in China are speeding up fulfilment. U.S.: Verizon 5G deployment in the Ports of L.A./Long Beach to improve efficiency.
Agriculture	Precision farming: 5G IoT sensors for soil, crop, and livestock monitoring; drone-based crop imaging and spraying (with real-time HD video via 5G); autonomous tractors and farm machinery controlled via 5G; smart irrigation systems (adjusting water use based on sensor data); supply chain tracking from farm to market.	EU's *5G-Victori* project – 5G drones monitoring vineyards in Spain (for targeted irrigation). Ireland's smart dairy farm trials with 5G collars and sensors are improving herd health and reducing waste. **India**: Airtel 5G smart farming initiative (Bangalore hydroponics with wireless sensors) improved yields. **Japan**: 5G robotic tractors in Hokkaido trials.
Health & Emergency (cross-sectoral)	(Note: Not core to industrial, but important overlap) Remote surgery and telemedicine over 5G, ambulance telemetry to hospitals, AR for emergency	*5G Health* pilot in Finland – remote ultrasound

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	responders, 5G wearable sensors for health monitoring (reducing hospital visits). Also, disaster response drones and connectivity (e.g., 5G portable cell for firefighters).	conducted with low-latency 5G. Italy's 5G ambulance demos (real-time patient data to ER). China: 5G telemedicine used during COVID in Wuhan for remote CT scans. U.S.: UC San Diego 5G medical campus integrating AR for training. (These improve service efficiency and reduce travel emissions in healthcare.)

2.4.1. Manufacturing (Industry 4.0)

In manufacturing, 5G enables the vision of *Industry 4.0*: highly flexible, data-driven production with wireless connectivity at its core. With 5G's reliability and low latency, factories can connect sensors, machines, and workers in real time. This means **mobile robots and AGVs** can be used on the factory floor without fear of losing connectivity (unlike with Wi-Fi). For instance, the EU's **5G-SMART** project equipped a Bosch semiconductor factory in Reutlingen with a private 5G network; they successfully demonstrated cloud-controlled AGVs moving materials and even ran industrial Ethernet protocols over 5G links for machine control [34]. This replaced fixed wiring and allowed more flexible production layouts. Beyond productivity, 5G deployments can eliminate up to 80 % of copper cabling on the shop floor and enable certified human-robot collaboration areas compliant with ISO 10218 safety envelopes. 5G also powers **augmented reality for maintenance:** e.g., an engineer wearing AR glasses can receive live instructions or 3D overlays via 5G when repairing a machine, thus reducing downtime and errors. Ericsson's factory in Kista, Sweden, trialled this: technicians used AR on 5G to service robots, speeding up the process. Additionally, **massive IoT** in factories (hundreds of sensors monitoring vibration, temperature, etc.) helps implement predictive maintenance: the moment a machine shows an anomaly, it flags it, so parts can be replaced before a breakdown (avoiding energy and material waste from catastrophic failures). In terms of sustainability, smart factories can optimize energy usage by adjusting machine operations based on real-time data; one example is using 5G sensors to turn off idle machines or intelligently control HVAC and lighting only where workers are present, cutting electricity usage.

Global context: Europe has many *model factories* testing 5G, thanks to initiatives like 5G-ACIA (a forum uniting manufacturers and telcos). Germany, Sweden, and Italy host notable pilots (Audi's "factory of the future" with 5G, Ericsson's own smart production line, COMAU's 5G robotics in Italy). The U.S. is catching up: Ford and AT&T collaborated on a private 5G network in a Michigan plant to wirelessly configure cars coming off the line. In Asia, China has over *2,000 5G-connected factories* as part of its Industrial Internet program: e.g., Haier's appliance factory uses 5G to connect every workstation and AGV, reportedly raising efficiency by

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~20%. Overall, manufacturing is poised to be one of the largest beneficiaries of 5G/B5G, with improved productivity and lower resource waste.

With energy, carbon, and material sustainability pillars addressed, Section 2.4 shifts focus to **sector-specific use cases**—illustrating how these enabling capabilities translate into value in manufacturing, energy, mobility, and beyond.

Factory modernisation puts new strains (and opportunities) on the energy grid. The next subsection shows how 5G supports smarter, greener **energy and utilities** operations.

Evidence points to **controlled commercial adoption** in smart factories, with many deployments still at **pilot scale**. Representative trials (e.g., 5G-SMART consortium–2024) and commercial projects (ABB/Ericsson-2023) illustrate the shift. See Annex B (Germany, Spain) for additional regional cases.

2.4.2. Energy and Utilities

The energy sector (encompassing power generation, transmission, distribution, and also oil & gas) is undergoing a transformation to meet decarbonization goals, often termed the energy transition. 5G plays a key role by providing the ultra-reliable, low-latency connectivity needed for a smarter and greener grid. In standalone 5G deployments, round-trip latency under 10 ms already meets the 3–5-cycle (50 Hz) window required by grid-protection tripping schemes, allowing protective relays to operate over wireless links. A primary use case is the **smart electricity grid**: Traditionally, utilities had limited real-time visibility into grid conditions, but with 5G sensors on lines, transformers, and at consumer endpoints (smart meters), they can monitor and control the flow of electricity dynamically. In the EU, projects like SOGNO (described earlier) showed that 5G-connected grid sensors and automation systems can reduce outages and losses [25]. Specifically, 5G allows quicker isolation of faults (meaning fewer customers affected and less energy not delivered) and dynamic balancing (so renewable energy isn't wasted when production spikes unexpectedly). Another use case is **integration of renewables**: Solar and wind farms are often in remote areas; 5G (including possibly 5G satellite backhaul or 5G fixed wireless links) can connect these sites to grid control centres with low latency, enabling techniques like fast frequency response (important when a cloud passes over a solar farm or a wind farm output fluctuates). In 2025, as Europe increases renewable penetration, such fast-reacting communication becomes critical to avoid blackouts, hence interest in 5G for grid stability. 5G can also link **electric vehicles (EVs)** into the energy system: for example, if many EVs are charging, a 5G-based control system might coordinate charging times or even draw power from car batteries (vehicle-to-grid services) to stabilize the grid. In terms of traditional utilities, **oil & gas** companies use 5G for *remote monitoring* of pipelines and rigs, reducing the need for maintenance travel (less fuel/emissions) and improving safety (preventing leaks/environmental harm through early detection). Drones patrolling pipelines, streaming HD video over 5G (where available) or via NTN, is one new practice.

Global context: European energy operators (like Italy's Enel or France's EDF) have run 5G pilots for substation automation and advanced metering. The U.K.'s 5G RuralFirst project trialled 5G for remote windfarm monitoring in Orkney. In the U.S., Duke Energy has experimented with private LTE/5G for grid control, and the National Renewable Energy Lab

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(NREL) is testing 5G for microgrids [35]. In Asia, China's State Grid has built a proprietary 5G network in some provinces just for utility use, demonstrating automated power restoration. The **bottom line** is that 5G enables a more resilient, efficient, and renewable-friendly energy system, a cornerstone for sustainable industry.

Utilities now advertise roles such as **Grid Edge Orchestrator**, **5G-Drone Inspection Pilot**, and **DER Flexibility Trader** (monetising aggregated solar-plus-storage via 5G-enabled VPPs).

With energy systems becoming data-rich cyber-physical platforms, similar connectivity is revolutionising **transportation** and **mobility**, from C-V2X safety to autonomous fleets.

Adoption is generally **pilot or early commercial**, especially in **smart grids and DER integration**. Experts stress that **assurance of uplink latency** and **resilience of telecom–OT integration** are gating factors (validated in Section 4.3, Table 22).

2.4.3. Transportation and Mobility

The transportation sector (spanning personal vehicles, public transit, and infrastructure) is both a significant economic domain and a target for emission reductions. 5G's role here is to enable smarter and safer mobility through real-time data exchange, often referred to as Cooperative Intelligent Transport Systems (C-ITS). A flagship use case is **Connected and Autonomous Vehicles (CAV)**: vehicles equipped with 5G (or its V2X variant) can communicate with each other and with road infrastructure. This has several benefits: improving safety (cars can broadcast hazard warnings or see around corners via networked sensors) and improving traffic flow (vehicles can platoon or adjust speeds to harmonize traffic). 5G's low latency is crucial for such coordination: for example, if a car brakes in an emergency, a following car can get that signal over the network almost instantly and brake too, even before its driver or onboard radar might react. Europe has heavily invested in testing these scenarios on transnational corridors (e.g., the *5G-CARMEN* project on a highway from Italy through Austria to Germany). Alongside 5G-CARMEN, cross-border pilots such as 5GCroCo and 5G-MOBIX have proven seamless C-V2X hand-over at speeds above 130 km/h on EU motorways, validating continuity of safety messages across national networks. Additionally, **smart traffic management** is an immediate win: cities are embedding cameras and IoT sensors at intersections, with 5G connectivity feeding data to AI traffic control systems. This can optimize light cycles, reduce idle times, and give priority to public transport, thereby cutting fuel use and pollution. For instance, in **Hamburg**, a 5G pilot connected traffic lights and barges in the port area; it achieved smoother traffic and also allowed faster clearance for ambulances [1]. Another emerging aspect is **urban air mobility and drones**: 5G can provide the communication backbone for managing autonomous delivery drones or even future air-taxis, ensuring they operate safely and efficiently in shared airspace (several EU projects, like *CORUS-XUAM*, examine 5G for drone traffic management). From a sustainability angle, transport is responsible for significant CO_2 emissions, so optimising it has big payoffs. Studies by the European Commission have indicated that C-ITS could reduce emissions by 5-15% by smoothing traffic flow.

Global context: Asia has been early in some V2X deployments – South Korea has 5G along parts of its highways, supporting some Level-3 autonomous driving features in cars. China has dozens of "5G smart road" pilots (e.g., in Jiangsu province, intersection cameras tell connected cars when pedestrians are crossing out of line-of-sight). The U.S. approach to V2X originally centred on a different technology (DSRC), but now C-V2X (cellular-based) is being adopted, and 5G AAU (Advanced Antenna Units) are going up along certain city corridors; Ford and other automakers plan C-V2X in upcoming models. In public transit, 5G can also improve operations: e.g., real-time monitoring of buses/trains, or even enabling autonomous shuttles. To conclude, 5G in mobility is about enabling **Smart Mobility** and eventually **autonomous mobility**, leading to fewer accidents, less congestion, and integration of electric and shared mobility, all contributing to a greener transport system.

Key roles include **C-V2X Safety Validation Engineer**, **Traffic-AI Data Curator**, and **Autonomous Fleet Remote Operator** overseeing Level-4 vehicles via 5G links.

Supply-chain nodes such as ports and warehouses share the same need for ultra-reliable wireless control, which is why logistics is the next focus.

Mobility use cases (V2X corridors, smart traffic) are **heavily piloted** in Europe, with scaling dependent on **slice orchestration** and **MEC integration** (see Section 2.2.1–2.2.2). Regional detail is provided in Annex B (e.g., Greece, Benelux).

2.4.4. Logistics and Smart Ports/Warehouses

Logistics is the lifeblood of commerce, and 5G is making supply chains more efficient and flexible. In large **ports**, for instance, 5G connectivity allows for remote operation of heavy equipment like cranes or straddle carriers. The operator can sit in a control room and control cranes via high-definition video links and controls over 5G, instead of physically being in a noisy, dangerous crane cabin. This not only improves safety and ergonomics but also efficiency (one operator might oversee multiple semi-autonomous cranes). The Hamburg port trial in the 5G-MoNArch project successfully tested such remote crane operations using a dedicated network slice [36]. 5G also connects IoT sensors on ships, containers, and infrastructure, providing real-time tracking of assets. Knowing exactly where a container is and when it's been loaded/unloaded helps optimize port throughput (reducing dwell times, thus less ship idle time burning fuel). **Warehouses** similarly benefit: 5G-connected autonomous forklifts and robots can handle goods more quickly. Because 5G has greater reliability and coverage than Wi-Fi in large facilities, the robots can roam freely without losing communications. This was illustrated in trials like **Alibaba's warehouse** in China that reportedly improved parcel handling efficiency using 5G-guided robots. Additionally, logistics companies use 5G for **fleet management**: trucks or delivery vans stream telematics to centres, helping with route optimisation (avoid congested or hazardous routes) and maintenance (fix issues before a breakdown causes delays). For cold-chain logistics (perishable goods), 5G sensors monitor temperature in real-time, preventing spoilage (which not only has economic cost but also environmental cost).

Global context: Ports in Europe (Rotterdam, Antwerp) have followed Hamburg's lead, implementing private 5G for operations: e.g., Antwerp's port uses 5G drones for surveillance of the vast area, reducing the need for patrol boat trips. In the U.S., ports in Los Angeles are adopting 5G to coordinate the movement of trucks and containers more efficiently, particularly after recent supply-chain crises. Singapore's port (one of the world's busiest) is deploying 5G as part of a mega-port automation project, including autonomous

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vehicles. All these lead to fuel savings (less waiting, optimized moves) and capacity gains. One can think of 5G as enabling **just-in-time, just-in-sequence** logistics at a new level of precision, which in turn reduces waste (unneeded inventory, fuel, time). In terms of public vs private drivers in this domain, many port and warehouse deployments are on **private 5G networks** (often run by an operator or vendor for the site owner), because they need guaranteed coverage and capacity on-site. German ports, for example, leverage local 3.7–3.8 GHz industrial licences to run fully private 5G SA networks independent of mobile-network operators. Public networks come into play for wide-area tracking (e.g., a logistics provider tracking trucks across the country via the public 5G network).

We see rising demand for **Port 5G Network Coordinators**, **Autonomous Crane Teleoperators**, and **Supply-Chain Digital-Twin Architects** experienced in GS1/EPCIS standards.

Beyond dense industrial zones, 5G is also transforming **agriculture and agri-food**, bringing connectivity to the most remote fields.

Logistics and port operations show the **fastest path to commercialisation**, typically on **private 5G + MEC**. The Port of Hamburg slice trial (2022) and partner inputs (see Annex B: Spain, Germany) illustrate early scale.

2.4.5. Agriculture and Agri-Food

Agriculture might seem low-tech, but it's increasingly data-driven under the banner of **smart farming** or **precision agriculture**. 5G enables reliable connectivity in rural areas where previous networks (3G/4G) might not have reached all fields or had capacity issues. With 5G, farmers can deploy **IoT sensors** across their crops to monitor soil moisture, nutrient levels, microclimate, etc., in real time. By aggregating this sensor data (often to a cloud platform), they can apply water or fertiliser exactly when and where needed, reducing resource use and runoff. For example, if soil sensors and weather data (delivered via 5G) show a certain part of a field needs water, an automated irrigation system can target that zone, rather than watering the whole field. Trials in India's Clover greenhouse (noted in a Telit case) showed wireless sensors improved crop yields while using resources more efficiently [37]. **Drones** with 5G connectivity are another game-changer: they can survey large fields with high-resolution cameras, instantly sending imagery for analysis of crop health (detecting pest issues or growth problems). 5G's bandwidth allows transmitting HD or multispectral video to AI systems that can tell the farmer where to spray or which areas to replant. Some drones can even do precision spraying of pesticides or nutrients, guided by this data, which means fewer chemicals overall (good for the environment and cost). **Livestock farming** also benefits: wearables on cattle (collars or implants) can monitor health signs and location. Over 5G, a farmer can get alerts if an animal shows signs of illness or wanders off, enabling timely intervention. Autonomous farm machinery is an emerging area: tractors or harvesters equipped with 5G can eventually be remotely controlled or operate in coordination. For instance, an autonomous tractor could be overseen by a farmer through a live 5G video feed and control link, plowing fields at off-hours with precision GPS – this is being piloted in Japan and Australia (though often using other wireless tech or pre-programming; 5G will improve responsiveness). From a sustainability perspective, these techniques translate into **higher yields with lower inputs**: i.e., more food produced per unit of water,

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fertiliser, and land, and less pollution. They also reduce the fuel usage and manpower needed (autonomous or remotely guided machines can operate more efficiently).

Global context: Europe has several testbeds: e.g., the **5G RuralFirst** project in the UK trialled IoT and drones on farms, and demonstrated that rural 5G can boost agricultural output. In the Netherlands, 5G is used in greenhouses to control the climate precisely. The U.S. Department of Agriculture has looked into "connected farms", and carriers like Verizon have partnered with AgTech firms for 5G pilot farms (especially as satellite-based Internet like Starlink also competes for rural connectivity). Developing countries might leapfrog with 5G for agriculture as well (India's 5G pilots include farming). Overall, agriculture might not demand the highest bandwidth, but it requires reliable coverage, an area where Europe's goal of blanketing even rural areas with 5G by 2030 is relevant for ensuring no farm is left offline. Upcoming 3GPP Release-19 NTN extensions will blend satellite and terrestrial 5G, keeping autonomous farm machinery connected even beyond conventional cell ranges.

Notable profiles include **Agri-IoT Deployment Specialist**, **Precision-Farming Data Scientist**, and **Autonomous Farm Machinery Technician**.

The rollout models behind these sectoral examples vary: some depend on enterprise-owned spectrum, others on public networks. The following subsection contrasts these **public vs. private drivers**.

Agricultural adoption remains **fragmented**, with most cases at **pilot or experimental scale** (e.g., vineyard monitoring, 2023 trials). Regional inputs (Annex B: Lithuania, Malta) confirm **heterogeneous maturity** and **low immediate scaling potential**.

2.4.6. Public vs. Private Drivers

Many of the above use cases are being driven by **private 5G deployments** or localised networks (especially in manufacturing, ports, and energy plants) because enterprises require guaranteed performance and security. Governments in Europe have facilitated this by releasing local spectrum and funding vertical trials (through programs like 5G PPP trials, or national 5G testbeds in countries like Germany, France, and UK). France's Petits Territoires d'Application (PTA) scheme illustrates this middle path, freeing 40 MHz in the 2.6 GHz TDD band for local industrial 5G. On the other hand, some use cases rely on **public networks** – notably those that cover wide areas or involve consumers (e.g., connected cars on public roads use the nationwide operators' networks; smart city applications often piggyback on public 5G with network slicing for city use). The success of these applications often requires coordination between the private and public sectors. For example, traffic management systems are usually run by city authorities but use telecom operator infrastructure; similarly, utility smart grids might use a mix of private utility-owned networks and public carrier services.

Blended deployment models spawn roles like **Local Spectrum Asset Manager** (negotiating licences) and **5G-as-a-Service Business Designer**.

Different deployment logics also shape **geographic patterns** of adoption across Europe, the U.S., and Asia.

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Overall, **public-sector funding** drives many early pilots, while **enterprise demand** dictates commercial scaling. This split mirrors expert observations that **integration capacity, not spectrum access, sets the pace** (see Section 4.3, Table 22).

2.4.7. Geographic Patterns

In Europe, we see a collaborative, pilot-driven approach: multiple stakeholders (industry, telecom, government) coming together in funded pilots to validate use cases (as listed above). The EU's emphasis is on use cases that also align with societal goals (safety, sustainability): e.g., many 5G PPP vertical demos had a green angle (smart energy, smart mobility). The U.S. adoption of 5G use cases is often more enterprise-led and ROI-focused: e.g., companies deploy private 5G if it clearly improves their operations' efficiency or cost. There is strong interest in industrial use cases, but fewer nationwide initiatives connecting them, although recently the U.S. DoT and others are investing in C-V2X roadside units, etc. Asia (particularly China) often takes a scale approach: the government identifies key sectors (like mining, ports, manufacturing) and the state-run operators then implement hundreds of "5G+industry" projects with those sector companies; some of these are pilot/demonstrators, but others are becoming permanent operations. This has led China to report large numbers of 5G use case deployments (e.g., "hundreds of smart factories", etc.), albeit the depth of each deployment varies. Mid-2025 GSA figures show Europe hosting roughly 18 industrial-grade private 5G networks per million inhabitants, versus 25 in South Korea and 12 in the United States.

Cross-regional expansion drives demand for Inter-Region **Compliance Leads** and **Global 5G Benchmarking Analysts**.

A rounded synthesis of sectoral and regional use-case momentum sets up the **final remarks**, which contextualise lessons learned and remaining gaps.

2.4.8. Final remarks

A recurring insight across all verticals is that skills forecasting must become a continuous exercise; keeping curricula aligned with fast-moving technology road-maps will be as critical as the infrastructure roll-out itself.

Going forward, as 5G-Advanced features roll out and costs come down, we can expect these use cases to move from pilot to mainstream. A critical factor will be the development of a skilled workforce that can manage the intersection of 5G and industry-specific needs, which is indeed one of the motivations of the **5G-DiGITs** project (to train talent across digital and green industrial technologies). Lessons learned from the early European pilots and the global comparisons should inform how curricula and training programs are shaped.

As section 2.4 culminates, the overarching talent theme is the rise of **Sector-Savvy 5G Solution Architects** who can translate generic connectivity capabilities into concrete, sustainable business value across verticals.

Geographic uptake correlates with **policy frameworks** and **industry mix**. For example, Germany/Spain emphasise manufacturing, Greece/Malta logistics

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and ports, and Lithuania/Ireland digital SMEs. Detailed evidence is provided in Annex B, which is analysed in Section 3.

2.5. Insights from Strategic Foresight and Roadmaps

To place the above findings in a broader context, we review strategic roadmaps and foresight studies from leading organisations, including industry alliances, standards bodies, and government strategies. The goal is to extract high-level **insights about the future trajectory** of advanced 5G and B5G, and how our project's focus aligns with these trajectories. We also examine European initiatives, such as the 5G PPPs' outcomes and the SNS Joint Undertaking's 6G roadmap, as well as global standards outlooks from ITU/3GPP, major policy goals (e.g., Europe's Digital Decade 2030 targets), and foresight from prominent industry analysts (Gartner, McKinsey, etc.). This provides a **strategic backdrop** highlighting opportunities and challenges on the horizon, and ensures our work in 5G-DiGITs is aligned with the cutting edge of innovation.
Table 4 distils five complementary foresight lenses that frame the detailed discussion in the following subsections, clarifying how technical roadmaps intersect with sustainability and skills-development imperatives.

Table 4. Strategic Road-Mapping Landscape for 5G-Advanced

Foresight source	Time-horizon & tech focus	Sustainability/resilience angle	Why it matters for 5G-DiGITs
SNS JU SRIA (EU)	6G vision to 2030; nine research pillars; €250 M call-1 + ≥15 testbeds live 2025	"Digitalised **and decarbonised** EU economy"; open & sovereign networks	Aligns curriculum with EU-funded flagship projects; fosters Open-RAN & sustainability skills
ITU IMT-2030 & 3GPP R18–R21	Global vision (draft 2024); R18 commercial 2024, R21 6G freeze 2030	Integrates sensing, AI-native security, and SDG alignment	Standards literacy & conformance testing become core learning outcomes
EU Policy targets (Digital Decade / Green Deal)	100 % Gigabit & 5G coverage; 10 000 green edge nodes by 2030; €300 bn capex need	Mandatory energy-efficiency & skills benchmarks	Highlights the financing, regulatory, and talent gaps that graduates must navigate
Industry analyst outlook (ABI, Gartner, McKinsey)	2024 = "Year of 5G-Advanced"; mass SA-5G ≥2027; early 6G pilots 2026–27	Warns of cost, spectrum & security pinch-points	Feed market-demand modules and entrepreneurship tracks
Horizon-scanning / weak signals	Quantum-safe security, reconfigurable surfaces, geo-political bifurcation risks	Focus on supply-chain resilience & wildcard innovation	Prepares learners for uncertainty via the *Resilience-Horizon Planner* profile

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2.5.1. European 5G/6G Roadmaps (5G PPP and SNS JU)

Europe's Public-Private Partnership on 5G (5G PPP), which ran through the 2010s, and its successor in Horizon Europe, the **Smart Networks and Services Joint Undertaking (SNS JU)**, have been steering the vision for beyond 5G. A key deliverable is the **Strategic Research and Innovation Agenda (SRIA)** for 6G. The 2022 SRIA, produced by the NetWorld Europe platform for the SNS JU, outlines the research priorities for 6G around 2030. One explicit theme is **sustainability**: it envisions 6G enabling a "fully digitalised and decarbonised European economy and society" [21]. It sets targets not just for technical performance, but also for energy efficiency improvements and coverage that leaves no region behind. The SRIA identifies nine technology areas (such as new radio paradigms, AI, and security) and plots timelines for their development [21]. Notably, the SRIA is a *living document* that is updated as technology evolves, indicating Europe's adaptive planning approach. In terms of process, Europe has already invested heavily in 6G research: through SNS JU's first calls, over €250M was granted to 6G flagship projects in 2023 (in areas such as smart radio surfaces, AI for networks, sub-THz systems). Moreover, there is transatlantic collaboration: a joint EU-US work plan in 2023 identified "6G for sustainability" as a priority collaboration area [20], aiming to align efforts on Sustainable 6G (reducing footprints and maximizing the technology's positive impact on society). This is significant as it underscores a common understanding that future networks must be greener by design. For advanced 5G, the 5G PPP, in its final phase, has published white papers that summarize 5G achievements and remaining gaps. For example, a 5G PPP Architecture Working Group book (2023) highlighted the need for a trustworthy and sustainable 6G architecture, building on lessons learned from 5G deployments [38]. Overall, the European vision envisions 5G-Advanced bridging to 6G in the second half of this decade, with a push for early 6G trials around 2026-2027 to secure a global leadership position. Under SNS JU Call 2, a network of at least fifteen 6G Experimental Facilities is scheduled to be operational across Europe by 2025, providing open-access testbeds for SMEs and academia. This forward-looking approach also emphasizes **open networks** (Europe aims to foster standards like Open RAN to thrive by the 6G era, promoting vendor diversity) and sovereignty (building European capacities in key technologies such as chips and cloud, aligning with the EU's industrial strategies).

Roles such as **6G R&D Program Manager, Open RAN Ecosystem Coordinator, and SRIA Compliance Analyst combine telecom expertise with skills in partnership and funding**.

These EU-centric ambitions must align with global standardization timelines; therefore, we next examine the outlooks of ITU, 3GPP, and IEEE.

The **SNS-JU SRIA 2022/2024** is the primary reference for the European trajectory, consolidated in **Table 5**, which summarises 5G-Advanced milestones through to early **6G trial expectations** (~2026–2028).

2.5.2. Global Standards and Industry Outlook (ITU, 3GPP, IEEE)

On the global stage, the **International Telecommunication Union (ITU)** sets the standards for next-generation mobile requirements. The **IMT-2030** process for 6G is already underway:

- **Vision / Framework** – Recommendation ITU-R M.2160, adopted **November 2023**, sets the overarching objectives for IMT-2030.
- **Minimum technical performance requirements** – expected **mid-2026**.
- **Evaluation & specification submissions** – **2027-2030**.

Early indications from the ITU focus groups suggest that 6G will emphasise not only higher data rates but also integrated sensing, AI-native operation, and explicit support for the UN Sustainable Development Goals (SDGs), reflecting a commitment to societal impact [39].

Meanwhile, the **3rd Generation Partnership Project (3GPP),** the consortium responsible for the 5G family of standards, maintains the following roadmap:

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- **Release 18** (5G-Advanced Phase 1): Stage 3 freeze **March 2024**; ASN.1/OpenAPI freeze **June 2024**.
- **Release 19** (5G-Advanced Phase 2): functional freeze **September 2025**.
- **Release 20** (additional 5G-Advanced iteration plus initial 6G study items): Stage 3 freeze **March 2027**.
- **Release 21** (IMT-2030 Phase 1), planned as the **first fully normative 6G release**, with ASN.1/OpenAPI freeze targeted for **Q1 2029**.

This timeline implies that the second half of the 2020s will feature a **dual track**:

1. **Continuous enhancement of 5G**: deployment of Rel-17/18 features such as NR-Light for IoT, improved sidelink, high-accuracy positioning, and reduced-capacity RedCap devices.
2. **Consolidation of 6G foundations:** Rel-20 studies maturing into Rel-21 normative work, aligned with the ITU IMT-2030 requirements schedule.

Industry outlooks (e.g., GSMA and GSA reports) predict that by **2025-2027,** 5G will have saturated most major markets (with a large proportion of Standalone 5G deployments), allowing resources to pivot towards 6G. **ABI Research** labeled 2024 as “the year of 5G-Advanced” as the first commercial implementations of Release 18 reach the market, setting the stage for the subsequent 6G cycle [40].

The **IEEE** community is equally active: its **IEEE Future Networks Roadmap (v4, 2025)** catalogues enabling technologies beyond 5G, including terahertz communications, optical wireless, and AI-driven network automation.

A cross-cutting imperative across all standardisation domains is **security and resilience**. Rising cyber-threat levels drive work on quantum-resistant cryptography, AI-based intrusion detection, zero-trust architectures, and self-healing capabilities. EU-US cooperation has already singled out “resilience mechanisms from supply chain to recovery after attacks” as a joint priority for 6G [20]. These considerations inform both the final releases of 5G Advanced and the earliest 6G designs. Demand is therefore growing for specialized roles such as Standards Strategy Specialists, Quantum-Safe Security Engineers, and AI-Native Conformance Testers who can navigate overlapping Standard Development Organizations (SDOs).

Table 5 summarizes the principal standardization milestones for 5G-Advanced and 6G across the main industry and policy bodies. The indicative timelines for 3GPP Rel-18 (2024), Rel-19 (2026), and Rel-21 (2029–2030) are also summarized in **Table 5**, noting that exact freeze dates remain subject to SDO consensus.

Table 5. At-a-glance timeline of key 5G-Advanced and 6G milestones

Body / Process	Milestone	Scope	Date (actual or target)
ITU-R – IMT-2030	Vision / Framework (Rec. M.2160)	Objectives & usage scenarios for 6G	Nov 2023
ITU-R – IMT-2030	Minimum performance requirements	KPIs (peak rate, latency, reliability, energy/spectrum efficiency)	mid-2026 (planned)
ITU-R – IMT-2030	Evaluation & submissions window	Candidate RIT/SRIT technologies	2027-2030 (planned)
3GPP	Release 18 – 5G-Advanced Ph 1	Throughout, AI-based RAN, RedCap	Jun 2024 (ASN.1 freeze)
3GPP	Release 19 – 5G-Advanced Ph 2	Further AI, NTN enhancements, XR	Sep 2025 (functional freeze)

3GPP	Release 20 – 5G-Advanced Ph 3 + 6G studies	Energy saving, NTN Phase 2, 6G study items	Mar 2027 (Stage 3 freeze)
3GPP	Release 21 – IMT-2030 Ph 1	First normative 6G features	Q1 2029 (ASN.1 freeze target)
IEEE	Future Networks Roadmap v4	Tech landscape beyond 5G	2025
EU-US TTC	6G Resilience Framework	Supply-chain & cyber resilience guidelines	2025 (working draft)

Standard setting matters only insofar as it meets policy imperatives, so the next section tests these technical outlooks against the EU's **Digital Decade** and **Green Deal** targets.

2.5.3. EU Policy Targets: Digital Decade 2030 and Green Deal

The European Commission's **Digital Decade Policy Programme 2030 (DDPP)** translates political ambitions into four cardinal "digital compass" points: skills, infrastructure, business, and public services. Two targets matter most for mobile networks:

- **Connectivity:** by 2030, every EU household should enjoy gigabit speeds, and **all populated areas must have 5G coverage** [41]. Achieving this presupposes near-universal 5G Advanced deployment, paving the way for early 6G hotspots.
- **Edge infrastructure:** at least **10,000 climate-neutral, highly secure edge nodes** distributed across the Union by 2030 [42]. These micro-data centres, powered by renewables and advanced cooling, will deliver sub-10 ms latency while reducing backbone energy per bit.

Meeting the connectivity compass points requires over **€300 billion of incremental investment in fibre, standalone 5G, and densification** [41]. The Commission's **Gigabit Infrastructure Act** and **Connectivity Toolbox** aim to accelerate rollout through common rules on permits, spectrum, and rights-of-way.

Parallel to the Digital Decade, the **European Green Deal,** reinforced by the **Green Deal Industrial Plan (GDIP)** of 2023, commits the EU to climate neutrality by 2050 and at least **-55 %** net GHG reductions by 2030. The GDIP explicitly seeks to "secure Europe's place as the home of industrial innovation and clean tech" [29]. Sectoral roadmaps (REPowerEU, Sustainable and Smart Mobility, Circular Economy, etc.) emphasize digitalization, including 5G/6G, IoT, and AI, as an enabler of energy efficiency, emissions monitoring, and smart operations.

Consequently, EU funding lines such as **Horizon Europe**, **CEF Digital, and the Recovery and Resilience Facility increasingly prioritize projects that integrate** advanced connectivity with Green Deal objectives, mirroring this project's educational pilots.

Emerging specialist roles, therefore, include Digital Sustainability Policy Advisor, Connectivity Funding Navigator, and Impact Assessment Analyst, which bridge technical standards, financing instruments, and environmental metrics.

Table 6 contrasts the Digital Decade 2030 objectives with the European Green Deal ambitions, highlighting the connectivity capabilities and timelines that underpin each target. The table also aligns Digital Decade 2030 and Green Deal Industrial Plan targets with connectivity levers (e.g., ubiquitous 5G coverage, energy efficiency **KPIs**, **circularity reporting**).

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Table 6. Alignment of Digital Decade 2030 and European Green Deal targets with advanced connectivity

Programme	Pillar / Target	Connectivity relevance	Deadline
Digital Decade 2030	Gigabit for every household	Requires fibre to premise and 5G-Advanced fixed-wireless alternatives	2030
Digital Decade 2030	5G coverage in all populated areas	Stand-alone 5G densification; early 6G pilots	2030
Digital Decade 2030	80 % of adults with ≥ basic digital skills	Workforce able to adopt 5G/6G services	2030
Digital Decade 2030	≥ 10,000 climate-neutral edge nodes	Low-latency, energy-efficient data delivery	2030
European Green Deal / GDIP	Net-zero by 2050 (-55 % by 2030)	Network energy efficiency; renewable-powered sites	2030 / 2050
European Green Deal / GDIP	Double EU clean-tech manufacturing capacity (batteries, PV, heat-pumps)	Digital twins, 5G-enabled automation in factories	2030
European Green Deal / GDIP	REPowerEU 600 GW solar target	Smart-grid connectivity, massive IoT	2030

2.5.4. Industry Foresight

Global analyst houses refine the strategic picture by translating technology roadmaps into business value and adoption curves. Their latest signals converge on three threads: **enterprise-centric monetization, automation & AI Ops, and digital for green impact**.

- **Enterprise revenue shift:** McKinsey's 2025 *Playing to Win in B2B Telecom* study finds that, beyond-core B2B spending, is set to grow **2-3× faster than consumer connectivity**, opening a €150 billion-plus pool by 2028 and pushing enterprise solutions toward **roughly a quarter of operators' wireless revenues by 2030** [43]. To capture that, operators must bundle connectivity with private-network management, IoT platforms, and edge services.
- **Private 5G/6G TAM expansion:** Omdia's *Private 5G 2024-29 Analysis* (Jan 2025) projects the **enterprise 5G/6G total addressable market (TAM) to exceed €340 billion by 2030**, with private networks and edge-AI services accounting for more than half of the spend [43]. A May 2025 vendor assessment highlights Nokia, ZTE, and Ericsson as front-runners in end-to-end private network propositions.
- **Adoption trajectory on the hype curve:** Gartner's 2024 *Wireless Technologies Hype Cycle* places **network slicing and private 5G in the "Slope of Enlightenment", on track for mainstream productivity before 2030**, whereas 6G sits at the innovation trigger with commercial reality a decade away [45]. Large enterprises in manufacturing and logistics are expected to be early adopters of private 5G by 2025.
- **Operations automation imperative:** Heavy Reading's *5G AIOps Operator Survey* (Sep 2024) reports that **over two-thirds of operators plan to deploy AI-driven closed-loop automation by 2025** to manage network complexity and contain opex [46].
- **Digital-for-green upside:** STL Partners calculates that aggressive 5G adoption in key sectors (energy, transport, manufacturing) could **avoid 1.7 billion t CO_2 by 2030**, translating into a multi-billion market for IoT devices, analytics, and optimisation services [47].

Table 7 distils these analyst forecasts at a glance, mapping opportunity areas to time frames and skill demands. Analyst perspectives (see **Table 7**) converge on the enterprise value of private 5G,

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slicing, and edge; sustainability is a parallel driver, but uncertainty over ROI remains the gating factor.

Table 7. Analyst outlook on enterprise & sustainability value from advanced connectivity

Analyst / Source	Quantified forecast	Time horizon	Main beneficiaries	Talent signals
McKinsey (2025)	Up to **25 % of operator's wireless revenue** from enterprise solutions	2030	Telcos that build B2B platforms (private 5G, APIs)	5G/6G Business-Model Architect, Enterprise Partner Lead
Omdia (2025)	**€340 bn** enterprise 5G/6G TAM (private networks + edge AI)	2030	Vendors & integrators supplying industrial private networks	Private-Network Solution Engineer, Edge-AI Product Manager
Gartner (2024)	Private 5G & network slicing reach **Plateau of Productivity within 5–7 years**	2030	Manufacturing, logistics, and healthcare verticals	Network Slicing Service Designer, Factory Connectivity Lead
Heavy Reading (2024)	**> 66 % of operators** plan AI-Ops rollout	2025	CSP ops & automation vendors	AI-Native Network Operator, AIOps Platform Engineer
STL Partners (2023)	**1.7 Gt CO_2** abatement enabled by 5G	2030	Energy, transport, and ICT convergence ecosystem	Digital Sustainability Analyst, Green-Tech Solution Architect

2.5.5. Horizon Scanning – Weak Signals and Wildcards

Strategic foresight also monitors the periphery for weak signals and early-stage developments that can ripple into the mainstream. Recent signals cluster around **quantum-secure links, advanced materials, AI-generated RAN software, satellite-to-device connectivity, and hyperscaler incursions**.

- **Quantum-secure links:** In March 2025, SES and Singapore-based SpeQtral signed an MoU to build a satellite network for global quantum-key distribution, cementing plans to commercialise space-borne QKD and putting pressure on 6G security frameworks to become quantum-safe [48].
- **Graphene metasurface radios:** A June 2025 *IARJSET* study demonstrated a graphene-based, AI-tunable metasurface antenna operating in the 4–6 THz band, achieving high gain with around 60 % lower power than comparable mmWave arrays [49].
- **Generative-AI RAN software.** Aira Technologies unveiled **RANGPT™** (Nov 2023), a large-language-model tool that auto-generates RAN code and rApps, reportedly cutting development cycles by up to 70 % and accelerating open-source RAN innovation [50].

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- **Direct-to-device satellite broadband.** T-Mobile launched a public beta of its Starlink-based "T-Satellite" service in early 2025, initially supporting SMS messaging over satellite integration with the cellular network. A commercial rollout began on July 23, 2025, and data/app support is slated to start October 1, 2025, marking one of the earliest operational carrier-integrated LEO cellular services and intensifying competition for traditional terrestrial MNOs.
- **Cloud-hosted mobile cores.** In May 2024, Telefónica Germany (O_2) agreed to migrate one million 5G subscribers to an **AWShosted cloud-native core**, signalling how hyperscalers could capture a growing slice of the connectivity value chain [51].

Table 8 summarises these weak signals, their potential impact, and indicative time-frames. Wildcards here (e.g., hyperscaler-managed cores, quantum-safe cryptography) are exploratory signals; they are not deterministic forecasts.

Table 8. Horizon-scanning highlights for post-5G connectivity

Weak signal	Key milestone/evidence	Potential impact	Indicative window
Quantum-secure satellite links	SES–SpeQtral MoU for global QKD service (03-2025) [48]	Drives quantum-safe encryption requirements for 6G	2027-2035
Graphene metasurface antennas	AI-driven graphene antenna demo @ 4–6 THz (06-2025) [49]	60 % RF power cut; terabit devices	2028-2032
Gen-AI-generated RAN stack	Aira **RANGPT™** tool reduces RAN dev time 70 % (11-2023) [50]	Faster innovation; vendor shake-up	2025-2030
LEO direct-to-cell service	T-Mobile/Starlink beta texting launch (02-2025)	Global coverage; new pricing models	2025-2028
Hyperscaler mobile cores	Telefónica DE moves 1 M subs to AWS core (05-2024) [51]	Hyperscalers gain 10-15 % of enterprise spend	2024-2029

The emergence of such wildcards underscores the need for adaptable expertise. New roles gaining traction include **Wildcard Innovation Scout, Resilience Horizon Planner, and Quantum Telemetry Prototyper**—profiles that bridge deep-tech scouting with strategic risk assessment.

2.5.6. Final remarks

The five foresight lenses examined in sections 2.5.1 to 2.5.5 converge on a single message: the coming decade will be defined by **the simultaneous deepening of 5G-Advanced and early-stage 6G groundwork, under a strong sustainability and resilience mandate.** To keep pace, skills planning and curriculum design must shift from one-off updates to a continuous, evidence-based **cycle** that mirrors the release cadence of standards (annual 3GPP freezes, IMT-2030 milestones) and the rolling wave of EU policy targets. Table 9 distils the essence of the preceding subsections into a compact decision aid for WP5 stakeholders.

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Table 9. Strategic foresight synthesis for 5G-DiGITs (2025-2030)

Foresight lens	Salient 2025-2030 signals	Take-away for 5G-DiGITs
European 5G/6G roadmaps	SNS JU funds ≥ 15 pre-6G testbeds by 2025; SRIA targets AI-native, green networks	Align modules with EU flagship pilots; embed Open RAN & sustainability skills
Global standards trajectory	3GPP Rel 18 commercial 2024 → Rel 21 (first normative 6G) ASN.1 freeze Q1 2029	Teach "living-standards literacy" and conformance tooling to future engineers
EU policy ambitions	Digital Decade: 100 % gigabit + 5G pop. coverage & 10,000 green edge nodes by 2030	Use policy KPIs as learning objectives (energy-per-bit, edge-carbon limits)
Industry analyst outlook	Enterprise/private-5G TAM > €340 bn; AI-Ops becomes default by 2027	Prioritise B2B solution design, AI-driven ops, and entrepreneurship tracks
Horizon scanning & wildcards	Quantum-secure satellite links, GenAI-generated RAN code, hyperscaler cores	Train Resilience Horizon Planners able to spot wildcards & pivot curricula fast

Key synthesis points are the following:

- **Continuity and change:** Virtualisation, AI/ML, and energy-efficiency threads continue from 5G into 6G, while step-changes (THz bands, joint sensing-comm, extreme automation) introduce fresh uncertainties that teaching programmes must anticipate.
- **Skills-forecasting as infrastructure:** Embedding an annual ESCO-style update loop will keep occupational profiles (e.g., *AI-Native Conformance Tester* or *Quantum-Safe Security Engineer*) synchronised with technology releases and policy deadlines.
- **Values-led competitiveness:** Europe's differentiator is a triple focus on sustainability, trust, and inclusion; curricula should therefore integrate lifecycle-assessment literacy, ethics-by-design, and digital-divide mitigation alongside technical depth.
- **Strategic foresight leadership:** The programme should cultivate **Strategic Technology Foresight Leaders** capable of orchestrating cross-disciplinary teams, translating roadmaps into talent strategies, and maintaining an agile "watch-sense-adapt" loop across the consortium.

In short, the foresight review confirms that **resilience, technological, industrial, and human, is not a peripheral concern but the organizing principle for the 5G-to-6G era. Section** 3 now tests these strategic insights against on-the-ground realities across Europe, providing the feedback loop that will keep our education and innovation agenda future-proof.

These foresight insights provide the **forward-looking dimension** that complements Sections 2.2–2.4. Together, they underpin the cross-domain synthesis in Section 5 (Table 24, Table 25, Table 26, and Table 27).

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3. Market Intelligence and Regional Landscape Analysis

3.1. Methodology for Partner Input Collection

To complement the global and top-down insights obtained through the desk-based technology watch, this section integrates bottom-up **regional perspectives** contributed by consortium partners. The objective is to capture a **pan-European landscape** of how advanced 5G, Beyond 5G (B5G), and green industrial technologies are being addressed, supported, and adopted across diverse national and local contexts.

To ensure **consistency and comparability**, a **structured input template** was developed and distributed to all partners (see **Annex A**). The design of the template was directly informed by the findings and thematic structure of the desk research (Section 2), focusing on topics such as:

- Industrial adoption and sectoral focus
- National strategies and policy frameworks
- Regional readiness levels and barriers
- Sustainability linkages and innovation ecosystems

The goal was to guide partners in reflecting not only on available infrastructure or regulatory measures but also on **real-world implementation**, **ecosystem dynamics**, and any **noteworthy initiatives** or gaps in their specific regions.

The collection process was launched in June 2025, following an internal briefing and template walkthrough session. Partners were invited to provide concise, structured input based on their knowledge, local stakeholder networks, and publicly available data. The format allowed flexibility to accommodate differences in access to information and the maturity level of 5G deployment across regions.

Upon submission, all inputs were reviewed, harmonised, and consolidated by the **task leader** (UPV), ensuring alignment with the report's overall analytical framework. The resulting content serves as the basis for the regional snapshots, comparative analysis, and policy ecosystem mapping presented in Sections 3.2 to 3.5.

This methodology ensures that the report reflects both **strategic foresight** and **on-the-ground realities**, strengthening the validity of the findings and their relevance for subsequent tasks in WP5, including stakeholder engagement and strategic recommendations.

Given the length of the partner submissions, the full national/regional write-ups are provided in the B Annexes. Section 3 now presents a comparative, decision-oriented synthesis (descriptive tables in 3.2, followed by cross-cutting analyses in 3.3–3.5). This preserves traceability while improving readability and comparability. Furthermore, the findings in sections 3.2–3.5 are interpreted in light of the market research presented in Section 2, particularly the enabling levers described in Section 2.2 and the use-case families outlined in Section 2.4.

Partner inputs reflect data collected up to August 2025 using the template in **Annex A**. Where terminology diverged (e.g., "Industry 4.0" vs. "smart manufacturing"), we applied light harmonisation for comparability in Table 10 to Table 16.

3.2. National and Regional Snapshots at a glance

This subsection offers a self-contained picture of each partner's **policy posture** and **market reality** without requiring the reader to consult the B Annexes. Table 10 maps strategies, governance, and distinctive instruments; Table 11 summarises where adoption is material and what is holding it back. The reader can see Section 2 for the underlying enablers and use-case families.

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The table below (Table 10) summarises core strategy documents (what each region aims to achieve), regulatory/governance arrangements (how it is being implemented), and distinctive instruments (the levers that shape adoption).

Table 10. Strategies, Governance and Direction of Travel (by country/region)

Country/Region	Strategy & focus (what the strategy aims to achieve)	Regulatory & governance notes (how it's being implemented)	Distinctive instruments / emphases
Ireland	*Digital Connectivity Strategy 2023–2030* commits to **universal gigabit by 2028** and **5G in all populated areas by 2030**, positioning connectivity as an enabler for Industry 4.0, smart mobility, healthcare, and rural inclusion; complements *Harnessing Digital* and *Project Ireland 2040*.	DECC leads; **ComReg** handles spectrum; the **National Broadband Plan** provides rural backhaul that underpins 5G economics.	Rural revitalisation via *Our Rural Future* and **Connected Hubs**; strong public-private link between infrastructure, skills, and services.
Lithuania	*5G Guidelines 2020–2025* define staged rollout; in **June 2023** 5G was declared a **project of national importance** to fast-track permitting and coordination; CRA set **2025–2030** development goals (coverage and auction timing). Focus on **transport corridors (Via/Rail Baltica)** and household 100 Mbps.	Ministry of Transport & Communications (policy) and **CRA** (regulation); a **2021 multi-stakeholder memorandum** binds operators, municipalities and transport agencies to coordinated rollout.	**National-importance status**; sequenced auctions (**700/1500/2100 MHz in 2025**; **800/2300/2600 MHz in 2030**) aligned with EU policy.
Malta	*Malta Diġitali 2022–2027* treats 5G as a strategic enabler of the digital economy; **MCA** executed licensing across **700/3.6/26 GHz**; operators launched nationwide 5G.	MCA coordinates assignment and EU toolbox alignment; compact governance and **operator-led execution**.	Reliance on **EU instruments** (Digital Decade roadmap, EIB financing) and innovation/trust sandboxes; early **nationwide service** (Melita 2021; GO–Nokia 2022; Epic/Ericsson).
Spain	*España Digital 2026* and the *Estrategia 5G*	Ministry for Digital Transformation leads;	**SA-5G leadership**; governance links

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	couple **very high coverage** with a pivot to **closing the "adoption gap"**; **Standalone (SA) 5G** activated on 700 MHz/3.5 GHz/26 GHz.	**SETID** (spectrum) and **CNMC** (competition); **UNICO** backs rural backhaul and underserved areas.	**digital rights** and security (Carta de Derechos Digitales) to connectivity rollout.
Benelux (Belgium, Netherlands, Luxembourg)	**Belgium:** Digital Belgium/Wallonia and RRP back **Industry 4.0** and private 5G; **Netherlands:** *Digitalisation Strategy* + **5G Action Plan** + **Smart Industry** field-labs; **Luxembourg:** *Broadband Strategy 2020–2025* and **Accelerating Digital Sovereignty 2030**.	**Belgium:** BIPT auctions; **Netherlands:** permit simplification and support for **living-labs**; **Luxembourg:** 5G Taskforce and innovation agencies co-fund R&D.	**Ports/field-labs** (NL/BE), **private/local spectrum** (NL/BE), and **digital sovereignty** (LU) as policy signatures.
Germany	*National 5G Strategy (2017) + Gigabit Strategy (2022)*; **local/campus spectrum (3.7–3.8 GHz)** for industrial networks; security posture includes **Huawei/ZTE phase-out** timelines; strong Industrie 4.0 and IPCEI links to 5G-Advanced/6G.	BNetzA enables **private 5G**; federal & Länder support **living-labs** (e.g., CampusOS/5G.NRW).	**Security & sovereignty** emphasis; **tripartite innovation** (industry–academia–public) underpins deployment.
Greece	*National Broadband Plan 2021–27* and *Digital Transformation Bible 2020–25* set gigabit and 5G targets; funds and pilots connect connectivity with skills and digital public services.	Ministry of Digital Governance steers policy; **EETT** manages spectrum; active pilots in **energy, health, and smart cities**.	**Pilot-heavy diffusion** (e.g., COP-PILOT, 5G-TERRA), with rural/island inclusion and smart-community programmes.

In conclusion, all partners' countries align with EU Digital Decade goals, but the **deployment levers** differ: **Germany/Netherlands** lean on **private/campus 5G** and field-labs; **Lithuania** uses **national-importance status** and corridor-first rollout; **Spain** pivots from coverage to **usage**; **Ireland/Greece** tie connectivity to **regional inclusion and skills**; **Malta/Luxembourg** leverage compact governance and EU co-funding to orchestrate rapid execution.

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Table 11 translates sector notes into **plain language**: where adoption is visible first, and the **main frictions** are slowing scale-up. It mirrors the use-case families in Section 2.4.

Table 11. Where Adoption Is Happening—and What's Holding It Back

Country/Region	Leading adoption areas (what we see on the ground)	Principal gaps and frictions (what slows scale-up)
Ireland	**Manufacturing & logistics** pilots; **smart energy** (grid flexibility); **rural health/telemedicine** and digital public services—explicit policy link to regional development.	**Awareness/device mix**; **small-cell costs and planning pushback**; shortage of **advanced networking/automation skills**.
Lithuania	**Transport corridors** (Via/Rail Baltica) and **urban nodes** first; emerging **construction/manufacturing** digitisation.	**White-zone QoS**; **staged spectrum** (2025/2030); permitting process maturity—hence the **national-importance** designation.
Malta	**Nationwide operator 5G** plus early verticals in **health**, **mobility/logistics**, **smart cities**, **tourism (AR/VR)**.	**Small industrial base**; **SME skills/awareness**; densification constraints in heritage areas; ongoing security compliance.
Spain	**Manufacturing**, **energy**, **agrifood**, **ports/logistics**, **e-health**—with **SA 5G** underpinning many trials.	**Usage gap** despite high coverage; ICT-skills shortage; rural latency constraints
Benelux	**Belgium:** ports/logistics (Antwerp-Bruges), chemicals, hospitals; **Netherlands:** field-labs (agri, drones, smart industry), ports/refineries; **Luxembourg:** cross-sector pilots with sovereignty/NTN interest.	**SME ROI**, regulatory fragmentation (BE), **private-spectrum clarity** (LU/NL), and **skills** needs.
Germany	**Factory/campus 5G** (e.g., Siemens Amberg), **ports/logistics** (Hamburg), **energy/utilities**, and **healthcare** testbeds at scale.	**Security/vendor transition**, **edge-AI/OT-IT skills**, **multi-vendor orchestration** complexity.
Greece	**Private 5G in manufacturing** (e.g., Calpak), **energy flexibility pilots** (COP-PILOT), **telemedicine** (5G-TERRA), and **smart-tourism/cities**.	**SME costs and licensing friction**; need for **skills and incentives** to mainstream pilots.

Across partners, **manufacturing and logistics** lead; **energy systems** follow; **health** emerges where rural inclusion is a key consideration. Constraints are largely **demand-side** (skills, ROI, operational performance) rather than coverage, echoing Section 2's forecast for 2025–2030. Spain's low 5G traffic share, despite high coverage, highlights the need to align infrastructure with adoption strategies **and talent.**

Regional cases are classified under a **three-tier maturity model** (Pilot / Controlled Commercial, *Scaling*). Full evidence is detailed in Annex B, with Table 10 to Table 14 summarising adoption maturity across partner regions.

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3.4. Policy Frameworks and Government-Led Initiatives

Partners converge on EU-aligned objectives, but their **policy levers** differ. The table highlights the levers that most directly influence the odds of industrial adoption and shows how they map to the technical enablers outlined in Section 2.

In Table 12, for each lever, we indicate where it is observed and why it matters for industrial adoption.

Table 12. Adoption levers in policy (what's actionable)

Policy lever observed	Where we see it	Why it matters for industrial adoption
Local/campus spectrum regimes	Germany, Belgium, Netherlands, enabling private/local paths.	It enables factories/ports to operate on deterministic, secure networks (URLLC/TSN), moving beyond Wi-Fi and 4G to achieve real-time automation.
SA-5G emphasis with rural backhaul funds	Spain (SA cores; **UNICO** backhaul).	**Time-critical apps** need SA and fibre backhaul; demand-side incentives tackle the **usage gap**.
Living-labs & field-labs	Netherlands, Germany, and Greece pilots.	Converting PoCs to **repeatable playbooks**; lowers SME risk and builds local skills.
Security/sovereignty mandates	Germany vendor phase-out; Luxembourg sovereignty programme.	Clear security signals raise enterprise **trust**, stimulate domestic R&D, and stabilise investment.
Rural inclusion "by design"	Ireland (NBP backhaul + 5G densification).	Expands the **addressable market** (agri, remote health, utilities) and improves the political durability of investment.
Compact-state orchestration	Malta (MCA licensing + EU instruments).	National-scale demonstrators become feasible, accelerating end-to-end readiness in small markets.

The table below (Table 13) formalises the linkage between policy instruments and the enabling levers from Section 2.

Table 13. Policy lever → technical lever (from Section 2) → adoption effect

Policy lever	Technical lever it enables (Section 2)	Adoption effect seen in regions
Campus spectrum	**Private/Campus 5G** (Section 2.2.4)	Factory/port networks adopt **URLLC/TSN**, enabling automation at scale.
Rural backhaul funds	**SA 5G + Edge & cloud-native architecture**(Section 2.2.1–2.2.2)	**Latency stability** outside metros; rural industry/health becomes addressable.
Living-/field-labs	**Edge + AI/ML ops** (Section 2.2.2/§2.2.6)	From pilots to **repeatable playbooks** and SME adoption.

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Security/sovereignty	**Supply-chain clarity** (Section 2.5)	Enterprise **trust** rises; ecosystem investment accelerates.

The most effective instruments are **demand-side** (campus spectrum, labs, incentives, security clarity). Supply-side CAPEX alone seldom shifts SME behaviour; pairing it with **playbooks and skills** converts coverage into usage, as anticipated in Section 2.
Policy and funding measures listed in Table 12 and Table 13 reference **national 5G strategies (2020–2024)** and **EU recovery/resilience funding instruments**. Each entry is dated; see Annex B for the original policy documents.

3.3. Mapping of Industrial Adoption and Readiness Levels

Building on Section 2's enabling levers (Section 2.2), this subsection groups regions by the **enablers present** (private/campus spectrum, SA core, edge/MEC, living labs, security posture) and by where use cases **are material**. It focuses on observable conditions rather than arbitrary scores.
The clustering (Table 14) reflects partner evidence on adoption loci and enabling conditions, not simple coverage percentages.

Table 14. Readiness clusters (synthesis across partners)

Cluster	Who fits (evidence from partner data)	Where adoption is material	Enablers present	Scale blockers that remain
Advanced & scaling	**Germany, the Netherlands,Belgium, and Spain**	**Factory/campus 5G**, **ports/logistics**, **energy utilities**; SA 5G and private spectrum support complex use cases.	Private/local spectrum regimes; field-labs; strong industry–research ties; RRF/IPCEI	**Security/vendor transitions**; **SME ROI and skills**; multi-vendor/edge orchestration; strong infrastructure, but significant enterprise usage gap (ES)
Solid foundations, targeted acceleration	**Ireland; Greece**	Pilots in **manufacturing, health, energy, and public services** with inclusion goals.	Coherent national strategies; rural inclusion by design; dedicated funds/pilots (e.g., Phaistos)	**SME economics**, **skills**, and some **licensing friction**; support to shift from pilot to production
Compact-market, operator-led	**Malta**	Nationwide 5G with early **health/mobility/tourism** use-cases.	Fast licensing; EU alignment; finance via EIB and	**Limited industrial base**, **SME skills/awareness**, heritage-

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			national programmes	area densification constraints.
Corridor-first deployment	**Lithuania**	**Transport corridors and urban nodes**; construction/manufacturing digitisation is emerging.	**National-importance status**, sequenced auctions to 2030, household-availability goals	**White-zone QoS**, auction sequencing, permitting maturity

The table below (Table 15) links the technical levers in Section 2 to the patterns observed in partner regions, illustrating how specific enablers influence readiness.

Table 15. Crosswalk from Section 2 levers to observed regional maturity

Section 2 lever (what enables value)	Regions activating it (examples)	Use-cases that appear first	Readiness effect observed
Private/Campus 5G (Section 2.2.4)	Germany, Netherlands/Belgium	**Manufacturing** (AGVs/robotics/digital twins), **ports/logistics**	Moves regions into **advanced & scaling** via deterministic QoS/URLLC.
Edge & cloud-native (Section 2.2.2)	Germany; Spain testbeds	**Manufacturing, energy, and health**	Shifts from demos to **production** by hosting analytics near machines/patients/grids.
Standalone 5G (Section 2.2.1)	Spain (SA cores); Spain (SA cores active); Greece and Lithuania progressing with staged rollouts	**Mission-critical mobility**, **industrial URLLC**	**Latency/jitter stability** → readiness uplift outside metros.
Security/sovereignty (Section 2.5)	Germany; Luxembourg	**All verticals** (trust pre-condition)	De-risks enterprise adoption; catalyses ecosystem investment.

In conclusion, maturity correlates less with "% covered" and more with **stacking enablers** (campus spectrum + SA + edge + labs + security). Where these co-exist, pilots scale into **daily operations** in factories and ports; where pieces are missing, adoption remains **project-based** and ROI-sensitive.

Adoption clusters reveal that logistics/ports lead in Spain, Greece, and Malta, while manufacturing dominates in Germany and Lithuania, and digital SMEs are prevalent in Ireland, Belgium, and Sweden. These align with the sectoral patterns highlighted in Section 2.4.

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3.5. Comparative Analysis and Common Patterns Across Europe

This subsection distils **convergences** and **divergences** that matter for WP5 curriculum design and capacity-building, linking observed realities (Sections 3.2–3.4) back to the market research thesis in Section 2.

The table below (Table 16) consolidates cross-regional findings into curriculum-relevant implications.

Table 16. What's common, what differs, and what it implies (for WP5)

Dimension	Convergence across partners	Notable divergence	Implications for skills & curriculum (WP5)
Strategic framing	5G framed as **twin-transition infrastructure** (digital + green) across industry, mobility, energy, public services.	Emphasis on **sovereignty/security** varies (DE/LU high; others moderate).	Modules on **secure-by-design 5G**, supplier risk, EU toolbox/NIS2 compliance.
Deployment model	Broad 5G coverage aligned with EU milestones.	**Private/campus** (DE/NL/BE) vs **operator-led SA** (ES) vs **compact orchestration** (MT).	Tracks on **private-5G design/ops**, **slicing & SA**, **edge-cloud for industry**.
Adoption focus	**Manufacturing & logistics** lead; **energy** follows; **health/public services** recur.	Corridor-first (LT, e.g., Via Baltica/Rail Baltica) and smart-tourism (MT/GR, tourism and heritage pilots) weigh more locally.	Sector playbooks: **Factory 5G**, **Port/Logistics 5G**, **Grid & DER ops**, **Telemedicine**.
Barriers	**SME ROI**, **skills**, **operational performance** (latency/backhaul).	**Vendor transition** (DE), **white-zone QoS** (LT), **heritage-area densification** (MT).	Hands-on labs for **edge-AI ops**, **OT-IT integration**, **site design & optimisation** (incl. rural/heritage contexts).

Across partners, the bottleneck has moved from "Can we **deploy**?" to "Can we **operate, integrate, and justify** at scale?". For WP5, the most portable bundle is **campus-5G design/ops, edge-AI operations, industrial cybersecurity, and sector ROI playbooks** (manufacturing, logistics, energy, health).

This comparative analysis consolidates evidence from previous tables and detailed inputs in Annex B. It applies the **3-tier maturity classification** (*Pilot / Controlled commercial / Scaling*) to compare regional adoption, workforce gaps, and policy support.

3.6. Open Issues and Evidence Gaps

The regional inputs provide solid qualitative ground, and the expert interviews add validation and nuance. However, several **measurement** and **comparability** gaps remain that limit like-for-like benchmarking and hinder decisions on where to focus training and adoption support. The

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items below distil those gaps and propose **practical follow-ups**, now **triangulated** with interview insights rather than relying solely on partner narratives.

Interviews (to be developed in section 4) confirm that **ROI is driven by process re-engineering, integration effort, and assurance,** not only bandwidth/latency, reinforcing the need for **operational** and **outcome** metrics in addition to deployment counts.

Table 17. Evidence gaps and proposed follow-up actions

Evidence gap	Why it matters	Proposed follow-up and data source
Comparable adoption metrics across regions (e.g., % enterprises with private 5G, count of campus licences, share of mobile traffic on 5G, SA/MEC penetration)	Enables like-for-like **benchmarking** and tracking over time.	Define a **core indicator set** and collect via **NRAs/regulators**, national observatories, and operator transparency reports; use "traffic share on 5G" (e.g., Spain's 2.4% share despite 92% coverage) as a template KPI.
Sector-level SME ROI/TCO (by use case)	Interviews highlight **process + assurance-led ROI**; without sector TCO, adoption stalls.	From pilots/labs, capture **before/after KPIs** (downtime, OEE, defect rate, **energy per unit/bit**), plus **integration/training costs**; align with sector playbooks referenced in Section 3.5.
Operational performance outside metros (latency/jitter distributions, backhaul reliability, uplink constraints)	Time-critical apps depend on **predictable performance** in rural/peri-urban areas.	Deploy lightweight probes via partner corridors/field-labs; consolidate readings from **rural/backhaul programmes** already cited in partner files.
Security & sovereignty baselines (vendor policies, cert regimes, NIS2 posture, zero-trust adoption)	Trust/compliance shape vendor choice and **time-to-adoption**.	Compile a **country baseline** using government/regulator notices referenced by partners; add a short **enterprise survey** on segmentation, identity, and supply-chain policies.
Intra-regional granularity (e.g., Benelux, Baltics; corridors, ports, industrial zones)	Sub-national differences affect replicability and **localisation** of training.	Extend mapping for **Belgian regions** and **Dutch corridors**; add **Baltic comparators** consistent with the Lithuania approach.
Labour-market evidence for emerging roles	WP5 needs to target **scarce/portable** skill sets.	Triangulate **job postings**, training **enrolments**, and **wage premia** for connectivity, **edge-AI ops**, **OT-IT integration**, and **industrial cybersecurity** (national labour sources cited by partners).
Energy & sustainability measurement (green KPIs, LCA for 5G-enabled use cases)	Interviews stress **energy-aware operations**; evidence is patchy.	Define a **minimal green KPI pack** (e.g., kWh per processed GB, site-level energy curves, load-aware RAN policies) and gather from pilots using the Section 4 prompts.

This evidence plan complements the regional synthesis and interview validation (described in Section 5) by adding numbers where narratives dominate and

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standardizing what is currently reported heterogeneously. It prepares the ground for Section 5 by indicating **where synthesis can be quantified** (adoption baselines, SME ROI) and **where practices need documentation** (security baselines, resilience patterns), without pre-empting cross-sectional analysis here.

These gaps will be **stress-tested with expert perspectives** in Section 4.3–4.4 and integrated into the consolidated needs analysis in Section 5.2–5.4.

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4. Expert Interviews and Validation of Findings

4.1. Interview Design and Expert Profile Selection

To complement the findings from desk research and regional partner inputs, a targeted set of **expert interviews** (n = 10) was conducted between June and September 2025 as the third pillar of this intelligence-gathering effort. These interviews aim to provide **qualitative validation**, deeper **strategic insight**, and **forward-looking perspectives** on the technological and market dynamics surrounding advanced 5G and Beyond 5G (B5G) applications in green and industrial contexts.

The interview process was structured to ensure both **methodological rigor** and **practical relevance**. A semi-structured format was adopted to maintain a balance between thematic consistency across all interviews and flexibility to explore topics specific to each expert's domain.

Selection Criteria for Experts

Cohort composition: *10 experts (industry 6; academia 2; public/association 2), spanning 8 countries.*

Experts were selected to represent a **diverse cross-section** of stakeholders involved in the deployment, policy design, or innovation of 5G/B5G technologies. The selection aimed to ensure:

- **Sectoral diversity**: Industry (telecom, manufacturing, energy), academia, policy-making, and start-ups
- **Thematic relevance**: Experience with 5G or green industrial technologies, preferably at the intersection of both
- **Geographical spread**: Representation across multiple European countries or regional ecosystems
- **Strategic roles**: Preferably mid- to senior-level professionals (e.g., CTOs, research leads, innovation managers, digital policy advisors)

Each consortium partner was invited to propose at least one expert based on their professional networks and regional relevance. This distributed sourcing approach ensures a **broad and credible set of perspectives**, rooted in both local realities and sectoral expertise.

From Open Interviews to a Structured, Hybrid Format

The initial plan, as outlined in the project description, envisioned a series of **semi-structured interviews** with selected experts across the public and private sectors. However, as the interview design process progressed, it became clear that a more **structured and guided format** would enhance the comparability, accessibility, and quality of responses, particularly given the time constraints of expert participants.

This refinement was also influenced by the successful approach used in **Deliverable D2.1 (Needs Assessment Report)**, particularly the **"Industry Profile" interviews**. In D2.1, a combination of **multiple-choice questions and open-ended commentary fields** was used to gather both **quantifiable insights** and **rich qualitative reflections**. This approach proved highly effective in obtaining actionable stakeholder feedback, and it was deemed appropriate to replicate this structure, adapted to the specific context of D5.1.

Thematic Foundations and Mapping Process

To maintain alignment with the structure of Task 5.1, the interview design was built around the **seven core thematic areas** originally identified and reflected in the Table below (Table 18).

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Table 18. Thematic areas for the expert interview

Theme	Interview Question
1. Technology Maturity & Enablers	*From your perspective, what are the most mature and promising 5G or B5G technologies currently in play?*
2. Industrial Adoption Dynamics	*What industrial sectors (e.g., manufacturing, logistics, energy) are showing the highest adoption potential? What use cases are actually being implemented or tested in your experience?*
3. Sustainability Alignment	*How do you see 5G/B5G technologies supporting green or sustainable industrial innovation in practice?*
4. Barriers to Deployment	*What are the main barriers to scaling 5G/B5G applications in industry? (e.g., infrastructure, skills, cost, regulation)*
5. Emerging Signals / Future Outlook	*What trends, technologies, or gaps should we be watching in the next 3–5 years in this domain?*
6. Europe's Readiness and Positioning	*How would you rate Europe's readiness for industrial and green 5G innovation compared to global regions?*
7. Final Thoughts (optional)	*Is there anything else you'd like to share that hasn't been covered above?*

These themes were then **mapped into six cohesive interview sections**, ensuring logical grouping and natural conversational flow. The mapping process is summarised below:

Table 19. Interview sections

Original Theme	Mapped Interview Section	Notes
Technology maturity & enablers	1. Technological Maturity and Focus	Maintained structure; added multi-choice tech options
Industrial adoption dynamics	2. Sectoral Adoption and Use Cases	Inspired by D2.1 industry questions; includes sector examples
Barriers to deployment	3. Ecosystem and Barriers to Adoption	Translated into structured challenges + coordination rating
Sustainability alignment	4. Sustainability and Green Impact	Given its relevance, it was made into a standalone block
Signals for the future	5. Future Signals and Technology Outlook	Retains open-ended focus, exploring under-recognised trends
Europe's readiness and positioning	6. Europe's Position and Strategic Capacity	Includes both global comparison and the need for acceleration
Final thoughts	Closing question	Open space for expert-driven perspectives

Final Interview Structure and Design Choices

The final interview guide, included in **Annex C**, consists of:

- **6 thematic sections**
- **12 core questions**, each preceded by a **brief rationale** to help contextualise the intent
- A mix of **multiple-choice**, **Likert-scale**, and **open-ended** formats
- An estimated time commitment of **20–30 minutes**

This format enables the collection of both **structured data** (for comparison and analysis) and **in-depth narrative insights, while minimizing** the burden on participants.

The interviews were designed to be conducted either **live** (via video call) or via a **self-administered version** of the questionnaire, depending on the

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respondent's preference. The structure and tone were designed to be **professional but accessible**, making it feasible for use across a variety of interview contexts and national settings.

Next Steps and Integration

Responses from these expert interviews were analysed and synthesised in **Section 4.2 and beyond**, where they were used to:

- Confirm or challenge insights from desk research and regional data
- Provide **ground truth** on adoption barriers and opportunities
- Highlight **emerging signals** not yet widely documented
- Enrich the strategic implications developed in Section 5

The complete interview guide can be found in **Annex C**, and the results in **Annex D**. To ensure compliance with the General Data Protection Regulation (GDPR), and given the small number of participating experts (n=10, interviewed between June and September 2025), which increases the risk of re-identification, the responses in Annex D have been pseudonymised and anonymised. Verbatim comments are not reproduced; instead, any references to individuals, organisations, projects, or locations have been systematically removed or replaced with neutral placeholders, while preserving the analytical content of the input.

4.2. Key Themes Explored During Interviews

The **interview block** was designed to elicit evidence that could **confirm**, **nuance**, or **challenge** the findings from the **desk research (Section 2)** and the **regional analyses (Section 3)**, applying **resilience**—as framed in **Section 1.3**—as a **transversal lens** across all prompts. The structure followed the **Interview Guide (Annex C)** and drew on **anonymised responses** compiled in **Annex D**, balancing **comparability** (closed items) with **depth** (open commentary). This section outlines the thematic focus, instruments, and how each theme contributes to validation and synthesis **under the resilience lens defined in Section 1.3.**

4.2.1. Thematic Focus, Instrumentation, and Analytical Use

To keep interviews efficient for **senior profiles** while preserving **analytical rigour**, the questionnaire was consolidated into **four overarching themes**. Each theme corresponds to one or more **sections of the Interview Guide (Annex C)** and is supported by a mix of **multiple-choice**, **Likert**, and **open questions**. Table 20 summarises the **intent**, the **instruments** used, and the **analytical use** of the resulting evidence.

Table 20. Thematic coverage, instruments, and analytical use

Theme	Focus of inquiry	Instruments (Annex C)	Primary analytical use
Technology maturity & deployment	Readiness and near-term outlook for **SA core**, **MEC/edge**, **network slicing**, **Open**	**Shortlists** + **open justifications**; **maturity Likert** items (Sec. 1)	**Corroborate Section 2 signals**; anchor **Section 4.3** narratives on **"ready-now"** vs. **"watch-list"** technologies; frame

	RAN, **NTNs**, and **5G-Advanced**		**forward signals** in **Section 4.5**
Adoption drivers & barriers	**Sectors with tangible adoption**, **ROI logic**, **integration effort**, **regulatory clarity**, **skills readiness**	**Sector selection**; **barrier taxonomy** (Likert); open **why/why not** (Sec. 2–3)	Deepen **Section 3** patterns; populate **Section 4.4 validation matrix**; feed **gaps/opportunities** in **Section 5.2**
Resilience (security, continuity, sustainability)	Practices strengthening **assurance**, **continuity**, and **sustainability** (e.g., **zero-trust segmentation**, **multi-path/NTN backup**, **energy-aware operations**)	**Dedicated resilience prompts**; cross-references in other sections	Tie back to **Section 1.3 resilience framing**; inform **cross-domain implications** in **Section 5.1**
Talent and professional outlook	**Emerging hybrid roles**; **skills bottlenecks**; **translation needs** between **telecom**, **OT**, **cloud/edge**, and **sustainability**	**Forward-looking prompts**; **closing reflections** (Sec. 5–6)	Ground **Section 5.4 taxonomy**; guide **WP2/WP4 curriculum design** with targeted skills

Note: Responses were anonymised to avoid inadvertent re-identification in a small expert cohort. Claims are elevated only where they (i) recur across respondents and (ii) align with Sections 2–3 or provide a reasoned contradiction flagged explicitly in Sections 4.4 and 4.5.

4.2.2. Traceability to the Interview Guide (Question Mapping)

To ensure **procedural transparency** and **traceability** within the main text (without creating additional annexes), Table 21 condenses the original “coverage mapping” from the draft into a succinct **question-to-theme crosswalk**. This clarifies **what was asked** and **how it maps** to the themes above.

Table 21. Interview Guide (Annex C) → Theme crosswalk

Interview Guide section (Annex C)	Illustrative prompts	Mapped theme(s)	Notes on evidence type
Sec. 1: Technology	Perceived maturity of **SA core**, **MEC/edge**, **slicing**, **Open RAN**,	**Technology maturity & deployment**	**Shortlists** + **Likert** (comparability) +

maturity & innovation focus	**NTNs**; outlook on **5G-Advanced**		**open** rationales (context)
Sec. 2: Sectoral adoption & use cases	Where adoption is real, **use-case depth**, integration with **OT/IT**	**Adoption drivers & barriers**	**Sector tick-boxes** + **open** "why/why not"
Sec. 3: Ecosystem & barriers to adoption	**ROI framing, integration complexity**, **regulatory clarity**, and **skills**	**Adoption drivers & barriers; Resilience**	**Barrier taxonomy** (Likert) + coordination rating (1–3) + **open** justification
Sec. 4: Sustainability & green impact	**Energy-aware ops, efficiency gains, measurement practices**	**Resilience**	**Closed** indicators + **open** practices
Sec. 5: Future signals & technology outlook	**Critical signals**, **watch-list items**, dependencies for scale	**Technology maturity & deployment; Resilience**	**Open** forward-looking prompts
Sec. 6: Europe's position & talent needs	**Emerging roles, bottleneck skills, translation needs**	**Talent and professional outlook,** Technology maturity & deployment (Europe's comparative readiness)	**Open** reflection; role/talent naming

This dual-table approach keeps **Section 4.2** both **analytical** (Table 20) and **auditable** (Table 21), without expanding the annex set.

4.2.3. How Themes Connect to Triangulation

The interviews were not analysed in isolation. Each theme contributes evidence that complements the **desk research (Section 2)** and the **regional analysis (Section 3)**. The following paragraphs summarise the main types of insights expected under each theme and explain how they strengthen the overall analysis.

Note: Detailed distributions of responses are available in Annex D; the main text focuses on recurring patterns and material disagreements with analytical consequences.

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Technology maturity & deployment

Experts provided views on which technologies are already **deployable** and which remain at the level of **strategic outlook**. Clear agreement was found around **standalone 5G cores**, **edge computing/MEC**, and **private 5G networks** being ready for current adoption, while opinions were more divided on the maturity of **network slicing**, **Open RAN**, and **non-terrestrial networks (NTNs)**. This helps us distinguish between technologies that can shape the market in the short term versus those that require further development or integration.

Adoption drivers & barriers

The interviews went beyond identifying sectors of adoption by explaining **why** uptake is happening or lagging. A recurring pattern was the shift in justification from pure **performance gains** (e.g., lower latency) to more complex considerations such as **integration costs**, **assurance and reliability requirements**, and the availability of **skilled staff**. These qualitative insights complement the quantitative barriers listed in regional data, showing where enthusiasm meets practical constraints.

Resilience (security, continuity, sustainability)

Resilience emerged as a unifying concern. Experts emphasised the importance of **zero-trust security models**, **redundant connectivity paths** (often involving NTNs or satellite back-up), and **energy-efficient operations**. These insights allow us to connect technological innovation with wider societal and industrial priorities, such as **continuity of services** and **sustainability goals**.

Talent and professional outlook

Finally, experts highlighted the need for **new professional roles** that cut across domains: for example, engineers who can combine **telecom knowledge with cloud-native skills**, or specialists in **cyber-physical resilience**. This perspective directly informs the later identification of **emerging professions** and helps link technological and organisational readiness to the availability of talent.

4.3. Expert Perspectives on Technology Maturity and Market Evolution

The interviews provided **first-hand perspectives** on the maturity of advanced 5G and Beyond 5G (B5G) technologies and their expected **market trajectories**. This section synthesises expert assessments of **which technologies are "ready now"**, **which are still maturing**, and **which are emerging signals for the future**. The insights are reported thematically and compared against the **desk research (Section 2)** and **regional analyses (Section 3)** to highlight alignments and divergences.

4.3.1. Overview of Expert Assessments

Experts generally agreed that some technologies have **crossed the threshold into operational deployment**, while others remain **promising but immature**. Table 22 summarises how experts classified the major 5G/B5G enablers according to their current level of maturity.

Table 22. Expert views on technology maturity and market outlook

Technology	Perceived maturity	Expert consensus	Implications
Standalone (SA) 5G Core	**Mature / Ready now**	There is a broad agreement that SA cores are becoming the default in operator roadmaps; they are already deployed in several EU markets.	Foundation for **network slicing**, **QoS assurance**, and **5G-Advanced** features.
Multi-access Edge Computing (MEC) / Cloud-native networks	**Mature but scaling unevenly**	Recognised as technically stable; adoption depends on ecosystem readiness and integration with verticals.	Key enabler for **low-latency industrial use cases**; requires **cloud–telecom skill profiles**.
Private 5G Networks	**Ready now, strong momentum**	Viewed as the most immediate opportunity for enterprises, regulatory frameworks in Europe are accelerating uptake.	Expanding demand for **enterprise 5G architects** and **cyber-physical integrators**.
Network Slicing	**Emerging but not yet scaled**	Trials validated the concept, but full commercialisation remains limited; the complexity of orchestration is cited.	Strategic enabler for **vertical-specific services**; requires **slice design and QoS engineering** roles.
Open RAN	**Promising but integration-heavy**	Experts split: some see it as essential for vendor diversity, others emphasise performance and cost challenges.	Likely to gain traction in the **medium term**; drives the need for **system integration specialists**.
Non-Terrestrial Networks (NTNs)	**Early stage / strategic outlook**	Recognised for resilience and coverage but still experimental; linked to satellite–terrestrial integration.	Seen as a **resilience lever**, requires **aerospace–telecom hybrid skills**.
AI/ML-driven network automation	**Advancing rapidly**	Strong agreement that AI/ML will underpin energy management, optimisation, and “zero-touch” networks.	Immediate demand for **AI-for-telecom engineers** and **automation architects**.
6G precursors (e.g., sub-THz, sensing, semantic comms)	**Future horizon (post-2030)**	Mentioned by a few experts as “watch-list” signals, not yet market-relevant.	Requires **early curriculum modules** to prepare talent pipelines.

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4.3.2. Key Insights and Patterns

The validation exercise revealed several **recurring patterns** in how experts perceive the maturity and evolution of advanced 5G/B5G technologies. These patterns help distinguish areas of broad consensus from those where expectations remain divided:

- **Consensus on core enablers**
  Experts were aligned that **SA 5G cores**, **MEC/cloud-native architectures**, and **private 5G networks** are already **mature enough** for widespread deployment. These are seen as the **backbone** of current market evolution, consistent with both the **technology watch** and **regional adoption evidence**.

- **Cautious optimism on strategic enablers**
  Technologies such as **network slicing** and **Open RAN** were acknowledged as strategically important but remain **constrained by integration challenges** and **cost structures**. While pilots show potential, experts emphasised that **full-scale adoption** will depend on improvements in **orchestration tools**, **interoperability frameworks**, and the availability of **specialised talent**.

- **Resilience through NTNs and automation**
  A distinctive contribution from the interviews was the framing of **NTNs** and **AI/ML automation** as key **resilience levers**. NTNs were highlighted not primarily as a capacity solution, but as **continuity and coverage insurance** in crisis scenarios. Similarly, **AI/ML automation** was linked to both **operational efficiency** and **energy-aware optimisation**, confirming its dual role in **technical resilience** and **sustainability**.

- **Signals of the next wave**
  While few experts expect **6G enablers** (e.g., sub-THz links, semantic communication) to shape markets before 2030, their **early mention** indicates awareness of future research directions. This suggests an opportunity for **education and training** systems to start preparing **foundational knowledge** well before industrial uptake.

4.3.3. Implications for Market Evolution

From the expert perspective, the **market evolution of 5G/B5G** is shaped by three converging factors:

1. **Immediate deployment** of **SA cores**, **MEC**, and **private 5G**, which drive current investment and talent demand.
2. **Strategic but slower adoption** of **slicing** and **Open RAN**, whose scaling depends on integration capacity and skills availability.
3. **Resilience-driven priorities** (NTNs, AI/ML automation), which redefine how connectivity is valued—not just for performance, but for **assurance, continuity, and sustainability**.

Together, these perspectives validate the trends identified in Section 2, enrich the regional observations in Section 3, and set the stage for **triangulation in Section 4.4** and **forward-looking insights in Section 4.5**.

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4.4. Validation of Desk Research and Regional Data

The expert interviews were used to **validate the evidence base** established through the **desk research (Section 2)** and the **regional partner inputs (Section 3)**. This validation step ensures that the findings are not only based on literature and policy reports, but also grounded in the **practical experience of market actors and domain experts**.

The analysis showed a strong **alignment** between experts and earlier research on the **technologies that are already mature**, while also surfacing areas of **divergence**, especially concerning the **pace of adoption** and the **conditions required for scaling**.

4.4.1. Validation Matrix

Table 23 summarises how expert views aligned or diverged with the evidence from Sections 2 and 3.

Table 23. Validation of desk research and regional data by expert perspectives

Topic / Trend	Desk Research (Section 2)	Regional Analysis (Section 3)	Expert Validation (Interviews)	Outcome
Standalone 5G Core	Identified as a **key enabler** in global roadmaps.	Most regions reported **ongoing deployments**.	Experts confirm the SA core is **operationally ready** and becoming the new baseline.	**Confirmed**
MEC / Cloud-native	Highlighted as central to **low-latency services**.	Reported uneven progress across regions.	Experts agree on maturity, but stress that **ecosystem integration** is the bottleneck.	**Nuanced**
Private 5G networks	Flagged as **fast-growing in Europe** (esp. Germany, Spain).	Regional reports show **multiple pilots and licensing schemes**.	Experts call it the **most immediate business case**, with strong enterprise demand.	**Strongly confirmed**
Network slicing	Promoted as a **strategic enabler** in foresight reports.	Few concrete deployments in regional inputs.	Experts view it as **not yet scalable**, hindered by orchestration complexity.	**Partially challenged**

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Open RAN	Presented as a path to **vendor diversity**.	Adoption is mentioned mainly in pilot form.	Experts are divided: some highlight its **strategic value**, others stress **integration overheads**.	**Mixed validation**
NTNs	Horizon-scanned as part of the **resilience agenda**.	Limited mention in regional inputs.	Experts confirm NTN's role as **continuity and backup**, not mainstream capacity.	**Nuanced**
AI/ML automation	Cited as central to **future 5G-Advanced and 6G**.	Rarely mentioned explicitly in regional inputs.	Experts strongly emphasise **AI/ML for automation and energy efficiency**.	**Confirmed**
Skills and talent gaps	Identified in foresight and EU policy.	Regional reports note **integration and skills shortages**.	Experts consistently highlight **hybrid roles** as bottlenecks.	**Confirmed**

4.4.2. Key Patterns of Validation

When comparing expert perspectives with the evidence from desk research and regional reports, a number of **validation patterns emerged**. These include points of strong convergence, areas where expert views add nuance, and topics where the interviews partially challenge earlier assumptions:

- **High convergence**
  On **SA cores**, **private 5G networks**, and **AI/ML automation**, the interviews confirmed both the **desk research foresight** and the **regional evidence**, reinforcing these as the **anchors of current market evolution**.
- **Nuanced confirmation**
  For **MEC/cloud-native** and **NTNs**, experts agreed with their importance but clarified the **conditions**: MEC adoption depends on **vertical ecosystem integration**, while NTNs are valued for **resilience and continuity**, not as mainstream throughput solutions.
- **Partial challenges**
  The strongest divergence concerned **network slicing** and **Open RAN**. While foresight documents present them as imminent, experts stressed **operational hurdles** (complex orchestration, interoperability, integration costs) that slow down adoption. This highlights the need to **treat them as strategic but longer-term enablers**.
- **Talent as cross-cutting validation**

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Both Sections 2 and 3 flagged **skills shortages**, and experts reinforced this point with specific emphasis on **hybrid, translation-heavy roles**. This validation ensures that talent development remains a **core outcome** of WP5.

4.4.3. Implications for WP5

The validation process strengthens the credibility of the findings and highlights where **educational and training priorities** should focus:

- **Immediate focus**: skills for **SA core deployment**, **private 5G design**, **MEC/cloud integration**, and **AI/ML automation**.
- **Medium-term focus**: expertise in **network slicing** and **Open RAN**, once operational bottlenecks are addressed.
- **Cross-cutting focus**: embedding **resilience practices** (security, continuity, energy efficiency) into all professional profiles.

4.5. Forward-Looking Insights and Critical Signals

The expert interviews not only validated existing knowledge; they also revealed **forward-looking insights** and **critical signals** that point to how advanced 5G and Beyond 5G (B5G) technologies may evolve in the near future. These signals are important because they highlight **emerging priorities**, **uncertainties**, and **potential disruptions** that policymakers, industry actors, and education providers should keep under observation.

4.5.1. Emerging Priorities

Several themes emerged as **near-term priorities** for stakeholders:

- **Resilience-by-design.** Experts repeatedly emphasised that **continuity, security, and sustainability** must be treated as **baseline requirements**, not optional add-ons. This reinforces the idea that **resilience practices** such as **zero-trust architectures**, **redundant connectivity paths** (including NTNs), and **energy-aware optimisation** will increasingly guide network design.
- **Enterprise-driven adoption.** While public operator rollouts continue, experts have noted that the most immediate business cases are being realized in private 5G deployments across the manufacturing, logistics, and energy sectors. This points to enterprises as **early drivers of innovation** in advanced 5G, shaping demand for integrators and solution providers.
- **Automation as a necessity.** The role of **AI/ML** is expanding beyond experimentation into the **automation of assurance, optimisation, and energy management**. Experts see this as essential for handling the **complexity of cloud-native and distributed architectures**.

4.5.2. Critical Signals

Experts also highlighted a set of **critical signals**—weak signals or areas of divergence that may have a disproportionate impact in the medium term:

- **Network slicing remains strategic, but gated.** While widely seen as a **key enabler** for vertical-specific services, experts warned that **commercial**

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scalability is delayed by orchestration complexity, interoperability issues, and integration costs. This gap between expectations and reality is a crucial indicator for both the industry and training initiatives.

- **Open RAN as a contested space.** Interviewees were split: some highlighted it as crucial for **vendor diversity and innovation**, while others underlined **performance and integration challenges**. This divergence suggests that Open RAN could either accelerate in adoption with the right ecosystems or remain limited to niche contexts.
- **NTNs as resilience tools, not capacity solutions.** While often presented in foresight studies as an additional coverage layer, experts emphasized that non-terrestrial networks are primarily valued for their **continuity of service in critical scenarios**. This reframes their role from "mainstream infrastructure" to a **specialised resilience enabler**.
- **Early references to 6G.** Although not yet relevant for deployment, some experts mentioned **6G precursors** (e.g., sub-THz communications, semantic networks). Their appearance in interviews signals that **awareness of the post-5G horizon is already forming**, and that education systems may need to gradually incorporate foundational elements of these technologies.

4.5.3. Outlook

Taken together, these insights highlight a market that is **consolidating around a stable core (SA, MEC, private 5G)** while simultaneously facing **barriers to scaling** in strategic areas (**slicing, Open RAN**) and **experimenting with resilience enablers** (**NTNs, AI/ML automation**). The **critical signals** identified here are not yet mainstream trends but warrant close monitoring, as they may shape the direction of investment and talent needs in the coming years.

4.6. Key Takeaways

The expert interviews added depth and perspective to the desk research and regional analyses. The main takeaways are:

- **The interview framework delivered broad coverage.** By structuring discussions around four themes—**technology maturity**, **adoption dynamics**, **resilience**, and **talent outlook-** we captured both converging views and points of divergence.
- **A stable near-term core is visible.** Experts have pointed to standalone cores, edge/MEC, and private 5G networks as already being suitable for deployment, forming the practical foundation for current adoption.
- **Some enablers remain aspirational.** While **slicing** and **Open RAN** were acknowledged as strategically important, their widespread use is still constrained by orchestration complexity, performance questions, and ecosystem readiness.
- **Resilience concerns cut across all discussions.** Practices such as **redundant paths** (e.g., via NTNs), **zero-trust security**, and **energy-aware operations** are no longer seen as optional features but as integral requirements.
- **Talent emerged as the decisive factor.** Interviewees repeatedly highlighted the lack of **hybrid profiles** that can combine telecom, cloud, and operational expertise, identifying this as a barrier to scaling up adoption.
- **Signals for the future are starting to surface.** While **AI/ML automation** is already gaining mainstream use, early references to 6G concepts indicate that awareness of the post-5G horizon is growing within the expert community.

Together, these takeaways underline how expert insights both reinforce and nuance earlier findings. They also provide a natural bridge to **Section 5**, where the evidence from Sections 2–4 will be synthesised into strategic implications for education, skills, and resilience in advanced 5G and B5G.

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5. Synthesis of Findings and Strategic Implications

5.1. Cross-Domain Insights

Section 5.1 integrates the three pillars of evidence—**desktop research (Section 2)**, **regional inputs (Section 3)**, and **expert interviews (Section 4)**—into a cross-domain synthesis. The aim is to highlight **convergences**, clarify **divergences**, and present an **integrated perspective** on how advanced 5G/B5G is unfolding in Europe.

Convergences

Across all three pillars, the evidence aligns on a **stable near-term technology base**, the growing importance of **resilience practices**, and the **centrality of talent**.

Table 24. Areas of convergence across the three pillars

Topic	Desktop research (Section 2)	Regional inputs (Section 3)	Expert interviews (Section 4)	Synthesis
Near-term core technologies	SA core, MEC, and private 5G are identified as key enablers	National pilots, licences, and industrial corridors reported	Experts confirm these as "ready now" and already shaping deployments	A **stable core stack** underpins near-term adoption
Resilience	Reports highlight security and continuity needs	Evidence of sovereignty and sustainability concerns	Experts treat zero-trust, redundancy, and energy efficiency as baseline requirements	**Resilience-by-design** is becoming a universal expectation
Talent shortages	Anticipated new hybrid roles (5G + cloud + OT)	Regions' flag integration and skills bottlenecks	Experts confirm hybrid profiles as decisive for adoption speed	**Talent availability** is the system bottleneck

These convergences provide a strong foundation for defining **common priorities at the European level** and ensure that market evolution is understood in both technological and human-capital terms.

Divergences and nuances

Some topics showed **differences in emphasis** or required **expert correction**.

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Table 25. Divergences and nuances identified

Topic	Desktop research (Section 2)	Regional inputs (Section 3)	Expert interviews (Section 4)	Integrated takeaway
Network slicing	Promoted as a near-term enabler	Few concrete deployments reported	Experts: concept validated, but orchestration bottlenecks persist	**Strategic but gated** until tooling and skills mature
Open RAN	Framed as a pathway to vendor diversity	Adoption mostly in trials	Experts are divided: strategic for some, impractical for others	**Mixed outlook**; medium-term adoption conditional
NTNs	Horizon-scanned as a coverage/capacity tool	Rarely mentioned	Experts reframe NTNs as resilience/continuity enablers	**Repositioned** from mainstream to specialised role

These divergences demonstrate that **foresight studies often anticipate faster uptake** than regional realities or expert assessments suggest. The expert input is particularly valuable for **reframing expectations**—for instance, repositioning NTNs as continuity tools rather than throughput solutions.

Integrated perspective

Taken together, the three pillars produce a coherent view of the 5G/B5G landscape, showing how adoption is shaped by **technology readiness**, **scalability barriers**, and **systemic enablers**.

Table 26. Integrated cross-domain perspective

Dimension	Evidence integration	Strategic implication
Technology base	Consensus around SA, MEC, and private 5G as deployable now	These form the **anchor stack** for industrial adoption
Strategic enablers	Slicing and Open RAN are recognised as important but not yet scaled	Treat as **medium-term priorities**, requiring orchestration maturity and integration skills
Resilience	Literature, regions, and experts increasingly converge	Position **resilience-by-design** as a cross-cutting requirement, not an add-on

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Talent	All pillars flag hybrid role shortages	**Talent development** is the most urgent cross-domain intervention

This integrated perspective outlines a market where adoption is **anchored by a deployable core**, slowed by **scaling barriers** in strategic enablers, and increasingly defined by **resilience expectations** and **talent shortages**. These four dimensions provide the scaffolding for the next subsections: **market needs and gaps (5.2)**, **resilience implications (5.3)**, and **emerging professions (5.4)**.

5.2. Gaps, Opportunities, and Labour-Market Implications

This section distils **validated needs** and **persistent gaps** that emerge when the **technology outlook** (Section 2), **regional realities** (Section 3), and **expert perspectives** (Section 4) are viewed together. The focus is on what conditions must be in place for **scalable adoption** of advanced 5G/B5G, without repeating cross-domain implications (addressed in 5.3–5.4).

Reading Table 27 below, the **left column** captures the *condition that repeatedly limits scale*; the **middle columns** show where that condition was surfaced (technology watch, regional inputs, and expert validation); the **right column** sketches **non-overlapping** action directions. The consistent thread is that **assurance, integration, and skills,** more than radio features alone, determine the **pace of adoption.**

Table 27. Validated market needs and persistent gaps (synthesis of Sections 2–4)

Need / Gap	Evidence basis (2–4)	Why it matters	Action focus (high level)
Integration capacity at the edge (MEC + OT/IT)	Tech enablement in 2.2–2.4; uneven regional readiness in 3.x; experts: **ready tech, integration bottleneck** (4.3–4.4)	Low-latency use cases depend on **predictable edge integration** across telecom, cloud, and OT systems.	Promote **reference blueprints** and **interoperable stacks**; support **hands-on labs** with vertical partners.
Slice orchestration & multi-domain assurance	Slicing foresight in 2.2.1; scarce deployments in 3.x; experts: **strategic but gated** (4.3–4.4)	Without lifecycle tooling and QoS verifiability, **commercial scaling** of slices stalls.	Prioritise **toolchain maturity** (intent, telemetry, SLA/QoE) and **operational playbooks**.
Enterprise-grade private 5G patterns	Growth signalled in 2.2.4; multiple pilots/licences in 3.x; experts: **most immediate business case** (4.3–4.4)	Enterprises need **repeatable designs** and **security baselines** to reduce time-to-value.	Codify **campus network patterns** (RF/site, identity/segmentation, OT interlock) with **sector variants**.
Operational performance	Coverage vs. experience gap noted in 2.4; regional	Time-critical apps fail without **stable uplink/latency/backhau**	Establish **lightweight probing** and **assurance**

outside metros	unevenness in 3.x; experts: **assurance > peak throughput** (4.4)	l in peri-urban/rural zones.	**KPIs** to guide deployment priorities.
Security & sovereignty baselines (NIS2, zero-trust)	Policy drivers in 2.5/2.3.3; regional concern in 3.x; experts: **zero-trust as baseline** (4.5)	Trust/compliance determines **vendor choices** and **integration timelines**.	Define **minimum security baselines** and **conformance checklists** aligned with EU frameworks.
Energy & sustainability measurement	Green levers in 2.3; regional patchiness in 3.6; experts: **energy-aware ops** (4.5)	Without **comparable green KPIs**, it's hard to justify investments or optimise operations.	Adopt a **minimal KPI pack** (e.g., kWh/GB, load-aware policies, site energy curves) across pilots.
SME-level ROI/TCO evidence	Use-case claims in 2.4 vs. limited numbers in 3.x; experts: **ROI = process + assurance + integration** (4.4)	SMEs need **before/after** metrics to de-risk adoption decisions.	Collect **standardised TCO/benefit** datasets (downtime/OEE/defects /energy) from representative pilots.
Hybrid talent pipeline (telecom × cloud × OT × security)	Roles anticipated in 2.x; regional shortages in 3.x; experts: **decisive bottleneck** (4.3–4.5)	Scaling depends on **translational profiles** that bridge domains.	Develop **stackable skill pathways** and **co-taught modules** with enterprises. (Detailed roles in 5.4.)

While patterns are pan-European, the **pressure points differ by sector**: **manufacturing** and **logistics** prioritise **OT integration and uptime**; **energy & utilities** emphasise **resilience and security baselines**; **transport/mobility** require **edge assurance across corridors**. This aligns with the regional snapshots and expert emphasis on **enterprise-led adoption**.

Section **5.3** will translate the needs above into **resilience implications** (technical, operational, and human capital). Section **5.4** will ground the **talent response**—updating the existing taxonomy with **interview-confirmed roles** and competency threads—without repeating the gap statements here.

Additional Analytical Discussion

While the analysis above provides a comprehensive synthesis of the main opportunities and gaps associated with the 5G/B5G transition, it is equally relevant to understand the **labour-market dimension** behind these findings. The evidence gathered from desktop research, regional inputs, and expert interviews demonstrates that technological transformation is reshaping the demand for skills across industrial sectors.

To complement the qualitative assessment, an **indicative labour-market mapping** has been developed, following the reviewer's recommendation. This mapping visualises how sectoral dynamics translate into changes in employment and skills needs, identifying where job creation, re-profiling, or potential displacement is most likely to occur. The table builds on official international foresight and statistical sources to ensure methodological coherence.

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Data Sources and Methodological Approach

Given that D5.1's internal data were primarily qualitative, additional publicly available **evidence-based datasets** were reviewed to strengthen the analysis. The methodological foundation follows the *Cedefop/ETF/ILO (2024)* guide on foresight modelling [52], which describes the E3ME macro-econometric model and its application in the *EU Skills Forecast (2024)* [53]. Complementary empirical data were obtained from the *European Commission (2024)* [54], *Eurostat (2024)* [55], *OECD (2023)* [56], and the *World Economic Forum (2025)* [57].

Together, these sources provide a consistent multi-scalar perspective: OECD and ESDE cover sectoral structures and productivity, while WEF (2025) supplies global comparative evidence. The latter estimates a **net global employment growth of around 7 % by 2030**, with approximately **39 % of skills undergoing transformation** due to green and digital transitions. Within this context, sectors driven by 5G/B5G technologies (manufacturing, logistics, and infrastructure) are projected to be among the top contributors to job creation.

The table below integrates qualitative signals from the interviews (Section 4) and regional reports (Section 3) with quantitative trend ranges derived from the above sources.

In terms of **limitations,** the data express **directional changes** (↑ increase, ↓ decrease, ↔ transformation) rather than definitive forecasts. Differences among national labour-market structures, the rapid evolution of automation, and policy measures such as the AI Act may affect actual outcomes by 2030.

Table 28. Indicative Labour-Market Impact of Advanced 5G/B5G Adoption in Europe (2025–2030)

Sector	Indicative Labour Trend (2025–2030)	Main Drivers	Skills Gaining Importance	Skills at Risk / Potentially Obsolete
Manufacturing (Industry 4.0)	↑ +6 - 8 % net employment growth	Private 5G networks, edge AI, digital twins	Edge computing, robotic integration, data governance	Manual assembly and line operations
Logistics & Mobility	↑ +3 - 5 %	Smart ports, IoT tracking, automation of supply chains	Systems integration, data assurance, and AI-driven planning	Clerical routing / paper-based roles
Energy & Utilities	↔ (re-profiling)	Smart grids, non-terrestrial networks (NTN), and green transition policies	Cyber-resilience, energy analytics, and sustainability management	Manual metering and field maintenance
Public Infrastructure & Smart Cities	↑ +4 - 6 %	Urban IoT deployment, resilient network design	Digital planning, systems engineering, AI-enabled services	Traditional maintenance skills
Telecom Operations (Core Networks)	↓ −2 - −4 % (legacy roles)	Automation, self-optimising networks, cloud migration	Cloud-native Ops, DevSecOps, AI assurance	Manual NOC and hardware roles

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Note: Figures represent indicative directional trends derived from triangulated foresight evidence, not official employment forecasts.

The results confirm that **5G/B5G adoption generates more occupational transformation than displacement**. Sectors with embedded automation potential, such as manufacturing and logistics, show net employment gains due to productivity-driven expansion, while telecom operations face gradual task reconfiguration. Public-sector digitalisation and green-infrastructure projects create additional employment in resilience engineering and system integration.

The broader WEF (2025) evidence indicates that 5G/B5G technologies contribute significantly to global labour-market expansion, reinforcing the OECD (2023) and ESDE (2024) projections at the European level.

One final remark about **methodological complementarity:** this sector-level mapping sets the context for the **occupation-level analysis presented in Section 5.4.5**, which examines how these sectoral transitions translate into emerging professions and skill profiles.

5.3. Resilience Implications

Resilience has emerged across all three evidence pillars as a **defining requirement** of advanced 5G/B5G deployment. Rather than being treated as an *optional layer*, resilience practices are increasingly **built into adoption logic**—whether for **security**, **continuity**, or **sustainability**. The interviews in particular underscored that **resilience-by-design** is now expected by enterprises and regulators alike.

The main dimensions of resilience identified across Sections 2–4, together with their strategic implications, are summarised in Table 29.

Resilience in the **technical dimension** is no longer optional. The evidence shows that **redundancy, segmentation, and automation** must be treated as baseline features of network architecture. Enterprises increasingly expect service continuity even under partial failure, shifting resilience from a niche concern to a **design default**.

Table 29. Dimensions of resilience and their strategic implications

Dimension	How it surfaced (Sections 2–4)	Strategic implication
Technical resilience	Literature stressed security/continuity; regions flagged patchy implementation; experts cited **zero-trust segmentation**, **redundant paths (NTNs, multi-backhaul)**, **automation for recovery**	Position resilience features as **baseline in architectures**; promote **resilience drills** and **redundancy design** in enterprise deployments
Operational resilience	Regional partners noted corridor/peri-urban gaps; experts reframed NTNs as **continuity**	Define **assurance KPIs** (latency/jitter stability, uptime distributions) and

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	tools; both stressed **assurance > peak performance**	integrate them into **deployment roadmaps**
Human-capital resilience	Skills shortages were documented in foresight, regional inputs, and interviews; experts warned of a lack of **hybrid roles** for integration/security/energy	Develop **multi-domain training pathways** that ensure organisations can recover, adapt, and sustain connectivity under disruption

At the **operational level**, what matters most is not peak throughput but **predictable performance in real environments**. The interviews confirmed that adoption depends on the ability to guarantee stable **latency, jitter, and uplink performance**, particularly in peri-urban and industrial corridors. This reorients investment priorities toward **assurance metrics** that capture continuity.

Resilience also has a **human-capital dimension**. Without professionals who can bridge **telecom, cloud, OT, and cybersecurity**, organisations remain brittle even if technology is deployed. Developing **hybrid skills and multi-domain training pathways**, therefore, becomes a resilience measure in itself, ensuring organisations can recover, adapt, and sustain critical connectivity under disruption.

Finally, **sustainability** must be considered part of resilience. Experts repeatedly highlighted **energy-aware operations** and **AI-assisted optimisation** as mechanisms for ensuring both cost control and continuity in constrained environments. This links environmental performance directly with the capacity of networks and organisations to withstand shocks.

These four dimensions demonstrate that resilience is **multifaceted (**technical, operational, human, and environmental) and that each must be embedded into **both deployment strategies and training agendas**. Section 5.4 develops this further by identifying the **emerging professions** and talent profiles capable of delivering resilience in practice.

5.4. Emerging Professions and Talent Profiles

Building on the preceding synthesis of cross-domain trends and strategic opportunities, this section focuses on the identification of **emerging professions and talent profiles** that are expected to play a pivotal role in the deployment, operation, and evolution of advanced 5G and Beyond 5G technologies, particularly as they relate to resilience, sustainability, and sectoral transformation.

5.4.1. Framing the Shift in the Workforce Landscape

The convergence of **cloud-native 5G**, **edge/MEC**, and **enterprise private networks** is reshaping how connectivity is architected and, consequently, how work is organised and staffed. Across the three evidence pillars, we observe a decisive move **from function-centric roles** (separate telecom, IT, and OT teams) **to cross-domain, outcome-oriented roles** that blend **telecom engineering**, **cloud/DevOps**, **operational technology (OT)**, **security/resilience**, and **sustainability**. This shift is most visible where adoption pressure is highest, in **industrial campuses and logistics/energy sites,** and is reinforced by interview testimony that **hybrid profiles** now determine the **speed and safety of deployment**.

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Three forces, consistently observed in the desktop review, regional inputs, and expert interviews, explain this transition. First, **architectural programmability** (containerised cores, APIs, intent-based control, automation) collapses traditional demarcations between network, compute, and application layers; teams must operate **as integrated platform units** rather than silos. Second, **assurance and resilience**—expressed as **predictable latency/uplink**, **zero-trust segmentation**, **redundant paths (incl. NTN back-up)**, and **energy-aware operations**—are no longer optional "add-ons" but **baseline design constraints**, forcing tighter collaboration between connectivity, security, and operations. Third, **enterprise-led adoption** shifts talent demand away from generic operator roles toward **verticalized integration roles** able to translate production constraints, compliance, and safety into network/application design. Together, these forces redefine "the job to be done" from operating a network to **delivering assured digital continuity for industrial processes**.

To anchor these dynamics, Table 30 summarises the drivers of change, the triangulated evidence, and their implications for the workforce.

Table 30. Drivers of the workforce shift — evidence and implications

Driver of change	What the evidence shows (Sections 2–4)	Implications for the workforce
Cloud-native & edge programmability	Containerised cores, MEC, and automation are "ready-now"; slicing/Open RAN remain strategic but gated by orchestration and integration maturity. Experts emphasise tooling and CI/CD/observability gaps.	Roles must combine **telecom fundamentals with DevOps** (Kubernetes, CI/CD, observability) and **assurance engineering** (SLA/QoS).
Assurance & resilience-by-design	Enterprises prioritize stability and continuity over peak throughput; experts frame zero-trust, redundant paths (including NTNs), and energy-aware operations as baselines.	Emergence of **cyber-physical resilience** roles and **assurance-first architects** spanning security, connectivity, and operations.
Enterprise-led adoption & OT integration	Private 5G is the most immediate business case; regional inputs show sector pilots/licensing; experts stress **OT/IT integration** as the bottleneck.	Growth of **verticalized integration** roles able to translate **process, compliance, and safety** into network/application design.
Sustainability as an operational constraint	Green KPIs are patchy; interviews elevate **energy optimisation** and **AI-assisted efficiency** as operational necessities.	Addition of **sustainability-aware operations** capabilities (measurement, optimisation) to mainstream connectivity roles.

In practical terms, organisations are reconfiguring around **platform-oriented teams** that own end-to-end outcomes (from **RF/site** to **core/edge pipelines** and **security/observability**), rather than handing work across sequential silos. The **talent signal** is unambiguous: demand clusters around **orchestration and automation**, **enterprise 5G/OT integration**, **resilience and security**, **AI for networks**, and **sustainability-aware operations,** each requiring **translational competence** across previously distinct domains. This framing sets the stage for **5.4.2 (Triangulated findings)**

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and **5.4.3 (Talent profile taxonomy)**, where we substantiate and structure these role families with the interview-validated evidence base.

5.4.2. Triangulated Findings

This subsection consolidates **evidence from all three pillars**—the **technology watch** (Section 2), **regional inputs** (Section 3), and **expert interviews** (Section 4)—to identify the **role families** that are not only anticipated in literature but also **observed in regional practice** and **validated by experts**. The emphasis is on **where signals converge** and **what that means** for the talent taxonomy, as outlined in Section 5.4.3.

Table 31. Role signals triangulated across Sections 2–4

Triangulated finding	Desk research (Sec. 2)	Regional inputs (Sec. 3)	Expert interviews (Sec. 4)	Implication for taxonomy (Sec. 5.4.3)
Orchestration is the new bottleneck (slicing, multi-domain assurance)	Slicing highlighted as strategic; tooling maturity flagged in foresight.	Sparse large-scale deployments; partners report integration hurdles.	"**Strategic but gated**" due to orchestration & QoS lifecycle complexity.	Create a dedicated **Orchestration & Assurance** cluster (intent, telemetry, SLA/QoE).
Enterprise private 5G is the near-term growth engine	Private 5G is positioned as an immediate value in the industry.	Numerous pilots/licences in manufacturing, logistics, and energy.	Rated as the **most immediate business case**, OT integration is decisive.	Elevate **Enterprise 5G & Vertical Integration** roles (RF/site + identity/segmentation + OT).
Resilience-by-design is baseline (security, continuity, sovereignty)	Security/continuity is central in the technology outlook.	Policy/sovereignty concerns appear across regions.	**Zero-trust, redundant paths/NTN**, continuity planning treated as defaults.	Define **Resilience & Security** roles (cyber-physical resilience, hybrid connectivity).
AI/ML moves from PoC to operations	AI-native automation is emphasised for 5G-Advanced.	Limited explicit metrics regionally, but rising interest.	Strong push for **automation, assurance, and energy optimisation.**	Add **AI-for-Networks** roles (automation architect, telecom data/telemetry).
Edge integration determines latency outcomes	MEC/edge as a ready-now enabler.	Readiness is uneven; corridor/peri-urban gaps exist.	"**Integration at the edge**" is seen as a blocker	Thread edge skills into **all clusters** (cloud-native, real-time constraints).

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			more than radio limits.	
Sustainability shifts from reporting to operations	Green levers identified (energy-aware networks).	Patchy KPI baselines across regions.	**Energy-aware ops** cited as operational necessity.	Introduce **Sustainability-aware** competencies across roles (KPI packs, optimisation).
Talent shortages are systemic and hybrid	Literature anticipates hybrid roles.	Partners report integration/skills gaps.	Experts call hybrid profiles the **decisive constraint**.	Make **hybrid competency threads** explicit across the taxonomy.

Across pillars, **four role families** consistently emerge as priorities: **Orchestration & Automation, Enterprise 5G & Vertical Integration, Resilience & Security, and AI for Networks**. In addition, **sustainability-aware operations** emerge as a cross-cutting capability rather than a standalone niche. The **edge/MEC integration** theme repeatedly appears as the practical hinge for latency-critical use cases, confirming that **cloud-native depth** (Kubernetes, CI/CD, observability) must be woven into **every cluster**, not just the orchestration family. Finally, the **hybrid nature** of required skills (telecom × cloud/DevOps × OT × security × sustainability) moves from foresight to **validated constraint**, shaping how the taxonomy in 5.4.3 should be structured and how curricula should stack competencies.

5.4.3. Talent Profile Taxonomy

The triangulated evidence makes clear that the evolution of advanced 5G and Beyond 5G requires a **new taxonomy of talent profiles**. These profiles are not entirely new occupations, but rather hybrid extensions of existing ICT roles, expanded to encompass orchestration, resilience, and sustainability. They represent the **practical translation** of the trends identified in Sections 2–4 into workforce needs that education and training systems must anticipate.

To capture these dynamics, the taxonomy is presented in two complementary views. The first table (Table 32) provides a high-level overview of role families, including illustrative job titles, expected outcomes, and the contexts in which they are most relevant. The second table (Table 33) develops the competency detail, proficiency requirements, and validation based on the expert interviews. Together, these tables offer both a strategic and a technical perspective on the future workforce landscape.

Table 32. Emerging talent profiles – overview

Role family	Illustrative roles	Key outcomes	Typical contexts
Orchestration & Assurance	5G/Edge Orchestration Engineer; Slice Design & Assurance Specialist	Operable cloud-native 5G/edge platform; slice lifecycle management; measurable QoS/SLA	Operators, integrators, multi-tenant campuses

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Enterprise 5G & Vertical Integration	Private 5G Architect (OT-aware); Industrial Edge Application Engineer	Secure campus 5G designs; OT/IT integration; validated production changeover	Manufacturing, logistics/ports, energy/utilities
Resilience & Security	Cyber-Physical Resilience Engineer; NTN/Hybrid Connectivity Integrator	Continuity-by-design; zero-trust; tested failover plans	Critical infrastructure; distributed operations; corridors
AI-for-Networks	Network Automation Architect; Telecom Data/Telemetry Engineer	Closed-loop assurance; anomaly detection; energy-aware optimisation	Operators and large enterprises targeting zero-touch operations
Sustainability-Aware Operations	Green Network Operations Specialist; Energy Efficiency Analyst (Telco)	Defined energy KPIs; optimisation playbooks; regulatory-aligned reporting	Any 5G/edge footprint with significant energy exposure

This overview reveals that the workforce transformation is centered around five key areas: **Orchestration & Assurance**, **Enterprise 5G & Vertical Integration**, **Resilience & Security**, **AI-for-Networks**, and **Sustainability-Aware Operations**. Each addresses a specific adoption bottleneck or operational requirement identified across the three evidence pillars.

Table 33. Emerging talent profiles – competency detail

Role family	Core competencies (hybrid threads)	Proficiency focus	Validation note
Orchestration & Assurance	Cloud-native 5G core; Kubernetes/CI-CD; observability/telemetry; intent models; QoS/QoE engineering; automation toolchains	Advanced in cloud-native & assurance; Intermediate in RAN/core	Experts confirm orchestration bottlenecks as the main gating factor for slicing and assurance
Enterprise 5G & Vertical Integration	Spectrum/licensing; RF/site planning; identity & segmentation; OT protocols/safety; edge data pipelines	Advanced in OT integration & security; Intermediate in RF/site	Experts highlight private 5G as the most immediate business case, with OT integration as the decisive factor
Resilience & Security	Zero-trust; segmentation; multi-path/NTN interworking; failure injection/chaos drills; sovereignty/NIS2 baselines	Advanced in security architecture; Intermediate in NTN interworking	Experts emphasise resilience as a baseline and reframe NTNs as continuity rather than capacity solutions
AI-for-Networks	ML pipelines; streaming/time-series analytics; KPI	Advanced in data/ML	Experts describe AI/ML as moving

	normalisation; closed-loop control; model governance	operations; Intermediate in telecom domain knowledge	from proof-of-concept to operational necessity
Sustainability-Aware Operations	Energy metering/telemetry; kWh/GB metrics; AI-assisted optimisation; lifecycle assessment awareness; compliance frameworks	Intermediate to Advanced in measurement and optimisation	Experts identify energy-aware operations as essential for both cost control and resilience

The competency detail highlights that these role families are underpinned by **hybrid skill sets**. Telecom fundamentals (RAN, core, spectrum) remain necessary but are insufficient on their own. Practitioners must combine these skills with cloud-native and DevOps expertise, **OT integration and safety knowledge**, **security and resilience practices**, and **sustainability awareness**. The proficiency expectations indicate that specialisation in at least one of these areas (e.g., orchestration, OT integration, security, or AI/ML) must be complemented by intermediate knowledge in adjacent domains.

In **conclusion**, the taxonomy confirms that talent demand is not distributed evenly across traditional ICT categories but instead concentrates around **hybrid profiles** capable of bridging domains. This reinforces the expert interviews' finding that **talent availability is the decisive bottleneck for adoption**. The two tables, taken together, provide both a high-level and a granular view of these profiles, offering clear guidance for the design of curricula, training pathways, and certification schemes. Section 5.4.4 develops these implications further by linking the taxonomy to **curriculum and skills development strategies**.

5.4.4. Implications for Education & Skills. Handover to WP2 and Bridge to T5.2

Building on the role families and competency details established in Table 32 and Table 33 (Section 5.4.3), this subsection translates the taxonomy into concrete curriculum implications and **hands over** the resulting evidence to **WP2**. The intention is to preserve the **breadth × depth** logic validated across the three evidence pillars while keeping adaptations **non-disruptive,** given WP2's maturity. The handover will be used by WP2 to fine-tune syllabi, labs, and assessments, and will simultaneously seed the **recommendation stream under T5.2** for coordinated uptake by HE/VET and stakeholders.

Table 34 operationalises the hybrid skill signals from Table 32 **(overview)** and Table 33 **(competencies)**: depth in at least one family (orchestration/integration/assurance) plus intermediate literacy in adjacent domains (security, sustainability, AI). This mirrors the market pacing factors identified in Sections 2–4 (integration capacity and assurance readiness outweigh radio features in near-term adoption).

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Table 34. Curriculum implications derived from the talent taxonomy

Role family	Curriculum implications
Orchestration & Assurance	Integrate cloud-native foundations (containers, Kubernetes, CI/CD, and observability) into telecom pathways. Add slice lifecycle practices (create/modify/tear-down) and assurance engineering (SLA/QoS verification and telemetry reading). Require evidence of automated change and rollback capabilities.
Enterprise 5G & Vertical Integration	Co-deliver with industrial engineering: private 5G patterns, spectrum/licensing, **IT/OT/telecom** interworking; include sector casework (manufacturing, logistics/ports, energy) with safety/compliance checklists and **integration playbooks**.
Resilience & Security	Embed **zero-trust** segmentation, sovereignty baselines (incl. **NIS2** alignment), continuity planning, and **failure-injection** drills; require learners to design/defend continuity strategies for hybrid terrestrial/NTN settings.
AI-for-Networks	Extend data/ML tracks with **closed-loop** control for networks, model monitoring & drift, real-time telemetry; require anomaly-detection notebooks tied to assurance or energy optimisation tasks.
Sustainability-Aware Operations	Mainstream **energy KPIs** and optimisation (kWh per workload/process) into ops labs; relate to EU green frameworks; use short "operate-then-optimise" exercises with quantified before/after deltas.

Hands-on practice and policy literacy

Given experts' emphasis on "ready-now" stacks (5G SA + MEC + private 5G) and **assurance/integration** as bottlenecks, labs should prioritise:

- slice lifecycle + QoS verification with observability artefacts,
- **IT/OT** protocol mapping in a campus/private 5G scenario,
- fault/chaos drills with recovery metrics, and
- energy telemetry with optimisation loops.

Before presenting Table 35, it is important to clarify its purpose within this deliverable. The table should be read as a simple illustrative example of how the evidence gathered in D5.1 can be translated into curricular alignment for WP2. It does not intend to provide a definitive mapping, but rather to demonstrate the type of actionable input that WP2 can draw from Task 5.1. The detailed analysis of curricular implications — particularly at the level of each of the eight courses — will be carried out within WP2, most likely under Task T2.4 (Testing & Refinement). That is where the evidence from D5.1 should be systematically examined, tested against pilot teaching activities, and refined to ensure its effective integration into the educational outputs of 5G-DiGITs.

Table 35. WP2 courses — alignment summary and minimal-tweak actions

WP2 course (D2.2)	Primary linkage to role families	Where it already fits (per D2.2)	Minimal tweak recommendation	KPI / assessment hook to add

Introduction to Advanced 5G Technologies	Orchestration & Assurance; Resilience & Security	Foundations in evolution, enablers, standards.	Add a short **assurance primer** (SLA/QoS, observability) + 1-page KPI crib sheet.	Quiz item on **p95 latency/jitter** concepts; mini-case on **zero-trust** segmentation.
Network Architecture and Protocols	Orchestration & Assurance; AI-for-Networks	Covers slicing, virtualisation, orchestration, and protocols.	Insert a **slice lifecycle lab step** (create→modify→tear-down) with log evidence.	Rubric requires **SLA % verification** and a **telemetry screenshot** (observability).
IoT, Industry 4.0, and Smart Cities	Enterprise 5G & Vertical Integration; Resilience & Security	Vertical/campus applications prominent.	Add **OT protocol mapping worksheet** (e.g., Modbus/PROFINET) + safety/compliance checklist.	Include a **continuity plan** artefact (failover path; RTO/RPO).
Energy Efficiency and Sustainability in Advanced 5G Technologies	Sustainability-Aware Operations	LCA and energy-aware network design central.	Add a **telemetry mini-lab**: compute **kWh/workload**, write a 1-page optimisation memo.	Record **before/after kWh/workload** with reflection on trade-offs.
Entrepreneurship and Innovation in Advanced 5G Technologies	Enterprise 5G & Vertical Integration	Lean/innovation content established.	Add a **tech-ops ROI sheet** referencing **SLA % / energy**; 1 page on private-5G spectrum/licensing.	Business model canvas includes **assurance & energy** as cost/value levers.
Digital Skills for Beyond 5G Technologies	AI-for-Networks; Orchestration & Assurance	Cloud-native/AI/cyber threats present.	Add a simple **time-series anomaly** notebook using synthetic 5G KPIs.	Submit a **closed-loop sketch** (detect→act) + **model-monitoring** checklist.
Green Skills for Beyond 5G Technologies	Sustainability-Aware Operations	Circular economy, green value chains.	Add a **policy micro-brief** (where sustainability ops intersect **NIS2**) + KPI template.	Mock monthly **energy KPI** report aligned to a course case.

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Entrepreneurial Skills for Beyond 5G Technologies	Enterprise 5G & Vertical Integration	Execution capacity, access to finance.	Attach a **sector blueprint** annex (manufacturing/logistics/energy) with **assurance targets** fields.	Pitch deck must cite ≥2 KPIs (**SLA %, kWh/workload**) + a pilot-to-scale plan.

Note. All eight syllabi have passed CDT AB final review to an implementation-ready ("Green") status; the tweaks above can be delivered as **appendices, worksheets, or rubric fields** without reopening major structures

The preceding analysis of emerging professions and skills taxonomies provides a qualitative foundation for understanding how the 5G/B5G transition reshapes the talent landscape. To complement these insights, the following subsection (5.4.5) develops a **quantitative labour-market outlook**, translating the identified trends into **occupational projections and foresight indicators** consistent with EU-level datasets.

5.4.5. Labour Market Outlook for 5G/B5G-related Professions (2025–2035)

Building upon the sectoral analysis presented in Section 5.2, this subsection provides an **occupation-level perspective** on how 5G/B5G diffusion affects employment structures and professional demand. The focus shifts from industrial domains to **specific occupational clusters**, offering a finer understanding of which professions are expanding, stabilising, or declining, and what competencies underpin these shifts.

As a **methodological approach**, the analysis combines quantitative data from the **EU Skills Forecast (2024)** [53]—which operationalises the Cedefop/ILO foresight principles [52]—with validation from the *European Commission (2024)* [54], *OECD (2023)* [56], and *World Economic Forum (2025)* [57]. Occupational categories follow the **International Standard Classification of Occupations (ISCO-08)** [58], ensuring comparability with *Eurostat (2024)* [55].

Employment trends are expressed qualitatively (*High growth > +10 %*, *Moderate +5–10 %*, *Stable ± 5 %*, *Decline < −5 %*) for the 2030–2035 horizon. Skill-level classification (1–4) refers to ISCO-08 definitions.

In terms of **limitations,** forecast uncertainty stems from heterogeneous national adoption rates of 5G/B5G technologies, policy evolution, and differences in classification between ISCO-08 and ESCO digital-skills taxonomies.

Table 36. Employment Outlook for Key 5G/B5G-related Occupations in Europe (2025–2035)

Occupational Cluster	Example Roles (ISCO-08 codes)	EU Employment Outlook 2030–2035	Skill Level (1–4)	Emerging Competencies

Telecommunications & Cloud Infrastructure	2153 Telecommunications Engineers; 2523 Computer Network Professionals	**Moderate to High Growth (+6–10 %)**	4	Cloud-native operations, edge orchestration, AI network assurance
Cybersecurity & Data Integrity	2529 ICT Security Specialists	**High Growth (+10–14 %)**	4	Threat analytics, zero-trust architecture, resilience design
AI & Data Engineering	2511 Systems Analysts; 2512 Software Developers; 2513 Web and Multimedia Developers	**High Growth (+12–15 %)**	4	Machine-learning ops, data ethics, governance, generative AI integration
Sustainable ICT / Green Ops	2142 Civil Engineers (infrastructure); 2149 Engineering Professionals n.e.c.	**Moderate Growth (+5–8 %)**	4	Energy analytics, green software engineering, life-cycle assessment
Digital Education & Upskilling Facilitators	2359 Teaching Professionals n.e.c.; 2424 Training and Staff Development Professionals	**Stable (+2–4 %) but Strategically Critical**	4	Curriculum co-design, AI-assisted learning, competence forecasting

The occupational outlook demonstrates **sustained employment expansion** across advanced digital domains, particularly in **cybersecurity**, **AI/data engineering**, and **network infrastructure**. The *Future of Jobs Report 2025* [57] identifies these as the **fastest-growing global job families**, confirming the alignment of European forecasts with global patterns. Moreover, WEF (2025) projects a **net global labour growth of 7 %** and an average **skills transformation rate of 39 %**, indicating that most occupational change will result from role redefinition rather than displacement.

The following **methodological and analytical notes** are relevant:

- **Forecast modelling:** Cedefop's E3ME framework integrates macro-economic variables with occupational-skills matrices, estimating expansion and replacement demand [52], [53].
- **Classification coherence:** ISCO-08 ensures comparability with EU statistics; mapping to ESCO enables curricular alignment for Erasmus+ training design [58].
- **Limitations:** Future job content may evolve faster than occupational codes; cross-sectoral functions (e.g., AI ethics, data governance) are under-represented in current taxonomies.

In **conclusion**, this foresight-based occupational outlook complements the sectoral analysis of Section 5.2 by identifying **who** will perform the tasks created by 5G/B5G-driven transformations and **what competences** they will require. It highlights the necessity for targeted **reskilling pathways** in cybersecurity, cloud, and AI engineering, while

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confirming the pivotal role of **educators and training professionals** in transferring these competencies to the future workforce.

Bridge to T5.2

Beyond its direct curricular implications for WP2, the evidence base developed in Task 5.1 also provides a foundation for **Task 5.2**. While WP2 will translate the talent taxonomy into course content and training activities, T5.2 is responsible for bridging these findings with **external stakeholders, industry representatives, and education providers**. In this sense, T5.2 will use the outputs of D5.1 not only as **background evidence** but also as a **dialogue starter**, ensuring that the identified role profiles, competency gaps, and resilience priorities are validated, refined, and anchored in real ecosystem needs. By doing so, T5.2 will help consolidate the alignment between the skills agenda emerging from D5.1 and the broader innovation and policy objectives pursued by 5G-DiGITs.

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6. Conclusions and Outlook

6.1. Summary of Key Findings

Evidence triangulated across desk research, regional inputs, and expert interviews converges on a deployable near-term core for industrial adoption: **5G Standalone (SA) + Multi-access Edge Computing (MEC) + private 5G**. This "ready-now" stack consistently outperforms purely radio-centric upgrades as a source of immediate value in enterprise settings. In contrast, **network slicing** and **Open RAN** remain strategically important but are limited in the short to mid-term by **orchestration, assurance, and multi-domain integration capacity**, rather than by radio capabilities per se. These findings are synthesised in Table 24, Table 25, and Table 26, which distinguish areas of convergence and divergence across the three evidence pillars.

Adoption patterns are **enterprise-led**, with momentum concentrated in **logistics & mobility**, **manufacturing**, and **public infrastructure**. Interview tallies corroborate this focus and quantify technology prioritisation and barriers: **Private 5G (7/10)** and **edge/cloud-native (4/10)** were most frequently selected as short-to-mid-term value drivers, while **slicing (2/10)** was seen as strategically relevant but not yet scale-ready; **CAPEX/OPEX** and **unclear ROI** were cited as the top obstacles (**6/10** each). Regionally, policy levers are helpful, but the decisive accelerants are **assurance maturity** (stable uplink/latency with verifiable SLAs) and **integration capacity across IT/OT/telecom**.

Resilience emerges as a baseline requirement rather than an optional property. The analysis frames resilience as **technical** (redundancy, deterministic latency/uplink, coverage continuity), **operational** (incident response, vendor/SLA assurance), **human** (integration-capable teams), and **environmental** (energy-aware operations). **Non-terrestrial networks (NTN)** are positioned primarily as a **continuity/failover** instrument.

The decisive systemic constraint is **talent availability**, specifically **hybrid profiles** that combine telecom fundamentals with **cloud-native/DevOps**, **OT integration**, **assurance & security**, and **sustainability** literacy. The role taxonomy developed in Section 5.4 (Table 32, Table 33, and Table 34) operationalizes these needs into five families, **Orchestration & Assurance, Enterprise 5G & Vertical Integration, Resilience & Security, AI-for-Networks,** and **Sustainability-Aware Operations,** providing a direct bridge to education and training actions. Overall, Europe is viewed as **competitive but not dominant** in standards positioning, underlining the importance of accelerating **toolchain readiness** and **skills development** alongside infrastructure deployment. These conclusions integrate the cross-domain synthesis (from Table 24 to Table 29) and underpin the next-step actions outlined in Section 6.2.

6.2. Outlook and Next Steps within WP5

The implications for WP5 are direct. Building on the synthesis and the validated **market needs/gaps** (Section 5.2), the focus now shifts from analysis to **orchestrated action** across curricula, testbeds, and evidence frameworks:

- **Align training with the five role families:** WP5 (in coordination with WP2/WP4) should operationalize stackable pathways that combine breadth (telecom, cloud-native, OT, security, and sustainability) with depth in at least one specialization (e.g., **orchestration & assurance** or **OT-aware private 5G**): This ensures that programmes produce the hybrid profiles that enterprises and regions have identified as critical to scaling.
- **Institutionalise resilience-by-design:** Curricula and practicum should embed **zero-trust**, **redundancy design (incl. NTN interworking)**, **failure injection and recovery drills**, and **energy-aware operations** as default outcomes, reflecting how resilience is now assessed and procured in industrial contexts.
- **Prioritise orchestration and assurance toolchains:** Given that slicing and multi-domain QoS are **gated by lifecycle tooling**, WP5 should anchor labs around **intent models**, **telemetry/observability**, **SLA/QoE verification**, and **closed-loop automation**—turning strategic enablers into teachable, repeatable practice.
- **Codify enterprise private-5G patterns:** To shorten time-to-value, develop **reference blueprints** for campus networks (RF/site design, **identity & segmentation**, **OT interlock**, acceptance testing), aligned with the sectors where adoption is already moving.
- **Standardise assurance and sustainability evidence:** Adopt a **minimal KPI pack** (e.g., **latency/jitter distributions**, **uplink stability**, **backhaul reliability**, plus **kWh/GB** and **site energy curves**) to quantify ROI/TCO for SMEs and to align operations with EU green frameworks. This responds to interview calls for **process- and assurance-led ROI**, addressing the current heterogeneity of reporting.
- **Leverage regional testbeds for replication:** Utilize corridors, ports, and industrial campuses detailed in Section 3 to conduct hands-on integration labs and comparative measurements outside metropolitan areas—where predictable performance is most at risk yet most needed.

Taken together, these steps convert the evidence base into a **programme of work** that accelerates **scalable, resilient** adoption while building the **talent pipelines** Europe needs. D5.1 therefore provides not only a diagnosis of the market, but a **roadmap** for WP5 to act on—linking **education**, **industry practice**, and **policy baselines** in a coherent path to impact.

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Annexes

A. Partner Regional Input Template

Section	Guiding Question / Instruction	Expected Input Format
1. National/Regional Strategy Overview	Describe any national or regional **5G/B5G strategies**, digital transformation plans, or sustainability frameworks relevant to industrial tech development.	Short paragraph (150–300 words)
2. Key Industry Sectors and Adoption Areas	Identify **industrial sectors** where 5G/B5G is being adopted or tested (e.g., manufacturing, logistics, energy, health). Provide examples if possible.	List + brief explanation (100–200 words)
3. Relevant Projects or Pilots	Mention any known **pilot projects, testbeds, living labs**, or industry-academic initiatives using 5G/B5G in your region or country.	Bullet points or short paragraphs
4. Stakeholders and Innovation Ecosystem	List key **stakeholders** involved (e.g., telecom providers, universities, start-ups, clusters, government agencies) and describe their roles.	Bullet list with roles
5. Policy Framework and Public Support	Are there **public policies, funding schemes, or regulations** supporting advanced 5G/green tech deployment in industry? Describe main instruments or programs.	Paragraph or list (100–250 words)
6. Readiness and Barriers	Assess the **readiness level** of your region regarding industrial 5G use. Mention **barriers** such as cost, regulation, skills, infrastructure, or awareness.	SWOT-style or narrative (150–300 words)
7. Sustainability & Green Innovation Linkage	Highlight any links between **5G and sustainability goals** in your context: e.g., energy efficiency, circular economy, green factories, low-carbon strategies.	Short narrative (100–200 words)
8. Local Success Stories / Good Practices	Optional: Share one or two **noteworthy success stories** (projects, policies, use cases) that demonstrate progress or innovation in your region.	1–2 case summaries (max. 200 words each)
9. Additional Comments or Observations	Anything else you believe is relevant or unique about your regional landscape regarding advanced 5G or green industrial tech.	Open text

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B. Regional input

B1. Greece

B1.1. National/Regional Strategy Overview

Greece has been actively advancing its digital transformation and 5G/B5G strategies to enhance industrial tech development. Key initiatives include:

5G and Broadband Strategies

Greece's National Broadband Plan (2021-2027) aims to accelerate private investment and ensure widespread availability of high-capacity broadband services, including 5G/B5G. It is a cornerstone of its digital infrastructure strategy, aiming to propel the country into a Gigabit Society by ensuring universal access to ultra-high-speed fixed broadband and continuous 5G coverage by 2027. The plan sets ambitious targets, including:

- Gigabit connectivity for major socio-economic hubs.
- 100 Mbps minimum download speed for all urban and rural buildings, upgradeable to 1 Gbps.
- Uninterrupted 5G coverage for all major transport routes and populated areas.
- 50% household penetration for high-speed internet.

By delivering gigabit-capable networks to all households, complete 5G coverage on all highways, and vastly improved connectivity equity, the plan supports Greece's digital ambitions, fostering innovation, economic growth, and social cohesion alongside its broader Digital Transformation agenda.

Digital Transformation Plans

The Digital Transformation Bible (2020-2025), introduced by the Ministry of Digital Governance, outlines Greece's strategy for digital evolution. It focuses on:

- Connectivity: Expanding broadband and 5G infrastructure.
- Digital Skills: Enhancing digital literacy across society.
- Business Transformation: Supporting enterprises in adopting digital technologies.
- Public Services: Digitizing government operations for efficiency.
- Innovation: Leveraging advanced technologies like AI and blockchain.

More specifically, it aims at enhancing digital services for citizens and businesses, expanding high-speed connectivity (like 5G and fiber optics), promoting digital skills, and integrating emerging technologies such as artificial intelligence and cloud computing. Key priorities include the simplification of bureaucratic procedures, the development of digital identity systems, and support for start-ups and digital entrepreneurship. Funded in part by the EU's Recovery and Resilience Facility, the plan seeks to accelerate economic growth and improve public sector efficiency.

Sustainability Frameworks

Greece integrates sustainability into its digital strategy by promoting green technologies and energy-efficient digital infrastructure. The Digital Transformation Paper (2020-2025) aligns national efforts with EU sustainability goals, ensuring that industrial tech development is environmentally responsible. It is the country's national roadmap that sets out a comprehensive, stakeholder-driven plan to modernize Greek society and economy through digital technology. It identifies seven strategic pillars - connectivity, digital skills, digital public services, digital business, digital innovation, public data use, and advanced technologies - designed to align with EU standards and global best practices. Over 400 concrete projects are mapped out, spanning horizontal enablers like infrastructure, interoperability, and

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cybersecurity, as well as sector-specific actions in health, justice, education, environment, energy, agriculture, tourism, and more. A robust governance framework ensures agile implementation, continuous monitoring, and annual updates. These initiatives position Greece as a leader in digital connectivity and industrial innovation, fostering a tech-driven economy while maintaining sustainability.

B1.2. Key Industry Sectors and Adoption Areas

Several industries in Greece are benefiting from 5G/B5G strategies, digital transformation plans, and sustainability frameworks. Here are some key sectors:

Telecommunications & Digital Infrastructure

The telecom sector is at the forefront of Greece's digital transformation. Major operators like OTE, Vodafone Greece, and Wind Hellas are expanding fiber-optic networks and 5G coverage, with plans to reach 90% of the population by 2025. This enhances connectivity for businesses and consumers alike. The National Broadband Plan (2021–27) and the Digital Transformation Bible (2020–25) establish binding targets for nationwide gigabit connections, 100 Mbps baseline speeds for all homes, full 5G coverage on major transport routes, and 100% broadband in organized communities.

Smart Manufacturing & Industry 4.0

Greek industries are integrating IoT, AI, and automation into manufacturing processes. 5G connectivity enables real-time monitoring, predictive maintenance, and smart factories, improving efficiency and reducing costs. A notable example is the Calpak solar-heater plant in Loutraki, which uses a private 5G campus network (by COSMOTE and Ericsson) to connect robotic arms and AR tools, enabling real-time production monitoring and predictive maintenance. Greece also participates in large-scale trials that validate industrial KPIs such as ultra-reliable low-latency communications (URLLC) and edge computing performance.

Energy & Sustainability

The energy sector is leveraging digital solutions to optimize renewable energy production and smart grids. Greece's sustainability frameworks encourage green technologies, helping industries reduce their carbon footprint. An ongoing example of 5G/B5G deployment in Greece's energy and sustainability sector is the COP-PILOT initiative. Led by the University of Patras (UoP), this evolving project integrates real-time IoT data from distributed energy resources (DERs), advanced metering systems, and cloud-based analytics to optimize demand response and flexibility in electrical grids. With OTE/COSMOTE providing the 5G-enabled network backbone and leveraging their OpenSlice infrastructure manager, COP-PILOT facilitates ultra-reliable, low-latency communication for real-time energy flow management, DR activation, and dynamic orchestration of DERs.

Healthcare & Telemedicine

The healthcare sector is adopting 5G-enabled telemedicine, allowing remote consultations, AI-driven diagnostics, and connected medical devices. This enhances patient care, especially in rural areas. An ongoing 5G healthcare initiative in Greece is the 5G-TERRA project (January 2024–December 2026), which is deploying a 5G non-standalone, soon-to-be standalone, private/public network across rural mainland and island regions (Central Greece & Crete) to support advanced telemedicine services. Through this infrastructure, healthcare teams are already using real-time vitals monitoring from wearables, live video streaming for paramedics linked to remote physicians, handheld 5G ultrasound devices, and augmented reality-enabled tools to perform

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immersive diagnostics and consultations in remote clinics and ambulances.

Tourism & Smart Cities
In Greece, the tourism sector and emerging smart cities are actively embracing 5G and beyond-5G technologies to enhance visitor experiences and urban living. A standout example is The Ellinikon, a next-generation smart city project in Athens, which integrates full 5G coverage, IoT infrastructure, and AI-driven services to create a seamless, tech-enabled environment for residents and tourists alike. In the broader tourism industry, digital transformation efforts are leveraging 5G to support personalized services, real-time data analytics, and immersive technologies like augmented and virtual reality, aiming to elevate Greece's appeal as a high-tech travel destination. These innovations not only improve operational efficiency but also enrich the cultural and recreational experiences offered to visitors.

B1.3. Relevant Projects or Pilots

Greece has several 5G/B5G pilot projects, testbeds, and industry-academic initiatives driving digital transformation. Here are some notable examples:

Athens.5GLink – Open 5G Testbed (Athens)

Athens.5GLink is an open-access urban testbed launched in Athens to support 5G and Beyond 5G (B5G) experimentation. It allows researchers, start-ups, and telecom operators to test 5G standalone (SA) networks, edge computing, IoT applications, and network slicing in real-life city conditions. The testbed encourages ecosystem collaboration and is designed to scale throughout the Athens metropolitan area.

B5G/6G L-GRECO – Hybrid Testbed (NCSR Demokritos)

Hosted by NCSR Demokritos in Athens, the L-GRECO testbed is a sophisticated academic-industry platform for B5G and 6G experimentation. It includes dual 5G SA cores, a multi-vendor RAN setup (including mmWave), satellite/NTN emulation, and edge/cloud orchestration tools. With fiber interconnection to OTE Academy, it enables complex trials on AI-driven networks, IoT, and future communication technologies.

Trikala 5G Living Lab (City of Trikala & Vodafone)

The city of Trikala operates as a pioneering 5G living lab in partnership with Vodafone and municipal innovation agency e-Trikala. Building on existing smart city infrastructure, this initiative tests real-world use cases such as drone-based deliveries, intelligent mobility, and citizen-driven digital services. It reflects a strong example of how local government collaborates with industry to trial 5G solutions that directly serve communities.

CEF's 5G Large-Scale Pilot Call

Greece is participating in the Connecting Europe Facility (CEF) call CEF-DIG-2024-5GLSP-SMARTCOM-WORKS, open from late 2024 to February 2025. This supports

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5G standalone and edge deployments targeting smart community use cases—such as sustainable mobility, rural connectivity, and climate-resilient infrastructure. Greek municipalities and telcos are prime candidates to benefit.

Such initiatives position Greece as a regional leader in 5G innovation, fostering collaboration between industry, academia, and government.

B1.4. Stakeholders and Innovation Ecosystem

Greece's 5G and B5G ecosystem involves a diverse set of stakeholders, each playing a crucial role in advancing digital infrastructure and innovation. The telecom providers are at the forefront of deployment, with major companies such as OTE (Cosmote), Vodafone Greece, and Nova spearheading the expansion of 5G networks. These firms are responsible for building and maintaining the infrastructure, ensuring widespread coverage, and collaborating with industry partners to develop new applications.

Universities and research institutions also contribute significantly to the development and testing of 5G technologies. Institutions such as the National and Kapodistrian University of Athens, the Aristotle University of Thessaloniki, and the National Centre for Scientific Research "Demokritos" engage in research projects, pilot programs, and industry collaborations to explore the potential of 5G in various sectors, including healthcare, energy, and smart cities.

Start-ups and technology clusters play a vital role in fostering innovation and the commercialization of 5G applications. Organizations such as Corallia and Elevate Greece support emerging tech companies working on IoT, AI, and automation solutions that leverage 5G connectivity. These start-ups often collaborate with telecom providers and universities to develop cutting-edge solutions for industrial applications.

The Greek government, particularly the Ministry of Digital Governance, is responsible for setting policies, funding initiatives, and ensuring regulatory compliance. Through programs like the Digital Transformation Bible and the National Broadband Plan, the government facilitates investment in 5G infrastructure and promotes digital adoption across industries. Additionally, the Hellenic Telecommunications and Post Commission (EETT) oversees spectrum allocation and ensures fair competition among telecom operators.

International collaborations also play a role, with Greece participating in EU-funded projects such as IMAGINE-B5G, which supports large-scale trials and validation of Beyond 5G technologies. These partnerships enable Greece to stay at the forefront of technological advancements while integrating with broader European digital strategies. The combined efforts of these stakeholders are shaping Greece's digital future, driving innovation, and ensuring the successful implementation of 5G across various sectors.

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B1.5. Policy Framework and Public Support

Greece has implemented several public policies, funding schemes, and regulations to support the deployment of advanced 5G and green technologies in industry. These initiatives aim to accelerate digital transformation while ensuring sustainability.

The National Broadband Plan (2021-2027) is a key policy framework that promotes the expansion of high-capacity broadband and 5G networks. It sets ambitious targets, including gigabit connectivity for major socio-economic hubs and uninterrupted 5G coverage for transport routes and urban areas. The plan encourages private investment by removing administrative barriers and creating an investment-friendly environment.

The Digital Transformation Bible (2020-2025), introduced by the Ministry of Digital Governance, outlines Greece's strategy for digital evolution. It includes measures to enhance connectivity, digital skills, business transformation, public services, and innovation. This framework supports the adoption of 5G and green technologies across industries.

In terms of funding, Greece has established the Phaistos Fund, a venture capital initiative designed to support 5G-related start-ups and innovative projects. The fund provides financial backing to companies developing IoT, AI, and automation solutions that leverage 5G connectivity.

Additionally, Greece is integrating sustainability into its digital strategy through green financing mechanisms. The REFORM/SC2022/060 strategy focuses on greening public finance, optimizing green budgeting, and implementing green taxation measures. It also promotes long-term planning for sustainable industry financing, ensuring that businesses can access funding for energy-efficient digital infrastructure.

Regulatory measures also play a crucial role. Law 4727/2020 establishes a framework for 5G spectrum allocation, ensuring that radio frequencies are reserved for research, development, and innovation. This law facilitates the deployment of pilot networks and services on 5G infrastructure, fostering industry collaboration.

These policies and funding instruments position Greece as a regional leader in digital connectivity and industrial innovation, driving both technological advancement and sustainability.

B.1.6. Readiness and Barriers

Greece has made significant progress in industrial 5G adoption, but several barriers still affect its readiness level. The country has established a strong policy framework, including the National Broadband Plan (2021-2027) and the Digital Transformation Bible (2020-2025), which aim to accelerate 5G deployment and digital transformation. However, challenges remain.

One major barrier is cost. While Greece has encouraged private investment in 5G infrastructure, the high cost of network deployment and equipment remains a challenge for businesses, particularly small and medium enterprises (SMEs). The Phaistos Fund mentioned earlier provides financial support for 5G-related start-ups, but broader industry adoption requires additional incentives.

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Regulation is another factor. The Hellenic Telecommunications and Post Commission (EETT) oversees 5G spectrum allocation, ensuring fair competition among telecom operators. However, bureaucratic hurdles and slow licensing processes can delay network expansion and industrial applications.

The skills gap is also a concern. While Greek universities and research institutions are actively involved in 5G research and pilot projects, there is a shortage of specialized professionals with expertise in network engineering, cybersecurity, and AI-driven automation. This limits the ability of industries to fully leverage 5G capabilities.

Infrastructure readiness varies across regions. While urban areas like Athens and Thessaloniki have seen rapid 5G deployment, rural and remote regions still face connectivity challenges. Expanding fiber-optic networks and ensuring nationwide 5G coverage are key priorities.

Finally, awareness and adoption remain hurdles. Many industries are still in the early stages of understanding and integrating 5G technologies into their operations. While smart ports, logistics hubs, and manufacturing plants are testing 5G applications, broader industrial adoption requires education, training, and strategic partnerships.

Overall, Greece is making strides in industrial 5G readiness, but overcoming these barriers will be crucial for widespread adoption and economic impact.

B1.7. Sustainability & Green Innovation Linkage

Greece is actively integrating 5G technology with its sustainability goals, focusing on energy efficiency, circular economy, green factories, and low-carbon strategies. The National Action Plan on Circular Economy promotes resource efficiency, waste reduction, and industrial symbiosis, aligning with 5G-enabled smart manufacturing to optimize production processes and minimize environmental impact. 5G plays an enabling role by supporting the digital technologies necessary for efficient, data-driven, and sustainable practices. It facilitates real-time communication and data collection across sectors like manufacturing, logistics, and energy, enabling predictive maintenance, industrial symbiosis, and resource optimization. 5G also powers digital platforms that promote reuse, repair, sharing, and product-as-a-service models, while enhancing smart waste and resource management systems through sensor-based monitoring and automation. In supply chains, 5G supports transparency and traceability via IoT and blockchain integration, which is vital for eco-design and closed-loop systems. Additionally, it enables low-carbon logistics through smart routing and the use of electric and autonomous vehicles. Though not a direct policy tool, 5G acts as a critical infrastructure that underpins the operational success of circular economy initiatives.

The Greek government's Circular Transition Business Plan emphasizes green public procurement, industrial clustering, and digital transformation, which are enhanced by 5G-powered automation and IoT applications. These initiatives support energy-efficient smart grids, reducing carbon emissions and improving renewable energy integration. First, it embeds green and circular criteria into public procurement to stimulate demand for secondary materials, reuse, and repair. Second, the plan promotes industrial symbiosis and business clustering, fostering circular entrepreneurship, shared resource use, and integration with digital innovation and environmental industries. Third, it stimulates job creation by

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supporting collaborative-consumption models, repair services, and small-scale green ventures. 5G serves as a critical technological enabler that supports the transition to a circular economy by enhancing digital infrastructure across key sectors. Its ultra-fast, low-latency connectivity enables real-time monitoring, automation, and data exchange. 5G also powers smart logistics, energy-efficient supply chains, and intelligent waste management systems through Internet of Things (IoT) devices and sensor networks.

Finally, Greece's commitment to low-carbon strategies is evident in its green growth policies, which leverage 5G connectivity for real-time monitoring of emissions, smart transportation, and sustainable urban planning. These efforts position Greece as a leader in digital sustainability, ensuring that 5G adoption contributes to environmental and economic resilience.

B1.8. Local Success Stories / Good Practices

Trikala: Greece's First 5G-Enabled Smart City

Trikala, a mid-sized city in central Greece, has emerged as a European success story for digital transformation through smart city technologies enabled by 5G. In collaboration with Vodafone, e-Trikala, and the Ministry of Digital Governance, Trikala launched a living lab environment in which 5G supports a variety of public-interest services. These include autonomous shuttle buses, drone delivery of medical supplies, smart lighting, waste management systems, and real-time traffic control.

What makes Trikala exemplary is not just the technology but the inclusive policy model: local authorities actively engage citizens in co-designing services. Trikala has been recognized in international forums (e.g., Smart City Expo World Congress) as a scalable model for medium-sized municipalities across Europe, proving that 5G is not only an urban privilege but a driver for digital equity in regional Greece.

5G-TERRA: Bringing Advanced Connectivity to Remote Areas

5G-TERRA is a high-impact project launched in 2024 under the EU's "5G for Smart Communities" program, aiming to bring 5G Standalone networks to remote and rural regions in Greece. The project focuses on deploying advanced 5G infrastructure to enable applications such as telemedicine in isolated villages, precision agriculture, and remote education. Backed by a €4.95 million EU grant, 5G-TERRA bridges the connectivity gap through strategic partnerships between local municipalities, research centers (like NCSR Demokritos), and mobile operators. What makes 5G-TERRA stand out is its clear social impact—it connects communities that were previously underserved and demonstrates how targeted policy and funding can turn 5G into a tool for regional resilience and social inclusion.

B1.9. Additional Comments or Observations

One of the most distinctive features is Greece's archipelagic geography, with over 200 inhabited islands. This fragmentation presents logistical challenges but also makes Greece an ideal testbed for decentralized 5G and green tech pilot projects. On islands like Santorini, Rhodes, or Naxos, 5G can power smart microgrids, enable remote healthcare and tele-education, and support sustainable tourism services. These areas often lack robust

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infrastructure, so 5G-based solutions offer cost-effective and scalable alternatives for delivering critical services. A standout initiative is the GR-eco Islands program, which aims to transform Greek islands into fully digital and climate-neutral communities. Astypalea and Chalki are leading this transformation, integrating 5G networks with renewable energy systems, electric mobility, and digital public services. These islands serve as pioneering models for how 5G and green technologies can work in synergy to support sustainable, resilient communities. This regional approach sets Greece apart as a leader in sustainable island innovation within the EU.

Another emerging trend in Greece's 5G and green industrial tech landscape is the integration of AI-powered predictive analytics with 5G-enabled smart grids. This approach is being tested in Athens and Thessaloniki, where energy providers are using real-time data processing to optimize electricity distribution and reduce waste. By leveraging 5G's ultra-low latency, these smart grids can dynamically adjust power supply based on demand fluctuations, improving energy efficiency and sustainability.

Another recent development is the expansion of 5G-enabled precision agriculture in Crete and Thessaly, where farmers are using IoT sensors and AI-driven analytics to monitor soil conditions, water usage, and crop health. These systems provide real-time insights, allowing for data-driven decision-making that enhances yield efficiency while minimizing environmental impact.

Additionally, Greece is exploring 5G-powered autonomous maritime operations, particularly in Piraeus Port, where AI-driven vessel tracking and automated docking systems are being tested. These innovations aim to reduce fuel consumption, optimize logistics, and enhance port sustainability, making Greece a leader in smart maritime technology.

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B2. Germany

Note: the ordered references given in this section are also provided at the end of this section; do not confuse them with the general references in the rest of the document

B2.1. National/Regional Strategy Overview

The deployment of 5G and beyond-5G (B5G) technologies is central to the digital transformation of industrial systems in many developed economies. These advanced wireless networks provide the low latency, high reliability, and massive device connectivity necessary for enabling Industry 4.0 applications such as autonomous robotics, digital twins, and predictive maintenance. Both national governments and regional blocs have articulated comprehensive strategies that integrate 5G rollouts with broader digitalization and sustainability goals, aiming to create innovation ecosystems that are secure, scalable, and resilient.

Germany, as Europe's leading industrial economy, has positioned digital connectivity and sovereignty at the core of its technological roadmap. The federal government launched its National 5G Strategy in 2017, which was followed by the 2022 Gigabit Strategy. These initiatives set concrete targets for nationwide 5G coverage and fiber-optic connectivity by 2025, extending even to rural and industrial areas. The strategy includes a €12 billion funding envelope and regulatory reforms to fast-track infrastructure deployment, including a planned "acceleration law" that classifies fiber and 5G rollout as being of overriding public interest [1].

German industrial policy increasingly integrates 5G infrastructure with the ambitions of Industry 4.0. High-performance wireless connectivity is viewed as essential for supporting distributed control systems in smart manufacturing. To ensure supply chain security, the government also plans to phase out Huawei and ZTE components from 5G core networks by 2026, and from radio access networks (RANs) by 2029, aligning with the European Union's 5G Toolbox and "clean network" principles [2].

Parallel to infrastructure investment, Germany's Digital Strategy and Digital Agenda 2025 outline priorities in artificial intelligence, blockchain, and digital government. These are complemented by the "Arbeiten 4.0" and "Industrie 4.0" frameworks, which promote human-centred technological transformation of the workplace. A central theme is digital sustainability—ensuring that the adoption of technologies contributes to energy efficiency, labour resilience, and long-term environmental goals [3].

At the European level, the EU's Digital Decade Strategy sets out a coordinated roadmap to achieve universal gigabit connectivity and 5G coverage in all populated areas by 2030. The strategy is backed by the Digital Europe Programme and Horizon Europe funding, channelling investments into next-generation connectivity, cybersecurity, and microelectronics [4].

One of the EU's most powerful instruments for supporting industrial digital transformation is the Important Projects of Common European Interest (IPCEI) framework. Under this scheme, cross-border consortia receive EU and member state funding to develop strategic capabilities in semiconductors, cloud infrastructure, and 5G networks. For instance, Germany and Nokia recently announced an IPCEI-supported investment in 5G-Advanced and 6G-enabling chipsets worth over €360 million [5].

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Digital transformation efforts are also closely linked with the EU's climate neutrality objectives. The Recovery and Resilience Facility (RRF) requires at least 20% of funding to be allocated to digital and 37% to green projects. National and regional plans funded under the RRF are developing smart grids, digital twin infrastructure for industry, and training programs to close the digital skills gap [6]. These efforts are coordinated under the "Transition Pathways for Industrial Ecosystems" initiative, which aims to build green and digital resilience across sectors such as manufacturing, energy, and transport.

In summary, both Germany and the European Union have articulated strategic frameworks that link 5G/B5G deployment to industrial digitalization and sustainability. These strategies converge around the idea of technological sovereignty, environmental responsibility, and cross-border innovation. As industrial systems become increasingly reliant on real-time data exchange, AI inference at the edge, and integrated supply chains, these connectivity strategies will be foundational to the competitiveness and resilience of Europe's digital economy.

B2.2. Key Industry Sectors and Adoption Areas

Germany, as one of Europe's industrial leaders, is rapidly integrating 5G and Beyond 5G (B5G) technologies to transform operations across key sectors. This shift is reshaping labour market demands, with emerging digital professions and increased emphasis on technological resilience.

Manufacturing

The manufacturing sector, central to Germany's Industrie 4.0 agenda, is among the most advanced in adopting 5G. Features such as ultra-low latency and massive machine-type communications enable real-time automation, robotics, and predictive maintenance. Siemens, for example, has deployed private 5G networks at its Amberg facility, enhancing smart production [7].

New roles are emerging, including 5G system engineers, AI-driven quality analysts, and industrial cybersecurity specialists. These developments demand professionals with expertise in network reliability, edge computing, and fault-tolerant systems.

Logistics and Transportation

Germany's role as a European logistics hub has driven early 5G adoption in transport. At the Port of Hamburg, a 5G testbed with Deutsche Telekom supports network slicing for smart traffic, AR maintenance, and drone inspections [8].

5G enables vehicle-to-everything (V2X) communication, autonomous fleet control, and digital twins for supply chains. This drives demand for logistics automation engineers and specialists in connected vehicle systems.

Energy and Utilities

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The energy sector leverages 5G to support its shift toward decentralization and decarbonization. Ultra-reliable low-latency communication supports smart grids, real-time monitoring, and predictive fault management. EnBW has piloted 5G-based solutions for grid stability [9].

New roles include energy informatics specialists and infrastructure planners with 5G expertise. Ensuring resilience also requires cybersecurity professionals with knowledge of cyber-physical systems.

Healthcare

5G enables real-time diagnostics, mobile health units, and remote surgeries. Charité – Universitätsmedizin Berlin has used 5G to support mobile stroke units and telemedicine applications [10].

Emerging professions include remote patient monitoring specialists, medical cybersecurity experts, and engineers integrating 5G into healthcare devices and services.

Emerging Professions and Skills Demand

The cross-sectoral integration of 5G is generating roles such as:

- 5G Network Architects
- Edge AI Developers
- Industrial IoT Analysts
- Private Network Consultants
- Digital Ethics Officers

These require interdisciplinary skills spanning wireless tech, systems engineering, and data analytics. Germany faces a digital skills shortage, with an annual gap of over 100,000 ICT professionals [11]. Targeted training and reskilling will be essential.

Advanced 5G deployment in Germany is driving operational transformation and labor market evolution. Building a resilient, future-ready workforce will be crucial to realizing the full socio-economic potential of 5G and B5G technologies.

B2.3. Relevant Projects or Pilots

5G-Industry Campus Europe (5G-ICE)

Located in Aachen, the 5G-Industry Campus Europe is one of Germany's largest industrial 5G testbeds, operated by RWTH Aachen, Fraunhofer IPT, and Ericsson. It focuses on smart production, robotics, and real-time control using a private 5G standalone network [12]. The campus serves as both a research facility and a workforce training hub, testing AI, edge computing, and predictive analytics in live industrial environments.

5G-Testbed Hamburg Port Authority

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A leading urban testbed at the Port of Hamburg, developed with Deutsche Telekom, Nokia, and the Hamburg Port Authority, tests 5G-enabled logistics and public infrastructure via the EU's 5G-MoNArch project [13]. It demonstrated innovations like network slicing for smart traffic lights, environmental sensors, and drone navigation, underscoring 5G's role in urban resilience and port automation.

5G Smart Country / 5G Rural First

This rural pilot in Brandenburg explores 5G use in agriculture, healthcare, and municipal services, funded by BMDV and coordinated by Fraunhofer HHI [14]. Use cases include smart irrigation, drone crop analysis, and e-health services, helping reduce the urban–rural digital divide while building regional tech skills.

5G Berlin Initiative

5G Berlin is a public-private initiative involving TU Berlin, Deutsche Telekom, and the city government to pilot connected mobility and smart energy infrastructure [15]. One key project focuses on autonomous vehicles and V2X systems, creating demand for specialists in urban data engineering and network reliability.

5G Lab Germany

At TU Dresden, 5G Lab Germany partners with over 20 firms, including Vodafone and Bosch. The lab researches B5G topics such as tactile internet, massive MIMO, and real-time applications like AR/VR and autonomous drones [16]. It is also a major site for advanced telecom training.

CampusOS Initiative

Funded by BMWK and led by Fraunhofer Institutes, CampusOS develops open, modular 5G campus networks [17]. The project supports SMEs and promotes vendor-neutral infrastructure, driving expertise in Open RAN, edge orchestration, and cybersecurity.

TU Chemnitz 5G Testbed in Annaberg-Buchholz

In Saxony, the Smart Rail Connectivity Campus (SRCC)—a collaboration between TU Chemnitz, Annaberg-Buchholz, and Deutsche Bahn—is advancing 5G applications in rail mobility and regional development. This testbed uses a fully functional 5G standalone network along railway lines to trial ultra-low-latency communication for automated trains [18].

SRCC explores V2X protocols, condition monitoring, and resilient networks under diverse environmental and traffic conditions. It also supports training in transport informatics, rail cybersecurity, and mobile network engineering.

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B2.4. Stakeholders and Innovation Ecosystem

Telecommunications Providers

Major mobile network operators—Deutsche Telekom, Vodafone Germany, and Telefónica Deutschland—supply core 5G infrastructure and collaborate on industrial use cases.

Deutsche Telekom leads large-scale pilots like the Port of Hamburg and supports EU research (e.g., 5G-MoNArch) [19].

Vodafone Germany, partnering with TU Dresden, focuses on industrial connectivity and campus networks [20].

Telefónica Deutschland contributes to testbeds like 5G Berlin, emphasizing Open RAN and network slicing [21].

Universities and Research Institutes

Academic institutions shape Germany's applied 5G R&D.

RWTH Aachen and Fraunhofer IPT run the 5G-Industry Campus Europe for production tech and edge AI [22].

TU Dresden (5G Lab Germany) advances tactile internet and MIMO [23].

TU Chemnitz and the Smart Rail Connectivity Campus (SRCC) in Annaberg-Buchholz explore rural and rail use cases [18].

Fraunhofer Institutes (e.g., FOKUS, HHI) support modular testbeds and act as bridges between academia and industry [24].

Public Agencies

Federal and state agencies fund infrastructure and regulate deployment.

BMDV backs rural pilots (e.g., 5G Smart Country) and spectrum policy [25].

BMWK supports open campus networks (e.g., CampusOS) and SME participation.

BNetzA manages spectrum licensing for private 5G [26].

Start-ups and SMEs

Start-ups like EMnify and R3 Communications innovate in cloud-native 5G and low-latency systems [27]. SMEs contribute to testbed consortia, often through CampusOS or regional innovation hubs.

Industry Clusters and Alliances

Clusters like 5G-ACIA, Silicon Saxony, and its OWL align industrial needs with 5G standards and foster regional tech transfer [28]

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Germany's multi-actor 5G ecosystem balances infrastructure, research, regulation, and innovation. This coordinated model underpins industrial-scale, resilient 5G adoption.

B2.5. Policy Framework and Public Support

Germany's federal government has implemented a range of public policy instruments and funding schemes to support the industrial deployment of advanced 5G technologies, with increasing alignment toward green and sustainable digital infrastructures. These initiatives are framed within national strategies such as "Digitale Deutschlandstrategie 2025" and the High-Tech Strategy 2025, which recognize 5G and beyond (B5G) as key enablers for digital and ecological transformation.

One of the central instruments is the 5G Innovation Program, managed by the Federal Ministry for Digital and Transport (BMDV). Launched in 2019, this program provides funding for over 100 model regions, municipalities, and industrial partners to pilot private 5G networks, with a particular emphasis on applications in mobility, logistics, agriculture, and energy efficiency [29]. Projects such as 5G Smart Country and 5G Modellregion Kaiserslautern exemplify its focus on both technological advancement and environmental sustainability.

The "CampusOS" initiative, funded by the Federal Ministry for Economic Affairs and Climate Action (BMWK), promotes open and modular 5G campus networks to empower small and medium-sized enterprises (SMEs). It encourages vendor-neutral deployment and supports integration of energy-efficient components and edge-based processing for climate-friendly industrial use [30].

Additionally, the Environmental Innovation Programme and the Digital Now scheme provide financial incentives for companies that combine digital infrastructure upgrades with measurable ecological benefits, including reduced energy consumption through 5G-enabled process automation [31].

From a regulatory perspective, the Federal Network Agency (BNetzA) has made dedicated spectrum (3.7–3.8 GHz) available for private industrial 5G networks, facilitating localized and energy-optimized deployments in sectors such as manufacturing and utilities [32]. Moreover, Germany aligns its digital sustainability goals with EU directives, including the European Green Deal and the Digital Decade 2030.

Collectively, these instruments reinforce Germany's twin objectives of digital sovereignty and climate neutrality, positioning 5G as a foundational layer for sustainable industrial innovation.

B2.6. Readiness and Barriers

Germany demonstrates a high level of strategic and infrastructural preparedness for industrial 5G deployment, supported by a dense network of testbeds, proactive regulatory frameworks, and a robust industrial base. The availability of locally licensed spectrum (3.7–3.8 GHz) and the establishment of private campus networks have facilitated early adoption, particularly in the manufacturing and logistics sectors [33]. Leading industrial actors and research institutions have actively piloted use cases involving low-latency control systems, mobile robotics, and predictive maintenance [34].

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However, several critical barriers continue to constrain broader adoption. Cost remains a significant obstacle, especially for small and medium-sized enterprises (SMEs), which face high capital expenditure for network setup, spectrum licensing, and integration with legacy systems [35]. While public funding programs exist, access and administrative complexity often hinder SME participation.

Skills shortages represent another major challenge. A recent study by Bitkom indicates a growing demand for 5G-specific technical competencies—such as network slicing, cybersecurity, and edge computing—which are not yet widely available in the labour market [36]. The lack of interdisciplinary expertise further complicates the integration of 5G into traditional industrial processes.

On the regulatory front, although spectrum allocation is well-structured, concerns remain regarding long-term certainty, security standards, and interoperability. Fragmented compliance requirements across sectors also delay deployment [37].

Infrastructure gaps, particularly in rural and semi-urban industrial zones, limit consistent 5G performance, affecting sectors such as agriculture and energy. Additionally, awareness and strategic alignment among mid-tier firms remain limited, as many companies still view 5G as a future-oriented rather than immediately actionable technology [35].

B2.7. Sustainability & Green Innovation Linkage

Germany's deployment of 5G technologies is increasingly aligned with national and EU-level sustainability goals, particularly those targeting energy efficiency, carbon reduction, and the digital circular economy. 5G serves as a key enabler for green transformation across sectors by supporting real-time data flows, automation, and decentralized control systems.

In manufacturing, 5G enables smart factories where real-time monitoring and AI-driven process optimization reduce energy and material waste. Projects such as the 5G-Industry Campus Europe demonstrate up to 30% reductions in resource consumption through condition-based maintenance and adaptive production workflows [38]. This supports Germany's National Industrial Strategy 2030, which emphasizes climate-neutral production through digital innovation.

In the energy sector, 5G enhances grid flexibility and decentralized energy management, enabling real-time control of renewable inputs such as wind and solar. This contributes to Germany's Energiewende goals by improving the reliability of distributed, low-carbon grids [39].

5G also facilitates circular economy models. For instance, in logistics, 5G-enabled asset tracking and predictive maintenance extend equipment life cycles and reduce overproduction [40]. Moreover, 5G's support for digital twins allows continuous environmental impact monitoring throughout product life cycles, a key element of EU sustainable product policies.

However, 5G infrastructure itself poses energy challenges. To mitigate this, initiatives like CampusOS promote energy-aware 5G network design, including edge computing and power-efficient Open RAN components [41].

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Overall, 5G is increasingly viewed as a foundational infrastructure for sustainable digital transformation in Germany. Its integration into industrial and energy systems supports both resilience and climate neutrality objectives.

B2.8. Local Success Stories / Good Practices

Germany's 5G strategy has produced a range of sector-specific innovations beyond flagship testbeds. Two notable cases—one in rural mobility and another in green infrastructure—demonstrate the versatility of 5G applications.

5G Bavaria – Rural Mobility and Connected Agriculture

Spearheaded by the Bavarian Research Foundation, the 5G Bavaria initiative develops and tests rural mobility solutions in collaboration with Fraunhofer IIS and local industry. In Amberg-Sulzbach, autonomous shuttles and connected agricultural machinery were tested on public roads using 5G-enabled vehicle-to-everything (V2X) communication [42]. The initiative addresses both technological and regulatory barriers to rural connectivity, enhancing mobility, precision farming, and environmental monitoring. Early results show significant reductions in fuel usage and improved route efficiency, contributing to regional sustainability and digital inclusion.

Living Lab "5G Kaiserslautern" – Smart Building and Energy Management

Funded by the Federal Ministry of Transport and Digital Infrastructure (BMDV), the 5G Kaiserslautern Living Lab integrates 5G with building automation, smart energy systems, and IoT-based resource control [43]. The project involves the University of Kaiserslautern and regional energy utilities to create a 5G-based urban data infrastructure for near-real-time control of heating, lighting, and load balancing. Demonstrated reductions in energy consumption and enhanced data security highlight 5G's potential in achieving Germany's climate neutrality targets at the municipal level.

These projects exemplify Germany's distributed innovation approach and its commitment to embedding 5G in diverse socio-economic contexts.

B2.9. Additional Comments or Observations

Germany's approach to advanced 5G and green industrial technology is shaped by a combination of regulatory foresight, decentralized innovation ecosystems, and industrial policy alignment. One unique feature is the dedicated spectrum allocation for private 5G networks, allowing industrial firms—including SMEs—to operate localized networks tailored to their security, latency, and reliability needs [44]. This policy, introduced by the Federal Network Agency (BNetzA) in 2019, has accelerated the deployment of campus networks across sectors like automotive, chemicals, and machine tools.

Another distinctive factor is the integration of 5G with Germany's climate-neutral reindustrialization strategy, particularly through the High-Tech Strategy 2025 and GreenTech Innovation Strategy. These frameworks prioritize digital technologies as enablers of

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decarbonization, positioning 5G as critical infrastructure for green factories, energy-flexible manufacturing, and circular value chains [45].

Germany also benefits from a strong tripartite innovation model, linking industry, academia, and public institutions through applied research centres such as Fraunhofer, Helmholtz, and regional excellence clusters. Initiatives like CampusOS, 5G.NRW, and Smart Networks Germany foster collaboration between national and regional actors, enabling agile experimentation with Open RAN, network virtualization, and secure-by-design architectures [46].

Finally, Germany's emphasis on cyber-physical resilience—informed by its critical infrastructure protection frameworks—has driven a growing demand for secure, fault-tolerant 5G applications in areas like health, energy, and mobility. This makes the German 5G ecosystem not only technologically advanced but also deeply embedded in long-term sustainability and risk mitigation goals.

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B3. Spain

B3.1. National/Regional Strategy Overview

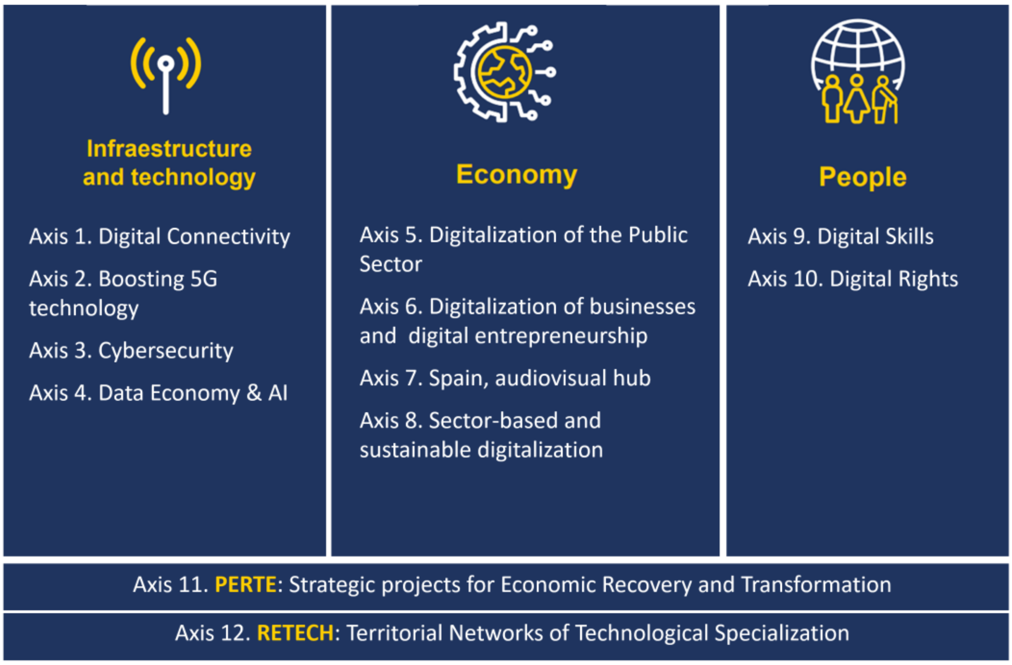

Figure 1. Three levers of the Digital Spain Agenda. Source [2]

Spain situates **5G as a cornerstone of *España Digital 2026***, its national roadmap for the twin **digital-and-green transition**. The dedicated **"Estrategia de Impulso de la Tecnología 5G"** commits to **full-population 5G coverage by 2030** and accelerates the rollout of **Standalone (SA) 5G** as the default architecture for industrial and public-service use cases.

Key strategic levers – visualised in **Error! Reference source not found.** – align **infrastructure, a doption incentives, and talent development so that 5G, AI, edge computing,** and future 6G research reinforce one another.

Coverage & Spectrum

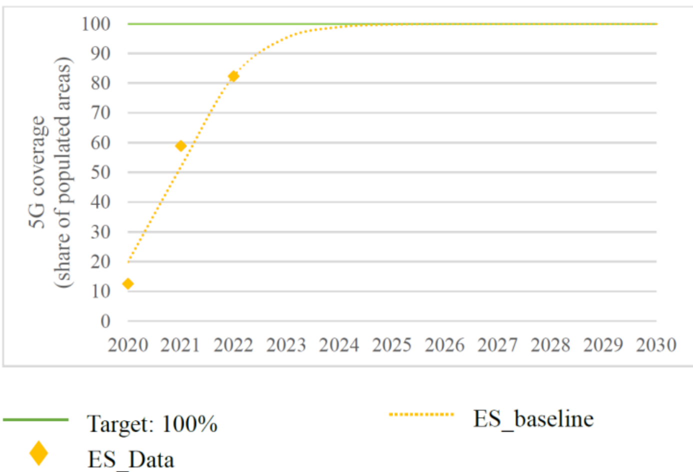

Figure 2. 5G rollout in Spain, historical data, and baseline trajectory towards 2030. Source [4]

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By 2024, Spain reached 92.3 % population coverage (68.9 % rural) and activated SA cores on the 700 MHz, 3.5 GHz, **and 26 GHz bands**. Shared-network models extend reach while preserving competition, and future auctions are reserved for underserved zones. Figure 2 charts the historical rollout and baseline trajectory to 2030.

Governance & Regulation

The **Ministry for Digital Transformation & Public Function** leads policy, with **SETID** managing spectrum and **CNMC** safeguarding competition. Spain's framework encourages **infrastructure-sharing**, embeds **digital-rights safeguards** (via the **Carta de Derechos Digitales**), and aligns with EU directives on AI ethics and cybersecurity.

Strategic Priorities (2024-- 2030)

- **Close the "adoption gap"** between near-universal coverage and still-low 5G traffic by stimulating B2B demand, ICT-skills programmes, and sector-specific ROI evidence.
- **Guarantee rural performance**, especially latency, through targeted UNICO-funding and backhaul upgrades.
- **Enable green transformation**, using 5G for **smart-grids, precision agriculture, and low-carbon logistics** while enforcing network energy-efficiency measures.

B3.2. Key Industry Sectors and Adoption Areas

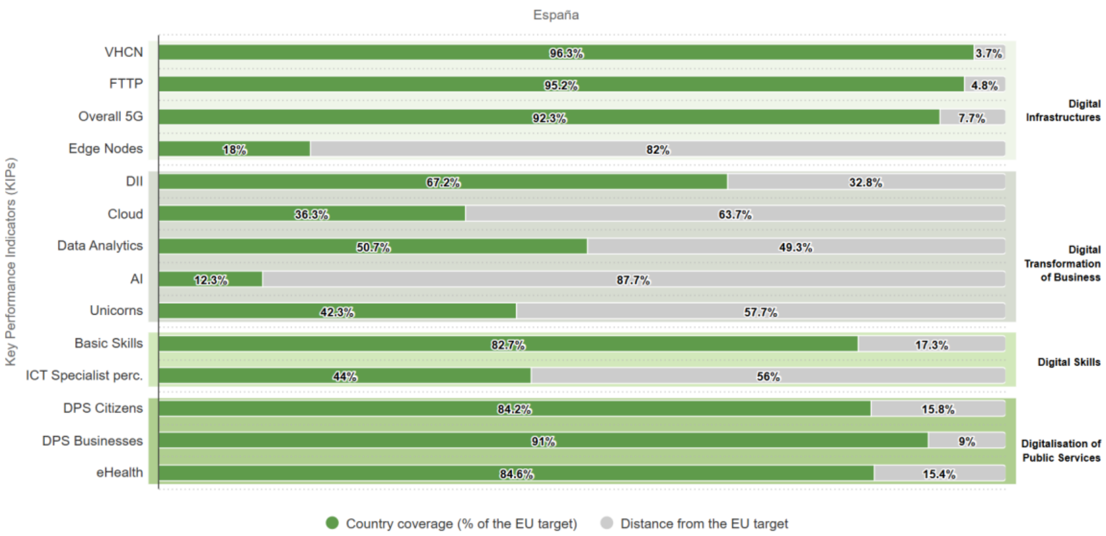

Figure 3. Observed Key Performance Indicators as a percentage of the EU target (2023). Source [1]

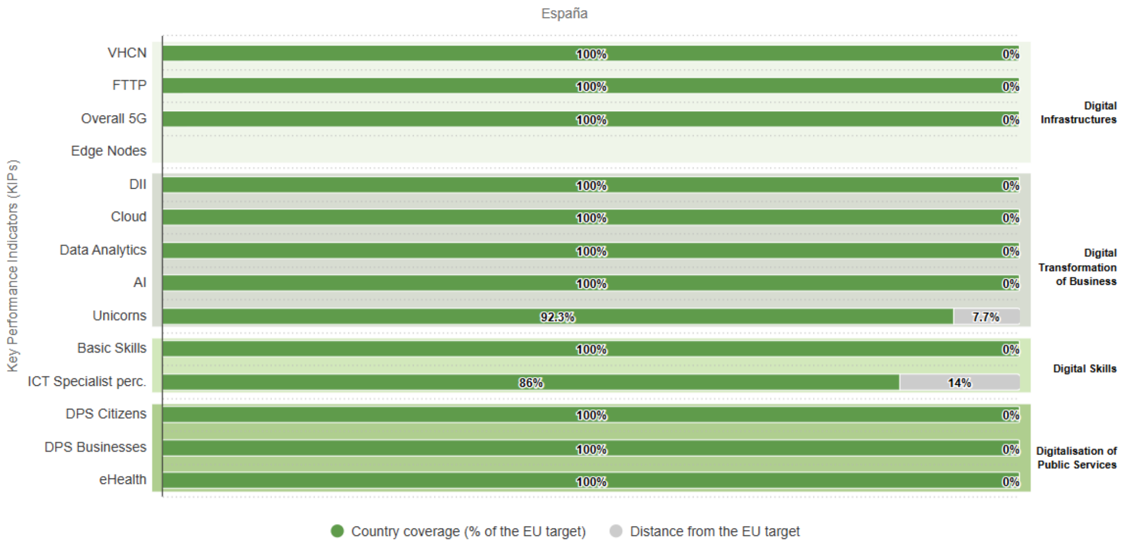

Figure 4. Observed Key Performance Indicators as a percentage of the EU target (2030 projection). Source [1]

Spain's near-universal 5G coverage has not yet translated into broad usage—only **2.4 % of mobile traffic ran over 5G in 2022, placing the country 25th globally**. Closing this "adoption gap" is therefore the top priority of *España Digital 2026*, which targets sector-specific ROI evidence, skills programmes, and demand-side incentives to lift enterprise uptake. Figure 3 and Figure 4 visualise current KPIs against EU targets and map each sector's transformation milestones.

Sector	5G/B5G Value Proposition	Illustrative Evidence
Manufacturing (Industry 4.0)	Digital twins, cloud-controlled AGVs, and collaborative robots on ultra-reliable, -low-latency links boost flexibility and cut wiring costs.	Automotive and appliance plants in **Navarra, Catalonia, and Castilla-La-Mancha run private SA networks for real-time** quality control and AGV fleets.
Energy & Utilities	Smart-grid automation and remote asset monitoring enable higher renewable penetration and faster fault response.	Iberdrola wind-farm telemetry and Endesa 5G-sensor substations demonstrate sub-10-ms protection schemes.
Agriculture & Agri-food	Precision farming with IoT soil sensors, drone imaging, and autonomous tractors lowers water and fertiliser use.	Remote-irrigation pilots near **Zaragoza** and drone-based vineyard monitoring in **La Rioja** report 20–30 % resource savings.
Logistics & Transport	Smart-port automation, fleet tracking, and predictive routing improve throughput and cut emissions.	5G-controlled crane tele-operation in Valencia port and real-time video for traffic management in **Madrid**.
Healthcare & Public Services	Mobile diagnostics, remote monitoring, and telesurgery expand care to underserved areas.	Telefónica's 5G medical-bus uploads CT scans from rural **Extremadura** to urban hospitals in seconds.

Tourism & Smart Cities	AR/VR visitor immersion and massive IoT city ops lift engagement and efficiency.	**Valencia's** AR tourism app drove a **77 % spike in 5G traffic during Fallas 2025**.

Early success in these verticals is reinforced by regional testbeds in **Madrid, Barcelona, Valencia, and Zaragoza, which provide shared sandboxes for SMEs, generate sector-specific playbooks,** and nurture local talent streams.

B3.3. Relevant Projects or Pilots

Spain is running a **geographically diverse portfolio of Stand-Alone (SA) 5G pilots** that target public services, industry 4.0, and rural inclusion. The selection below spans major urban, coastal, and rural zones in line with *España Digital 2026*.

Region / Site	Pilot Name & Lead Actors	Focus & Early Results
Madrid	**Real-Time Public-Safety Video Pilot** – Telefónica, Madrid Emergencias	5G SA uplinks stream 4K body-cam and drone feeds to the command centre with ≈25 ms end-to-end latency, improving incident awareness by +40 % and reducing response times by 18 %.
Barcelona	**Smart Logistics & Dynamic Transport Routing** – Mobile World Capital, TMB, Cellnex	Edge-hosted AI optimises bus and truck routes; 5G vehicle telemetry cuts downtown dwell time by 12 % during MWC 2025.
Valencia	**Smart-Port & AR Tourism Twin Pilot** – Valencia Port Authority, Telefónica	• **Port**: remote crane tele-operation and slice-secured IoT shaved container handling time by 8 %. • **City**: an AR festival app drove a **77 % spike in 5G traffic during Fallas 2025**, validating massive IoT crowd management.
Málaga (Andalusian Tech Parks)	**Industrial Automation Test Zone** – Ericsson, Dekra, Junta de Andalucía	Private 5G campus connects cobots and AGVs; early trials report 30 % wiring-cost savings and 25 % faster changeovers.
Zaragoza & Rural Aragón	**Precision-Agriculture & Remote-Irrigation Demo** – ITAINNOVA, Telefónica Tech	Soil-sensor IoT and drone imaging over SA 5G cut water usage by 23 % and boosted yields by 11 % across 1,200 ha of farmland.
Cross-regional (UNICO-backed)	**5G PPP & 5G Smart Communities Trials** – 5G PPP, Red.es	Rural SA roll-outs co-funded by UNICO 5G provide 95 % population coverage in target municipalities; trials align with EU 5G PPP vertical testbeds.

These pilots collectively:

- Cover **public safety, logistics, industry, tourism, and agriculture**, reflecting Spain's priority verticals.

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- Combine **public funding (UNICO, EU RRF) with private investment**, accelerating rural as well as metropolitan 5G utilisation.
- Provide **ROI evidence and talent pipelines** that directly support demand-side incentives under *España Digital 2026*.

B3.4. Stakeholders and Innovation Ecosystem

Spain's 5G/B5G landscape is driven by a **dense, multi-tier ecosystem that blends strong telecom incumbents with an unusually rich mix of research institutes, tech hubs,** and public-funding vehicles.

Layer	Key Players & Roles	Ecosystem Highlights
Telecom Operators & Infrastructure	**Telefónica (Movistar), Orange España, Vodafone Spain, Avatel-Xfera, and the new MasOrange JV anchor national coverage and co-invest** in rural SA rollout under the UNICO calls. Tower-co **Cellnex** provides neutral host sites for private & shared networks.	Operators received €669 m in UNICO 5G Redes Activas (2023-24) to light up > 2.1 m rural residents and 36,800 km of roads, ensuring public-private risk-sharing.
Public Agencies & Regulators	**Ministry for Digital Transformation & Public Function** (policy), **SETID** (spectrum), and CNMC (competition) give 5G a clear, pro-innovation rule-set, while **Red.es** administers EU & national grants.	Policies mandate infrastructure-sharing, embed the **Carta de Derechos Digitales,** and align with EU AI-security rules, creating both certainty and ethical safeguards.
Research Universities & Institutes	• **Universitat Politècnica de València (UPV)** – edge-IoT & SA core research, 5G-DiGITs member. • **ITAINNOVA** (Aragón) – precision-ag pilot lead. • **IMDEA Networks, CTTC, i2CAT, UPC** – EU 6G-SNS projects, Open RAN, and network-slicing labs.	Spain channels €60 m into 6G R&D, keeping academia-, industry labs plugged into the 6G-SNS and Hexa-X-II programmes.
Clusters, Testbeds & Tech Parks	**Mobile World Capital Barcelona/5G Barcelona**, **Málaga TechPark**, **Zaragoza Rail Tech Hub**, **Valencia Smart Port**, **Madrid 5G Lab**.	These hubs host open SA cores, edge-MEC nodes, and bonding with SMEs; the Barcelona & Valencia sites alone attract > 200 start-ups each year via 5G accelerator schemes.
Start-ups & SMEs	Growing pool in **edge-AI (Barbara IoT), smart-ag (Cubit), AR/VR (Visyon), network analytics (Amarisoft Ibérica)**.	Supported by regional **Digital Innovation Hubs** and **ENISA-backed venture funds** that prioritise 5G/green deep-tech.
International & EU-Level Links	Spain is active in **5G PPP/Smart Communities**, **UNICO**,	Cross-border pilots (e.g., Valencia Port's 5G slice

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	EU-RRF and **6G SNS**; Spanish sites lead work-packages in Hexa-X-II and BUILD-6G.	with Rotterdam) ensure Spain feeds back results to EU taxonomy and talent frameworks.

Ecosystem dynamics.

- **Public-private symmetry.** Robust UNICO and RRF grants de-risk rural build-outs while letting operators focus capex on SA cores and edge compute.
- **Academic-industry spill-overs.** UPV, ITAINNOVA, and Barcelona's i2CAT funnel PhD talent into start-ups and joint labs, closing Spain's "ICT-skills gap".
- **Cluster federation.** Tech-park testbeds share common APIs and KPI dashboards, so SMEs can port proofs-of-concept between regions, accelerating time-to-market.
- **Regulatory clarity.** SETID's spectrum roadmap and the **Carta de Derechos Digitales** give investors confidence that Spain can scale 5G ethically and competitively.

B3.5. Policy Framework and Public Support

Spain underpins its 5G roll-out with a **layered public-support model** that combines EU grants, national funding lines, and private co-investment.

	Budget (€M)
>>>> Digital Infraestructures and Connectivity Plan	**1.960**
>>>> Strategy for the promotion of 5G Technology	**1.514**
>>>> National Cybersecurity Plan	**1.000**
>>>> National Artificial Intelligence Strategy	**600**
>>>> Plan for the Digitalization of Spain´s Public Administration	**3.165**
>>>> SME Digitalization Plan	**5.000**
>>>> Spain Audiovisual Hub of Europe	**1.600**
>>>> National Plan for Digital Skills	**3.750**

Figure 5. Sectoral plans to boost digital transformation. Source [2]

Multi-level investment mix

- **EU Recovery & Resilience Facility (RRF)** earmarks **€680 m** for Stand-Alone (SA) 5G in rural zones lacking high-speed coverage.
- The national **UNICO 5G programme** funnels both grants and backhaul subsidies into underserved areas:
  - **UNICO 5G Redes Activas 2023** – €508 m → > 1.8 m residents, 30 000 km of roads.
  - **UNICO 5G Redes Activas 2024** – €161.3 m (second call) → 326,000 residents, 6,800 km of roads.

  - **UNICO 5G Redes Backhaul** – fibre to towns < 5,000 inhabitants, ensuring SA sites have gigabit links.

- Large-scale private commitment continues in parallel: the new MasOrange JV plans €4 bn capex (2024-- **26)** to densify 5G and fibre.

Demand-side incentives

Recognising the "adoption gap", Spain couples supply funding with **SME digitalisation vouchers, skills programmes, and sector playbooks** to stimulate business uptake and ROI evidence.

Regulatory & ethical levers.

- **Spectrum policy**—700 MHz + 3.5 GHz + 26 GHz—favours rural reach and industrial capacity, buttressed by mandatory **network-sharing** to lower costs.
- The **Carta de Derechos Digitales** embeds data-protection, algorithmic transparency, and human-centric AI into 5G rules, balancing innovation with trust.
- Oversight by **SETID** (spectrum) and **CNMC** (competition) gives operators clarity while keeping markets open.

Forward-looking public support

Spain channels **€60 m into 6G R&D** and aligns its funding calls with EU Digital Decade KPIs to ensure continuity from 5G-Advanced toward 6G.

B3.6. Readiness and Barriers

Spain combines **strong infrastructure readiness** with a **persistent usage gap**. On the supply side, operators have activated **Standalone 5G on 700 MHz, 3.5 GHz, and 26 GHz**, reaching **92.3 % population coverage (68.9 % rural)** by 2024, ahead of most EU peers. Progressive regulation (network-sharing, clear spectrum roadmap, digital-rights safeguards) and sizeable public funding (UNICO, RRF) further raise Spain's preparedness for industrial-grade 5G.

Yet real-world utilisation lags: **only 2.4 % of mobile traffic was carried over 5G in 2022**, placing Spain 25th worldwide. The main **barriers** behind this "adoption gap" are:

- **Limited cloud adoption (27 %)** – constrains edge computing, slicing, and other advanced services that monetise SA cores.
- **ICT-skills shortage** – a shortfall of network-engineering and cybersecurity talent slows enterprise integration of complex 5G setups.
- **Muted B2B demand & ROI uncertainty** – many SMEs still see 5G as a future upgrade rather than an immediate productivity lever.
- **Cyber-security concerns** – **98 % of Spanish firms** are deemed vulnerable to AI-driven threats, prompting cautious roll-outs.

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- **Residual rural latency issues** – despite coverage, higher round-trip times outside metros risk undercutting time-critical use cases such as remote surgery or autonomous logistics.

Mitigation actions are already in motion. *España Digital 2026* pivots public support from deployment to **demand-side incentives and skills programmes**, while a **€60 m 6G R&D push** keeps academia-industry labs focused on next-gen performance and security improvements. Success over the 2025-2030 window will hinge on:

- Scaling **sector playbooks** that quantify ROI for SMEs.
- Expanding **cloud and edge adoption**, especially among mid-tier manufacturers.
- Tightening **cyber-resilience frameworks** in line with the EU NIS2 directive.
- Continuing **latency optimisation** in rural cells via fibre backhaul upgrades and edge caching.

If these levers deliver, Spain should convert its infrastructure lead into **widespread industrial 5G uptake** well before the EU Digital Decade's 2030 deadline.

B3.7. Sustainability & Green Innovation Linkage

Spain frames 5G as a **dual-purpose climate tool**—cutting the network's own footprint while maximising its "handprint" across other sectors.

- **Greener networks by design.** Operators are deploying **AI-driven deepsleep modes and massive MIMO radios to curb RAN power draw, a practice Telefónica imported from pan-EU trials that cut radiounit energy use by up to 55 % at off-peak** hours. Dynamic energy-saving features are now a regulatory KPI under the national UNICO calls, supported by Spain's pledge to meet the EU target of **<10 kWh / TB by 2030**.
- **Decarbonisation enablers.** Low-latency SA 5G underpins smart-grid automation, digital-twin factories, **and V2X traffic smoothing**, helping utilities integrate renewables and logistics firms cut idle fuel use. The **SOGNO** and **5G-SmartGrid** pilots, in which Spanish labs participate, show double-digit line-loss reductions and faster fault isolation.
- **Twin digital-and-green transition.** Spain's agenda mirrors the wider **EU "Twin Transition"**—using pervasive gigabit/5G coverage as a lever for net-zero industry—and allocates RRF funds to projects that prove both digital and climate value.
- **Circular-economy push.** Telefónica and MasOrange have endorsed EU Right-to-Repair targets, launching **device-take-back schemes** and testing **modular radios** tracked via 5G IoT for reuse.
- **Emerging green-tech roles** include **Network-Energy-Optimisation Engineers, 5G-for-Smart-Grid Integrators, and Twin-Transition Strategists, blending RF, AI,** and sustainability reporting skills.

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B3.8. Local Success Stories / Good Practices

- **Valencia Smart-Port & Fallas AR app** – Remote crane operations cut container handling time by 8 %, while the festival app triggered a **77 % surge in 5G traffic**, offering a textbook case of tourism-plus-logistics synergy.
- **Zaragoza Precision-Ag Testbed** – SA 5G links soil sensors, drones, and autonomous tractors across 1,200 ha, lowering water use by 23 % and raising yields by 11 %.
- **Madrid Public-Safety Video Pilot** – 4K body-cam streams over 5G SA cuts emergency response times by 18 %.
- **Málaga Tech-Park Automation Zone** – Private 5G campus reports 30 % wiring-cost savings and 25 % faster production changeovers, a replicable model for SME-heavy industrial parks.

B3.9. Additional Comments or Observations

Spain's **infrastructure lead** (92 % pop-coverage, SA live since 2023) contrasts with its **usage lag** (2.4 % 5G traffic share). Bridging this gap will hinge on cloud adoption, SME-friendly ROI playbooks, and deeper cybersecurity resilience—areas already flagged in the 2024 Digital Decade Country Report. The government's pivot toward **demand-side vouchers and skills pipelines** suggests the policy mix is evolving from "build" to "benefit".

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B4. Ireland

B4.1. National/Regional Strategy Overview

Ireland is undergoing a significant digital transformation, with 5G positioned as a cornerstone for economic growth, innovation, and social inclusion. The Irish government has laid out a series of strategies to accelerate this digital shift.

Digital Connectivity Strategy

Ireland's Digital Connectivity Strategy 2023–2030 sets the tone for the country's digital ambitions over the next decade. More than just a roadmap for infrastructure, it defines connectivity as a national enabler of innovation, productivity, and inclusion. It commits to universal Gigabit broadband by 2028 and 5G coverage in all populated areas by 2030, aligning with the EU's Digital Decade targets.

In this context, 5G is seen not merely as a telecom upgrade, but as critical infrastructure for many areas from smart manufacturing to clean energy and digital public services, providing economic competitiveness, rural development, and sustainability. The strategy outlines how these goals will be achieved: through a mix of public-private investment, regulatory streamlining, and a coordinated national approach to spectrum, planning, and shared infrastructure.

This positions 5G as a key part of Ireland's wider transformation — not only in cities, but in rural and regional areas where digital exclusion has long been a barrier to opportunity. The strategy complements broader frameworks like Harnessing Digital, and together they create a policy ecosystem that connects infrastructure investment with real economic and societal outcomes.

Harnessing Digital: The Digital Ireland Framework

Ireland's national digital strategy, Harnessing Digital: The Digital Ireland Framework, launched in 2022, outlines the country's digital vision through to 2030. Structured around four pillars: enterprise digitalisation, digital infrastructure, digital skills, and digital public services, the strategy highlights how digital transformation must be inclusive, sustainable, and innovation-led.

Within this agenda, 5G is a core enabler. It's framed not just as a technology, but as a foundation for modernising Ireland's economy and public services, especially in areas like Industry 4.0, smart cities, sustainable mobility, healthcare, and rural innovation. The strategy stresses the importance of high-capacity, low-latency networks in unlocking these opportunities. It also encourages public-private collaboration, national policy alignment, and targeted investment incentives. This positions 5G as central to both economic competitiveness and long-term resilience, ensuring no region or sector is left behind.

Project Ireland 2040

Project Ireland 2040, updated in 2024, is Ireland's long-term strategic plan for spatial and infrastructure development up to 2040. It's made up of two interlinked frameworks (the National Planning Framework and the National Development Plan) and allocates €116 billion to public

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investment. Crucially, digital connectivity is treated on equal footing with physical infrastructure like roads, housing, and energy.

5G plays a strategic role in this vision, given that it recognises that high-quality mobile and broadband infrastructure are essential for regional balance, smart growth, and environmental sustainability. In particular, it supports targeted 5G and fibre rollouts to reduce urban–rural divides and enable regional hubs to grow. National Strategic Outcomes like “Enhanced Regional Accessibility” and “Strengthened Rural Economies and Communities” explicitly integrate digital infrastructure, framing 5G as necessary for achieving sustainable development, supporting remote work, and enabling innovation outside Dublin and other cities.

Our Rural Future

Ireland’s Our Rural Future: Rural Development Policy 2021–2025, launched in March 2021, places high-quality digital connectivity, including 5G, at the core of its rural revitalization agenda. It envisions robust broadband and mobile networks as essential for supporting remote work, learning, healthcare, and enterprise in smaller towns and villages. Recognizing the shift toward remote and hybrid work accelerated by COVID-19, the strategy specifically emphasizes expanding connectivity through initiatives like ConnectedHubs.ie, a national network of rural co-working hubs enabled by government support to foster local economic development.

While not naming 5G explicitly in every instance, the policy’s goal of “optimising digital connectivity for rural communities and enterprises” inherently supports the deployment of next-generation wireless technologies, including 5G, to bridge the urban–rural digital divide. By promoting shared digital infrastructure, co-working environments, and remote work infrastructure, Our Rural Future sets an enabling environment for 5G-powered smart agriculture, telemedicine, and local enterprise, reinforcing its alignment with broader digital and green objectives.

National Broadband Plan

The National Broadband Plan (NBP), launched in 2018 and updated in 2021, is one of Ireland’s most ambitious infrastructure projects. Its goal is to deliver high-speed fibre broadband to over 560,000 premises across 96% of the country’s landmass by 2026 (areas that wouldn’t otherwise be served by commercial operators). While fibre-first in its design, the NBP is a critical enabler for 5G deployment. The vast fibre rollout provides the backhaul needed to support 5G base stations, especially in rural areas where mobile densification would be difficult without public intervention.

By 2024, over 300,000 premises had been passed and nearly 1,000 Broadband Connection Points (BCPs) were active, mostly in schools, libraries, and community centres. The NBP aligns closely with Ireland’s broader digital policies, supporting the 2030 target of 5G in all populated areas. More than an infrastructure scheme, the NBP lays the groundwork for a digital ecosystem that includes 5G, making advanced services in health, transport, energy, and enterprise possible across all regions of the country. It reflects the clear national strategy to invest in foundational infrastructure to unlock future innovation, sustainability, and inclusion, enabling future smart services in agriculture, health, logistics, and energy.

B4.2. Key Industry Sectors and Adoption Areas

The rollout of 5G in Ireland is designed to empower a range of industrial sectors, each with distinct needs and innovation potential:

Manufacturing, Smart Manufacturing, and Industry 4.0

In the Irish context, manufacturing stands out as a particularly strategic sector for 5G adoption. Across the national policy landscape (especially in the Digital Connectivity Strategy), 5G is not presented solely as a telecommunications upgrade, but as a critical digital infrastructure enabling smart manufacturing. The emphasis is on how 5G supports core Industry 4.0 capabilities: automation, real-time monitoring, predictive maintenance, and digital twins, all of which require low latency, high reliability, and dense device connectivity.

This policy focus is reinforced in the Digital Ireland Framework (Harnessing Digital), where manufacturing is explicitly identified as a transformation priority. While consumer adoption of 5G has been modest (only 5% of Irish consumers were using 5G by early 2021), and 64% felt they didn't know enough about it, according to Deloitte, the industrial uptake tells a different story. In global studies, 65% of manufacturers consider 5G essential for improving operational efficiency, 56% expect gains in product quality, and 53% foresee higher machine productivity. Real-time quality control, cited by 61% as a top driver, is a clear example of where 5G adds direct value on the factory floor.

Ireland's strategies strongly align with these goals. They depict 5G-enabled manufacturing not only as a driver of competitiveness but also as a lever for regional development and sustainability. The use of 5G to interconnect sensors, robots, and production systems allows for faster, leaner, and more adaptive operations. It is a practical route for Irish industry to future-proof itself while contributing to national goals around balanced growth, innovation, and green transition.

Logistics and Mobility

Logistics and mobility represent another key area where 5G is poised to make a significant difference in Ireland's economic and social spheres. The government's Digital Connectivity Strategy and Harnessing Digital framework clearly identify smart mobility and intelligent transport systems as priority sectors to leverage 5G's ultra-reliable low-latency communication and massive device connectivity. These features are crucial for real-time vehicle tracking, fleet management, and dynamic traffic optimisation, which together boost efficiency and sustainability in the logistics sector.

According to Deloitte's research, while consumer awareness of 5G is still growing, with only 5% adoption as of early 2021, there is strong industry interest. For example, 62% of logistics companies globally expect 5G to improve supply chain visibility, and 58% anticipate reductions

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in delivery times thanks to connected and autonomous vehicles. This aligns with Ireland's Project Ireland 2040, which highlights transport and connectivity infrastructure as essential enablers of regional accessibility and economic inclusion. The strategy's emphasis on "Enhanced Regional Accessibility" is especially relevant here, as 5G can transform rural and peri-urban logistics, reducing bottlenecks and supporting last-mile delivery solutions.

The National Broadband Plan also underpins this sector's evolution by ensuring fibre connectivity can serve as a robust backbone for 5G networks even in less densely populated areas. This makes 5G-enabled logistics practical outside the main cities, supporting Ireland's ambition for balanced regional development. Moreover, by integrating 5G in mobility, Ireland can advance green transport goals through better traffic management, electrification, and shared mobility services, all contributing to a low-carbon future as envisioned in the country's broader sustainability frameworks.

Energy & Sustainability

The energy sector is emerging as one of the most critical beneficiaries of advanced 5G infrastructure in Ireland, especially in the context of decarbonisation, decentralised generation, and grid modernisation. The Digital Connectivity Strategy clearly highlights 5G's role in enabling smarter, more resilient energy systems. By supporting ultra-reliable low-latency communications and massive IoT device connections, 5G allows for real-time monitoring of distributed energy resources, intelligent demand-response systems, and predictive maintenance in renewable infrastructure.

This is particularly important in a country like Ireland, where wind energy already accounts for over 35% of electricity generation. The integration of small-scale solar, wind, and battery storage into the grid requires next-gen communications to coordinate multiple energy sources across wide geographic areas. As laid out in Project Ireland 2040 and Harnessing Digital, digital infrastructure is not a separate pillar but a necessary backbone for energy transition. The synergy between 5G roll-out and Ireland's sustainability goals is clear: smarter grids are only possible with dense, responsive, and secure connectivity.

Moreover, Harnessing Digital identifies "smart energy" as a key innovation driver. 5G enables remote sensor networks for better energy efficiency in industrial facilities, commercial buildings, and smart homes, making it central to both climate action and competitiveness. It's not just about upgrading networks—it's about future-proofing Ireland's energy resilience while unlocking new green growth opportunities.

Healthcare & Telemedicine

Ireland's digital strategy sees healthcare not only as a public service to digitalise, but as a high-impact sector where 5G can deliver transformative results. Both Harnessing Digital and the Digital Connectivity Strategy point to health innovation—especially in rural settings—as a priority area for next-gen connectivity. 5G is uniquely suited for telemedicine, real-time diagnostics, mobile clinics, and wearable health monitoring systems, all of which rely on ultra-low latency and secure data flows.

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This is particularly urgent in the context of rural healthcare access. Our Rural Future document calls for expanded digital health services and sees connectivity as a critical tool for reducing inequalities between urban and rural populations. Although the document doesn't always mention 5G by name, its emphasis on "high-quality mobile and broadband" as foundational infrastructure makes it clear that wireless innovation is part of the policy's core vision.

The pandemic fast-tracked acceptance of remote healthcare delivery, but its long-term effectiveness depends on the kind of capacity 5G offers. For instance, high-definition video consultations or remote surgery support require bandwidth and reliability far beyond 4G or DSL. As of 2024, over 1,000 Broadband Connection Points (BCPs) have been deployed across Ireland, many in public health centres and community hubs, serving as early enablers for this shift. With the groundwork being laid by the National Broadband Plan, full 5G integration can now bring healthcare access and quality to an entirely new level.

Agriculture and Rural Industries

Agriculture is another sector where 5G adoption is not beneficial. In Ireland, rural industries represent both a cultural backbone and a key economic contributor. Strategies like Our Rural Future and the Digital Connectivity Strategy acknowledge that bringing next-generation connectivity to farms, fisheries, and rural enterprises is fundamental to ensuring long-term viability and competitiveness.

5G enables precision agriculture, including automated irrigation systems, soil sensors, drone monitoring, and livestock tracking. These technologies improve productivity, reduce environmental impact, and make data-driven farming a reality even in remote regions. According to the Harnessing Digital – Progress Report 2024, Ireland continues to prioritise support for smart farming under the broader EU digital transition, and 5G is highlighted as essential infrastructure to scale those innovations.

The National Broadband Plan further supports this transformation by rolling out fibre backhaul to areas that commercial operators have historically neglected. With over 560,000 premises targeted—many of them farms or rural homes—this backbone makes it economically feasible for telecom providers to roll out 5G coverage in regions previously off the digital grid. When combined with rural co-working hubs and innovation spaces promoted through ConnectedHubs.ie, 5G deployment can radically transform not just how farming is done, but also how rural businesses connect, trade, and grow.

B4.3 Relevant Projects or Pilots

Ireland has initiated several 5G-focused projects that serve as testbeds for innovation:

Dublin Docklands 5G Testbed
Led by Dublin City Council, this project explores 5G applications in smart lighting, environmental monitoring, and data-driven public service management. It serves as a living lab to test next-generation urban infrastructure solutions and supports collaboration with tech companies and academic institutions.

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CONNECT Research Centre
Based in Trinity College Dublin, this SFI-funded centre partners with industry and government to explore 5G and beyond. It focuses on network innovation, spectrum efficiency, and IoT applications relevant to sectors like health, agriculture, and mobility.

Irish Manufacturing Research (IMR) facility in Mullingar
Vodafone and IMR launched a 5G Standalone private network for testing advanced Industry 4.0 use cases: automated production, robotics, IoT sensors, and AR/VR applications.

Confirm Centre (University of Limerick)
This wireless testbed uses 5G (plus 6G/Wi-Fi 6) to trial smart factory tech. In late 2020, they demonstrated robotic control over 5G (the first of its kind in Ireland), highlighting potential for wireless flexibility in precision manufacturing
Such initiatives position Greece as a regional leader in 5G innovation, fostering collaboration between industry, academia, and government.

Technological University of the Shannon (TUS), Athlone
Collaboration with Three Ireland, Ericsson, and Samsung has established a 5G Standalone testbed supporting "smart agriculture" pilots. For instance, the iTarra autonomous tractor from Roscommon uses real-time soil data via 5G to optimise fertiliser and includes safety overrides if humans enter the field.

TSSG (WIT) Agricultural Sensor Project
Researchers are testing farm-grade IoT devices such as leg-mounted sensors on cows in order to detect early signs of lameness and track general welfare, ensuring productivity and compliance, supported by 5G network trials.

B4.4. Stakeholders and Innovation Ecosystem

Ireland's 5G innovation ecosystem is driven by a mix of public agencies, telecom companies, academic institutions, start-ups, and civil society.

Government agencies

- *Department of the Environment, Climate and Communications (DECC):* Leads the Digital Connectivity Strategy.
- *ComReg:* Manages spectrum allocation and monitors compliance with safety and performance standards.

Telecom Providers

- *Three Ireland*: Claims the most extensive 5G network, focusing on coverage in both cities and rural areas.
- *Vodafone Ireland*: Focuses on quality of service and enterprise partnerships.
- *Eir*: Expands 5G as part of its fiber and mobile convergence plans.

Academia and Research

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- CONNECT at Trinity College
- Insight Centre for Data Analytics (UCD, NUI Galway): Partners in data-intensive 5G applications.

Industry and Start-ups

Focus on 5G deployment supported by Enterprise Ireland:

- *Benetel:* designs O-RAN–compatible 5G radio units, essential for flexible, multi-vendor network architectures. They've been showcased at Mobile World Congress alongside Enterprise Ireland in 2019, demonstrating capabilities for both rural connectivity and smart city scenarios.
- *Alpha Wireless:* manufactures 5G antenna systems, including concealed small cells for street furniture like lighting poles. As part of the Enterprise Ireland delegation at MWC 2019, they emphasised aesthetics and performance—aligning with smart infrastructure goals in Ireland's digital framework

B4.5. Policy Framework and Public Support

Strategic Policies

- Digital Connectivity Strategy (2023–2030): Provides €2 billion funding for 5G and broadband infrastructure.
- Harnessing Digital: Integrates 5G into wider digital public service reform and private sector productivity.
- National Broadband Plan (NBP): Although fiber-centric, it complements 5G by increasing backhaul access.

Public Investment and Grants

- Project Ireland 2040 infrastructure investment supports telecom and connectivity deployment.
- Enterprise Ireland and IDA Ireland offer innovation grants for companies piloting advanced tech like 5G.

Regulatory Support

- ComReg spectrum auctions (700 MHz, 3.6 GHz) have enabled telecoms to deploy 5G strategically.
- Planning permissions and mast development are streamlined under national development plans, though not without public resistance.

B4.6. Readiness and Barriers

Readiness

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Ireland shows medium-to-high readiness for industrial 5G:

- Around 84% of the population are being covered by 5G since 2022.
- The number of mobile connections in Ireland increased by 117 thousand (+2.2 percent) between the start of 2024 and the beginning of 2025.
- Strong digital public services and digital skills base.
- Regulatory and funding frameworks are in place.

Barriers

- Low Public Awareness: According to Deloitte (2023), 64% of Irish consumers don't understand what 5G does.
- Device Compatibility: Many users still rely on non-5G smartphones.
- Infrastructure Challenges: Small-cell deployment in dense urban and rural areas is costly.
- Planning Opposition: Communities sometimes oppose mast installations due to visual and health concerns.
- Skills Shortage: Advanced networking and industrial automation skills are in short supply.

B4.7. Sustainability & Green Innovation Linkage

5G plays a role in Ireland's sustainability goals, supporting green industrial transformation:

- **Smart Energy Systems**: 5G enables the real-time control of smart grids, supports efficient distribution of renewables, and integrates with home and commercial energy management systems.
- **Reduced Emissions in Transport**: Through 5G, smart traffic systems, e-mobility coordination, and autonomous vehicles can significantly reduce congestion and emissions.
- **Industry Efficiency**: In manufacturing and logistics, 5G allows for leaner, more efficient production systems, reducing waste and energy consumption.
- **Green Digital Policies**: All national strategies—Digital Connectivity, Harnessing Digital, Project Ireland 2040—emphasize the green potential of digital infrastructure.

B4.8. Local Success Stories / Good Practices

Three Ireland's 5G Expansion

As the first operator to launch 5G in 2020, Three has expanded its coverage to 121 locations, including smaller towns and rural areas. This supports digital inclusion and gives SMEs access to modern infrastructure.

Dublin Smart Docklands

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A successful example of a smart urban testbed, the project is notable for multi-stakeholder collaboration. It has allowed testing of 5G-powered air quality sensors, crowd management, and smart lighting, showing the public benefit of tech-driven urban design.

B4.9. Additional Comments or Observations

Ireland's 5G trajectory reflects a balancing act between technological ambition, regulatory maturity, and public engagement. While progress is evident, especially in policy coherence and network coverage, adoption by both consumers and industry lags behind infrastructure readiness.

Opportunities lie in leveraging 5G for economic decentralisation—making rural Ireland more viable for remote work, smart agriculture, and local entrepreneurship. However, unlocking this potential will require increased public education, strategic investments in digital literacy, and stronger alignment between private and public stakeholders.

Finally, the integration of 5G with emerging technologies, such as AI, edge computing, and digital twins, will define Ireland's next leap forward. For this, an agile, inclusive, and green 5G ecosystem is essential.

B4.10. Resources/References

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B5. Lithuania

B5.1. National/ Regional Strategy Overview

- GUIDELINES for the development of fifth-generation mobile communications (5G) in the Republic of Lithuania for 2020–2025 were approved by Resolution No. 577 of the Government of the Republic of Lithuania of June 3, 2020. The guidelines set out the stages of 5G communication development, identified and defined technical, legal, and organizational measures, the implementation of which would create favorable conditions for the deployment and development of 5G communication in Lithuania.

- At its meeting on 21 June 2023, the Government of the Republic of Lithuania recognised the development of fifth-generation mobile communications (5G) as a project of national importance. The status of a project of national importance creates conditions for the sustainable development of electronic communications infrastructure, i.e. allows for faster and more efficient preparation of territorial planning documents and implementation of planned communications infrastructure solutions. The granting of the status of a project of national importance is part of the agreement (memorandum) "On the implementation of 5G communication in Lithuania", signed on October 12, 2021 between the Ministry of Transport and Communications, the Lithuanian Association of Municipalities, the Communications Regulatory Authority, JC LAKD, VšĮ "Plačiajuostis internetas", JC "LTG Infra" and mobile operators Telia Lietuva, "Bitė Lietuva", "Tele2", to which 39 Lithuanian municipalities also joined. THE PURPOSE OF THE MEMORANDUM is to ensure the effective and coordinated development of 5G communications, including uninterrupted 5G communications in the international transport corridors "Via Baltica" and "Rail Baltica", and the availability of electronic communications networks capable of ensuring a connection speed of at least 100 Mbps to at least 95 percent of Lithuanian households. IMPLEMENTATION OF THE MEMORANDUM – the Signatory Parties agree that: 1) The Ministry of Transport and Communications, in order to accelerate the development of electronic communications infrastructure throughout the territory of Lithuania, will seek to grant the status of a project of national importance to the development of 5G communication in Lithuania; 2) Bitė, Tele2, Telia and other 5G communication service providers that have signed the Memorandum (hereinafter referred to as the Operators) will cooperate with the Ministry of Transport and Communications in preparing the necessary documents and will provide information to substantiate the importance of this project; 3) The Association of Lithuanian Municipalities and the municipalities joining the Memorandum will cooperate with the Operators and other Signatory Parties and will seek to create favorable conditions for the development of 5G communication in order to ensure reliable 5G connection for local residents and businesses; 4) LAKD and LTG Infra will cooperate with Operators and other Signatories to ensure reliable and uninterrupted 5G connectivity on international transport corridors and other national roads, railways and their stations; 5) The Signatories, within their competence, will strive to ensure the availability of a connection with a speed of at least 100 Mbps by 2025 to at least 95 percent of households in the country.

- On March 31, 2025, the Communications Regulatory Authority of the Republic of Lithuania announced the development goals for broadband mobile communication networks until 2030, presented the nearest plans for frequency auctions. The plan

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provides for the following main indicators of service availability and quality: by the end of 2027 - to ensure a connection speed of at least 30 Mb/s in built-up areas for all households; by the end of 2028 - a speed of at least 100 Mb/s for 95 percent of households in "white zones" (areas where there are no or no commercial investments in high-speed connections); by the end of 2030 - a speed of 100 Mb/s in settlements with more than 200 residents. To achieve these goals, the Communications Regulatory Authority plans to organize auctions of the 700 MHz, 1500 MHz and 2100 MHz radio frequency bands in 2025. The auction of the 2600 MHz and 800 MHz frequency bands, combined with the 2300 MHz frequency band, is planned for 2030, after updating the development goals and taking into account the connectivity policies of Lithuania and the European Union. It is expected that additional frequency resources, together with next-generation (5G and higher) technologies, will help ensure higher-quality communication services.

B5.2. Key Industry Sectors and Adoption Areas

In order to ensure a smooth, economically justified and effective development of 5G communication, it is planned that 5G communication in Lithuania should be launched in 2021 and developed throughout the territory of the state, starting with the largest cities and strategic state facilities. By 2025, it is planned to cover the most important land transport corridors and urban areas with ultra-fast mobile communication. It is aimed that 5G communication should first be developed (commercial 5G communication services have been started): 1. by 2022 in at least one of the five largest cities in the Republic of Lithuania by population – Vilnius, Kaunas, Klaipėda, Šiauliai or Panevėžys; 2. by 2023 in the five largest cities in the Republic of Lithuania by population; 3. by 2025 in urban areas, international land transport corridors ("Via Baltica", "Rail Baltica") and other main roads and main railway lines of national importance, airports and seaports.

5G Integration in the **Lithuanian Construction Sector**. The construction sector has long been one of the least digitized, but 5G technologies open up new opportunities to modernize this area. The main applications of 5G in the construction industry: Remote construction site monitoring: 5G connectivity allows for real-time transmission of high-quality video from the construction site. This allows project managers, architects and engineers to monitor the construction process remotely, respond quickly to emerging problems and make decisions. Real-time coordination of work: 5G connectivity ensures smooth transmission of large drawings, 3D models and other data between the construction site and the office. This reduces the likelihood of errors and improves team communication. Augmented reality (AR) integration: Construction workers wearing AR glasses can see virtual drawings superimposed on a real structure. 5G ensures that this data is transmitted without delays, and the images are detailed and accurate. Remote control of construction equipment: 5G connectivity allows construction equipment to be controlled from a safe distance. This is especially important when working in hazardous areas where it is unsafe for a person to be. Ensuring worker safety: Smart helmets and other wearable devices can transmit information about the location of workers, their health status and potential threats. The application of such solutions allows construction companies to save time and money, reduce the likelihood of errors and improve occupational safety.

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5G application in the **Lithuanian manufacturing sector**. In the manufacturing sector, 5G technology is becoming one of the main engines of Industry 4.0, enabling advanced automation, robotization, and flexible manufacturing systems. Key 5G application areas in the manufacturing sector: Flexible manufacturing infrastructure: 5G allows for the creation of a wireless manufacturing infrastructure that can be easily reconfigured according to changing needs. This reduces investments in cables and ensures a flexible machine layout. High-level automation: Due to the extremely low signal delay (1 ms), 5G allows for precise coordination of the actions of robots and automated systems in real time. Remote equipment control: Production equipment can be controlled remotely, monitored for its operating parameters, and respond promptly to failures or other problems. Real-time quality control: High-resolution cameras and sensors connected to the 5G network can perform real-time product quality control using artificial intelligence. Big data analytics: 5G enables the collection and analysis of vast amounts of data from manufacturing processes, which helps optimize production, predict failures, and reduce downtime. Manufacturing companies that implement 5G technology can achieve significant efficiency gains, reduce production costs, and improve product quality.

B5.3. Relevant Projects or Pilots

The Communications Regulatory Authority of the Republic of Lithuania (CRAT), in order to assess the quality of electronic communications services, conducted 218 thousand measurements of mobile Internet access indicators in 2024. Mobile communication parameters were measured while driving in a car and in a passenger train carriage.

The summarized results show that the average Lithuanian data reception speed in the Telia network reached 250.9 Mb/s, in the Tele2 network – 176 Mb/s, in the Bitė network – 147.2 Mb/s. Compared to the previous year, almost a 35 percent growth in data reception speed was recorded.

The main factor in the growth of data reception speed was the implementation of 5G technology in operator networks: the average data reception speed of 5G technology in the Telia network reached 385.6 Mb/s, in the Tele2 network – 357.3 Mb/s, and in the Bitė network – 298.7 Mb/s. The influence of this technology on data reception speed is especially noticeable in cities – according to measurements carried out in the territories of 5 major Lithuanian cities, the average reception speeds ranged from 211.7 to 436.5 Mb/s, depending on the operator.

“5G technology can ensure significantly higher internet data transmission speeds for a larger number of users; therefore, the average mobile internet speed directly depends on how communication operators develop the 5G communication network,” comments Jūratė Šovienė, Chairwoman of the CRAT, on the results of the study.

According to the data provided by the operators, in November 2024. The number of registered 5G base stations in the Telia network was 1,577, in Bitė– 696, in the Tele2 network – 396 5G base stations.

However, the data shows that in remote areas away from large cities, the 5G network is much less developed, and the differences in speed are extremely pronounced: for example, in Panevėžys city, the average speed reaches 347 Mb/s, while in the county – only 170.4 Mb/s; in Vilnius city – 297.3, and in the county – only 194.4 Mb/s.

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The average data acquisition speed, calculated based on measurements on railways, in 2024 ranged from 91.3 to 136.4 Mb/s, depending on the operator. Although it has increased compared to the indicators of 2023, there were also sections where the connection conditions significantly deteriorated or the provision of mobile Internet access service was interrupted altogether.

"In order to implement the goals of Lithuania's broadband development and 1Gb/s connectivity for all by 2030, it is necessary to accelerate the development of the 5G network. The Communications Regulatory Authority of the Republic of Lithuania encourages mobile operators to increase investments in communication infrastructure and expand network coverage not only in major cities, but everywhere where there is a need to use fast and reliable internet connectivity. It is also important that state institutions and municipalities reduce bureaucratic obstacles that complicate the implementation of new projects - permit issuance processes often take several years, limiting the possibilities to develop base stations or fiber-optic networks. In order to achieve more efficient infrastructure development, it is necessary to coordinate the development of communication networks with transport, energy, and urban planning strategies," reminds J. Šovienė.

- Development of a product for optimizing and managing risks and resources of 5G vehicles and their swarms (5G-FARRO). Total eligible costs of the project € 3,209,324,70. The aim of this project is to create the product 5G-FARRO, which is an integral part of the 5G transport system, without whose functionality, effective 5G transport cannot be created or function reliably and safely. This project contributes to the Transport Development Program of the Ministry of Transport and Communications of the Republic of Lithuania, Progress Measure No. 10-001-05-04-01 "Increasing the value created by the transport system and the efficiency of infrastructure use". The 5G-FARRO product will be used throughout the life cycle of 5G vehicles, in order to increase their added value and competitiveness. The use of this product will also aim to ensure the safety and reliability of 5G vehicles from their development to operation, by monitoring 5G vehicles remotely, which requires 5G low data latency, fast large data transmission, high reliability, and precise location functionalities.

B5.4. Stakeholders and Innovation Ecosystem

- Lithuania's Ministry of Transport and Communications (Susisiekimo ministerija) oversees Lithuania's digital connectivity policy. Its responsibilities include steering the development of broadband infrastructure, coordinating actions, and monitoring implementation—particularly in areas with limited availability or lacking competition among service providers. Within this framework, the Ministry also serves as the country's Broadband Competence Office.

- The State Digital Solutions Agency (Valstybės skaitmeninių sprendimų agentūra) under the Ministry of Transport and Communications is participating in the process of shaping state policy in the development of information and communications technologies in Lithuania and coordinating its implementation.

- Public Enterprise Plačiajuostis Internetas (Broadband Internet) is a non-profit entity owned by the Ministry of Transport and Communications and is responsible for the implementation of the national digital connectivity strategy. Plačiajuostis Internetas

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manages the national wholesale backhaul fibre network, functioning as a wholesale provider. It grants equal access to all retail operators, allowing them to deliver high-speed internet services to households, businesses, and public as well as private institutions—such as municipalities, schools, libraries, and hospitals—across Lithuania's rural areas.

- The Communications Regulatory Authority (Ryšių reguliavimo tarnyba) is the independent national regulatory institution that monitors and regulates Lithuania's digital connectivity markets.

B5.5. Policy Framework and Public Support

The state supports the development of digital communication networks in rural areas, which are unattractive for private investors using various funds (ERDF, EAFRD, EGADP) to build ultra-high-bandwidth networks in remote areas.

The Lithuanian Economic Recovery and Resilience Plan supports the digital transformation with EUR 73 million in reforms and investments in connectivity to further develop the deployment of ultra-high-bandwidth networks, including 5G and fiber-optic infrastructure, in rural and remote areas.

The investment project "High-speed communication infrastructure" aims to connect 5,000 areas to gigabit speeds in areas where these services would not be provided on a commercial basis. The follow-up project plans to ensure ultra-high-speed digital connectivity for 14,909 households, 1,348 enterprises, and enable 138 electronic communications service providers to use the infrastructure created during the project.

Key measures for the digital transition. Lithuania's Recovery and Resilience Plan allocates significant resources to the digital transition through a mix of reforms and targeted investments. Around €73 million are directed to strengthening connectivity by expanding very high-capacity networks—both fibre and 5G—particularly in rural and remote areas. An additional €282 million is devoted to the digitalisation of the public sector, alongside initiatives to improve digital skills for diverse groups such as children, employees, civil servants, and older citizens, while also tackling the shortage of IT specialists in the labour market. The plan also promotes the uptake of advanced digital technologies in the private sector, for example, by supporting science–business collaboration and digital innovation in cultural industries. A further €103 million is earmarked for the creation of innovative digital tools, including language-specific solutions for Lithuanian, to ensure universal access to digital resources and foster the development of new technologies, services, and products across research and business communities.

B5.6. Readiness and Barriers

Infrastructure development in Lithuania is hampered by bureaucratic barriers. Publicly owned properties are rarely accessible for the construction of communication towers, road and railway managers restrict cable laying, and cultural heritage protection institutions consider antennas to be visual pollution. Only a few contracts have been signed during the year since the law was implemented, which was supposed to encourage easements.

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The Communications Regulatory Authority sought to find out why the development of fiber-optic networks in Lithuania has stalled and interviewed service providers. Among the 7 main obstacles to building new gigabit networks were the lack of appropriate infrastructure or obstacles posed by landowners, the lack of information about planned construction, and obstacles to obtaining permits. Other reasons include the remaining territories with low population density, low purchasing power of the population, no demand for broadband services, and buildings not adapted for building networks.

What measures could accelerate the development of gigabit networks? According to J. Šovienė, one of them is to improve the laws and by-laws of the Republic of Lithuania by removing unjustified administrative and technical obstacles. In order to achieve faster and more efficient development of gigabit communication, it is necessary to make communication cables or channels for their installation an integral part of road, street, and railway infrastructure. It is no less important to improve the Topography and Engineering Infrastructure Information System (TIIS) so that all information about infrastructure development plans is easily presented and accessible.

"If we want the name of Lithuania to be associated with digital progress in Europe again, we must change our approach to infrastructure. The development of fiber-optic networks must become a state priority, and not the subject of insoluble disputes between individual communication service providers, land owners, and road managers. Only in this way will we be able to ensure that digital communication becomes a competitive advantage for Lithuania, and not a brake," says the Chairperson of the Communications Regulatory Authority.

Lithuania continues to face several **digital challenges**. The rollout of 5G has been slower than planned, and the gap between urban and rural broadband infrastructure remains substantial. At the same time, digital skills across the population are relatively low, the supply of ICT professionals is insufficient, and many SMEs and start-ups show only limited progress in adopting advanced technologies and digitalisation practices.

B5.7. Sustainability & Green Innovation Linkage

The possibilities of the 5G network are not limited to faster browsing, the opportunity to enjoy new gaming experiences, and other things that make everyday life more fun and smooth. The potential of 5G technology is much greater. With the help of technology, opportunities open up to lay the foundations for a sustainable future.

"Digitization is not valuable in itself; it must be filled with content. 5G technology provides the existing digital infrastructure with greater capacity, reliability, and efficiency. This opens up opportunities for innovation and a new way of working for companies and society as a whole. Some new opportunities we can already imagine today, some we cannot yet," says Indrė Bimbirytė-Yun, Sustainability Project Manager at Telia* (one of the largest mobile operators in Lithuania).

More data – more accurate insights

One of the most important questions is how digitalization can encourage the development of a greener, safer, and more engaged society? When it comes to sustainable resource use and

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management, it is important to mention the Internet of Things and big data – using all of this, we can already connect all infrastructure, such as buildings, roads, electricity grids, and water pipes.

As the number of sensors, actuators, systems, and data grows, the current 4G capacity will simply not be enough – this is where 5G comes in, which was first and foremost designed with things in mind and how they will communicate with each other. So with 5G we will be able to connect even more things, and the data collected will allow us to make more informed decisions, help us manage, optimise, and automate processes more intelligently.

New opportunities for both cities and regions

From an environmental perspective, such management will mean smarter use of natural resources. Using the data collected, it will be possible, among other things, to control and optimise energy and water supplies, as well as use less fossil fuels through smart transport.

New services and opportunities will open up not only in cities: 5G technology can also be of significant use in more remote areas, contributing to reducing the differences between cities and regions.

“Various services are not equally accessible in rural areas and cities. For example, the distance to healthcare or educational institutions is usually greater in less populated areas, and it is also more difficult to find a job there. Digitalization creates conditions to reduce these distances and increase the availability of necessary services,” says I. Bimbirytė-Yun.

From healthcare to education

Remote healthcare is one of the areas in which 5G technology will help reduce the aforementioned differences. The high speed of the 5G network means that doctors will be able to not only consult patients in real time, but also provide them with assistance while being in a completely different location. It will also be possible to set up mobile medical or screening points - this has already been tested by Telia and Ericsson in Sweden, where a 5G-connected bus with mammography equipment traveled in one region.

Unmanned drones can also be used, for example, to urgently deliver a defibrillator or other emergency aid to hard-to-reach places while an ambulance is waiting.

The same unmanned aircraft can also be used in other areas, for example, to detect forest fires before they spread. Or to manage a farm more efficiently and accurately: to control pests, water, spray and otherwise care for crops.

There are also great opportunities for the development of the education system. Using digital tools and fast and reliable connections, more people will be able to learn remotely, and by moving lectures and lessons online, the need to physically go to an educational institution will decrease.

B5.8. Local Success Stories / Good Practices

Telia Lietuva was one of the first to launch active 5G development, declaring ambitious goals to cover most of the country's territory and population as soon as possible. The company uses both lower frequencies for wider coverage and higher frequencies for

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higher speeds in cities and industrial areas. Telia's 5G connection is already available in many large cities and is rapidly expanding to smaller towns and rural areas.

Bitė Lietuva is also actively deploying a 5G network, emphasizing not only speed, but also network quality and the creation of new services. The company is investing in network modernization and base station upgrades to ensure a smooth transition to the new technology and offer customers the real benefits of 5G.

Tele2 competes in the market by gradually expanding its 5G network, focusing on the most densely populated areas and strategic locations. The operator emphasizes the importance of smart investments and strives to make 5G available to the widest possible range of users.

B5.9. Additional Comments or Observations

In 2024, Lithuania achieved 99.71% overall 5G coverage – one of the best results in the EU, where the average is 94.35%. Even in sparsely populated areas, Lithuania achieved 99.06% 5G coverage (EU average – 79.57%). We are also leading in the 3.4–3.8 GHz frequency band coverage area, where our result is 75.13%, compared to the EU average of 67.72%.

According to the Communications Regulatory Authority, the 5G coverage in Lithuania is ensured by one operator – Telia Lietuva, which can provide 99.7% of households with 5G services. Other operators still have room for improvement: Bitė Lietuva covers 74.4%, Tele2 – 68.1%.

The coverage of fixed very high-speed networks (VHCN) in Lithuania in 2024 reached 78.29%, while the EU average was 82.49%. The annual growth is just 0.3%, while in the EU it is 4.9%. This shows that the development of infrastructure, especially in rural areas, is slow, and the private sector is reluctant to invest due to low return on investment.

Looking ahead, 5G development in Lithuania will undoubtedly continue. It is likely that 5G coverage will become almost universal in the next few years, and the quality and accessibility of services will only improve. However, the real revolution lies not in the connection itself, but in the opportunities it provides to create new services and products.

Lithuania has the potential to become not only a passive user of 5G, but also an active creator of innovations. Our country has strong technology universities, promising start-ups are growing, and government institutions are declaring support for digital transformation. We can expect to see more 5G testbeds or sandboxes in various areas – from autonomous transport to smart energy. Cooperation between science, business, and the public sector will be a key factor determining success.

One of the more interesting aspects is the development of the so-called “private 5G networks”. These are specialized, isolated 5G networks designed for specific companies or industrial areas (e.g., factories, ports, hospitals), ensuring the highest level of security, reliability, and productivity according to individual needs. Such solutions can become an important impetus for the Lithuanian industry.

While we are talking about 5G, the world of technology does not stand still. Already now, scientists and engineers around the world are working on 6G technology concepts, which promise even higher speed, lower latency, and new, today difficult to imagine opportunities. It

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is important for Lithuania not only to successfully master 5G, but also to monitor global trends and prepare for future technological leaps.

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B6. Malta

B6.1. National/ Regional Strategy Overview

Malta treats next-generation mobile connectivity as a central enabler of its digital economy agenda. Policy direction is anchored in Malta Diġitali 2022–2027, which positions digital infrastructure and spectrum policy as key "strategic enablers" and aligns national actions with the EU's Digital Decade objectives for ubiquitous 5G coverage and gigabit connectivity by 2030. The strategy frames the government's role as policy-maker, regulator, and catalyst, and ties digital rollout to competitiveness, public service transformation, and sustainability goals.

On the spectrum, the Malta Communications Authority (MCA) leads planning and awards. Malta issued a National Roadmap for the UHF band (470–790 MHz) in 2018 to repurpose the 700 MHz band in line with EU decisions, paving the way for 5G in low-band spectrum. Subsequent MCA workstreams have updated spectrum plans and processes to support 5G deployment.

In 2021, the MCA set out the assignment process and licence conditions for the 700 MHz, 3.6 GHz, and 26 GHz "pioneer bands," and launched a call for expressions of interest for 3.6 GHz. With demand not exceeding supply, the MCA proceeded to direct assignment to qualified applicants under the published decision framework. Rights of use in 3.6 GHz were granted (for example, to Melita in April 2021), and the MCA's licences page reflects current holdings in 800/900/1800/2100/2600/3600 MHz across GO, Epic, and Melita. The national frequency plan and annual MCA strategy updates continue to align Malta's allocations with EU harmonisation and ITU revisions.

Commercial 5G deployment has followed these regulatory steps. Melita announced Malta's first nationwide 5G service in May 2021; GO selected Nokia in January 2022 for a seven-year nationwide 5G rollout; and Epic offers 5G on selected plans, with Ericsson as its 5G RAN vendor. These market launches complement the policy framework and demonstrate operator investment in line with national and EU targets.

At the EU level, Malta's connectivity agenda is further embedded in the Commission's "Digital connectivity in Malta" country page and in Malta's Digital Decade Strategic Roadmap 2023–2030, which tracks progress against EU coverage and performance goals (for example, 5G in all populated areas and gigabit for all households by 2030). National planning and spectrum releases are explicitly tied to these milestones.

In summary, Malta's approach combines:

1. a whole-of-government digital strategy (Malta Diġitali),
2. an MCA-led spectrum roadmap and licensing across 700 MHz/3.6 GHz/26 GHz,
3. continuous frequency-plan updates, and
4. active operator deployments (Melita, GO, Epic).

Rather than adopting a specific "project of national importance" status as in some countries, Malta integrates its 5G rollout into a broader digital transformation strategy closely aligned with EU Digital Decade objectives.

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B6.2. Key Industry Sectors and Adoption Areas

The first and most immediate area of 5G adoption in Malta has been the telecommunications sector itself. All three national operators — GO, Melita, and Epic — have launched 5G services and are investing heavily in upgrading their radio access networks and backhaul capacity. Epic partnered with Ericsson for a full 5G network modernisation, while GO entered a multi-year agreement with Nokia to roll out a nationwide 5G infrastructure.

Beyond the operators, healthcare is one of the verticals most frequently identified as a beneficiary of 5G. National surveys highlighted strong expectations for telemedicine and remote patient monitoring, where 5G's low latency and bandwidth capacity can support wearable devices, continuous monitoring, and secure transfer of medical data.

The manufacturing and logistics sectors are also viewed as areas where 5G could drive productivity and innovation. Although Malta's industrial base is smaller than that of larger EU economies, interest in Industry 4.0 practices is growing. 5G enables real-time monitoring of machinery, predictive maintenance, remote equipment control, and smart logistics networks that increase efficiency and reduce downtime.

In the area of public services and smart cities, 5G is seen as a critical enabler for digital transformation. Plans emphasise the importance of ensuring 5G availability across urban areas and along major transport corridors, supporting applications such as traffic management, connected mobility, and wide-scale sensor deployment.

Finally, tourism and cultural heritage, which represent a central pillar of Malta's economy, are increasingly linked to digital innovation. 5G can enhance visitor experiences through augmented and virtual reality applications, provide real-time translation and guide services, and enable advanced monitoring of cultural heritage sites.

B6.3. Relevant Projects or Pilots

Epic has launched a large-scale network modernisation programme supported by European Investment Bank financing. This initiative accelerates 5G deployment and fibre expansion, with a goal of achieving near-nationwide coverage while upgrading the core network for future demand.

GO Malta has entered a long-term partnership with Nokia to implement a nationwide 5G rollout. This covers both new 5G radio deployments and the modernisation of existing infrastructure, helping to improve coverage density and performance.

Beyond telecommunications, Malta is testing 5G in mobility applications. Through the metaCCAZE project, pilot sites in Malta and Gozo are being prepared for connected, on-demand electric buses. Site visits and workshops are assessing route suitability, charging infrastructure, and community needs, with the goal of advancing sustainable, connected transport.

In addition, Malta's broader innovation strategy, particularly the AI Launchpad 2030 framework, positions the country as a test bed for emerging digital technologies. The initiative highlights how 5G can support pilot projects in health, energy, transport, and tourism by providing the advanced connectivity layer needed for AI-driven solutions.

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B6.4. Stakeholders and Innovation Ecosystem

The Malta Communications Authority is the central regulator overseeing spectrum allocation, licensing, and alignment with EU connectivity policies. It has also convened stakeholders through initiatives such as its 5G Think Tank.

The three national operators — GO, Melita, and Epic — are the main drivers of deployment. Each has committed to national rollouts, often working with global vendors. Their infrastructure investments provide the foundation for industrial and sector-specific adoption.

From the public sector side, the Government of Malta integrates 5G into national digital transformation strategies, while the Malta Digital Innovation Authority promotes innovation and trust in emerging technologies.

Universities and research institutions participate in EU-funded projects, contributing pilot initiatives in areas such as mobility and IoT. International financing, including loans from the European Investment Bank, supplements Malta's domestic capacity to support large-scale network investments.

This ecosystem is characterised by close collaboration between regulators, operators, and government, reflecting Malta's small size and need for coordinated action.

B6.5. Policy Framework and Public Support

Malta's digital policies are aligned with the EU's Digital Decade, setting targets for ubiquitous 5G coverage and gigabit connectivity by 2030. The *Malta Diġitali 2022–2027* strategy positions advanced connectivity as a national enabler of digital and sustainable growth.

The regulatory framework is based on the European Electronic Communications Code, implemented nationally to guide licensing, spectrum use, and network security. The Malta Communications Authority has defined assignment processes for the 700 MHz, 3.6 GHz, and 26 GHz bands, while ensuring compliance with European harmonisation and the EU 5G security toolbox.

Public support is available through ERDF-backed digitalisation grants, co-funding for smart and sustainable investments, and national R&I programmes that cover technology development and commercialisation. Malta also operates a technology assurance sandbox to help firms pilot innovative 5G-enabled systems in a supervised environment.

Additional funding streams from the Recovery and Resilience Plan and European financial institutions reinforce these efforts, ensuring that industry has access to both regulatory clarity and financial incentives for 5G adoption.

B6.6. . Readiness and Barriers

Malta is technically well-positioned for 5G: spectrum has been assigned, all operators have launched services, and national strategies are aligned with EU milestones. The country's small size makes nationwide coverage easier to achieve, and early rollouts already cover much of the population.

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Challenges remain, however. Operators face high capital costs for dense infrastructure in a small market where industrial demand is limited. Malta's economy is dominated by services rather than manufacturing, reducing the number of firms positioned to adopt advanced industrial use cases.

Skills gaps in advanced connectivity and limited awareness among SMEs also slow adoption, with many businesses prioritising more basic forms of digitalisation. Infrastructure densification in historic city centres requires careful planning and can delay deployment. In addition, regulatory and security requirements impose continuous obligations on operators and smaller partners.

B6.7. Sustainability & Green Innovation Linkage

In Malta, the role of 5G in advancing sustainability is framed within the national digital strategy, which connects 5G deployment to sustainability objectives. Operators upgrading to 5G are introducing more energy-efficient infrastructure, reducing network energy intensity even as data traffic grows.

Transport and mobility projects, such as connected and autonomous e-bus demonstrations, are expected to cut emissions by enabling smarter public transport systems. In industry, applications like real-time monitoring and predictive maintenance can reduce waste and optimise resource use, although they remain at an early stage in Malta.

Tourism and heritage management also offer sustainability opportunities: digital experiences supported by 5G, such as augmented reality tours, can reduce the physical burden on cultural sites while maintaining their economic and cultural value.

Finally, Malta's Recovery and Resilience Plan links connectivity with renewable energy and digitalisation as complementary drivers of the green transition, embedding 5G within a broader framework of sustainable development.

B6.8. Local Success Stories / Good Practices

Epic's large-scale modernisation programme stands out as a good practice. With substantial external financing, the operator has accelerated 5G deployment and fibre expansion, aiming for nationwide coverage and future-proof network infrastructure. The project demonstrates how a relatively small market can leverage EU instruments to achieve ambitious connectivity goals.

Another notable initiative is the metaCCAZE Living Lab in Malta and Gozo, where pilot sites have been identified for testing connected, on-demand electric buses. The project brings together local authorities, research institutions, and citizens to explore operational and sustainability aspects of autonomous mobility. This illustrates how Malta can serve as a test bed for advanced transport solutions, combining 5G connectivity with low-carbon technologies.

B6.9. Additional Comments or Observations

Malta's pathway to 5G illustrates the dynamics of a small island state integrating into a wider European digital and regulatory framework. Its scale offers advantages in terms of achieving full

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coverage quickly and coordinating stakeholders efficiently, but it also limits the size of the industrial base able to adopt advanced 5G use cases.

The country is positioning itself less as a manufacturing hub and more as a **test bed economy**, where pilots in mobility, healthcare, tourism, and AI can be trialled at national scale and then scaled outward to larger markets. This strategy fits with Malta's broader ambition to attract international partnerships and to leverage EU funding to overcome its domestic market limitations.

Another distinctive feature is the **strong role of European instruments**. Both regulatory direction (through EU harmonisation and the 5G security toolbox) and financial support (through the EIB and recovery funds) are essential for Malta's progress. This reliance on EU-level mechanisms is not unusual for smaller member states, but it underscores how Malta's 5G rollout is tightly embedded in collective European policy rather than driven by purely national initiatives.

Finally, Malta's emphasis on aligning 5G with **digital trust and innovation frameworks** (such as the AI Launchpad and the technology assurance sandbox) shows a particular policy choice: to link connectivity not just to infrastructure, but also to safe experimentation with new technologies. This may prove to be an area where Malta differentiates itself within the EU landscape, using its compact scale to combine regulatory agility with deployment of advanced connectivity.

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B7. Benelux

B7.1. 1. National/Regional Strategy Overview

BELGIUM

Belgium has several national and regional strategies and frameworks that are highly relevant to 5G/Beyond 5G (B5G), digital transformation, and sustainable industrial technology development. These policies aim to enhance competitiveness, innovation, and environmental responsibility across sectors. Belgian Recovery and Resilience Plan (RRP) is a national plan that aims to use European Union funding for the economic recovery and transformation of the country. Belgium received around 5.9 billion in EU grants, about 27% of the total plan, which targets digital transformation. Investments in 5G are expected in infrastructure, cybersecurity, and Industry 4.0.

5G/B5G strategy focuses on stimulating digital connectivity through measures like reducing administrative burdens for network operators, promoting fiber readiness, and ensuring a proactive 5G framework. Key Goals and initiatives include:

- Promoting Digital Connectivity
- Reducing Roll-out Costs
- Streamlining Regulations
- 5G Pilot Projects
- Cybersecurity
- Futureproofing Healthcare
- EU Alignment

Focus:

- Facilitate 5G deployment for industrial and public uses.
- Encourage B2B and vertical applications.
- Foster innovation ecosystems around private and campus 5G networks.

Digital transformation plans

At the federal level, Belgium's digital transformation is shaped by the Belgium plan, the Recovery and Resilience digital invest-focus, and the once-only data-sharing framework. Regional implementations like Digital Flanders and Digital Wallonia execute these strategies locally with programs targeting citizen engagement, e-government, inclusion, and infrastructure.

Main themes:

- digital uses
- smart territory
- digital economy
- digital innovation
- digital administration

Sustainability frameworks

Belgium has several sustainability frameworks at both the national and regional levels that are directly relevant to industrial technology development, especially for companies aiming to integrate green innovation, digital tools, and climate-resilient manufacturing practices. The focus areas are:

- Climate-neutral industry
- Circular economy
- Smart energy systems
- Green R&D & innovation (Sustainable design platforms)
- Data-driven ESG tools (AI for impact analysis, digital twin simulation)
- Industrial symbiosis (Waste/resource matching platforms)
- Regulatory compliance (Digital Product Passport, ESG data infrastructure)

THE NETHERLANDS

The Netherlands has developed several strategic national and regional frameworks that focus on 5G/Beyond 5G (B5G), digital transformation, and sustainability, especially for industrial technology development. 5G is available in many areas like Amsterdam, Rotterdam, and The Hague; coverage is gradually expanding. 5G was first launched in the Netherlands in 2020 by major providers like KPN, Vodafone, and T-Mobile.

The Dutch Digitalisation Strategy describes how the Netherlands can optimally and responsibly use the social and economic opportunities offered by the digital transformation. This is possible with:

- Privacy protection
- Cybersecurity
- Digital skills
- Fair competition

Priority themes and actions:

- Artificial intelligence
- Using data to tackle social issues and stimulate economic growth
- Digital inclusion and skills
- Digital government
- Digital connectivity
- Digital resilience

Key elements to the industry:

- Digital infrastructure investment, including 5g and edge computing
- Public-private innovation ecosystems
- Support for AI, robotics, and IoT integration in industrial sectors
- Emphasis on cybersecurity and digital resilience for critical infrastructure

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5G Action Plan refines the objectives of the Dutch Digitalisation Strategy; the plan's goal is to provide high-quality connectivity. This plan is published by the Ministry of Economic Affairs and Climate Policy to accelerate 5G adoption and support digital transformation in strategic sectors. Key objectives:

- Widespread 5G coverage
- Gigabit connectivity
- Spectrum allocation
- Infrastructure development
- Infrastructure development
- Promoting 5G use cases

Smart industry initiative (Dutch Industry 4.0 Agenda)

The Netherlands Industry 4.0 Agenda, known as “Smart Industry”, emphasizes the adoption of technologies like artificial intelligence, big data, cloud computing, and cybersecurity to modernize its manufacturing processes. Key aspects:

- Digitalization (integration of AI, data analytics, robotics, and 5G into production processes)
- Connectivity
- Flexibility
- Collaboration
- Field Labs (physical locations where companies can experiment with and implement Smart Industry technologies)
- Digital innovation hubs (to help companies transition to Smart Industry)
- Strong Engineering Base

Dutch Climate Agreement & Circular Economy Roadmap

The government, with the National Programme for the Circular Economy (NPCE), wants the economy to be fully circular by 2050:

- Targets for carbon neutrality by 2050, including decarbonizing industry through digital technologies
- Digital monitoring of energy use, emissions, and material flow in industrial processes
- Support for smart grids, energy flexibility platforms, and sustainable logistics solutions
- Alignment with digital twin and IoT developments for resource-efficient manufacturing.

Regional ecosystems supporting 5G/Industry transformation

- Brainport Eindhoven: a leading high-tech hub with a focus on 5G, photonics, and smart manufacturing.
- 5Groningen: a northern Netherlands testbed for 5G-enabled agriculture, mobility and health.
- Port of Rotterdam: major 5G innovation zone for autonomous logistics and industrial automation.

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LUXEMBOURG

In Luxembourg, there are several national and regional strategies, policies, and initiatives that promote 5G/B5G deployment, digital transformation, and sustainability in industrial technology.

STRATEGIC FRAMEWORKS

Ultra-high-speed broadband strategy 2020-2025

Overseen by the Ministry of State's Department of Media, Connectivity and Digital Policy, this strategy aims to provide Very High-Capacity Network (VHCN) to the entire country, including rural zones. A dedicated 5G Taskforce was established to guide Luxembourg's 5G rollout.

Accelerating Digital Sovereignty 2030

A cross-government initiative launched in May 2025, aligning strategies in AI, data, quantum technologies, and connectivity to establish digital independence and competitiveness. 5G is a key component of Luxembourg's goals of innovation.

Luxinnovation, the national innovation agency, manages the Fit4 programs and acts as a facilitator for public-private partnering, grant access, and digital transformation roadmaps. The **Digital Transformation Department** with the **Digital Innovation Hub** supports SMEs and corporations in adopting cutting-edge connectivity and automation tools, including 5G, IoT, AI, and HPC.

FUNDING INSTRUMENTS

Joint Call for 5G Communication Technologies

An investment co-sponsored by the Ministry of State, the Ministry of the Economy, Luxembourg National Research Fund (FNR), and Luxinnovation. Funding was awarded to seven selected public-private R&D projects in areas such as smart cities, Industry 4.0, robotics, V2X, and network resilience.

B7.2. Key Industry Sectors and Adoption Areas

BELGIUM

Belgium is actively deploying and testing 5G and B5G technologies across several industrial sectors, often through private networks, living labs, EU-funded pilots, and regional innovation programs.

Manufacturing

In this sector, 5G/B5G applications are used for Cobots and real-time quality control. For example, Flanders Make, which supports the manufacturing industry, has:

- 5G-enables smart factories using robotic arms, digital twins, and collaborative robots (cobots)
- B5G applications in machine-to-machine communication with low latency

Logistics and Transportation

Port of Antwerp-Bruges is the port authority that manages the ports of Antwerp and Bruges. It was among the first to launch a private 5G network in collaboration with Citymesh and Nokia. Use cases include drone inspections, augmented safety systems, and autonomous barges. Indeed, in this sector, 5G/B5G applications can be used in real-time tracking of goods and vehicles, autonomous logistics vehicles, and high-accuracy warehouse automation.

Energy and utilities

In the energy sector, 5G can be used to improve worker safety, video surveillance, mobile logistics, grid monitoring, mobile substations, smart meters, real-time drone inspections of wind turbines, sensor monitoring, fire prevention, and thermal data over 5G.

BASF Antwerp, one of Belgium's largest chemical production sites, is testing a private 5G network. Use cases: mission-critical wireless communication for staff in hazardous zones, live HD video surveillance to monitor sensitive installations. For mobile logistics, enabling autonomous guided vehicles and remote-controlled inspection tools.

Benefits:

- enhanced worker safety and faster emergency response
- reliable, low-latency communication in high-risk industrial environments
- support for IoT-enabled predictive maintenance

Healthcare: the sector is adopting 5G to remote surgery and telemedicine, biosensors monitoring, real-time communication with specialists, and AR/VR training for medical staff. AZ Groeninge Hospital, the first in Belgium with a private 5G network, tests robotic surgery, remote monitoring, and AR training.

Public safety

Use cases: live video surveillance, secure group communications, and drone-based crowd monitoring. For first responders, there are pilot projects for 5G-enabled bodycams and real-time data streaming during emergencies.

Smart cities and tourism

5G can be used to connect public transport, intelligent traffic systems, and urban monitoring and planning. Orange Smart City pilots use real-time urban video analysis and mobility pattern tracking in cities like Liege.

In the sector of tourism, the adoption of 5G is important to:

- enhanced visitor experience
- efficient event production (mobile 5G setups reduce costs and improve flexibility at festivals)
- sustainable tourism infrastructure

NETHERLANDS

In the Netherlands, 5G and B5G technologies are being adopted or piloted across several key industrial sectors.

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Manufacturing (Smart Industry)

In this sector, the use cases are:

- Wireless control of automated production lines
- Digital twins for predictive maintenance
- Augmented reality (AR) for remote support and training
- Mobile robots and AGVs in factories

For example, Brainport Eindhoven uses advanced manufacturers piloting private 5G networks to enable real-time machine communication, or Fieldlab Flexible Manufacturing tests 5G-enabled cobots and machine learning in production environments.

Logistics and transport

KLG Europe is a global logistics service provider in Waalwijk, Netherlands, in partnership with KPN. They use a hybrid private 5G network on-site, including a local 5G gateway and edge compute node, ensuring that mobile data from automated guided vehicles (AGVs) is processed locally for minimal delay. Furthermore, the EU-funded 5G-Blueprint project developed and validated cross-border teleoperation of vehicles and vessels using 5G connectivity and network slicing. Teleoperation enables remote driving of vehicles and vessels, potentially reducing driver shortage, improving safety, and optimizing operational cost efficiencies. Coordinated network slicing and cross-border 5G cohesion allow continuous remote control even when vehicles traverse national boundaries.

Agriculture & Environment

The 5Groningen project in rural North Groningen tests applications in agriculture (self-driving cars and monitoring of crop diseases), energy, environmental sensing, logistics, and healthcare. All leveraging 5G for remote data collection in sparsely populated areas. This 5Groningen project is an initiative of Economic Board Groningen, KPN, the Dutch Telecommunications Agency (Agentschap Telecom), Vodafone, Huawei, Ericsson, TNO, the University of Groningen, SURF, and the Hanze University of Applied Sciences.

Healthcare

In the Netherlands, 5G technology introduces advanced applications like robotic surgery, remote patient monitoring, and faster data transmission for diagnostics and treatment. This improves emergency response and develops more things like 5 G connected ambulances with real-time location tracking.

Smart cities & Public services

Urban field labs in Delft and The Hague host experiments in drone-assisted rescue, smart traffic control, air quality sensors, evacuation systems, and building safety innovations using private 5G networks.

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LUXEMBOURG

National strategy emphasizes digital sovereignty and resilience, which complements sustainable development and climate targets by enabling smarter systems with trusted infrastructure. 5G applications are being exploited in many sectors. Use cases in manufacturing & Industry 4.0:

- Smart factories
- Real-time quality control
- AR-based worker assistance
- Predictive maintenance

Use cases in Agriculture & Agritech:

- Precision farming
- Robotic harvesting
- Environmental monitoring
- Indoor farming automation

Mobility & smart transport:

- Vehicle-to-everything (V2X)
- Autonomous driving
- Traffic optimization
- Logistics teleoperation

Healthcare:

- Remote diagnostics
- Connected hospitals
- Mobile health units
- Data-intensive care delivery

Projects involve Centre Hospitalier Emile Mayrisch and Les Hôpitaux Robert Schuman.

Utilities & Environmental monitoring:

- Smart water metering
- Predictive maintenance
- Real-time infrastructure control

Smart cities:

- Crowd monitoring
- Smart lighting
- Waste collection
- Energy optimization
- Public safety

Non-terrestrial & critical networks:

- Resilient connectivity
- Satellite 5G integration
- Emergency network

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National strategies and testbeds are focused on real-world industrial transformation in areas that support both economic competitiveness and sustainability goals.

5G-PLANET is a project focused on creating a digital twin of the country's 5G infrastructure to raise public awareness about 5G technology, particularly its application in connected mobility. A "digital twin" is a virtual representation of a physical object or system, like a 5G network, that allows for testing, analysis, and optimization without affecting the real-world counterpart. 5G network digital twin platform developed by the Luxembourg Institute of Science & Technology (LIST) with support from the Ministry of State's Department of Media, Connectivity & Digital Policy (SMC). 5GPLANET stands for "5G Platform for Learning and Awareness on Network Evolution and Transport". It allows stakeholders – governments, telecom providers, researchers, and the public – to stimulate, test, and visualize how 5G can improve real-world scenarios. Objectives are:

- Education & awareness
- Policy and Planning Support
- Scientific & Technical Innovation

B7.3. Relevant projects or Pilots

BELGIUM

Orange 5G Lab

The labs utilize a 5G Standalone (SA) network, which is the most advanced 5G standard, providing high speeds and low latency. The lab is a facility where businesses can explore and develop new applications using 5G technology. It's a place for companies to:

- discover 5G's possibilities
- develop and test new 5G applications
- collaborate with Orange experts and other businesses

Proximus 5G Innovation

Proximus is actively innovating with 5G in Belgium by offering a dedicated platform for businesses to explore and test 5G applications, including co-creation labs and mobile private networks. 5G applications are being promoted across different industries: healthcare, industry, logistics, and other sectors.

FPS Economy 5G Projects

The Belgian Federal Public Service Economy (FPS Economy) is actively involved in facilitating the development and implementation of 5G technology in Belgium. Its role involves working on a framework to ensure Belgium is prepared for the adoption of 5G and the IoE (Internet of Everything). The FPS Economy, through initiatives like the 5G pilot projects subsidy program, provides financial support to encourage innovative 5G applications and research, and they are committed to streamlining the process of deploying 5G infrastructure by reducing administrative difficulties and costs for network operators.

Imec

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It is an international research & development organization, active in the fields of nanoelectronics and digital technologies; it is actively involved in 5G research and collaborating with industry leaders, research institutions, and government agencies.

Multitel/A6K

A6K is a hub that brings together various stakeholders (industry, start-ups, universities, research centres) to foster innovation, particularly in engineering. It offers office spaces, unique equipment like a 5G lab, and a super calculator. Multitel specializes in areas like IoT, network engineering, applied photonics, and artificial intelligence.

A6K, in collaboration with Multitel and others, established Wallonia's first 5G lab at the A6K hub in Charleroi. This lab, developed by the A6K 5G consortium, provides a platform for companies and research centres to test and develop 5G applications, especially for industrial purposes. For example, Multitel designed a 5G modem for sensors used in a project measuring noise and air pollution in Durbuy.

Citymesh Living Labs

It refers to Citymesh's initiative focused on developing and testing smart city solutions in real-world environments. There are "living labs" that are essentially urban areas or specific locations where Citymesh, a Belgian technology company, deploys and experiments with various technologies like WiFi, 5G, IoT sensors, and data platforms in specific areas.

5G-Blueprint

It is a research initiative focused on developing a technical architecture, business model, and governance structure for seamless, cross-border teleoperated transportation using 5G connectivity. It aims to explore the potential of 5G for enhancing efficiency and safety in logistics and passenger transportation across borders.

NETHERLANDS

In the Netherlands, there are several well-known 5G/B5G pilot projects, testbeds, living labs, and academia-industry initiatives, many touching on transport, logistics, mobility, and related innovation sectors.

5Groningen is a field lab and living lab in the Northern Netherlands, focusing on the testing and development of 5G and related technologies; it's an initiative of Economic Board Groningen. Included trials are drones inspecting production facilities, autonomous shuttles, smart ambulances, precision agriculture scenarios, and edge-based sensor networks in sparsely populated areas.

Do IoT Field Lab is an open innovation platform that accelerates innovation in the field of Internet of Things (IoT), with a strong focus on 5G technology, particularly in areas like mobility, logistics, healthcare, and safety. Do IoT Field Lab allows for testing in realistic environments, bridging the gap between research and practical application.

5G-Blueprint: Horizon 2020 initiative involving the Dutch Ministry of Infrastructure, KPN, port operators, logistics firms, and research institutes in the development of a testbed for cross-border teleoperation of vehicles and inland vessels, including

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remote docking, driver-in-loop trials, network slicing, and roaming continuity across the NL/BE borders.

Shell Pernis Refinery Field Lab (Rotterdam area): this is one of Europe's largest industrial 5G labs in industrial logistics & maintenance. They tested new technologies for safety and efficiency, like mobile inspection robots and smart helmets.

LUXEMBOURG

The country's 5G ecosystem includes diverse pilot projects across agriculture, manufacturing, mobility, utilities, healthcare, and smart cities. These initiatives leverage 5G's ultra-low latency, edge computing, AI, IoT, and network slicing capabilities to support industrial transformation and sustainability goals. Many projects are coordinated by LIST and SnT, in partnership with POST Luxembourg, research institutes, public agencies, and private companies.

PILOT PROJECTS & TESTBEDS

SmartSpires Living Lab (Belval District)

This project, with 5G-plus-edge computing towers, is turning Belval into a smart city demonstrator. Acts as an urban 5G/edge living lab testing real-time sustainability applications and scalability across Europe. SmartSpires and agricultural/factory use cases, through real-time IoT, automation, and AI-enabled planning, actively support:

- resource efficiency
- Low-carbon mobility
- Circular economy

Smart Water Eislek uses 5G-connected meters and sensors to monitor water usage, pressure, and quality, and enables predictive maintenance and real-time leak detection. It is carried out by POST Luxembourg, DEA, and Nexunity.

5G-AGROBOT uses IoT robotics in greenhouses, with sensors and cameras connected via 5G for low-latency automated harvesting and intelligent crop management. It includes AI algorithms to optimize operations and crop quality. Partners are Fesh Haff, Frontier Connect, and LIST.

5G-ARTEMIS combines 5G with augmented reality, AI, and additive manufacturing for:

- Real-time quality control
- Production monitoring
- Technician support in smart factories

Partners are Dropslab, University of Luxembourg/SnT (Interdisciplinary Centre for Security, Reliability and Trust).

5GDrive enables autonomous driving and remote vehicle control via high-definition video and sensor data.

PASTA-5G-V2X develops transparent vehicle-to-everything antennas for better rural/urban coverage.

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Partners include POST Luxembourg, Ohmio, LIST, and IEE.

Smart Water Eislek uses 5G-connected meters and sensors to monitor water usage, pressure, and quality, and enables predictive maintenance and real-time leak detection. It is carried out by POST Luxembourg, DEA, and Nexunity.

LiLa 5G: hospital living lab for real-time data sharing across hospital sites, improving clinical response and diagnostics.

IoT Healthcare Platform: a secure platform using 5G to connect healthcare systems, devices, and hospitals across Luxembourg.

Micro 5G (Drone platforms): led by the University of Luxembourg, this research project explores how drones mesh processing and data offloading via 5G to enhance flight autonomy and coordination. Focuses on mobility, logistics, and security applications.

Lux5GCloud (Smart Agriculture & Data Cloud) is a data-driven demonstration platform combining 5G, IoT, satellite (EO), and ML to monitor soil moisture, drought, and crop conditions in real-time. Led by LIST with Luxembourg, Frontier Connect, InTech, GOMSPACE.

B7.4. Stakeholders and Innovation Ecosystem

BELGIUM

Telecom providers, like Proximus, Telenet, Orange, and DIGI, play a crucial role in the rollout and application of 5G technology. They are responsible for building and maintaining the 5G infrastructure, offering 5G services to consumers and businesses, and driving the development of new applications and use cases for 5G.

Universities and Research Institutions play a vital role in the development and application of 5G technology. They contribute through research, education, and large-scale trials, focusing on various aspects of 5G, including its technical capabilities, potential use cases, and impact on different sectors. Universities collaborate with industry partners, research centres, and governmental agencies. They participate in initiatives like the “5G large-scale pilots – 5G and Edge for Smart Communities” project to test and validate 5G solutions for smart communities.

Start-ups and Scale-ups, their key role concern:

- developing innovative 5G applications
- Accelerating 5G adoption
- Driving economic growth
- Fostering collaboration and innovation

They also contribute to driving 5G innovation and adoption by developing and implementing new applications and solutions. Orange Belgium, in particular, through initiatives like the Orange 5G Lab and Orange Fab, provides resources and partnerships to help start-ups scale their 5G-related businesses.

Industry Clusters and Associations play a critical enabling and coordinating role in the development and adoption of 5G applications across sectors. Their role is to bridge the gap between research, industry, and government. Industry clusters and Associations create an ecosystem thanks to the connection of stakeholders; Agoria

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(Belgium's technology industry federation) hosts working groups and task forces for 5G, AI, and IoT integration across sectors. Their role is also important to promoting 5G use cases and innovation, advocacy and policy support, funding access and project development, training, skills development, and awareness.

Government Agencies and Regulators

Government agencies and regulators play a strategic, regulatory, and enabling role in the development and deployment of 5G applications. The BIPT (Belgian Institute for Postal Services and Telecommunications) acts as the primary regulator, managing the radio frequency spectrum and allocating user rights for 5G frequencies. The government also focuses on reducing administrative burdens and rollout costs for network operators to stimulate 5G deployment. Furthermore, the government is addressing dependencies and ensuring the security of 5G networks through regulations and assessments.

EU and International Collaborations play a significant role in shaping 5G applications in Belgium, particularly through funding, standardization, and cybersecurity initiatives. The European Union's 5g Action Plan, along with public-private partnerships, provides financial support and a framework for research and innovation in 5G and beyond. Belgium participates in international research projects like 5G-Blueprint, which focuses on using 5G to improve logistics and transport efficiency across borders.

NETHERLANDS

Dutch Ministry of Infrastructure and Water Management (including Rijkswaterstaat) serves as project coordinator in key initiative (e.g., 5G-Blueprint), helps shape policy, oversees road/pot infrastructure integration, and ensures regulatory compliance. Flemish Department of Mobility and Public Works (Belgium) co-leads business-model and governance design for cross-border trials as part of the Benelux corridor projects. Agentschap Telecom, now known as Rijksinspectie Digitale Infrastructuur (RDI) or the Dutch Authority for Digital Infrastructure, is a governmental agency in the Netherlands responsible for overseeing and regulating telecommunications and digital infrastructure, and it also plays a role in 5G application and regulation.

Fundamentals are Telecom operators & Infrastructure providers like KPN that provides 5G networks, Telenet Group that participates in teleoperations trials in Belgium-Netherlands corridor projects, and Eurofiber Nederland that specializes in fiber-optic backbone connectivity for 5G base stations.

ITS & Software providers are important because they provide intelligent transport systems, traffic management, network slicing, offer logistics-focused software, data analytics, and business use-case support.

Ports, logistics & transport companies are also involved in 5G applications and its regulation. Transport and logistics are fundamental to developing testbeds, use cases, and improving collaboration between stakeholders.

They also play a role in the Automotive sector and teleoperation technology providers.

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Universities and research centres play a crucial role in driving 5G innovation and its applications through research, development, and collaboration with industry and government. Imec (Interuniversity Microelectronics Centre) is a technical coordinator of 5B-Blueprint, deep R&D in connectivity, edge architecture, network slicing, and autonomous systems. HAN University of Applied Sciences & HZ University of Applied Sciences conduct applied research and pilot validation on mobility, logistics innovation, and system integration. TNO (Netherlands Organisation for Applied Scientific Research) supports testbed design, advanced use case research, and field validation in transport-logistics contexts.

Advisory board experts from logistics, automotive, ports, transport management, and spectrum regulation cover project direction, policy relevance, exploitation strategy, and stakeholder alignment.

LUXEMBOURG

Luxembourg's 5G ecosystem is collaborative and cross-sectoral, with:

- Public agencies guiding strategy and funding,
- Telcoms enabling network infrastructure and use case trials,
- Research centres conducting applied innovation,
- Start-ups and tech firms turning 5G into real-world applications.

At the government level, there are several stakeholders that play a vital role in Luxembourg's 5G/B5G ecosystem. The Department of Media, Connectivity & Digital Policy (SMC) oversees national 5G strategy, regulation, and infrastructure coordination. Supports pilot projects and funding. The Ministry of Economy promotes industrial innovation using 5G in strategic sectors, co-funds R&D programs with FNR and Luxinnovation. Luxembourg National Research Fund (FNR) provides research grants for public-private 5G R&D collaborations. Luxembourg Institute of Standardisation, Accreditation, Safety and Quality of Products and Services (ILNAS) supports regulatory frameworks and technical standards for 5G adoption. Régie des Bâtiments & Smart City Consortia enable 5G integration in urban infrastructure and smart city testbeds.

Telecom operators, like POST, Orange, and Proximus, provide infrastructure, partners, or use cases. They support industrial 5G pilots and are involved in smart city and network innovation. Also, they develop 5G network APIs and experimentation platforms.

The principal players in 5G projects are institutions and universities like LIST (Luxembourg Institute of Science and Technology) and the University of Luxembourg; they drive R&D and pilot projects. Start-ups and industry co-develop use cases and applications of 5G. Several consortia emerged from the "5G communication technologies" call, and this allows for cross-referencing actors in various sectors; 7 funded projects as of late 2024.

B7.5. Policy Framework and Public Support

BELGIUM

Belgium supports advanced 5G and green tech deployment in industry through a combination of public policies, funding schemes, and regulations, at both federal and regional levels, often

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aligned with EU programs. About national and regional public policies, there is the Digital Belgium Strategy (Federal), which is a strategy that focuses on the digital transformation of the economy, including 5G rollout and Industry 4.0, and the Federal Recovery & Resilience Plan (NextGenEU), which includes digital infrastructure and the green transition. At the regional level, for example, there is the Digital Wallonia Strategy, which focuses on smart industry, smart mobility, and smart energy. In Belgium, some European programs are used like Horizon Europe (co-funding that includes advanced 5G use cases and Green ICT), CEF Digital (infrastructure funding, connecting Europe facility), and the Digital Europe Programme. Belgium also has green tech and energy-specific instruments, like Green Deal Industry Initiatives for low-emission industrial processes and smart energy via 5G-enabled IoT, and Energy Transitions Funds that concern funding projects at the intersection of energy efficiency and digitalization. At least, related to regulations and enablers, Belgium has:

- 5G spectrum auctions (managed by BIPT): include coverage obligations to promote industry-wide access to 5g
- Environmental & cybersecurity frameworks
- Energy efficiency rules

NETHERLANDS

Connectivity Action Plan aligned with the Digitalisation Strategy sets strategic goals:

- Full national 5G coverage in populated areas by 2030
- Reservation of band spectrum for private/local enterprise networks
- Unified permit rules for small-cell deployment
- Support for innovation pilots and living labs

Also:

- emphasizes municipal-national coordination
- Simplified zoning/licensing for 5G antennas
- Resilience/security standards for advanced networks

Framework of **Private 5G Spectrum License enables manufacturers, logistics firms,** or testbeds to deploy their own private 5G network for B5G use cases in secure enterprise-controlled environments.

The **Do IoT Vouchers for 5G Innovation** (regional grant) provided money to experiment with 5G in operator-neutral field labs. This supports early-stage pilots in verticals such as logistics, drone delivery, smart environment sensing, AgriTech, and healthcare.

Through the **EU Recovery and Resilience Facility (RRF)** and broader **NextGeneration EU/MFF 2021-2027** funding, the Netherlands has access to billions for digitalisation and sustainability-related projects, many of which support 5G innovation and green-tech deployment in industry. The **EU-wide Electronic Communications Code** and Implementing Regulation (EU 2020/1070) created a light regime for small-cell roll-outs, exempting many small 5G antenna installations from town-planning permits. The Netherlands has adopted these measures to accelerate deployment in smart cities, campuses, ports, and industrial zones.

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National Growth Fund funds strategic innovation projects in sectors like microelectronics, telecom, and energy. Around €61 milion is allocated to the Future Network Services (FNS) programme through 2030, supporting Dutch 6G/5G-Advanced R&D and commercialisation.

LUXEMBOURG

A major initiative launched in late 2023 by the Ministry of State's Department of Media, Connectivity and Digital Policy, the Ministry of the Economy, the Luxembourg National Research Fund (FNR), and Luxinnovation to offer companies and research institutions a new funding opportunity to support consortia wishing to take advantage of 5 G communication technologies in their field, research, or activity. Designed as a two-phase public-private funding call aimed at stimulating R&D and deployment of 5 G in sectors such as smart environment, smart cities, and Industry 4.0. Seven projects are selected and receive a total budget of £10.54 million. The public scheme is co-administered by FN, which provides funding up to £ 700,000 per project for public research organisations to support their project-related costs, and the Ministry of the Economy, which co-finances company-borne costs up to £ 700,000 per project, under its R&D aid scheme. support projects over a maximum duration of 36 months, specifically focusing on innovation in 5G, IoT, edge computing, AI, and complementary technologies such as satellite comms.

Luxembourg benefits from several EU-wide funding initiatives:

- connecting Europe facility- digital (CEF-digital) targeting large-scale 5 G pilots, edge integration, smart communities, and transport corridor connectivity
- Digital Europe programme supports strategic digital technologies, including supercomputing, AI, cybersecurity, and the rollout of digital innovation

These EU funds complement the recovery and resilience facility (RRF) under REPowerEU, part of Louxembourg's recovery plan. Luxembourg has allocated £241 million total; 80,1% of that supports green objectives with 37z5% dedicated to digital transition.

At the national level, SNCI (Société Nationale de Crédit et d'Investissement) offers a suite of financial instruments for companies and start-ups; innovation loans for R&D projects, typically covering up to 25% of eligible costs, and equipment and medium/long-term loans for infrastructure investments. Luxinnovation provides funding, navigation support, and access to national and EU programs. OPERates the digital innovation hun (DIH), HPC Competence Centre, and the Gaia-X national hub to accelerate digital and green transformations

B7.6. Readiness and Barriers

BELGIUM

Belgium is relatively advanced in preparing for industrial 5G applications, particularly in manufacturing, logistics, and smart cities. Strengths are strong telecom infrastructure, an advanced R&D ecosystem, strategic pilot zones, and supportive public policy. Key barriers to industrial 5G deployment are:

- cost of infrastructure

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- Spectrum & regulatory complexity (for example, regulatory fragmentation between federal and regional levels)
- Skills gap (lack of technical professionals)
- Awareness & use case maturity (industrial leaders demand concrete, often use case testing remains pilot-scale)
- Fragmented ecosystem adoption (uptake is slower in rural zones)

NETHERLANDS

The Netherlands is considered highly advanced and "early ready" in terms of industrial 5G/B5G adoption, particularly for sectors like logistics, transport, manufacturing, and smart cities. However, industrial use is still emerging, and there are several barriers preventing widespread deployment. Key barriers:

- Cost & ROI Uncertainty
- Limited awareness in SMEs
- Skill gaps
- Infrastructure gaps in industrial zones
- Organizational & regulatory complexity

The Netherlands is well-positioned to scale industrial 5G, especially in enterprises and national corridors (ports, logistics chains). For SMEs and full-sector transformation, more work is needed on cost-sharing models, skill-building, infrastructure access, and sector-specific playbooks.

LUXEMBOURG

Luxembourg is moderately to highly ready for industrial 5G use, especially in terms of infrastructure and government support. However, adoption across the industry remains uneven, and several barriers persist.

One of the barriers is the costs; high upfront investment for private 5G networks, edge devices, and integration. Also, the regulation is still complex or unclear for industries because of the spectrum licensing for private networks. The skill gaps are a fundamental challenge for 5G applications, as there is low awareness, and many projects are in pilot or proof-of-concept stages.

B7.7. Sustainability & Green Innovation Linkage

BELGIUM

In the Belgian context, 5G and sustainability goals are increasingly interlinked. While 5G is not a sustainability solution, it is an enabling technology that supports green innovation and contributes to key aspects of the EU Green Deal and Belgium's climate and circular economy strategies. Key links between 5G and sustainability goals:

- energy efficiency in industry. 5G enables real-time monitoring and control of machines, production lines, and utilities in smart factories.

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- Support for the low-carbon and net-zero industry. Link with the EU ETS, 5G helps industrial actors meet emissions reporting and carbon reduction goals.
- Circular economy and smart resource use. 5G-enabled IoT tracking improves the traceability of products, materials, and waste streams
- Green mobility and logistics
- Smart energy and renewable integration. For example, Belgium's EnergyVille, in collaboration with imec and VITO, explores 5G for decentralized energy systems.
- Remote work, automation & dematerialization

In conclusion, 5G is a critical enabler of sustainability in Belgium's industrial and urban ecosystems. Belgium must accelerate deployment of private 5G networks, incentivize SME adoption, and integrate 5G in circular economy roadmaps and climate action plans. The challenges to be faced concern the costs of 5G infrastructure energy use, the awareness gap, and the investment hurdle because green and digital co-investments are costly without targeted incentives.

NETHERLANDS

In the Netherlands, 5G and sustainability goals are increasingly intertwined. 5G/B5G technologies are seen as key tools for reducing emissions, optimizing resource use, and supporting the circular economy. For example:

- Shelle Pernis refinery uses private 5G networks to monitor and reduce energy waste and optimize operations.
- The 5G-Blueprint project trials teleoperated electric trucks and forklifts, reducing driver travel and emissions.
- Several Industry 4.0 pilots in the Do IoT Fieldlab (TU Delft) aim to prove that high private 5G networks reduce environmental impact in automated production systems.
- Trials at Unmanned Valley use 5g drones and sensors for remote monitoring of materials and infrastructure, key to circular maintenance models.
- Green Village (TU Delft campus) deploys 5G environmental sensing for smart energy districts.

The Netherlands' Digitalisation Strategy explicitly ties 5G and digitalization to climate resilience, energy transition, and resource efficiency.

LUXEMBOURG

In Luxembourg, 5G technology is increasingly recognized as an enabler of sustainability goals, supporting the country's commitment to the EU Green Deal, REPowerEU, and its National Energy and Climate Plan (NECP).

Energy efficiency and industry:

- 5G enables real-time monitoring and automation
- Supports leaner production and reduced power consumption

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For example, projects like 5G-ARTEMIS use 5G + AR for real-time smart manufacturing, contributing to leaner production processes.

Smart agriculture and water use:

- optimizes water, energy, and fertilizer usage
- support precision agriculture with AI and robotics

5G-AGROBOT enables autonomous indoor farming

Green mobility:

- enables autonomous, low-emission transport
- reduces traffic congestion and CO2 emissions 5G DRIVE and PASTA-5G-V2X projects support V2X communication. Green factories:
- enables predictive maintenance and reduces waste
- enhances AR/VR and teleoperation for sustainable production
- 5G supports digital twins for real-time energy optimization. Smart energy
- 5G enables smart grids and energy-efficient infrastructure
- supports dynamic load management and V2G integration
- facilitates renewable energy deployment

B7.8. Local Success Stories / Good Practices

BELGIUM

Port of Antwerp-Bruges uses a private 5G network for smart port operations in the Flanders region, in partnership with Proximus, Nokia, and Citymesh. The use cases are smart logistics, remote control, and autonomous operations. The project was about to enable real-time, mission-critical communications across a vast industrial and maritime environment. This is one of Europe's first operational private 5G networks in a port environment. The private 5G network is strongly supported by regional, federal, and EU policies.

NETHERLANDS

Shell Pernis + KPN Private 5G Network, one of the first industrial private 5G networks deployed in the Netherlands, at Shell's Pernis refinery, one of the largest in Europe. Partners are Shell Netherlands, KPN (Telecom provider), and Ericsson (Infrastructure provider). Use cases:

- 5G to enable remote inspection drones, autonomous ground robots, and real-time sensor data for predictive maintenance
- Supports AR/VR training and live diagnostics for field engineers in hazardous environments.

Sustainability and Safety:

- Cuts down unnecessary manual inspections (lowers emissions and risk)
- Improves operational efficiency (reduces energy waste)
- Enhances safety by minimizing human exposure to hazardous tasks

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LUXEMBOURG

5G-AGROBOT is the main example of a successful project story. This is an innovative project that integrates 5G, robotics, and AI to enable smart, sustainable agriculture in Luxembourg. use cases:

- deployment of autonomous robots in indoor farming facilities powered by low-latency 5G
- AI and computer vision are used for precision irrigation, fertilization, and harvesting
- real-time environmental monitoring to optimize crop yields and reduce waste

This project is important because it is considering a model project linking digital innovation to green tech, as it has a sustainability impact by reducing water and energy use, enabling local food production with minimal environmental footprint, and contributing to Luxembourg's circular and green economy strategy.

B7.9. Additional Comments or Observations

BELGIUM

Belgium's regional landscape has several unique features and strengths that position it as a promising testbed and innovation hub for advanced 5G and green industrial tech. First of all, Belgium has a strategic geographic and economic position, it has the major transport corridors, and this makes it a natural candidate for 5G-enabled logistics. Belgium has world-class research institutes like imec, EnergyVille, and Flanders Make, and it also hosts major innovation campuses and living labs that link academia, start-ups, and corporates.

Regional governments are merging their digital and green strategies in line with European policies, and Belgium is one of the first EU countries to enable local/private spectrum licensing to run dedicated 5G networks. At least, in Belgium, it is possible to create a cross-border and multilingual collaboration thanks to the federal structure and multilingual regions. The presence of both high-tech leaders and traditional industries allows for testing 5G in low- and high-tech environments.

NETHERLANDS

The Netherlands is not just a user of 5G, it is a testbed, connector, and policy innovator, enabling the responsible integration of 5G with green industrial transformation. Its ecosystem thrives on collaboration. Experimentation and international orientation make it a model region for digital sustainability.

LUXEMBOURG

Luxembourg has unique characteristics that make it particularly relevant in the context of advanced 5G and green industrial technology. first, its central location makes it a test-bed for EU-wide cross-border 5G mobility projects. Its proximity to Germany, France, and Belgium enables joint infrastructure deployment and regulatory coordination, and it

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supports the EU's goal of pan-European 5 G corridors for autonomous transport. Luxembourg is home to SES, one of the world's largest satellite operators, and this makes it a pioneer in non-terrestrial network (NTN) 5Gapplications, aligned with future 6 G architecture. The University of Luxembourg's SnT and LIST both maintain strong industry-academic links, and the government plays an active innovation leadership role, not just a regulatory one:

- funds pilot, subsidizes R&D, and enables test environments
- developed a 5G strategy early with clear sustainability alignment

The Fit 4 Sustainability and Fit 4 Digital programs directly support industries in greening their operations using advanced tech.

In the end, Luxembourg integrates digital and green transitions.

B7.10. Resources/References

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C. Interview Guide

General topics to cover in the interview

This interview seeks expert insight into the adoption, value, and evolution of advanced 5G and B5G technologies in European industrial contexts, especially their role in enabling sustainable digital transformation. It supports the 5G-DiGITs project, focused on the intersection of 5G and Green IT training.

Section 1: Technology Maturity and Innovation Focus
Context:
Understanding how experts perceive the current state of advanced 5G/B5G technologies is essential for assessing readiness for deployment and identifying which technical enablers are gaining traction.

Q1.1 How would you describe the **maturity level** of advanced 5G/B5G technologies in your sector or ecosystem?

☐ Still in research/pilot stage (not deployed)
☐ Limited real-world deployment (early trials & pre-commercial pilots)
☐ Actively deployed in controlled settings (commercially deployed in limited scenarios)
☐ Broad deployment underway (fully deployed across core business functions)

Optional comments:

Q1.2 Which of the following **technology areas** do you see as the most promising in the short-to-mid-term? *(Select up to 3)*

☐ Open RAN (O-RAN)
☐ Private 5G networks
☐ Network slicing
☐ Non-Terrestrial Networks (NTNs)
☐ Edge computing and cloud-native 5G
☐ AI/ML network management
☐ 5G-Advanced (Release 18+)
☐ Green/energy-efficient networking (sustainability-by-design 5G)
☐ mmWave / advanced spectrum use
☐ Others

Why these?

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Section 2: Sectoral Adoption and Use Cases
Context:
We want to identify where real-world use of 5G is emerging, what drives it, and whether it aligns with industrial transformation goals.

Q2.1 In which **industry sectors** do you observe the most active adoption or interest in 5G/B5G?
(Select all that apply)
☐ Manufacturing (e.g., smart factories, AGVs, predictive maintenance)
☐ Energy/utilities (e.g., smart grids, renewable integration, grid monitoring)
☐ Logistics and mobility (e.g., port automation, fleet tracking, C-V2X)
☐ Agriculture (e.g., precision farming, autonomous equipment)
☐ Health (e.g., remote diagnostics, real-time patient monitoring)
☐ Public infrastructure (e.g., smart cities, traffic management, digital twins)
☐ Construction and Smart Buildings
☐ Media and Entertainment (e.g., AR/VR streaming, broadcast innovation)
☐ Other: _____________
Any notable use case examples?

Q2.2 What are the **primary motivations** driving adoption in these sectors?
☐ Operational efficiency (e.g., real-time analytics, predictive control)
☐ Process automation and digitalisation
☐ Environmental sustainability (e.g., decarbonisation, energy savings)
☐ Worker safety and remote operations
☐ Regulatory compliance
☐ Competitive advantage or innovation leadership
☐ Customer demand or market pull
☐ Other: ____________
Please elaborate if needed:

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Section 3: Ecosystem and Barriers to Adoption
Context:
The successful deployment of 5G/B5G in industrial and green applications depends not only on technology but on the readiness and cohesion of the wider innovation ecosystem. This includes regulatory clarity, investment frameworks, supply chains, and skilled human capital.

Q3.1 What are the most significant **barriers** to deploying 5G/B5G in your industrial or regional context? *(Select all that apply)*

☐ High infrastructure cost (CAPEX/OPEX)
☐ Lack of a qualified workforce (technical or sector-specific)
☐ Immature vendor or integrator ecosystem
☐ Regulatory uncertainty or delays
☐ Low awareness or understanding of 5G value in the industry
☐ Cybersecurity or privacy concerns
☐ Short investment horizon / unclear ROI
☐ Limited access to spectrum or delays in allocation
☐ Other: ____________

Additional insights:

Q3.2 How would you rate the current level of **coordination** and **alignment** between key stakeholders (industry, policy, academia, start-ups) in your region?
1 = Very weak | 5 = Excellent
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

📝 *Comment on what's missing/misaligned or working well:*

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Section 4: Sustainability and Green Impact
Context:
The alignment between 5G deployment and environmental or sustainability goals is a central concern of the 5G-DiGITs project. We seek to understand not just whether 5G reduces environmental impact, but how, where, and why green considerations influence real-world deployments, and what expectations exist for future sustainability performance.

Q4.1 In your experience, is environmental **sustainability** a key driver in the design, adoption, or promotion of 5G/B5G technologies in your context?

☐ Yes – it's a primary design/deployment driver
☐ Somewhat considered but secondary
☐ No – other drivers dominate (e.g., productivity, innovation)

Please share any relevant examples or comments:

Q4.2 In what **ways** do you believe 5G/B5G can **best support** environmental sustainability? *(Select up to 3)*

☐ **Energy efficiency** in networks and industrial operations (e.g., RAN optimisation)
☐ Smart grids and real-time energy management
☐ **Remote operations** that reduce physical travel or fuel use
☐ **Digital twins** for decarbonisation, maintenance optimisation, etc.
☐ **Support for circular economy** (e.g., tracking, recycling, modularity)
☐ Sustainable supply chains and logistics
☐ **Sustainable agriculture** (e.g., precise water/fertilizer control)
☐ Other: ____________

Optional elaboration:

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Q4.3 Does your organization measure or plan to measure the sustainability footprint or handprint of its 5G/B5G deployments?

☐ Yes – already measuring impact (KPIs or LCA)
☐ Planning to implement such assessments
☐ No current plans
☐ Don't know

Optional elaboration:

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Section 5: Future Signals and Technology Outlook
Context:
Strategic foresight can help identify the technological and market shifts that may shape the future of industrial 5G and green innovation. Experts are invited to share their views on what might come next, both mainstream trends and emerging signals.

Q5.1 What future 5G/B5G-related technologies or trends do you believe are currently **underestimated** or **overlooked**?
☐ AI-native network architecture (automated design, zero-touch ops)
☐ Spectrum innovation (e.g., THz bands, dynamic sharing)
☐ Integration of sensing and communications (joint comm-sense networks)
☐ New materials and hardware (e.g., graphene, neuromorphic chips)
☐ Quantum-secure or ultra-trustworthy communication
☐ Biologically inspired network models
☐ Non-Terrestrial Networks (LEO, HAPS, direct-to-device satellites)
☐ Decentralised edge-cloud continuum (e.g., AI at the edge)
☐ Convergence with verticals (e.g., 5G + energy grid digital twins)
☐ Other: ____________
Optional elaboration for under/over estimation:

Q5.2 Where do you expect to see the **most significant evolution** in 5G deployment over the **next 3–5 years** in Europe?
☐ Private industrial networks (e.g., ports, factories)
☐ AI-driven network automation and energy optimisation
☐ Cross-border or multinational industry testbeds
☐ Policy-driven 5G for sustainability (e.g., EU Green Deal, edge rollout targets)
☐ Increased uptake in non-tech sectors (e.g., agri-tech, health)
☐ Other: ____________
Optional elaboration

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Section 6: Europe's Position and Strategic Capacity
Context:
As global innovation accelerates, it is vital to understand how Europe compares to other regions in industrial 5G and B5G deployment, sustainability leadership, and ecosystem maturity. This section seeks to assess both perception and reality regarding Europe's global standing and what is needed to close strategic gaps.

Q6.1 How would you rate **Europe's positioning** in industrial 5G and green innovation relative to other regions?
☐ Leading globally
☐ Competitive
☐ Catching up
☐ Lagging behind
What are Europe's key strengths or gaps?

Q6.2 In your opinion, what **type of support** or **action** would most accelerate industrial 5G/B5G adoption in Europe? *(Select up to 3)*
☐ Greater funding for pilot projects or testbeds
☐ Skills development and workforce upskilling
☐ Regulatory harmonisation across borders
☐ Strategic public procurement and demand aggregation
☐ SME/start-up engagement and support
☐ Better integration of green KPIs into digital policy
☐ Other: ___________
Optional elaboration:

Q6.3 Is Europe **well-positioned** to shape global standards or norms in future networks (e.g., Open RAN, secure-by-design, sustainable 6G)?
☐ Yes – Europe is setting global benchmarks
☐ Somewhat – Europe contributes but is not dominant
☐ No – Others (e.g., Asia, US) are more influential
☐ Don't know
Optional elaboration:

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Closing

Q7.1 Is there anything else you believe is **critical for Europe's 5G and green industry roadmap** that hasn't been covered in this interview?

Open comment

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D. Interview results

In compliance with the General Data Protection Regulation (**GDPR**), the verbatim textual comments provided by experts in the survey have not been included in this deliverable. Instead, the qualitative input has been subject to a process of **pseudonymisation** and **anonymisation** designed to eliminate any risk of direct or indirect identification of individual participants. This decision was taken given the limited size of the expert sample, which increases the risk of re-identification if raw comments were disclosed.

The applied procedure involved the systematic redaction or generalisation of any references to natural persons, organisations, projects, programmes, cities, or countries, as well as the removal of contact details (e-mail addresses, telephone numbers, URLs) and specific dates. Neutral placeholders (e.g., [ORGANIZATION], [REGION], [CITY]) were inserted where necessary to maintain the interpretative value of the statements without retaining identifiable elements. This ensures that the anonymised corpus retains its analytical relevance for the purposes of the project while fully respecting the GDPR principles of data minimisation and protection of data subjects' rights.

General aspects

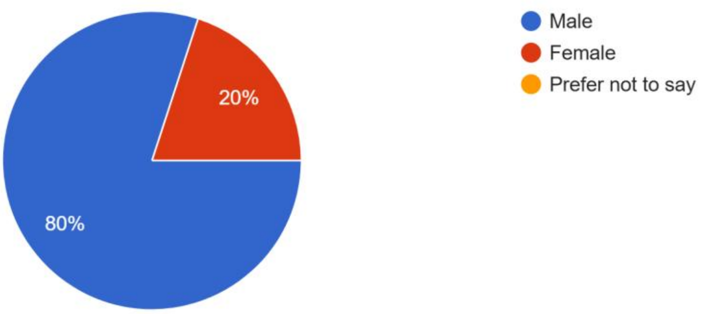

Figure 6. Questionnaire result. Gender distribution

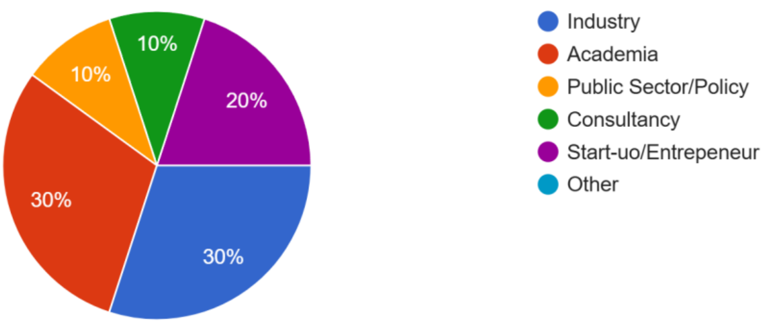

Figure 7. Questionnaire result. Main sector of activity distribution

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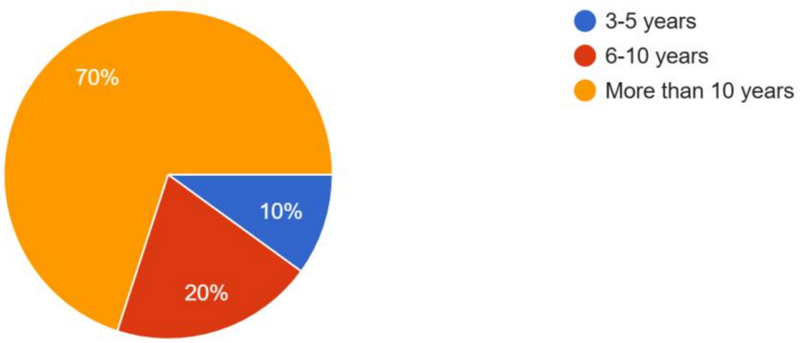

Figure 8. Questionnaire result. Years of Experience in this Sector

Technology Maturity and Innovation Focus

How would you describe the maturity level of advanced 5G/B5G technologies in your sector or ecosystem?

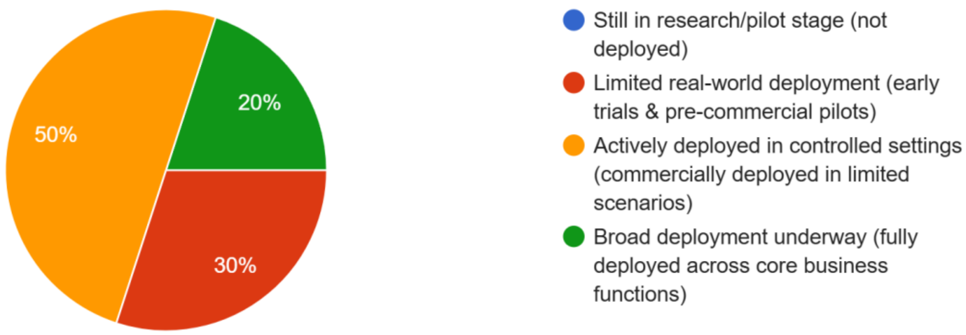

Figure 9. Questionnaire result. Maturity level of Advanced 5G/B5G

Textual elaboration (anonymized):

- **Expert01:** Actively deployed in controlled settings (commercially deployed in limited scenarios). Over the past few years, [REGION] universities have played a pivotal role in piloting and testing 5G and B5G technologies, often through participation in EU-funded research projects such as [ORGANIZATION] and [ORGANIZATION]. Academic initiatives have focused on developing and validating use cases across various domains—such as smart cities, e-health, intelligent transportation, and Industry 4.0—within controlled lab environments and testbeds. Leading universities, including the National and [ORGANIZATION] [ORGANIZATION] of [CITY], have established 5G testbeds and living labs that enable experimentation with network slicing, edge computing, and URLLC. Although large-scale commercial deployment across the academic sector is still limited, collaborations with [ORGANIZATION] operators and industry partners have enabled small-scale, real-world trials in campus environments and select urban areas. These trials are bridging the gap between theoretical research and practical implementation, showing a clear trajectory toward broader adoption. In summary, the academic sector in [REGION] demonstrates a high level of engagement with 5G/B5G technologies, with deployments actively taking place in controlled settings and commercial use cases emerging in limited but strategic scenarios.

- **Expert02:** Actively deployed in controlled settings (commercially deployed in limited scenarios). There is significant deployment of 5G available in [REGION] as well as in other parts of the world. The period of rollout and adoption has already taken place for mobile broadband users. The public 5G for consumers is widely available, and advanced technologies for industry, such as private networks with very low latency or high reliability functionalities, are mainly found in limited commercial deployments. Certainly, in early adopters. We are talking about specific areas: drone airports or logistics campuses, and the use cases are very well defined and controlled. We have not yet reached mass deployment in critical business functions on a widespread basis.
- **Expert03:** Limited real-world deployment (early trials & pre-commercial pilots). Advanced 5G/B5G technologies are being tested through pilot projects and limited commercial trials, especially in industrial and smart city scenarios. While foundational 5G is live, key B5G features like slicing, ultra-low latency, and edge integration are not yet broadly deployed.
- **Expert04:** Limited real-world deployment (early trials & pre-commercial pilots). There is a dearth of available investment capital from potential customers of these technologies, so real-world deployments are limited.
- **Expert05:** Broad deployment underway (fully deployed across core business functions). 5G is a reality in many fields
- **Expert06:** Actively deployed in controlled settings (commercially deployed in limited scenarios)
- **Expert07:** Limited real-world deployment (early trials & pre-commercial pilots). Currently, limited 5G SA deployments have been commercially performed, while the majority of the commercial 5G systems are NSA. More limited is the integration of 5G within vertical industries, which still rely on 4G or Wi-Fi or other technologies, such as LoRaWAN.
- **Expert08:** Broad deployment underway (fully deployed across core business functions). There is significant deployment of 5G available in [REGION] as well as in other parts of the world. The period of rollout and adoption has already taken place for mobile broadband users.
- **Expert09:** Actively deployed in controlled settings (commercially deployed in limited scenarios). Full 5G technology/systems are mostly applied in vertical industries (specific use cases)
- **Expert10:** Actively deployed in controlled settings (commercially deployed in limited scenarios). As an example, [ORGANIZATION] provides FWA (Fixed Wireless Access) to its subscribers through its 5G SA deployment

Which of the following technology areas do you see as the most promising in the short-to-mid-term? *(Select up to 3)*

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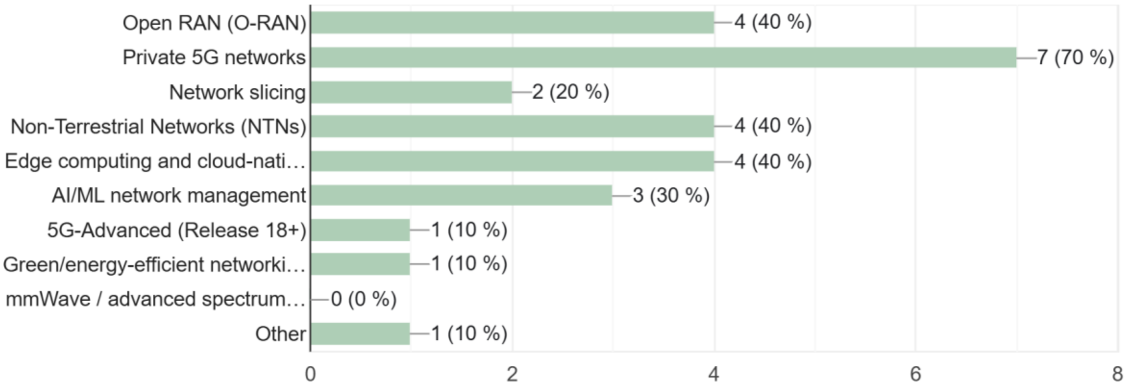

Figure 10. Questionnaire result. Most promising technology areas

Textual elaboration *(anonymized):*

- **Expert01:** AI/ML network management; 5G-Advanced (Release 18+); Green/energy-efficient networking (sustainability-by-design 5G). The application of artificial intelligence and machine learning to network operations is rapidly transforming how networks are designed, optimized, and maintained. AI/ML enables predictive and autonomous network management, including traffic forecasting, real-time fault detection, and dynamic resource allocation. These capabilities are essential for coping with the complexity and scale of 5G and beyond, paving the way for self-organizing, self-healing infrastructures. 5G-Advanced marks a significant evolutionary step, introducing features such as improved support for XR (extended reality), non-terrestrial networks (NTNs), integrated sensing and communication (ISAC), and advanced network slicing. These are expected to unlock new use cases in manufacturing, healthcare, transportation, and public safety. Finally, with pressure to reduce ICT's environmental impact, green networking is critical. Technologies that reduce energy consumption—through intelligent sleep modes, energy-aware routing, and efficient hardware—are being developed. Sustainability-by-design principles are becoming integral to standards and roadmaps, ensuring deployments are both high-performance and environmentally responsible.
- **Expert02:** Private 5G networks; Network slicing; Edge computing and cloud-native 5G. Private 5G networks are key for industry, offering scalable cybersecurity and guaranteed performance. Edge computing is inseparable from industrial 5G: for robotics or real-time analytics, processing must occur close to the source. Network slicing allows different slices with guaranteed features (e.g., one for mass sensor communications, another for critical machine control).
- **Expert03:** Private 5G networks; Edge computing and cloud-native 5G; AI/ML network management. These are seen as most promising due to enterprise demand, low-latency requirements, and the need for intelligent, automated networks.
- **Expert04:** [ORGANIZATION]; Private 5G networks; AI/ML network management. Between standardisation work and open initiatives, there are opportunities for smaller players to deploy into multi-vendor environments, especially in areas like Open RAN and private 5G. However, the availability of investment capital remains a challenge. AI/ML for BSS/OSS automation is seen as an easier win, positioned as efficiency and cost reduction.
- **Expert05:** V2X communications.

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- **Expert06:** [ORGANIZATION]; Edge computing and cloud-native 5G. Moving AI onto edge devices requires a reliable communication channel, especially in environments where industrial Wi-Fi is unavailable.
- **Expert07:** Private 5G networks; non-terrestrial networks (NTNs); Edge computing and cloud-native 5G. To achieve the full potential of 5G in industries, private deployments with full access to core and RAN are required. Advances are expected in NTN/TN integration, since NTN is now a 3GPP access technology. Edge capabilities are also expected as integrated services from operators.
- **Expert08:** [ORGANIZATION]; Private 5G networks; non-terrestrial networks (NTNs). Revenue opportunities are expected from the interplay between 5G and NTNs, the adoption of open approaches, and wider private network uptake.
- **Expert09:** [ORGANIZATION]; Private 5G networks; non-terrestrial networks (NTNs). Open approaches provide access to all stakeholders. Private 5G networks are already in operation. There is growing interest in NTNs.
- **Expert10:** Private 5G networks; Network slicing; non-terrestrial networks (NTNs). This view is based on customer interest, market surveys, and the maturity level of available technologies.

Sectorial Adoption and Use Cases

In which industry sectors do you observe the most active adoption or interest in 5G/B5G? *(Select all that apply)*

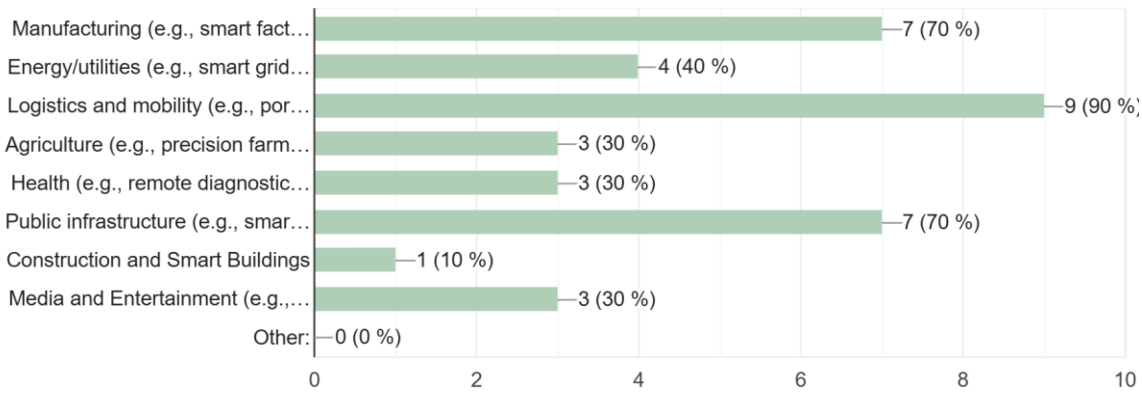

Figure 11. Questionnaire result. Industry sectors with the most active adoption of 5G/B5G

Textual elaboration *(anonymized):*

- **Expert01:** Manufacturing/Industry 4.0; Smart cities; Healthcare; Transportation & logistics; Energy/utilities. Interest is primarily driven by automation, monitoring, and control, and data-driven optimization (e.g., for predictive maintenance and real-time quality assurance). Smart-city pilots frequently focus on infrastructure monitoring and public services. Healthcare interests include remote diagnostics and connected devices. Logistics explores asset tracking and autonomous operations. Energy focuses on grid monitoring and distributed resources.

- **Expert02:** Manufacturing; Smart cities; Public safety; Transport; Media/entertainment. Industrial automation and mission-critical services (e.g., connected robots) dominate. Smart cities and public safety demand real-time responsiveness. Transport requires low-latency communications for operational control. Media/entertainment explores enhanced user experiences and live content production.
- **Expert03:** Manufacturing; Logistics; Energy/utilities. Use cases include predictive maintenance, robotics/cobots, automated guided vehicles, and process monitoring. Logistics benefits from private 5G due to mobility and interference challenges for Wi-Fi. Energy looks at the monitoring and control of distributed assets.
- **Expert04:** Smart cities; Manufacturing; Transport; Healthcare. Private networks are a key enabler.
- **Expert05:** Transport & logistics; Manufacturing; Public safety; Agriculture; Ports. These sectors are exploring private networks, edge analytics, and sensing for operational efficiency and safety.
- **Expert06:** Manufacturing; Transport; Ports/logistics. Early adoption stems from clear ROI in automation and tracking. Ports are a focus area due to coverage, mobility, and reliability requirements.
- **Expert07:** Manufacturing; Logistics; Smart cities; Healthcare; Energy. These sectors are the most engaged in pilots and limited commercial deployments.
- **Expert08:** Manufacturing; Public safety; Utilities; Transport; Media/entertainment. The combination of private networks and edge/cloud is enabling progress.
- **Expert09:** Manufacturing; Smart cities; Transport; Healthcare; Agriculture. The ecosystem is still fragmented, with many proofs of concept rather than mass rollouts.
- **Expert10:** Manufacturing; Logistics; Smart cities; Healthcare. Private networks, edge computing, and AI-driven operations are common themes across these sectors, considering the engagement of SMEs in various R&D proofs-of-concept.

What are the primary motivations driving adoption in these sectors?

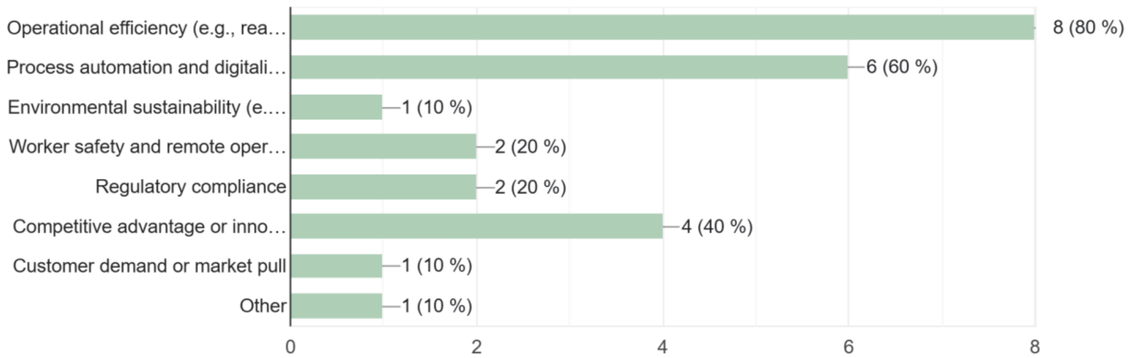

Figure 12. Questionnaire result. Primary motivations for 5G/B5G adoption

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Textual elaboration *(anonymized):*

- **Expert01:** Environmental sustainability (e.g., decarbonisation, energy savings); Customer demand or market pull. Sectors are under pressure to reduce environmental impact, and 5G/B5G is seen as enabling more energy-efficient and sustainable operations. Smart city initiatives optimise resources (lighting, traffic, waste), yielding savings and lower emissions. In healthcare, remote diagnostics and telemedicine reduce travel and hospital visits, contributing to sustainability. Policy and funding at national and EU levels reinforce this. At the same time, expectations for faster, smarter, more connected services (healthcare, urban services, mobility) push adoption.
- **Expert02:** Operational efficiency (e.g., real-time analytics, predictive control); Process automation and digitalisation; Competitive advantage or innovation leadership. The main motivation is economic: efficiency and automation reduce costs and boost productivity. Sustainability is a benefit, but investment decisions today are justified primarily by competitiveness and optimisation.
- **Expert03:** Operational efficiency; Competitive advantage or innovation leadership; Other.
- **Expert04:** Operational efficiency. Budget constraints make OpEx reduction a key driver of adoption.
- **Expert05:** Process automation and digitalisation; Regulatory compliance.
- **Expert06:** Operational efficiency; Process automation and digitalisation; Worker safety and remote operations.
- **Expert07:** Operational efficiency; Process automation and digitalisation; Regulatory compliance.
- **Expert08:** Operational efficiency; Competitive advantage or innovation leadership. Often, adoption is about replacing less flexible legacy technology, not because an application “needs” 5G.
- **Expert09:** Operational efficiency; Process automation and digitalisation; Worker safety and remote operations. 5G enables MEC and cloud-native solutions required for automation and remote operations.
- **Expert10:** Operational efficiency; Process automation and digitalisation; Competitive advantage or innovation leadership.

Ecosystem and Barriers to Adoption

What are the most significant barriers to deploying 5G/B5G in your industrial or regional context? ***(Select all that apply)***

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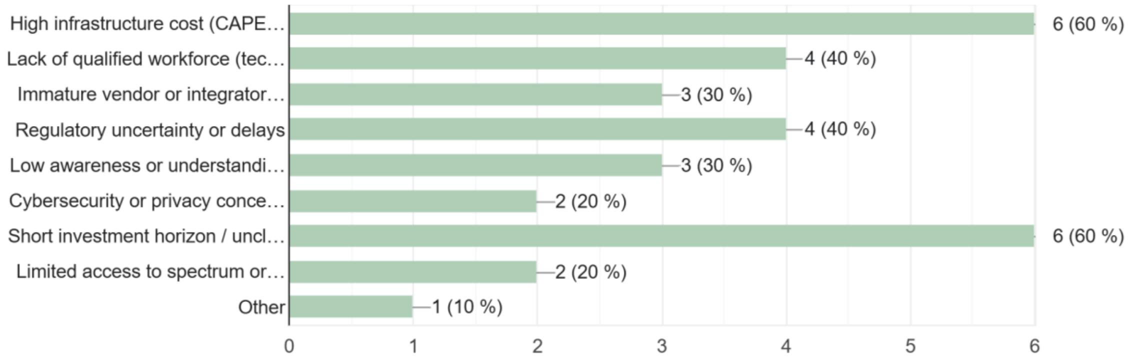

Figure 13. Questionnaire result. Barriers to deploying 5G/B5G

Textual elaboration *(anonymized):*

- **Expert01:** Lack of investment capital; Unclear ROI; Fragmented ecosystem. Limited funding slows trials and commercial rollouts. Enterprises hesitate without clear business cases and proven gains.
- **Expert02:** Spectrum availability/cost; Device ecosystem maturity; Skills gap. Access to suitable spectrum bands and device availability are bottlenecks. There is also a shortage of skilled professionals for design, deployment, and operations.
- **Expert03:** Regulatory complexity; Permitting and site access; Security/compliance requirements. Complex multi-stakeholder environments and lengthy approval processes delay deployments. Security and compliance raise cost and integration complexity.
- **Expert04:** Cost of private networks; Vendor lock-in concerns; Integration with legacy systems. Enterprises fear high capex/opex and dependency on a single vendor. Interoperability with existing OT/IT systems is challenging.
- **Expert05:** Lack of proven use cases; Limited awareness among decision makers; Market fragmentation. Without clear references and benchmarks, decision makers delay adoption. Fragmentation across devices, platforms, and vendors complicates end-to-end solutions.
- **Expert06:** Coverage and indoor penetration; Availability of SA features; Integration with edge/cloud. Reliable coverage and mature SA features are still limited in many industrial locations, making it hard to meet strict SLAs.
- **Expert07:** Cost and uncertainty in monetisation; Risk aversion; Skills gap. Companies are cautious about new network paradigms and lack internal capabilities to operate them.
- **Expert08:** Regulatory hurdles; Spectrum/licensing models; Time-to-market constraints. Complex rules for private/industrial spectrum and multi-tenant models slow progress.
- **Expert09:** Legacy technology inertia; Integration costs; Vendor interoperability. Replacing or integrating with entrenched systems is costly and risky.
- **Expert10:** Investment constraints; Device availability; Uncertainties about monetising the required (high) investments.

How would you rate the current level of coordination and alignment between key stakeholders (industry, policy, academia, start-ups) in your region?

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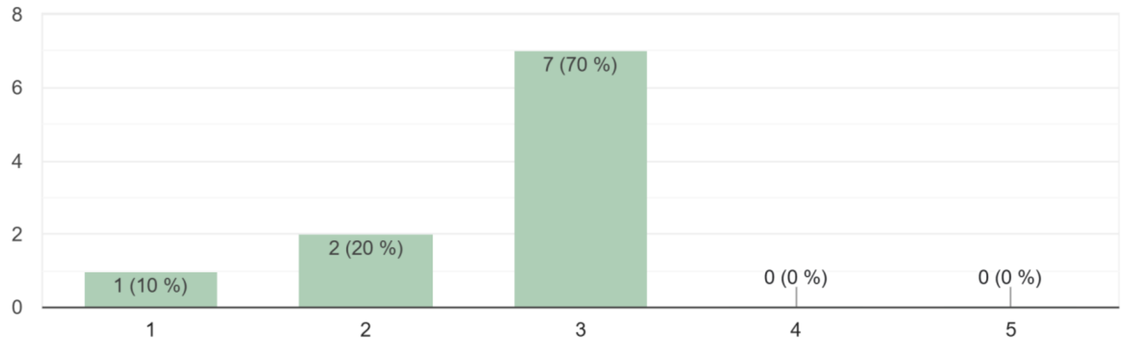

Figure 14. Questionnaire result. Level of alignment between key stakeholders

Textual elaboration *(anonymized):*

- **Expert01:** 3. There have been notable efforts to foster collaboration through national digital strategies, EU-funded projects, and the creation of testbeds and innovation hubs involving universities, telecom operators, and public agencies. Academia is active in research and pilots; the government provides funding and regulatory frameworks. However, coordination remains fragmented, with inconsistent long-term planning and weak communication. Start-ups/SMEs struggle to access infrastructure, funding, and partnerships. Industry players beyond telecom (healthcare, energy, logistics) are only sporadically involved. Greater multi-stakeholder platforms, clearer policy–industry roadmaps, and targeted support for start-ups would help.
- **Expert02:** 3. Many pilot projects and initiatives financed by regional/EU funds exist, which is positive. However, projects are often uncoordinated. Industry, policymakers, and universities operate in parallel rather than as an integrated ecosystem. This is not unique to 5G; it repeats with other emerging technologies. Harmonised regulation and joint investment strategies at the [REGION] level are missing, leading to market fragmentation. Over time, standards usually emerge de facto.
- **Expert03:** 3. There is a growing number of start-ups with strong technical knowledge and alignment with operators and vendors. The main challenge is demonstrating differentiation and compelling ROI in concrete customer projects.
- **Expert04:** 2. Policy in many countries is disjointed and unfocused. Vendors could accelerate development with more cohesive policies, similar to how unified GSM standards drove innovation in the 1990s.
- **Expert05:** 2. Policy exists but lacks budgetary support.
- **Expert06:** 3. Coordination should come more from the government level, rather than relying solely on academia and industry. Still much work to do.
- **Expert07:** 1. Absence of a viable business model that unites different stakeholders.
- **Expert08:** 3. Regulatory barriers remain stronger in the EU compared to other markets. This helps explain why regions such as Asia or North America adopted features earlier, conducted trials earlier, and launched deployments sooner. [REGION] lags behind.
- **Expert09:** 3. Partial collaboration exists but needs improvement.
- **Expert 10: 3. Lack of horizontal, cross-sector initiatives at the** national level.

Sustainability and Green Impact

In your experience, is environmental sustainability a key driver in the design, adoption, or promotion of 5G/B5G technologies in your context?

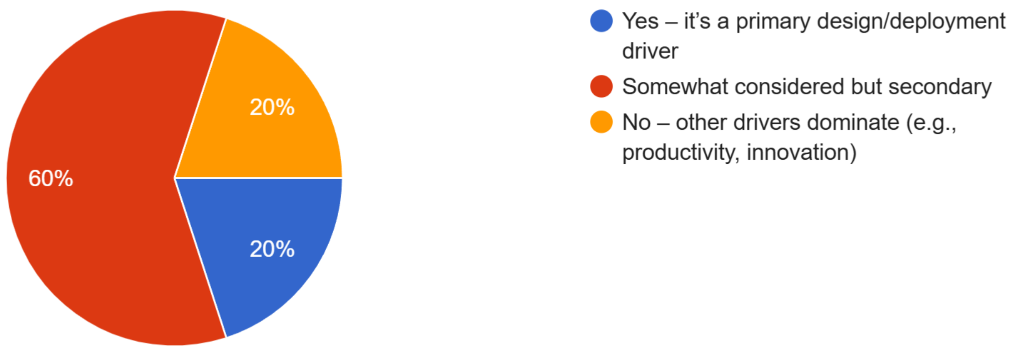

Figure 15. Questionnaire result. Environmental sustainability as a key driver in design and adoption

In what ways do you believe 5G/B5G can best support environmental sustainability? *(Select up to 3)*

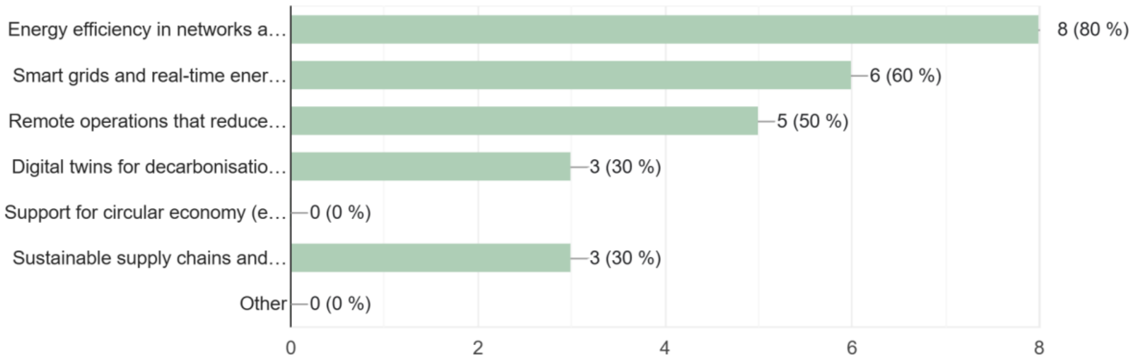

Figure 16. Questionnaire result. Ways of 5G/B5G to best support environmental sustainability

Textual elaboration *(anonymized):*

- **Expert01:** Energy efficiency in networks and devices; Optimised resource use in cities/industry; Enablers for remote operations. 5G can lower energy per bit through advanced sleep modes and intelligent scheduling. In industry and cities, connected sensors and analytics improve resource allocation (lighting, traffic, waste, water). Remote operation and predictive maintenance reduce travel/emissions.
- **Expert02:** Energy efficiency and smart operations via automation and AI/ML. Telemetry-rich networks allow dynamic power management and targeted interventions with measurable environmental impact.

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- **Expert03:** Enabling remote monitoring and control; Reducing travel; Precision operations in agriculture and industry. Remote inspections via robots/drones, and better process control, reduce waste and emissions.
- **Expert04:** Smart grids and utilities; Integration with renewables; Demand-response optimisation. 5G supports granular monitoring and control of distributed energy resources.
- **Expert05:** Industry automation; Predictive maintenance; Digital twins. These accelerate efficiency gains and reduce material/energy waste.
- **Expert06:** Logistics and supply chain optimisation; Fleet management; Asset tracking. Better routing and scheduling reduce fuel consumption and emissions.
- **Expert07:** Energy-aware network design; Edge computing to avoid unnecessary backhaul; Efficient spectrum use. Edge/MEC reduces data transport requirements, and adaptive RAN features reduce energy consumption.
- **Expert08:** Environmental monitoring; Smart buildings; Public services optimisation. Real-time sensing enables targeted actions that reduce footprint across multiple domains.
- **Expert09:** Telemedicine/remote care; Remote work; Smart campuses. Reductions in commuting and onsite visits have measurable effects.
- **Expert10:** The sustainability potential depends on wider digital transformation. Some selected solutions are already in production, but the net impact requires system-level metrics and holistic analysis.

Does your organization measure or plan to measure the sustainability footprint or handprint of its 5G/B5G deployments?

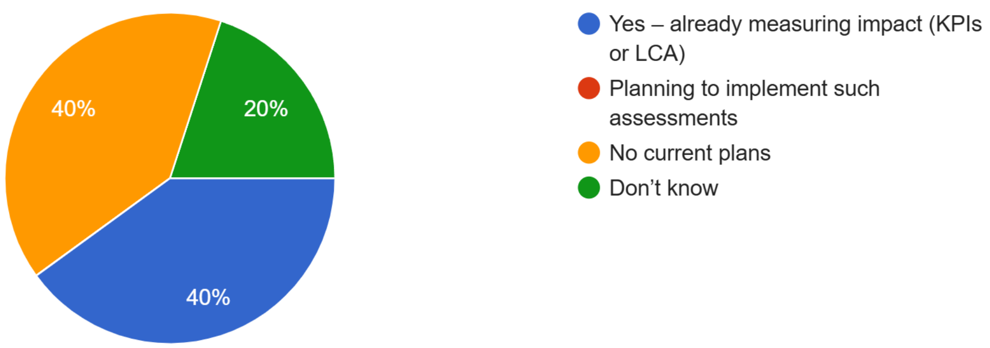

Figure 17. Questionnaire result. Actual measurement of 5G/B5G deployments

Textual elaboration *(anonymized):*

- **Expert01:** No current plans. The [ORGANIZATION] of [CITY] does not yet measure the sustainability footprint or handprint of its 5G/B5G deployments, which are still limited. While there is academic interest in green networking, energy-efficient design, and sustainable ICT, no formal metrics have been applied. Future projects aligned with EU sustainability goals may incorporate such assessments.
- **Expert02:** Yes – already measuring impact (KPIs or LCA). Most organisations still lack standardised metrics for assessing net sustainability impact.

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ISO14000 certification does not directly apply. Measurement is complex, as it must cover network energy consumption, product/service lifecycle, and computing/telecom costs, balanced against savings elsewhere. Standardised KPIs and Life Cycle Assessment (LCA) methodologies are needed.

- **Expert03:** Yes – already measuring impact (KPIs or LCA).
- **Expert04:** Don't know.
- **Expert05:** No current plans.
- **Expert06:** Yes – already measuring impact (KPIs or LCA).
- **Expert07:** No current plans.
- **Expert08:** Yes – already measuring impact (KPIs or LCA). Some software components help industries monitor CPU and memory usage of applications, comparing idle vs. loaded conditions, to evaluate consumption.
- **Expert09:** No current plans.
- **Expert10:** Don't know.

Future Signals and Technology Outlook

What future 5G/B5G-related technologies or trends do you believe are currently underestimated or overlooked?

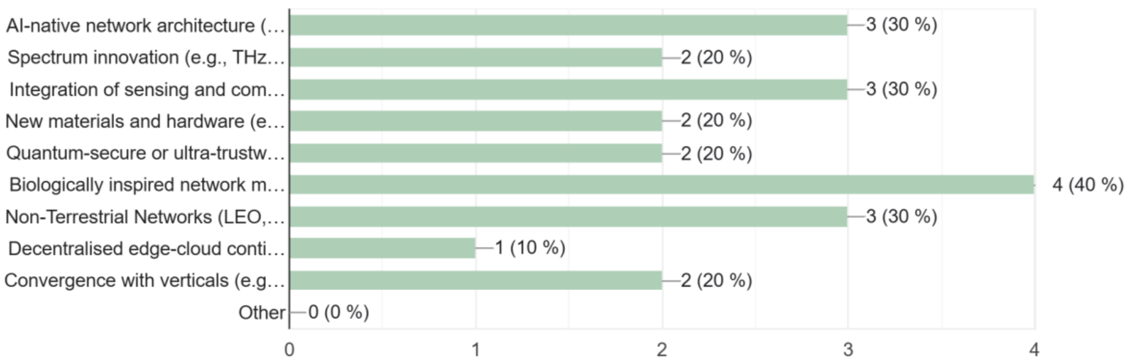

Figure 18. Questionnaire result. Underestimated 5G/B5G-related technologies

Textual elaboration *(anonymized):*

- **Expert01:** AI-native network architecture (automated design, zero-touch ops); Quantum-secure or ultra-trustworthy communication. While AI is often discussed as a tool for optimization, the deeper shift toward AI-native architectures is underestimated. Embedding AI agents across all layers enables real-time adaptation, self-healing, and predictive optimization. Similarly, the urgency of quantum-secure, ultra-trustworthy systems is acknowledged but still under-integrated. Trust must be built into the control, data, and management planes from the outset.
- **Expert02:** Integration of sensing and communications (joint comm-sense networks); Convergence with verticals (e.g., 5G + energy grid digital twins). Joint

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sensing/communication will enable high-precision mapping and environmental awareness. Vertical convergence is also underestimated: it's not just about 5G serving industries, but industries reinforcing 5G.

- **Expert03:** AI-native network architecture; Quantum-secure communications; Convergence with verticals; non-terrestrial networks. These hold strong potential for managing complexity, extending coverage, and creating cross-sector innovations with tangible business cases.
- **Expert04:** AI-native network architecture; non-terrestrial networks (LEO, HAPS, direct-to-device satellites). NTNs, private 5G, and 5G chipsets in consumer devices will be essential for ubiquity. Applying AI to OSS/BSS can unlock efficiency and innovation.
- **Expert05:** Non-terrestrial networks (LEO, HAPS, direct-to-device satellites). Low-orbit satellites could be a game changer for connectivity.
- **Expert06:** New materials and hardware (graphene, neuromorphic chips); Biologically inspired network models; non-terrestrial networks. These areas need more time, focus, and clearer KPIs/ROI.
- **Expert07:** Integration of sensing and communications; Biologically inspired models; Decentralised edge-cloud continuum (AI at the edge). These are gradually underestimated as focus stays on incremental evolutions of prior generations.
- **Expert08:** Spectrum innovation (THz bands, dynamic sharing). Beyond mmWave, much ground remains unexplored due to regulation, hardware constraints, and legacy systems.
- **Expert09:** Spectrum innovation; Integration of sensing and communications; Biologically inspired models. These areas are under-researched and deserve more effort.
- **Expert10:** New materials and hardware (graphene, neuromorphic chips); Biologically inspired models. These are part of ongoing 5G/6G R&D projects but often overlooked in broader roadmaps.

Where do you expect to see the most significant evolution in 5G deployment over the next 3–5 years in Europe?

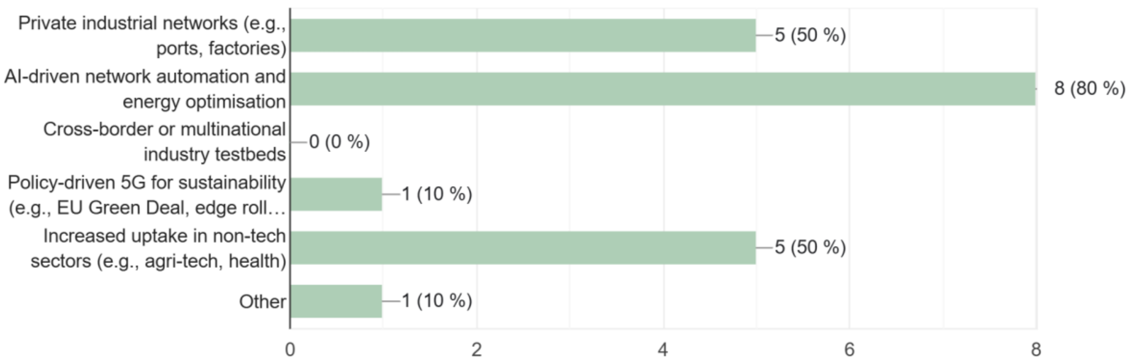

Figure 19. Questionnaire result. Areas with the most significant evolution in 5G deployment

Textual elaboration *(anonymized):*

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- **Expert01:** AI-driven network automation and energy optimisation; Increased uptake in non-tech sectors (agri-tech, health). Expect acceleration in AI-driven automation to handle dense multi-vendor deployments and energy demands. AI systems will dynamically optimise RAN, spectrum, and workloads for efficiency. The biggest societal impact will be in agriculture (autonomous farming, precision irrigation, drone monitoring) and healthcare (telemedicine, connected ambulances, real-time diagnostics). Funding at [REGION]/EU levels supports these areas.
- **Expert02:** Private industrial networks (ports, factories); AI-driven network automation. Tangible growth will come in private networks where business cases are clear. Generative AI and multimodal models will also be critical for automating operations and optimising energy consumption, though overreliance could reduce transparency.
- **Expert03:** Private industrial networks (ports, factories). The clearest opportunities are in controlled industrial environments.
- **Expert04:** AI-driven automation at OSS/BSS level. Open standards and protocols could unlock service innovation across [REGION] networks.
- **Expert05:** Uptake in non-tech sectors (agri-tech, health). A revolution in sensing is expected.
- **Expert06:** AI-driven automation and uptake in non-tech sectors. Early experiments already show tangible ROI for customers.
- **Expert07:** Private industrial networks; AI-driven automation; Uptake in non-tech sectors. Private 5G networks will unleash new potential in agriculture and healthcare once their value is proven.
- **Expert08:** AI-driven automation; Uptake in non-tech sectors. Expect growing reliance on AI for energy savings, and adoption in sectors that may bypass legacy connectivity paths using mobile/satellite.
- **Expert09:** Private industrial networks; AI-driven automation. Cases already exist, and further growth is expected over the next 3–5 years.
- **Expert10:** Private industrial networks; AI-driven automation; Policy-driven 5G for sustainability (e.g., [REGION] edge rollout targets). Momentum will depend on stakeholder engagement and regulatory frameworks.

Europe’s Position and Strategic Capacity

How would you rate Europe’s positioning in industrial 5G and green innovation relative to other regions?

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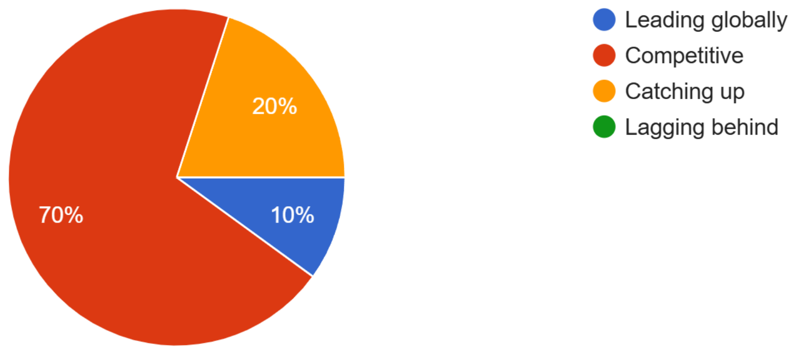

Figure 20. Questionnaire result. Europe's position in industrial 5G

Textual elaboration *(anonymized):*

- **Expert01:** *Catching up.* As a [REGION] [ORGANIZATION] professor engaged with research and innovation ecosystems, I believe the most impactful action would be the creation of regional testbeds and innovation hubs directly embedded within key industrial sectors (e.g., agriculture, energy, logistics). These should be co-funded by EU structural funds and national recovery plans, and tightly connected to SMEs, research institutions, and regulators. In parallel, workforce upskilling is needed through [ORGANIZATION]-industry micro-credentials and applied training programmes, ensuring engineers and domain specialists can work at the telecom/AI/sectoral intersection.
- **Expert02:** Funding is needed to reduce upfront investment risk, especially for large-scale trials. Training professionals who understand both technology and business is critical. Real innovation often comes from agile start-ups and SMEs, so they must be integrated into the ecosystem. Large corporations sometimes block innovation. Universities often focus more on academic goals. Societies that integrate research ecosystems progress faster.
- **Expert03:** To accelerate adoption, [REGION] should bridge the gap between R&D and large-scale deployment by scaling pilots, leveraging public procurement to create demand, and empowering start-ups to deliver value-driven use cases with major operators and integrators.
- **Expert04:** Funding for pilots and testbeds made [REGION] a global leader in mobile telecoms in earlier decades. This approach should be encouraged again, but focused on real-world applications. Regulatory alignment and speed are key to adoption.
- **Expert05:** *Leading globally.* Financial challenges remain, with operators facing economic constraints that limit investment.
- **Expert06:** *Catching up.* These areas are interconnected and should be the focus of efforts going forward.
- **Expert07:** Access to facilities is key for fostering innovation. EU testbeds are now available to support experimentation and activities.
- **Expert08:** *Competitive.* In digital services, [REGION] depends heavily on non-[REGION] tech giants. This could improve with a stronger engineering funding mindset and goal-oriented strategy from policymakers.
- **Expert09:** The regulatory framework should be harmonised. SMEs should be more involved and supported, especially for [ORGANIZATION] deployment.

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- **Expert10:** In my opinion, these areas deserve priority, though without neglecting others.

In your opinion, what type of support or action would most accelerate industrial 5G/B5G adoption in Europe? *(Select up to 3)*

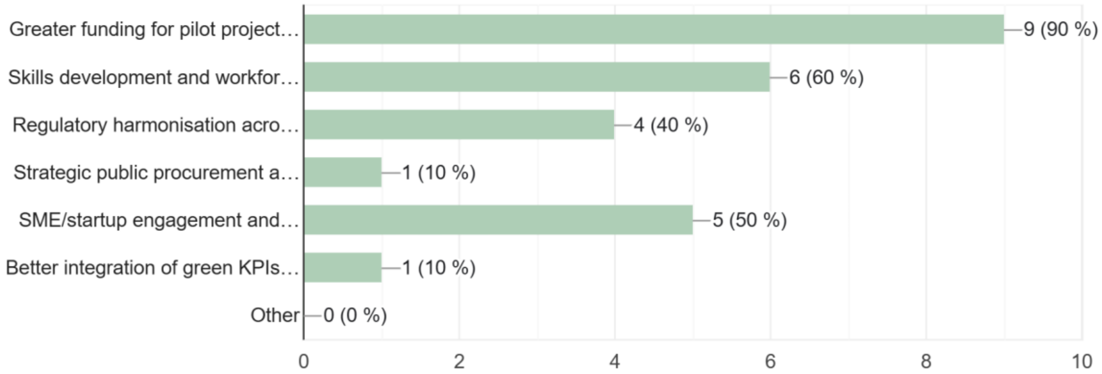

Figure 21.Questionnaire result. Supportive actions to most accelerate industrial 5G/B5G adoption in Europe

Textual elaboration *(anonymized):*

- **Expert01:** Greater funding for pilot projects or testbeds; Skills development and workforce upskilling. As a [REGION] [ORGANIZATION] professor closely engaged with research and innovation ecosystems, I believe the most impactful action would be the creation of regional testbeds and innovation hubs directly embedded within key industrial sectors (e.g., agriculture, energy, logistics). These should be co-funded by EU structural funds and national recovery plans, and tightly connected to SMEs, research institutions, and regulators. In parallel, targeted support for workforce upskilling through [ORGANIZATION]-industry microcredentials and applied training programs is needed, ensuring engineers, technicians, and domain specialists can work at the telecom/AI/sectoral intersection.
- **Expert02:** Greater funding for pilot projects or testbeds; Skills development and workforce upskilling; SME/start-up engagement and support. More funding is required to reduce upfront investment risk and support large-scale trials. It is critical to train professionals who understand both the technology and the application/business side. Real innovation often comes from agile start-ups and SMEs, so it is vital to integrate them into the ecosystem, as large corporations sometimes block innovation. Universities often focus on academic interests. Societies that integrate these ecosystems progress faster.
- **Expert03:** Greater funding for pilot projects or testbeds; Strategic public procurement and demand aggregation; SME/start-up engagement and support. To accelerate adoption, [REGION] should bridge the gap between R&D and deployment by scaling pilots, leveraging public procurement to create demand signals, and empowering start-ups to deliver use cases with major operators and integrators.
- **Expert04:** Greater funding for pilot projects or testbeds; Regulatory harmonisation across borders. Funding for pilots and testbeds made [REGION] a global leader in mobile telecoms in earlier decades. This approach should be encouraged again, but focused on real-world applications. Regulatory alignment and speed are key to adoption.
- **Expert05:** Greater funding for pilot projects or testbeds. Lack of available money is a limiting factor, especially with operators facing financial stress.

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- **Expert06:** Greater funding for pilot projects or testbeds; Skills development and workforce upskilling; Regulatory harmonisation across borders; Better integration of green KPIs into digital policy. These areas are interconnected and should be priorities for the future.
- **Expert07:** Greater funding for pilot projects or testbeds; Skills development and workforce upskilling; SME/start-up engagement and support. Testing facilities and access are key for fostering innovation. EU now has a network of experimentation testbeds ready to support such activities.
- **Expert08:** Greater funding for pilot projects or testbeds; Skills development and workforce upskilling; SME/start-up engagement and support. The dependency of [REGION] on non-[REGION] tech giants could be reduced with a stronger engineering funding mindset and goal-oriented strategy from policymakers.
- **Expert09:** Regulatory harmonisation across borders; SME/start-up engagement and support. The regulatory framework should be harmonised, and SMEs should be more involved and supported, especially for [ORGANIZATION] deployment.
- **Expert10:** Greater funding for pilot projects or testbeds; Skills development and workforce upskilling; Regulatory harmonisation across borders. In my opinion, these are the most important priorities, without neglecting others.

Is Europe well-positioned to shape global standards or norms in future networks (e.g., Open RAN, secure-by-design, sustainable 6G)?

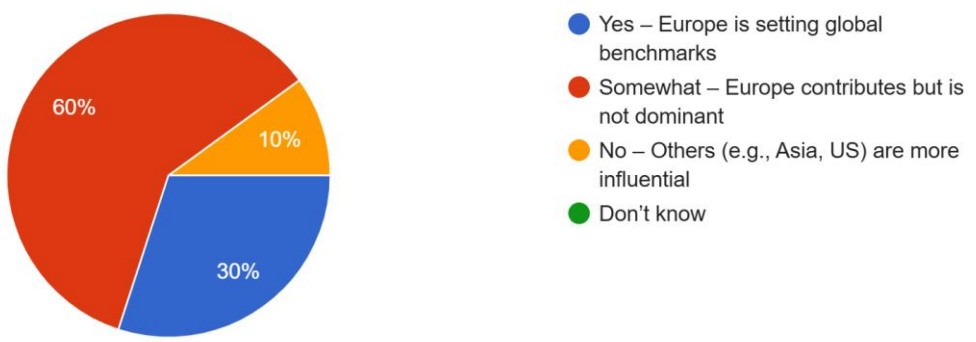

Figure 22. Questionnaire result. Europe's position to shape standards in future networks

Textual elaboration *(anonymized):*

- **Expert01:** Yes – [REGION] is setting global benchmarks. [REGION] is well-positioned to shape global standards in future networks, particularly in areas like [ORGANIZATION], secure-by-design principles, and sustainable 6G, thanks to strong regulatory frameworks, research leadership, and a values-driven approach. The emphasis on digital sovereignty, environmental responsibility, and cybersecurity gives [REGION] normative power, even if it lacks the market scale of the U.S. or China. By prioritising openness, interoperability, and ethical design in policy agendas, [REGION] can lead the global conversation not only on technical standards but also on governance models.

- **Expert02:** Somewhat – [REGION] contributes but is not dominant. Through bodies such as [ORGANIZATION], [REGION] plays an important role in standardisation, especially around openness and sustainability. However, the influence of U.S. and Asian tech giants in intellectual property and market scale is undeniable. [REGION] often leads in defining principles (security, sustainability) but does not dominate the global scene.
- **Expert03:** No – Others (Asia, U.S.) are more influential.
- **Expert04:** Somewhat – [REGION] contributes but is not dominant. [REGION] and Asia dominate here; the U.S. lags behind.
- **Expert05:** Yes – [REGION] is setting global benchmarks.
- **Expert06:** Yes – [REGION] is setting global benchmarks.
- **Expert07:** Somewhat – [REGION] contributes but is not dominant.
- **Expert08:** Somewhat – [REGION] contributes but is not dominant. [REGION] is seen by others (N.A., China) as a reference for "good use of technology," but those regions follow their own paths in production. Regulation should not stifle innovation, but [REGION] needs a different framework for long-term leadership and independence.
- **Expert09:** Somewhat – [REGION] contributes but is not dominant. There is progress in [ORGANIZATION] in [REGION], but more needs to be done. Secure-by-design is also crucial to accelerate progress.
- **Expert10:** Somewhat – [REGION] contributes but is not dominant.

Closing

Is there anything else you believe is critical for Europe's 5G and green industry roadmap that hasn't been covered in this interview?

Textual elaboration *(anonymized):*

- **Expert01:** I would like to emphasize the strategic role of universities as regional innovation engines and skills accelerators. Universities should be more deeply integrated into the deployment ecosystem, not just as research partners, but as living labs for industrial 5G/B5G applications in sectors like energy, agri-tech, and smart manufacturing. This includes enabling testbed access for SMEs, co-developing sector-specific 5G curricula, and fostering interdisciplinary talent that combines telecom, AI, and sustainability expertise.
- **Expert02:** A critical aspect for [REGION] that has not been highlighted enough is that current public policies focus on the energy efficiency of the 5G network itself. We should create mechanisms (fiscal, procurement, etc.) that reward companies that demonstrably use 5G to decarbonise their operations. Do not incentivise decarbonisation only during the operation of the EU-funded Next project.
- **Expert03:** Yes. [REGION] must rethink its telecom market structure and enable sector consolidation to strengthen operators' investment capacity. The current fragmentation limits scale and hampers long-term innovation. In parallel, regulatory frameworks should evolve to create a truly level playing field and enhance competitiveness on the global stage. Without

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these changes, [REGION] risks falling behind in strategic infrastructure and technological sovereignty.

- **Expert04:** I think there is a chance for 5G/B5G to displace Wi-Fi across a broad market (industrial, enterprise, consumer) as combined Wi-Fi chipsets become more available, eSIM gets wider adoption by carriers, Private 5G requires a broader set of devices that are 5G capable, and carriers create attractive (possibly bundled) tariff plans. This could be a real "bottom-up" leadership driver for [REGION], especially for infrastructure & consumer electronics vendors.
- **Expert05:** [No elaboration provided]
- **Expert06:** [No elaboration provided]
- **Expert07:** It is important for the successful adoption of B5G in non-tech verticals and markets that the provision of a trustworthy B5G network is ensured. Thus, techniques and solutions for user-centric and trustworthiness provision are key to realising successfully the [REGION] 5G roadmap.
- **Expert08:** We should also talk about the energy sector, which is the main component behind the information & technology systems. Which measures are we talking about to guarantee a green energy supply and a robust grid?
- **Expert09:** Probably more analysis on the costs/financial part for investments in 5G/B5G technology/systems.
- **Expert10:** [No elaboration provided]

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