Nordregio

THE ROLE OF 5G

in the Transition to a Digital and Green Economy in the Nordic and Baltic Countries: Analytic Report

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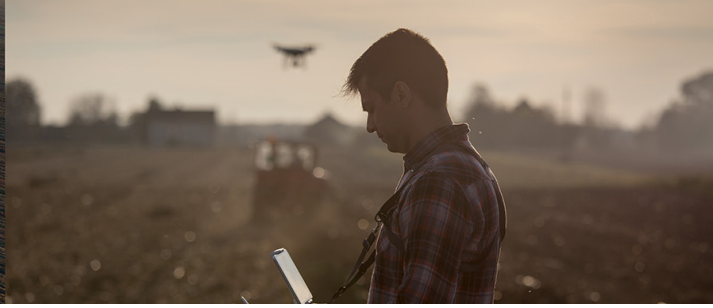
NORDREGIO REPORT 2023:7

Contents

Executive Summary

This is the first analytic report from the "Nordic-Baltic 5G Monitoring Tool" project and provides an overview of the status of 5G roll-out and its industrial uptake in the eight Nordic and Baltic countries as well as the three autonomous territories, the Faroe Islands, Greenland and Åland. The aim is not only to present the roll-out status across the region but also to put these insights into a broader political and technological context. It describes some of the most relevant testbeds and policy initiatives, provides examples of successful and promising use cases, and highlights existing strengths and ongoing challenges in the Nordic-Baltic region. Juxtaposing these against established goals emphasises areas for possible future co-operation and knowledge exchange between the Nordic and Baltic actors to encourage sustainable innovation and competitiveness across the region.

Key takeaways from the report:

- **The role of 5G in national policy targets**: many Nordic and Baltic countries have well-defined national policy targets related to digital strategies or 5G roadmaps/action plans, which address 5G roll-out and implementation in realising their digitalisation goals.

- **Countries exhibit different degrees of ambition**: while Denmark and Finland are placed above the EU average in terms of 5G coverage, coverage by more than one operator remains below the EU average in the other countries – even in urban areas. Norway and Sweden are an exception, with a high number of 5G applications already in use.

- **Although there is a considerable number of 5G activities in the region, the percentage of deployed applications remains low**: while 5G activities, including applications, testbeds and innovations hubs, may promote a dynamic vision of the region, a high percentage of these are still at a testing and prototyping development stage (around 45%), and involve a considerable degree of public funding.

- **The potential for innovation and competitiveness has not yet been fully realised:** despite several investments in the rollout of 5G technology, a common challenge across all countries is the realisation of 5G's true potential for innovation and competitiveness. The business case for 5G remains limited.

- **The number of 5G applications in the transport/mobility vertical is prominent:** nevertheless, it is worth noting the many 5G development activities linked with smart cities, healthcare, education, welfare, and public administration in the Nordic-Baltic Region, as other leading areas of 5G application.

- **Cyber security considerations must become more prominent:** as 5G accelerates the digitalisation of fundamental services, security issues on various levels have come to the fore. While elaborating on the risks and developing adequate cyber security strategies has slowed the roll-out process in certain cases, cyber security's significant role has become more apparent.

- **What about The Just Green Transition?** As the 5G ecosystem will generate a substantial increase in electricity demand, impacting the entire value chain, a broader discussion concerning responsible and sustainable 5G development and future rollouts of mobile technologies must be encouraged. The deployment of 5G networks may aggravate existing national digital divides, especially between urban and rural areas (related to the high cost of creating infrastructures in areas of lower population density). Further research is needed to explore the environmental footprint and the societal effects of 5G roll-out and industrial uptake.

- **5G's potential does not guarantee an automatic transformation:** 5G implies significant adjustments in different areas, from network infrastructure, systems and applications to data ethics and privacy and workforce implications. These and other challenges, associated with *inter alia* social inclusion, signal the importance of 5G but also the need to expand co-operation and synergies in different areas in the region.

- **Importance of overcoming knowledge barriers:** the need for increased knowledge exchange and the definition of common roadmaps and guidelines to encourage harmonised 5G deployment, as well as highlighting the value of co-operation in the region, remains a priority.


1. Introduction

The Nordic societies are among the most digitally advanced in Europe, supported by strong political commitments, investments and a shared vision of becoming the most sustainable and integrated region in the world by 2030, with a particular focus on a green, competitive, and socially sustainable transition (Danish Presidency of the Nordic Council of Ministers, 2020; Nordic Council of Ministers, 2020).

Since "1G", all subsequent technologies have enabled new capabilities and requirements and introduced new opportunities in terms of applications and market opportunities (Mendonça et al., 2022). Fifth-Generation mobile technology (5G) is one of the latest mobile technologies impacting all sectors of the global economy and society as a whole. Offering massive machine-type communication (mMTC), and ultra-reliable low-latency communication, 5G has been portrayed as a key component of the next phase of global economic digital development and political discussions (Robles-Carrillo, 2021). By providing a pathway to greater use of automation, the Internet of Things (IoT) and Artificial Intelligence (AI), the deployment and use of 5G can have the potential to address some of societies' most pressing issues, from health and elderly care to supply chain challenges and greener transport solutions. It is also expected to accelerate digital innovation, stimulating new products and services, new manufacturing processes and new business models, as well as supporting the development of innovative and inclusive solutions to social and environmental challenges (COM, 2023; World Economic Forum and PwC, 2020).

As 5G roll-out and uptake accelerate across the Nordic-Baltic region, varying asymmetries in 5G deployment and application can be observed, with noticeable gaps threatening to deepen existing digital divides. By sharing knowledge and experience and discussing shared challenges, substantial gains can be achieved by the countries involved. An important first step in this process is the development of a methodologically sound and consistent approach to mapping digital development across the region. The 5G Nordic- Baltic Monitoring Tool Project was instigated in 2021 to address this challenge with an overarching aim to "contribute to the development of a more integrated, connected, and inclusive Nordic Region by developing and maintaining an evidence-based analytical tool to monitor the roll-out of 5G in the countries and independent territories of the Nordic-Baltic Region."

This report presents the current status of the 5G roll-out, outlining the activities and progress to date in each country within the region based on the project's data collections. Providing an overview of the most relevant findings may help uncover potential areas that could benefit from regional 5G Nordic-Baltic co-operation. By highlighting some of the challenges and bottlenecks associated with accelerated 5G uptake and innovation, the report aims to define further areas in which additional co-operation is needed to advance the region's status as a digital frontrunner in Europe. The insights presented here can form a valuable contribution to a dialogue on shared joint solutions, ensuring an integrated, connected, and inclusive region and cementing the region's status as a digital frontrunner in a European and global context.

Box 1: The 5G Nordic-Baltic Monitoring Tool Project

The Nordic-Baltic 5G Monitoring Tool project is conducted by Nordregio under the guidance of a 5G Expert Group and the Nordic Council of Ministers (MR-Digital secretariat). The Expert Group (project reference group) consists of 11 selected experts in the field of 5G, representing the different Nordic and Baltic countries as well as the autonomous regions.

The project started at the end of 2021 and will be completed by the end of 2023 and is intended as a contribution to the discussion surrounding 5G's innovation potential in the Nordic and Baltic countries.

Several of the project activities (deep dive story maps on 5G for healthcare in the Nordic region here & 5G and the Drone Ecosystem here as well as the 5G matchmaking Events) showcase applications and facilitate connections between actors. The primary Project deliverable is, however, the 5G Nordic-Baltic Monitoring tool: the "5G Data Hub" featuring a municipality 5G coverage indicator as well as documenting mapped 5G activities in the region: Nordic-Baltic 5G Data Hub (arcgis.com).

The expectation is that the project and the 5G Data Hub will promote cross-border co-operation in the industry verticals, offering increased potential for Nordic-Baltic added value and be a source of inspiration by highlighting opportunities and creating a working dialogue to address different types of barriers and drivers.

For more information on the Project go the the Nordregio Digitalisation Portal DigiHub : https://nordregioprojects.org/digihub/

2. Digital Transformation and Competitiveness through 5G in the Nordic-Baltic Region – An Overview

Previous research has shown that 5G technology plays a pivotal role in driving GDP growth. PwC estimates that 5G will add $1.3 trillion to global GDP by 2030 (PwC, 2021). In 2016, the European Commission launched its 5G Action Plan to boost European-level efforts for the deployment of 5G infrastructures and services (European Commission, 2016). The Action Plan sets out a clear roadmap for public and private investment in 5G infrastructure, opening opportunities for new digital-economy and business models. This strategic initiative intended to make 5G a reality for businesses and citizens across the European Union and was boosted by the 2018 EU Electronic Communications Code, which merges EU telecommunications rules into a single regulatory framework (European Commission, 2018). The recent European Declaration on Digital Rights and Principles further provides a policy foundation that also addresses the wider societal benefits and demand for increasing digitalisation across European countries (European Commission, 2023).

Although the 5G roll-out is well underway, Europe still lags somewhat behind its global peers. In Europe, 5G accounts for only 2.5% of total mobile connections, compared to 14.2% in North America and 28% in the China/Japan/Korea region (GSMA, 2022a). However, 5G investment is increasing as part of a concentrated effort to enhance European digital autonomy. The European telecom sector achieved a record capital expenditure (CapEx) of €56.3bn in 2021, up from €52.5bn in 2020 and €51.7bn in 2019, respectively (European Telecommunications Network Operator's Association, 2023). This reflects increased investment in fibre and 5G networks. However, delays in 5G network roll-outs and the implementation of EU objectives within member states may be contributing factors to the digital divide in the region.

The Nordic-Baltic region is widely perceived as at the forefront of digital technology and services, deployment, and use. Nonetheless, despite various similarities, extended areas of co-operation and ambitious policies, certain differences remain between countries, e.g. in terms of roll-out speed and conditions as well as 5G applications use.

With almost 34 million inhabitants, the region represents about 7.3% of the total EU population. Unemployment rates range from 19.5% in Lithuania to 1.34% on the Faroe Islands to 2.1% in Norway. Overall unemployment rates in the region are comparatively close to the EU average of 8.2% (see Figure 1). There is ongoing debate regarding the potential effects of 5G-facilitated automation on employment in the region, leading to uncertainty in various employment fields. However, Campbell et al. argue that the 5G value chain has the possibility to create approximately 22 million jobs globally by 2035, particularly in fields related to telecommunications infrastructure, new technology and employment (Campbell et al., 2017).

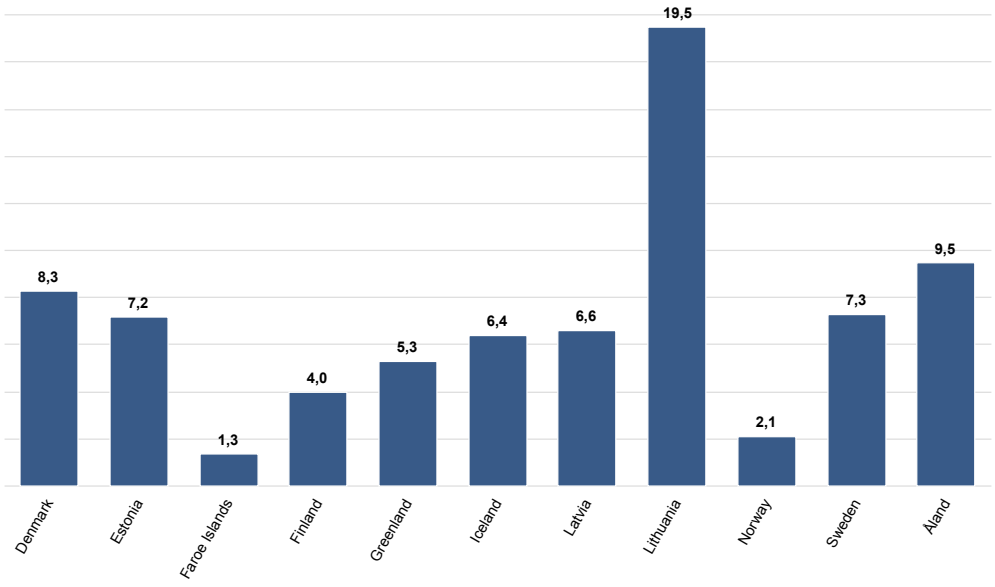


Figure 1: Unemployment in the Nordic-Baltic Region.
Data: Ålands statistik- och utredningsbyrå, 2023; Greenland Statistics, 2020; OECD, 2022a. All data from 2021, Greenland and Iceland 2020.

Emerging technologies, better connectivity and advancing digitalisation are set to have a comprehensive impact on several sectors central to employment and innovation and can sustain overall economic stability in the region. The area of human health and social work is the largest employment sector in the Nordic-Baltic region, followed by wholesale, manufacturing and education (see Figure 2). The application of 5G in this area promises novel medical procedures facilitation while alleviating increasing pressures on the system and its personnel.

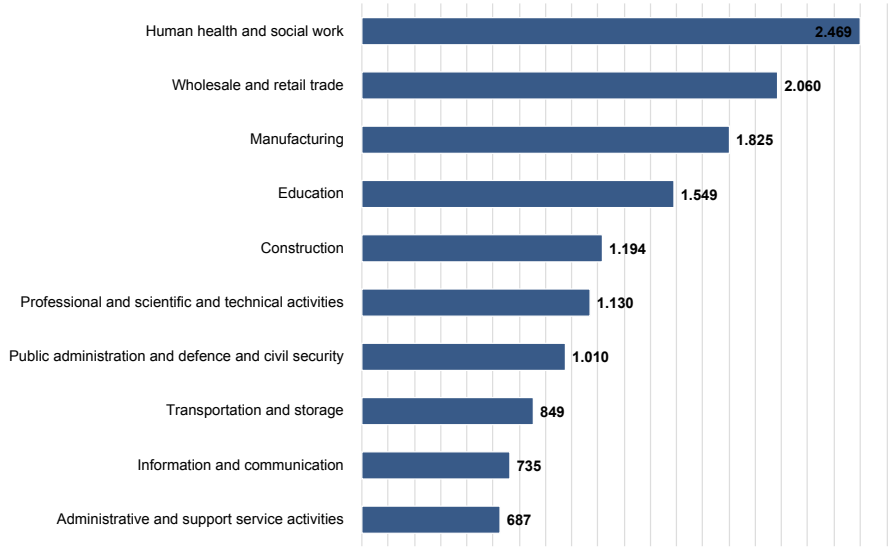


Figure 2: Share of sectors in employment in the Nordic-Baltic region (Top 10). Selection of the ten largest sectors in terms of employment.
All Data: OECD, excluding the autonomous territories Greenland, Faroe Islands and Åland.

Expected 5G technology demand and potential are further reflected in the increasing usage of the Internet of Things (IoT) and Artificial Intelligence (AI) applications by businesses in the region. Combined with 5G, AI and IoT triangulate the concept of *Intelligent Connectivity* (Vermesan et al., 2020). The term hints at the interoperability and a certain interdependence of the three technologies that can harness and manage the benefits of increased Internet speed, decreased latency and ever-growing data sets and complex systems.

The growing application of AI and IoT by businesses in the region has been documented statistically. For instance, in 2021, over 40% of Swedish businesses with more than ten employees were utilising IoT, representing an increase from 20% in 2020 (see Figure 3). Similar expansion in the use of AI by companies can also be seen. Danish enterprises employing AI technologies such as image or speech recognition, computer vision or natural language processing in their work have increased to almost 24% compared to just 9% in 2020 (see Figure 4). Furthermore, AI-centred start-ups in the Nordic and Baltic countries have been able to attract considerable amounts of venture capital investments. According to OECD data, Swedish start-ups operating in the field of AI almost quintupled venture capital investments in 2022 compared to 2020, reaching approximately $ 950 million in investments. Estonian and Finnish enterprises have also experienced an upward trend in venture capital investments, with Estonia achieving a sum of over $300 million and Finland over $100 million, respectively. In the closely related field of Big Data start-ups, similar trends could be observed, with stark increases noted in 2021, led by Lithuanian start-ups receiving over $300 million in venture capital investments.

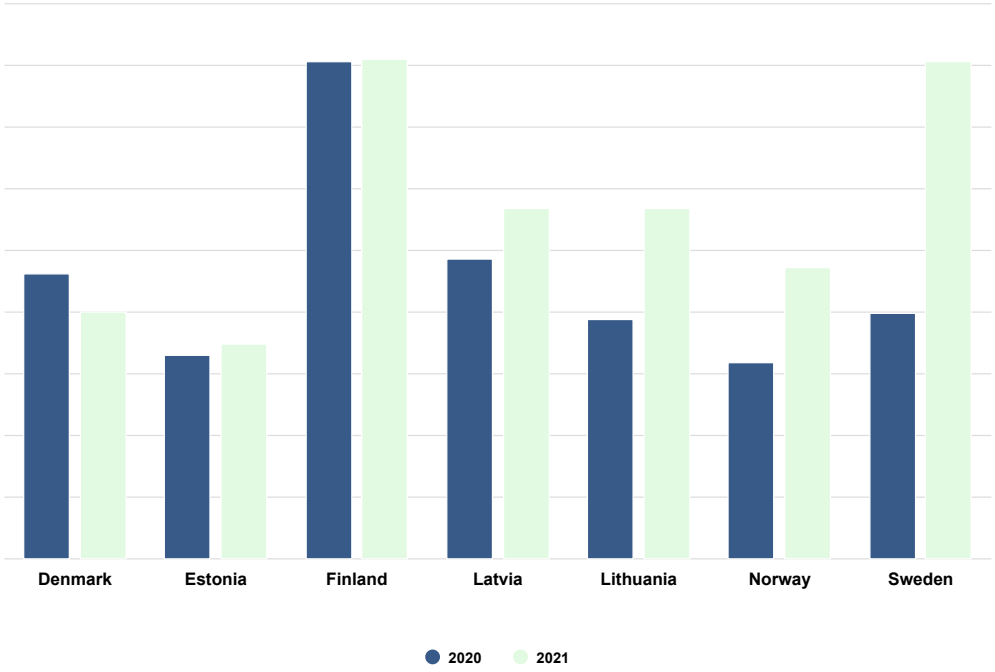


Figure 3: Businesses in the Nordic-Baltic region utilising IoT in 2020 and 2021.
All data: OECD.

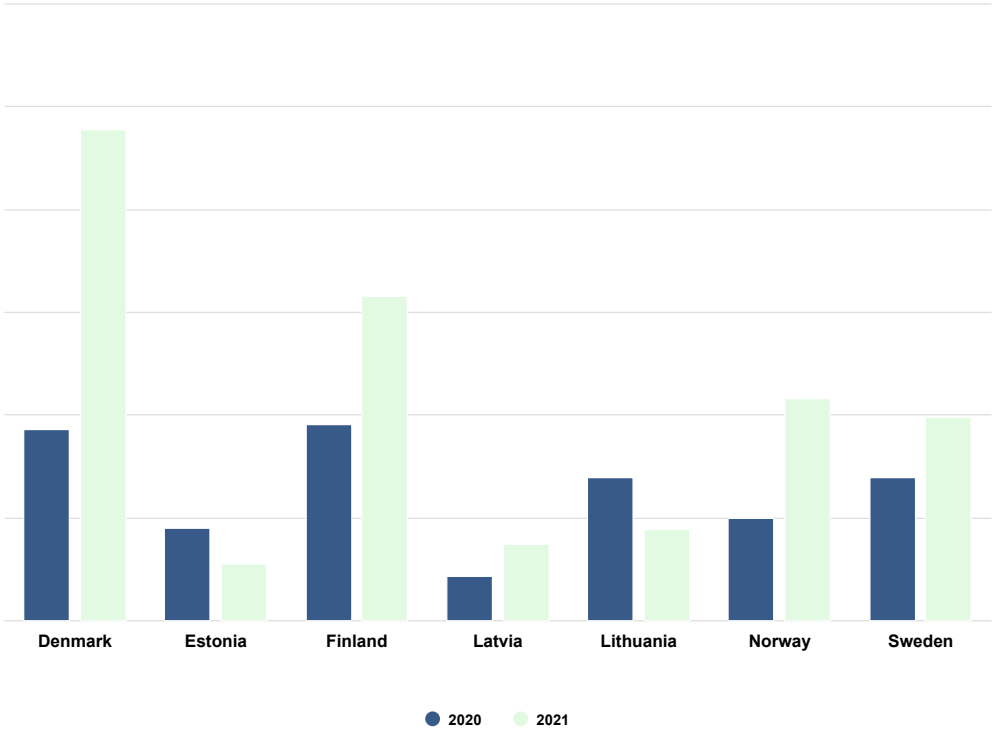


Figure 4: Businesses in the Nordic-Baltic region utilising AI in 2020 and 2021.
All data: OECD.

As the trends indicate, 5G constitutes a prerequisite for the further advancement of innovative business solutions and economic and sustainable growth in some of the leading sectors in the Nordic-Baltic Region. The challenges arising from moving from promise to implementation point to the need for more information. Where and what 5G activities are being developed? What is the development stage of applications

already being evaluated? What are the frontrunner verticals in 5G development in each country? Who are the main 5G ecosystem actors? Addressing these questions will help uncover some of the main challenges ahead while identifying areas with the greatest potential to build on regional strengths through Nordic-Baltic co-operation, an essential element in enabling stakeholders to work together to unlock the opportunities presented by this technology.

3. Mapping the Nordic-Baltic 5G Landscape: Some Methodological Considerations

To explore the questions put forward in section 2, a questionnaire was used to map 5G activities systematically and comprehensively across the Nordic-Baltic Region. The data collected was intended for use in the 5G Nordic Baltic Monitoring Tool – "5G Data Hub" – and to contextualise and strengthen the analytic capacity of the quantitative indicator of "percent of households with 5G coverage".

Further information on the 5G Nordic-Baltic Monitoring Project's process for developing a harmonised mapping tool to monitor the roll-out of 5G can be found at https://arcg.is/000PyL.

The process surrounding question design was assisted by several national (Nordic-Baltic) workshops (with participants representing actors engaged in 5G activities in the region, including businesses, industry, technology, telecommunications and research) that took place during the first phase of the 5G Nordic Baltic Monitoring Tool Project (2021), and from a consultation process with the 5G Expert Group Members (see Box 1) to test the survey's questions and structure. The objective was to develop a common systematic Nordic-Baltic 5G data collection strategy (Table 1).

Main areas of the survey
Description of the 5G activity
Technology
5G Ecosystem actors
Type of 5G activity
Development stage

Table 1: Main topic areas of the 5G Nordic Baltic Monitoring Tool Project survey

The survey was launched in April 2022 and concluded at the end of that year. It was circulated to a sample of 5G ecosystem actors identified during the first phase project. This initial pool of specialists was also invited to snowball sample the survey (identified experts were asked to nominate others).

To ensure comprehensive data and mitigate possible valuable information omissions, this initial process was supplemented with extended desk research by reviewing and screening a wide range of publications, reports, and websites, identifying 5G activities, followed by a validation process[1]

In all, this process collated 180 5G activities in the Nordic-Baltic Region, including both 5G applications and testbeds/innovations hubs, and concluded in December 2022. Some conceptual considerations concerning the principal areas of the survey will be discussed in the next subsections.

3.1 Mobile Technology and the 5G Ecosystem: Vendors; Operators and Other Actors

5G stands for the Fifth Generation of mobile technology, with its key features being the enabling of faster download and upload speeds, low latency, higher capacity, and improved coverage when contrasted with previous standards, e.g., 4G and 3G technologies (Blind and Niebel, 2022a). Nevertheless, just as 4G relied on 3G/2G existing infrastructures, 5G technology is expected to co-exist with 4G, as well as with the most recent 6G (Mendonça et al., 2022). In the survey, this distinction was acknowledged and "4G going for 5G"; and "5G and beyond" activities were mapped.

In relation to the 5G ecosystem, it is recognised that it consists of a complex multi-actor system involving a wide range of stakeholders, from governments, regulatory institutions, research institutions/academia, businesses, and industry, to telecommunications companies/providers and equipment manufacturers/vendors. Several layers in which different actors and technologies co-evolve and have mutual dependencies and interlinkages have been identified:

- Provisioning ecosystem – actors that take part in developing, delivering, and providing 5G services, e.g. Telecom operators
- 5G vertical ecosystems – the vertical industries, i.e. sectors such as health and manufacturing, that can take advantage of 5G services.
- 5G business ecosystem – comprising businesses and organisations such as research and education, governance, standardisation, and finance (5G PPP, 2021). At the EU level, the European Commission and BEREC (Body of European Regulators for Electronic Communications) are the main public and regulatory agencies (Blind and Niebel, 2022a).

As both a complex and systemic technology, it is important to address the 5G ecosystem's ability to enable new applications that will transform various industries and sectors and its impact on business dynamics. In the survey, operators and vendors were identified as the main actors but other relevant stakeholders also came to the fore (business, industries, civil society and academia).

1. When a 5G activity not included in the survey was identified, the contact person was invited to revise the information and include it in the data set.

3.2 5G Testbeds and Innovation Hubs & 5G Applications

When mapping 5G in the Nordic-Baltic area, two main activities were identified: testbeds/innovation hubs and 5G applications/use cases. There is currently no single established definition of what constitutes a "5G testbed". In general, they can be described as situations containing a principal aim of promoting a controlled environment within the fifth-generation mobile networks where companies, academia and organisations can evaluate innovative ideas and applications. In the development of a 5G ecosystem, testbeds play a central role in the development of new use cases and can be seen as an important means of overcoming the knowledge barriers often accompanying new technologies and which can hamper their broader dissemination, instead of promoting synergies and creating new technical and commercial service deployment models (5G PPP, 2021). As several innovation hubs, city labs, and projects appear to encompass the same 5G objectives and allow verticals (including SMEs and academia) to test and validate specific applications that are dependent upon the technology, a broad "testbed/innovation hub category" was used.

Use cases and applications as specific terminology are used here as synonyms. A use case could describe a specific application/trial/business model that involves 5G technologies (Gilles and Toth, 2021). Overall, 5G use cases display heterogeneity in terms of the specific application, user needs, and user skills. Some examples of 5G use cases include, for instance, remote surgery, augmented reality (AR) and virtual reality (VR) applications, factory automation, self-driving cars, etc. (Gilles and Toth, 2021; Knieps and Bauer, 2022). Use cases can, in short, be described as showcases and are considered fundamental in driving 5G, signalling stakeholder awareness and market interest (from enterprise/academia/industry), as well as sharing and building knowledge and encouraging co-operation(5G PPP, 2021; Blind and Niebel, 2022a). In the 5G ecosystem, stakeholders with more limited capabilities can also examine use cases as a way to avoid repeating mistakes and to overcoming knowledge barriers (5G PPP, 2021).

Regarding development stages, three main categories, inspired and adapted from Tikhvinskiy (2016), were used to describe the 5G applications phase (Table 2).

5G Development Stage	Definition
Conceptual/Research	Idea development, design, beginning of research – theoretical development
Testing/Prototype	Conceptual proof – including prototyping production, testing, refinement
Deployed/Commercial Use	Market-ready and deployed

Table 2: 5G Development stage

3.3 Verticals

In this context, the term "vertical" refers to a specific industry or sector enabled by the deployment of 5G networks and related technologies. In the identification of verticals at a Nordic-Baltic level, the point of departure was the categorisation offered by Målberg et al. (2019). As it addressed 5G development at a Nordic-Baltic level, the vertical taxonomy presented by the authors seemed adequate and suited to the regional specificity. In an iterative process, other verticals were then added from the survey results and adjusted to better address the ever-changing nature of the 5G landscape at a Nordic-Baltic level (Table 3).

Vertical	Definition	References
5G R&D	Vertical focused on research and development activities on 5G technology and its applications in a particular industry or sector.	(Målberg et al., 2019)
Advanced Automation / Manufacturing / Industry	Vertical, including applications in Industry 4.0, for instance, industrial control and process automation, planning and design systems, remote operation, massive information exchanges, etc.	(Målberg et al., 2019)
Education, Health and Welfare	Vertical combining different activities focusing on reducing the societal burden. In healthcare, for instance, this includes telemedicine and patient monitoring, remote surgery, health data processing, connected ambulances, etc. In education, 5G has a variety of possible uses, particularly in urban/rural settings. These include use cases linked to remote learning, enhanced mobile broadband for large campuses, immersive lessons through AR and VR, smart classrooms and campuses, etc.	(5F Americas, 2021; 5G PPP, 2021; CAPGEMINI, 2022; Gilles and Toth, 2021)
Energy, Environment, Agriculture and Aquaculture	Vertical including applications in smart grids, remote monitoring, energy efficiency, farm monitoring and analytics, automated farm vehicles, sensor-based field monitoring, artificial intelligence supporting more resourceful land leverage and increased crop yield, pest and weed eradication using drones and AI, livestock/fish welfare and monitoring via geofencing and sensors, etc.	(5F Americas, 2021; Accenture Strategy, 2021; Gilles and Toth, 2021)
Media, Entertainment and Gaming	Vertical including several applications from mobile media and content production, digital advertising, gaming, augmented reality, virtual reality applications, advancements in mobile wearables, i.e., VR and augmented and mixed reality (AR/MR), high immersive environments (better graphics, shapes, textures, sound), etc.	(5F Americas, 2021; 5G PPP, 2020; Gilles and Toth, 2021)
Mission-Critical / Defence	Vertical focused on public protection and disaster relief. It includes emergency services and law enforcement applications, etc.	(5G PPP, 2020; Målberg et al., 2019)
Mobility and Transport	This vertical includes sustainable and climate-efficient transport solutions; transport system and connected vehicles; remote-controlled airborne services, etc.	(Målberg et al., 2019)
Smart Cities	Including 5G applications in transport, healthcare, education, building management, city governance (smart traffic, smart waste management, smart parking, smart pollution control) etc.	(5G PPP, 2021; Gilles and Toth, 2021)

Table 3: 5G Verticals

4. 5G Status-Quo in the Nordic and Baltic Countries and the Autonomous Regions

In the fast-paced emerging technologies environment, constant change is inevitable. This section provides information on the status of the 5G roll-out processes in the Nordic-Baltic region in late 2022 and early 2023. To mitigate any omission of important information, the data collection process for the country reports includes a variety of source strands based on inputs from several workshops and conversations with the 5G Monitoring Tool Project Expert and Reference Group (Box 1), as well as extended desk research focusing on a wide range of publications, reports, use cases, statistics and indexes listed in the references section, interviews with relevant stakeholders in the 5G ecosystem and information from the Mapping 5G Applications Survey detailed in section 3.

As the information presented this report risks becoming rapidly outdated, the country chapters' "overview of key findings" sections will be made available in the 5G Data Hub to keep them updatable and to continue to provide a current and contextualised overview of the 5G roll-out status in the region. A link to the digital table can be found in each table's caption.

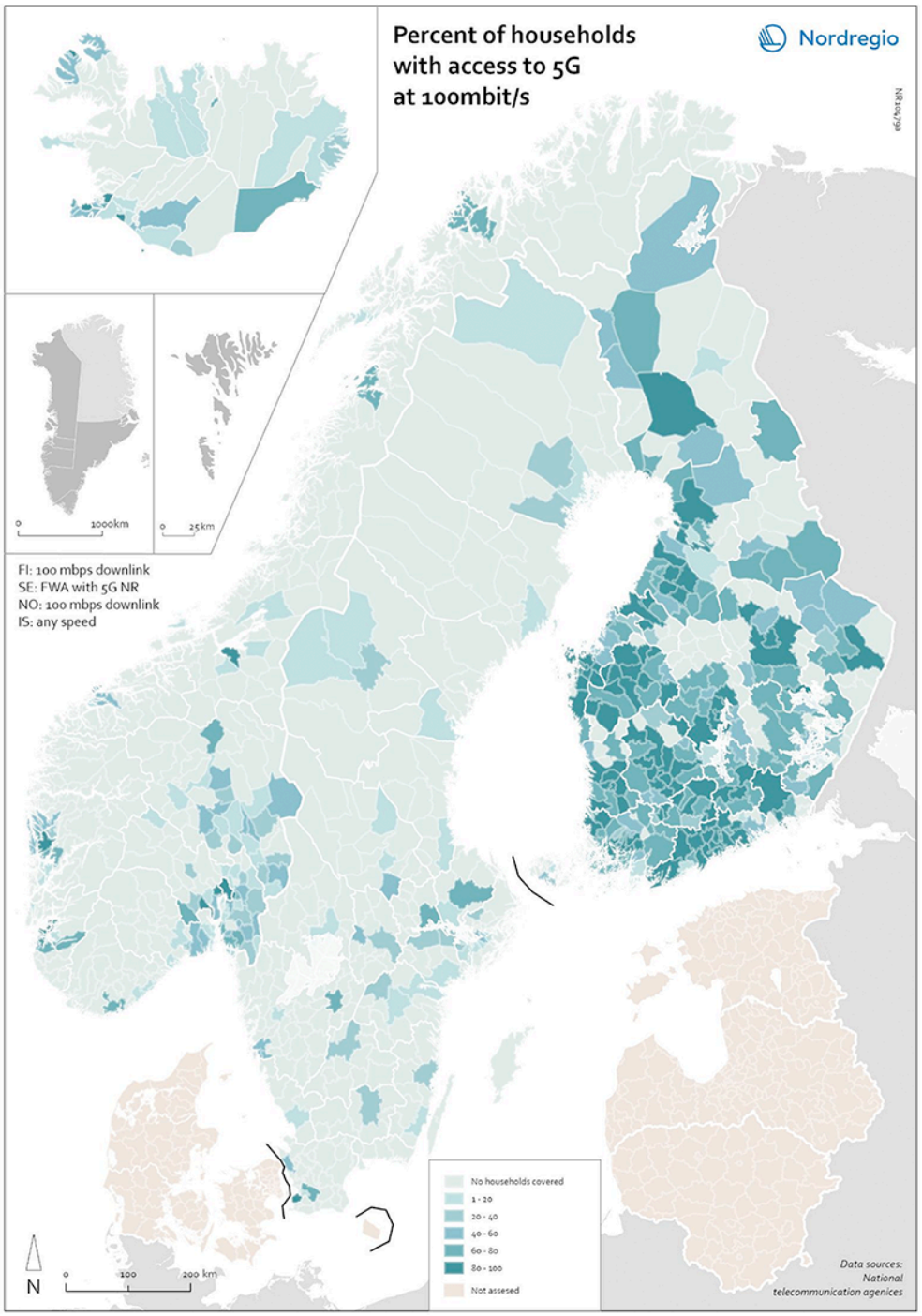


Figure 5: Percent of households with access to 5G at 100mbit/s (Nordregio).

4.1 Denmark

Overview key findings

Commercial Operators	Vendor Collaboration	Band & Year of Allocation
TDC Net	Ericsson	- 700/900 MHz, 2019 - 1,500 MHz, 2,100 MHz, 2,300 MHz, 3,5GHz, 26 GHz, 2021
Hi3G (3 Danmark)	Ericsson	- 700/900 MHz, 2019 - 2,100 MHz, 3,5 GHz, 26 GHz, 2021
TT-Network (Telia and Telenor)	Nokia	700/900 MHz, 2019 1,500 MHz, 2,100 MHz, 3,5 GHZ, 26 GHZ, 2021
Roll-out Indicators (DESI)	**Denmark**	**EU**
5G spectrum: Assigned spectrum of total harmonised 5G spectrum	99% As of 04 2022	56% As of 04 2022
5G coverage: populated areas covered by at least one operator	98% In 2021	66% In 2021
Challenges and Strengths		
Lack of data on user experiences Privacy and cyber security concerns		

Table 4: Overview of key findings for Denmark.
(DotEcon, 2023.; EU Digital Decade, 2022; European 5G Observatory, 2021; European Commission, 2022a; Kechiche, 2022; Telia, 2023).
5G Data Hub

Overview commercial network roll-out and coverage

According to international rankings, such as the European Commission's Digital Economy and Society Index (DESI), Denmark performs well in terms of 5G roll-out. In October 2022, about 99.3% of the Danish population had access to the 5G network with an average download speed of 33.1Mbps (European 5G Observatory, 2022a). Nevertheless, variations in Internet speed still exist across the country. In the 5G Monitoring Tool Project workshops, national experts reported that this issue will be addressed at a regional level by evaluating each region's specific needs based on user data and experiences and adapting speeds accordingly.

National policy targets on 5G

In Denmark, the Danish Energy Agency, responsible for telecom regulations, prepared an ambitious roadmap titled "5G Action Plan for Denmark" in partnership with relevant stakeholders, published in February 2019 (Danish Energy Agency 2019). The document highlights the country's objective of becoming an international leader in the 5G field (European 5G Observatory, 2021). Currently on track to meet its goal of offering all populated areas 5G coverage and improved speed by 2030, Denmark aims to secure more providers in the future. Another important element in this context is the Danish Recovery and Resilience Plan (RRP), which includes the goal of providing high-speed Internet access (minimum 100 Mbps) in remote and rural areas

of Denmark, where coverage remains limited "due to the lack of sufficient market incentives" (European Commission, 2022a).

Spectrum allocation and auctions

To date, 5G spectrum auctions have been held in both 2019 and 2021. According to the European 5G Observatory, 100% of both the 700MHz and the 26GHz bands have been assigned, and 97.50% in the 3.6GHz band.[2] The 700/900 MHz auction was held in March 2019, and TDC, Hi3G and TT-Network (Telia & Telenor) acquired licenses for a total of DKK 2.21 billion, valid from April 2020. This was followed by the 5G launch by TDC NET in September 2020 and by Telenor in mid-November 2020. The multi-band auction (1500 MHz /2100 MHz/2300 MHz/3.5 GHz/26 GHz) was held in April 2021 (European 5G Observatory, 2021). TDC Net, Hi3G Denmark and TT-Network acquired licenses in this auction, as outlined in Table 4.

Regulation on private networks or local permits for specific verticals/industries

In Denmark, a portion of the 3740-3800 MHz spectrum has been acquired by TT-Network for leasing/sub-licensing arrangements. The company is obliged to lease access to local enterprises and public institutions for private networks. There is currently no data available on what demand this has generated (Plum Consulting, 2022).

Commercial 5G roll-out and status by operator

TDC was identified as one of the main operators in the Danish market, with several other operators also on their way to 5G roll-out (Table 5). Regarding vendors, Ericsson displays a significant market penetration, closely followed by Nokia.

Testbeds, innovation hubs and networks

In the 5G applications survey 2022 several 5G testbeds and innovation hubs were identified in Denmark, albeit only a few. A summary of these findings can be found in Table 6.

Operator	Vendor collaboration	Roll-out status
TDC Net	Ericsson	TDC reached 99% of Denmark with 5G in 2021. YouSee Denmark, which is associated with TDC, emerged as the best 5G availability operator in the Nordic Region.
Hi3G (3 Tre Danmark)	Ericsson	Launched 5G network in December 2021 in some parts of Copenhagen. Expanded to reach 70% population coverage in 2022 and plans to expand further in the 3.5 GHz band, covering 100% of the population in 2023.

Table 5: Commercial 5G roll-out and status by operator in Denmark.
Sources: EU Digital Decade, 2022; Kechiche, 2022; Telia, 2023.

2. [1]The report of the European 5G Observatory explains the evaluation of the bands assignment as follows: "to achieve 100%, a country must assign 60MHz in the 100MHz band, 400MHz in the 3.6 GHz band and 1000 MHz in the 26GHz" (European 5G Observatory, 2022a).

	Public vs private	Focus
5G Innovation Hub (Innovation HUB)	Private (TDC NET and Ericsson)	- Boston Dynamics 5G airport inspection - 5G agriculture with Padborg Transportcenter - 5G robot Fable for distance learning - Content production over 5G during the opening of Parliament - Drone U-Space – Innovation Fund Denmark
5G Smart Aarhus	Public	Aarhus City Lab with focus on mobility, parking, waste disposal management, digital art & culture, events, exhibitions, public hearings etc.
5G Smart Production Lab, Aalborg	Public	Testing and advancement of industrial 5G systems
Precision Positioning TAPAS, Aarhus	Public	Testbed for Precision Positioning and Autonomous Systems

Table 6: Testbeds, innovation hubs and networks in Denmark.
Source: Data from the "Mapping 5G applications 2022 survey" (last updated 2022).

5G verticals and use cases

In Denmark, the most prominent verticals can be found in the field of Media, Entertainment and Gaming, as well as Smart Cities and Transport/Mobility (Figure 6).

Nevertheless, use cases for 5G remain largely at the testing stage, pointing to a still limited market uptake, even if business stakeholder involvement indicates an interest in 5G applications that could materialise in future market opportunities and growth (Figure 7).

Of particular note regarding successful 5G applications is the Health Drones project, completed in 2022, with the aim of integrating drones into the Danish healthcare system, and the 5G Enabled Communication Infrastructure for Unmanned Aerial Systems (GENIUS) project focussing on developing a novel 5G UAS network by building upon and shaping the current 5G roll-out (Genius 2022).

Several 5G trials are being pursued in the media and entertainment vertical. For instance, Telia, TV2 Denmark and a Copenhagen-based lighting company (BB&S) have trailed 5G-connected lamps for television production and filmmaking, with the aim of improving cost efficiency in broadcasting (Telia, 2020). TV2 also participated in the European 5G-RECORDS Project that aims to develop, integrate, validate, and demonstrate specific 5G components in end-to-end 5G infrastructures for professional AV media content production (5G-RECORDS, 2022). In 2022, several trials took place in Copenhagen during the staging of the Tour de France, focussed on multiple camera wireless studio tests (Brainstrup, 2022).

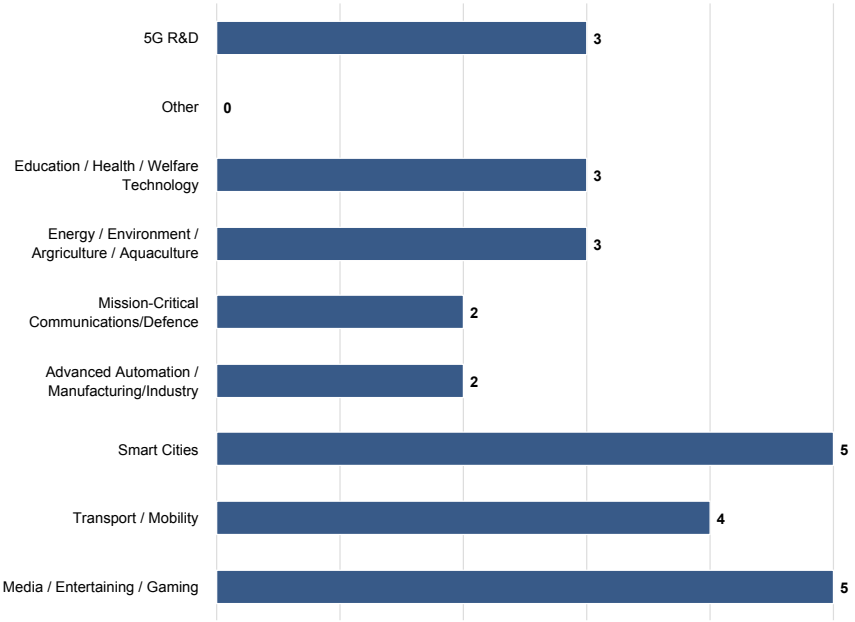


Figure 6: Main verticals in Denmark.

n=27, multiple answers possible.

Source: Data from the "Mapping 5G Applications 2022 Survey" (last updated 2022).

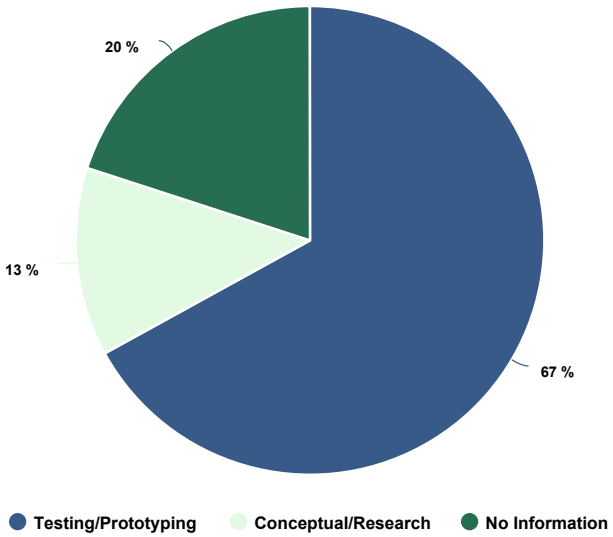


Figure 7: Use cases by development stage and overview of main stakeholder types.

Source: Data from the "Mapping 5G Applications 2022 Survey" (last updated 2022).

Denmark's status according to international indicators

Indicator	Denmark 2022	EU 2022
2c1 5G spectrum Assigned spectrum as a % of total harmonised 5G spectrum	99% 04 2022	56% 04 2022
2c2 5G coverage % of populated areas covered by at least one operator as reported by operators and national regulatory authorities	98% 2021	66% 2021

Table 7: Denmark's status according to international indicators.
Source: Digital Economic and Society Index 2022 (European Commission, 2022a)

Challenges and strengths

The Danish Energy Agency's ambitious 5G action plan is ongoing: by 2022, access to the 5G network with an average download speed of 33.1Mbps for 99.3% of the Danish population had been achieved (European 5G Observatory, 2022a). The focus of the action plan is on frequencies, roll-out, regulation, and use cases to foster a successful roll-out and use of 5G (Danish Energy Agency, 2019).

As Denmark is also at the forefront of the renewable energy transition, with ambitious legislative commitments to emissions reductions of 70% by 2030 and carbon neutrality by 2050 (OECD, 2022), the deployment of 5G networks can play a vital part by enabling the monitoring and management of renewable energy sources, such as wind turbines and solar panels, helping Denmark achieve its climate goals.

Infrastructural investments, especially widespread 5G coverage in rural areas, remain a challenge due to high infrastructure cost, lower population density and the need for significant co-ordination with local authorities.

During discussions in the context of a 5G Monitoring Tool Project workshop, several Danish 5G experts pointed to a lack of relevant user data, both quantitative and qualitative, impeding further progress. Additional insights on user experiences and their specific needs could support the further improvement of speed in certain parts of the country while also helping to create incentives for other industry and business branches to use 5G for their own development.

The limited interest in 5G from industry stands in stark contrast to the possibilities it offers to both agriculture and industry, given Denmark's long heritage within these areas. The 5G network will be a determining element in ensuring future competitiveness and allowing for greater automation and efficiency.

Privacy and cyber security concerns were also raised during the workshop as another important topic to be considered in the further advancement of 5G technologies. The increased connectivity and data processing capabilities of 5G networks come with the potential for cyberattacks and other security threats, calling for security measures and conducive regulatory frameworks to ensure the protection of sensitive data and critical infrastructures.

4.2 Estonia

Overview key findings

Commercial Operators	Vendor Collaboration	Band & Year of Allocation
Tele Eesti AS	Nokia	3410-3800 MHz, 2022
Telia Eesti AS	Ericsson	3410-3800 MHz, 2022
Elisa Eesti AS	Nokia	700 MHz, 3,5 GHz 2022
Roll-out Indicators (DESI)	**Estonia**	**EU**
5G spectrum: Assigned spectrum of total harmonised 5G spectrum	0% As of 04 2022	56% As of 04 2022
5G coverage: Populated areas covered by at least one operator	18% In 2021	66% In 2021
Challenges and Strengths		
Delayed roll-out due to comprehensive cybersecurity regulations		

Table 8: Overview of key findings for Estonia.
Sources: ERR, 2021; European Commission, 2022b; Morris, 2022; O'Grady, 2022. 5G Data Hub

Overview commercial network roll-out and coverage

Estonia places highly in several digitalisation rankings and has reached ubiquitous 4G coverage (see, e.g., European Commission, 2022b). The Estonian Digital Agenda has set ambitious targets for 2030, focussing on digital public services, cybersecurity and improved connectivity across the country (Ministry of Economic Affairs and Communications, 2021). However, the country's 5G roll-out has experienced some delays, resulting in a nominal 33.3% coverage of the Estonian population in October 2022. The most recent auction for 26 GHz was still ongoing in early spring 2023, with results expected by summer 2023. Questions have been raised as to whether the high cyber security standards put in place by the Estonian government were a primary cause of delay in the 5G roll-out process (ERR, 2021; European 5G Observatory, 2022a).

National policy targets on 5G

In line with common European goals, the Estonian government is striving to provide 5G coverage to the entire population by 2030. However, achieving this goal also depends on future infrastructure investments in regions outside the main urban areas. Estonia's 2020 Digital Agenda further outlines the country's ambition of providing 5G along the country's main transport routes. As a long-term goal, the strategy aims to prepare for a smooth adoption of 6G in the future (Ministry of Economic Affairs and Communications, 2021).

Spectrum allocation and auctions

In January 2019, the Estonian Minister of Entrepreneurship and Information Technology introduced a draft regulation laying the foundation for the development of 5G networks in the 3.6GHz band. Two months later, a 5G spectrum roadmap

presented plans to auction the 700 MHz spectrum in the first half of 2020. The auction for the 390 MHz spectrum in the 3.6 GHz band was suspended in April 2019 due to a complaint regarding tendering rules favouring certain companies and hindering competition. The process resumed with revised rules in 2020, with the auction itself postponed to 2021. A second auction took place in the summer of 2022 when mobile operator Elisa won the first license in the 3.5GHz band with a bid of €7.206 million. Telia won the second license for €8.50 million, while the third license went to Tele2 at the reserve price of €1.597 million. The final set of auctions was concluded in November 2022 for the 700MHz spectrum. Telia, Elisa and Tele2 emerged victorious from the bidding rounds with bids of €2.11 million (Elisa), €2.01 million (Telia) and €2.00 million (Tele2), respectively (TeleGeography, 2022a).

Companies that obtain a license are obliged to provide coverage of 50% to every county within two years and 95% within four years. Five counties are exempt from this rule due to interference from Russian TV broadcasters (TeleGeography, 2022a).

Regulation on private network or local permits for specific verticals/industries
Considering the recent final auctioning process concluded in November 2022, no regulation on private networks or local permits for specific verticals/industries could be identified.

	Vendor collaboration	Roll-out status. Coverage of costumers
Tele2 Eesti AS	Nokia	In July 2022, Tele2 Estonia activated 5G in parts of Tallinn.
Telia Eesti AS	Ericsson	In August 2022, Telia Estonia's 5G network covered 33% of the population using its 3.5 GHz license.
Elisa Eesti AS	Nokia	Launched 5G in June 2022.

Table 9: Commercial 5G roll-out and status by operator in Estonia.
Sources: ELISA Eesti, 2022; TeleGeography, 2022b, 2022c.

	Public vs private	Focus
5G Tallink	Private	5G test and exploration area at the Port of Tallinn. Platform to provide cruise ships and passengers with a fast and stable Internet connection (Ericsson, 2022; Investinestonia, 2017).
Taltech's IoT and 5G Platform (Tallinn University of Technology)	Public	TalTech invited companies to evaluate their new products and services on a special platform. Entrepreneurs, start-ups and other companies can evaluate their products and services in real-time and collect feedback from both industry and researchers.

Table 10: Testbeds, innovation hubs and networks in Estonia.
Source: Data from the "Mapping 5G applications 2022 survey" (last updated 2022).

5G verticals and use cases

Most 5G initiatives in Estonia centre on the Transport and Manufacturing verticals, but it should be noted that only a small number of 5G applications were identified in the context of the Project (see Figure 8).

Cross-Border co-operation within the Transport/Mobility vertical is worth highlighting, as Estonia is involved as a partner in the 5G-ROUTES project – a 5G-PPP Phase 3 project devoted to validating 5G field trials on Connected and Automated Mobility (automotive, railway and maritime sectors) in the "Via Baltic North" 5G cross-border corridor (Latvia-Estonia-Finland) (5G Routes project consortium, 2022). The 5G trial network of the Port of Tallinn is another notable example in this vertical, which delivers internet connectivity to commercial cruise ships and their passengers when in port and is one of the first operational 5G trial networks with an ecosystem of partners, customers and consumers (Ericsson, 2022a). In the area of industrial 5G applications, the Ericsson Tallinn smart factory is also testing augmented reality troubleshooting, precise indoor localisation and work environment monitoring (Ericsson, 2022b).

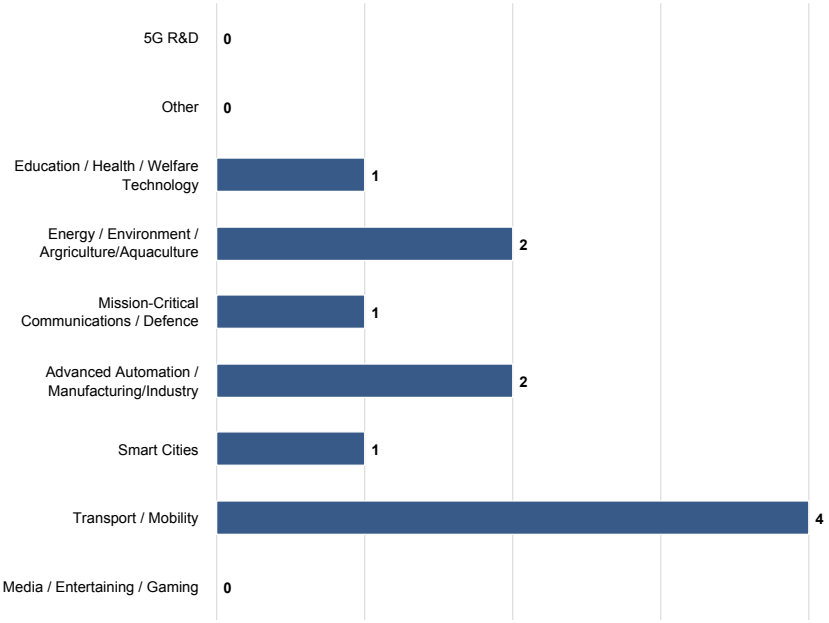


Figure 8: Main verticals identified in Estonia

n=11, multiple answers possible.

Source: Data from the "Mapping 5G applications 2022 survey" (last updated 2022).

Indicator	Estonia 2022	EU 2022
2c1 5G spectrum Assigned spectrum as a % of total harmonised 5G spectrum	0% 04 2022	56% 04 2022
2c2 5G coverage % of populated areas covered by at least one operator as reported by operators and national regulatory authorities	18% 2021	66% 2021

Table 11: Estonia's status according to international indicators.
Source: Digital Economic and Society Index 2022 (European Commission, 2022b)

Challenges and strengths

Estonia introduced a set of cyber security regulations for 5G networks in December 2021. The adoption of this legal framework was seen as a prerequisite for the 5G frequency auction and has been discussed and developed over roughly three years (ERR, 2021). While enabling secure 5G connectivity in Estonia, these legal underpinnings have also been perceived to slow the pace of 5G roll-out (Lobjakas, 2020).

The significant investment costs associated with 5G network infrastructures may prove one of the main barriers for Estonia and risk further exacerbating existing digital divides and coverage concerns between urban and rural areas due to these costs in areas of lower population density.

As a small country rolling out 5G, co-operation and the establishment of synergies with other Nordic and Baltic actors are of vital importance, e.g. the "Via Baltic North" 5G cross-border corridor.

4.3 Finland

Overview key findings

Commercial Operators	Vendor Collaboration	Bands & Year of Allocation
Elisa Oyj	Nokia, Ericsson, Huawei	- 713 - 723 / 768 - 778 MHz, 2017 - 3.54-3.67GHz, 2018 and in Åland: 3.54-3.64GHz, 2020 - 25.1 - 25.9 GHz, 2020
Telia Finland Oyj	Nokia, Ericsson, Huawei	- 723 - 733 / 778 - 788 MHz, 2017 - 3.41-3.54GHz, 2018 and in Åland: 3.41-3.51GHz 2020 - 25,9 - 26,7 GHz, 2020
DNA Oyj (Telenor)	Nokia, Ericsson, Huawei	- 703 - 713 / 758 - 768 MHz, 2017 - 3.67-3.8GHz, 2018 - 26.7 - 27.5 GHz, 2020
Ålcom (only Åland)	Ericsson	3.7-3.8 GHz, 2018
Roll-out Indicators	**Finland**	**EU**
5G spectrum: Assigned spectrum of total harmonised 5G spectrum	99% As of 04 2022	56% As of 04 2022
5G coverage: Populated areas covered by at least one operator	72% In 2021*	66% In 2021
Challenges and Strengths		
- Further improve 5G coverage in rural areas - Limited market uptake due to good 4G service - Forerunner in 5G roll-out, technology, and deployment of local networks - Forerunner in 5G/6G R&D and co-operation		

Table 12: Overview of key findings for Finland and Åland.
*Sources: European Commission, 2022c; Traficom, 2023).*Data used in this table for all countries stems from the DESI 2022 report. More recent data provided by Traficom indicates a 98% coverage of households in 4Q of 2022.* 5G Data Hub

Overview commercial network roll-out and coverage
As of October 2022, Finland had an overall coverage of 80%, and almost 100% of the three Pioneer bands have been assigned (European 5G Observatory, 2022a). With its 5G roll-out beginning in 2019, Finland was one of the first countries to adopt 5G technology (Laine-Lassila, 2021) and is a frontrunner in 5G roll-out and coverage.

National policy targets on 5G
In 2019, the Finnish Ministry of Transport and Communications (Traficom) published a strategy for digital infrastructure: "Turning Finland into the world leader in communications networks – Digital infrastructure strategy 2025". The strategy promotes the implementation of 5G and supports the construction of optical fibre networks (Ministry of Transport and Communications, 2019).

Spectrum allocation and auctions
Finland's spectrum allocation has concluded. The roll-out of 5G networks in the 3.5 GHz band began in 2019. The 26GHz band auction took place in June 2020. Telia, DNA and Elisa each acquired a licence for €7 million each.

Regulation on private network or local permits for specific verticals/industries
Finland is one of the few countries, together with Denmark and Sweden, that has introduced a local licensing system (Plum Consulting, 2022).

	Vendor collaboration	Roll-out status
Elisa Oyj	Ericsson	Elisa was the first operator to launch a commercial 5G network in Finland. In June 2022, Elisa achieved a population coverage of 80%.
Telia Finland Oyj	Nokia	In 2021, Nokia deployed a 5G Standalone Core network which allows Telia to offer advanced 5G services such as slicing
DNA Oyj (Telenor)	Nokia	In June 2022, DNA achieved a population coverage of 68%.

Table 13: Commercial 5G roll-out and status by operator.
Sources: Elisa, 2022; TeleGeography, 2022d, 2021.

	Public vs private	Focus
Tampere Testbed Hervanta	Public	Testing platform conducted within ERDF project Smart City Test Area + Towards Automated Transport
5G Test Network	Public	Aalto University 5G test network
SCOTT – Secured Connected Trustable Things	Public	Secure use of IoT EU-funded Project. Ended 2020
5G VIIMA	Both	Platform with four trial sites: Almar Industry Campus; ABB Smart Grids; Port Oulu Industry Campus; NOKIA Digital Factory. Use of 5G in support of Industry 4.0
Kalmar Port automation test field	Private	5G stand-alone network for Technology and Competence Centre in Tampere - automation test field
5G Test Network Turku	Both	Test Network at Turku University of Applied Sciences
ASCENT	Public	Proof-of-concept testbed for frequency sharing scenarios between 5G satellite and terrestrial components
5G Force	Public	Open 5G platform for new algorithms, applications etc.
5GFINLOG (5G Future Innovation Platform for Logistics)	Public	Testbed for 5G logistics and port testing in the Port of Hamina Kotka
5GTNF – 5G Test network Finland	Both	Offer trial support and infrastructure configurations, expand the Finnish ecosystem for 5G R&D and 5G and AI
Smart City Espoo – The Keera District	Both	Use of circular economy, mobility and IoT solutions in the Kera District
AISA (AI-based Situational Awareness)	Both	Utilisation of situational awareness created by AI and versatile sensing
Urbansense 5G Testbeds	Public	5G Testing environment and innovation platform to monitor the urban environment
5G Enhance	Both	Horizon 2020 project composed of FI research team (VTT, FHG, UOULU and Accelleran) focussing on large-scale trial activities on the real-life testbed in EU and Japan, in enhanced mobile broadband access network in crowded environments.

Table 14: Testbeds, innovation hubs and networks.

Source: Data from the "Mapping 5G applications 2022 survey" (last updated 2022).

5G verticals and use cases

There are several use cases in Finland (and Åland) that build on 5G technology. As can be seen in Figure 9, most Finnish use cases can be placed in the Transport vertical, which is a market leader ahead of Smart Cities and Advanced Automation in the Manufacturing Industry.

An example from the transport vertical is the GACHA project, consisting of the "world's first autonomous shuttle bus for all weather conditions", launched in Helsinki in 2019 (Sensible4, 2022).

Although Finland displays advanced progress in the use of 5G for innovation across different sectors and industries, a closer look at the specific development status of the use cases identified within this project reveals that a majority of applications are still in a testing/prototyping phase. Only about 4.3% of the projects have reached a higher Technology Readiness Level (TRL) at this point in time (see Figure 10).

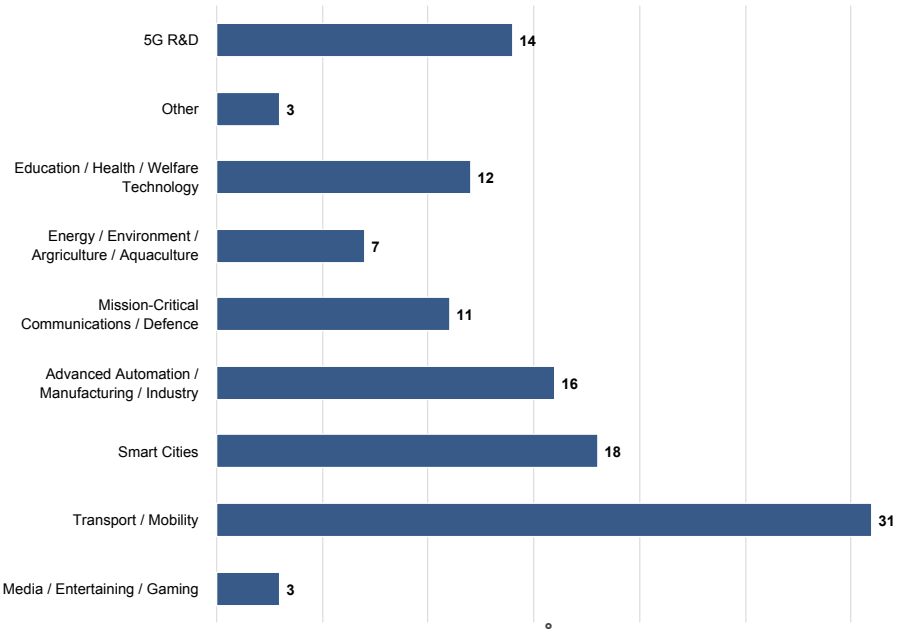


Figure 9: Main verticals identified in Finland, incl. Åland.

n=116, multiple answers possible.

Source: Data from the "Mapping 5G applications 2022 survey" (last updated 2022).

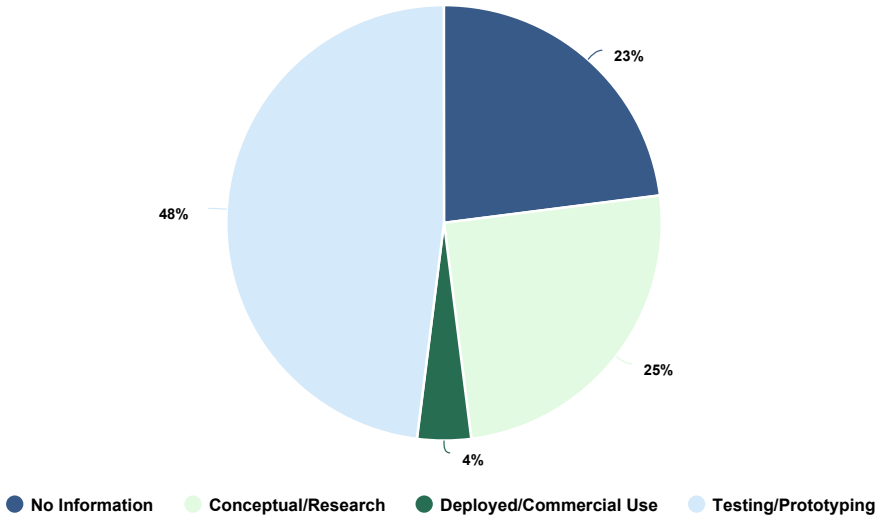


Figure 10: Status of 5G use cases in Finland incl. Åland

Indicator	Finland 2022	EU 2022
2c1 5G spectrum Assigned spectrum as a % of total harmonised 5G spectrum	99% 04 2022	56% 04 2022
2c2 5G coverage % of populated areas covered by at least one operator as reported by operators and national regulatory authorities	72% 2021	66% 2021

Table 15: Finland's status according to international indicators.
Source: Digital Economic and Society Index 2022 (European Commission, 2022c)

Challenges and strengths

Finland has presented a fast and successful 5G roll-out. This may partially be due to the country's historically strong ICT industry that helped pave the way for 5G technology, coupled with Finnish society's culture of innovation and new technology development. In addition, effective government support for research and development, promoted by the 2019 "Digital infrastructure strategy 2025", has also played an important part in Finland's investment in 5G, enabling the growth of an active ecosystem of actors within the field (Ministry of Transport and Communications, 2019). The country is home to several leading 5G companies, including Nokia, further boosting Finland's 5G frontrunner credentials. Nokia is currently one of Europe's largest providers of telecommunications equipment devoted exclusively to the development of 5G technology and patenting (Buggenhagen and Blind, 2022).

Nevertheless, improving digital connectivity in sparsely populated areas was mentioned as an ongoing challenge in a 5G Nordic-Baltic Monitoring Tool workshop with Finnish 5G experts. As Finland is a geographically large country comprised of vast rural districts, providing 5G coverage to all areas may prove difficult, as servicing low population densities can be unprofitable for 5G network operators and thus impact the availability of 5G-enabled services where there is an actual greater need for them (e.g. in healthcare).

There remains a limited understanding and market uptake of potential use cases of 5G, particularly in the industrial sector (Blind and Niebel, 2022). This situation must

improve if a more fruitful usage of 5G is to be encouraged. To that end, the Finnish Transport and Communications Agency and its 5G Momentum ecosystem have been promoting activities focussing on accelerating 5G technology uptake in industry, business, and society.

4.4 Iceland

Overview key findings

Commercial Operators	Vendor Collaboration	Bands & Year of Allocation
NOVA	Huawei	- 800 MHz, 2020 - 3.6 – 3.7 GHz, 2020
Síminn	Ericsson	- 700 MHz, 2020 - 3.5 – 3.6 GHz, 2020
Vodafone	Huawei	- 800 MHz, 2020 - 3.7 – 3.8 GHz, 2020
Challenges and Strengths		
- Collaboration with Huawei on 5G roll-out - Increase digital connectivity in rural areas		

Table 16: Overview of key findings for Iceland.
Sources: Ericsson, 2022c; ITU, 2020a; Kris, 2020; NOVA, 2021; Vodafone, 2022, The Electronic Communications Office of Iceland, 2023. 5G Data Hub

Overview commercial network roll-out and coverage
The 5G roll-out in Iceland began in 2020. By the end of 2021, 5G reached 50% of the population and by the end of 2022 75%. All major towns in Iceland have 5G service today and the coverage is approximately 80% of the population (data provided by The Electronic Communications Office of Iceland 2023).

National policy targets on 5G
The government's vision is for Iceland to be a class leader in digital solutions underpinned by solid and secure infrastructures. A primary goal is to expand the 5G network and increase speed in the coming years.

Spectrum allocation
The 700, 800, 2100 and 2600 MHz and 3,6 GHz frequencies have been allocated (ITU, 2020a). Limited industrial use of 5G has taken place in Iceland, with the available 5G network primarily regarded as a testbed for everyday users.

	Vendor collaboration	Roll-out status
NOVA	Huawei	Nova began testing 5G in February 2019 and launched its network officially in May 2020. Its service area reaches all major towns and villages in Iceland.
Síminn	Ericsson	Síminn aims to achieve 90% of 5G coverage by the first half of 2025.
Vodafone	Huawei	Vodafone launched its 5G network in September 2022 and aims to expand its 5G coverage over the next two years.

Table 17: Commercial 5G roll-out and status by operator.
Sources: Ericsson, 2022c; NOVA, 2021; Vodafone, 2022, The Electronic Communications Office of Iceland, 2023.

Testbeds, innovation hubs and networks
No relevant information could be identified.

5G verticals and use cases
Upgrading health care services and improving accessibility in some of the more rural and remote parts of the country are seen as areas where 5G capabilities offer enormous potential. The three Icelandic network providers, Nova, Síminn and Vodafone Iceland, partnered in May 2020 to install antennas in several rural areas. This has expanded access to the Icelandic 112 emergency line and saved lives. As the owner of 112, the state funds the towers while the providers are responsible for technical oversight and service. This partnership is made possible by Multi-Operator Core Networks technology (project survey data).

Challenges and strengths
Similar to Greenland and the Faroe Islands, geography and demographic factors (low population density, with the majority of the population concentrated in metropolitan areas) point to the need for significant investment considerations and associated financing challenges.

Nevertheless, several conversations with Icelandic 5G experts as part of the Nordic-Baltic Monitoring tool project emphasised the wide-ranging potential the technology has to offer. Two key areas include benefits in distance health care for remote areas and increased automation across various industries. Other examples included agriculture, in particular greenhouse vegetable farming (e.g., automatic watering, irrigation, and fertilizer distribution), the fishing industry and aquaculture.

The partnership with Huawei has come under considerable criticism due to data misuse allegations levelled at the Chinese telecommunications company (Kris, 2020).

4.5 Latvia

Overview key findings

Commercial Operators	Vendor Collaboration	Band & Year of Allocation
Bite Latvija	Ericsson	- 700 MHz, 2021
Telia	Ericsson	- 3.4-3.7 GHz, 2017
Tele 2	Nokia	- 700 MHz, 2021 - 3.5-3.6 GHz, 2018
Latvijas Mobilais Telefons (LMT)	Nokia	- 700 MHz, 2021
Roll-out Indicators	**Latvia**	**EU**
5G spectrum: Assigned spectrum of total harmonised 5G spectrum	63% As of 04 2022	56% As of 04 2022
5G coverage: Populated areas covered by at least one operator	0% In 2021	66% In 2021
Challenges and Strengths		
- Slow roll-out process - Leading role in defence vertical		

Table 18: Overview of key findings for Latvia.
Sources: Curwen and Whalley, 2023; European Commission, 2022d; Latvian Public Broadcasting, 2022; LETA, 2021; Morris, 2022. 5G Data Hub

Overview commercial network roll-out and coverage
Latvia has allocated most of the licenses in the 700 MHz (100%) and the 3.6 GHz band (87.50%), while allocation in the 26 GHz band is lacking (0%) (European 5G Observatory, 2022a). However, the roll-out process is still underway, leading to 0.0% coverage of the overall Latvian population in 2021 according to the European Digital Economy and Society Index (DESI) (European 5G Observatory, 2022a; European Commission, 2022d).

National policy targets on 5G
In February 2020, the Latvian Cabinet of Ministers approved the national 5G roadmap (European Commission, 2020; Latvian Ministry of Transport, 2020a). This 5G deployment roadmap summarises the main aspects of 5G infrastructural development in cities and along land transport routes and sets an expected timetable for delivery.

Latvia also adopted the Digital Transformation Guidelines for 2021–2027 with a stated goal of 50% 5G coverage for all large urban areas (in Latvia – Riga, Jelgava, Liepāja, Daugavpils) and along all land transport highways (Latvian Ministry of Transport, 2020b)

Spectrum allocation and auctions
Latvia has assigned 100% of its 700MHz band, 87.50% of its 3.6GHz band and 0.00% of its 26 GHz band. Tele2, Latvijas Mobilais Telefons and Bite Latvija acquired

licenses in the 700MHz band at auction in 2021 (European 5G Observatory, 2022b). Licences for frequencies on the 3.5GHz band were auctioned in both 2017 and 2018.

Regulation on private network or local permits for specific verticals/industries
Latvia is home to Europe's first 5G defence testbed, supplemented by two new standalone 5G networks deployed by Nokia and Ericsson. The testbed was launched by LMT in partnership with the Latvian National Armed Forces and the Latvian Ministry of Defence. Its purpose is to facilitate defence innovation testing on a variety of networks, and it has been in operation since November 2020. The site is also open to NATO allies to jointly develop, evaluate, and demonstrate 5G applications (The Baltic Times, 2022).

	Vendor collaboration	Roll-out status
Bite Latvija	Ericsson	An agreement between Bite and Ericsson was signed in May 2022, and the goal was to build 200 new 5G base stations in 2022
Telia	Ericsson	Telia offers its mobile services in Latvia through LMT
Tele 2	Nokia	Launched 5G technology in two sites in January 2020
Latvijas Mobilais Telefons (LMT)	Nokia	Launched 5G access for private households in 2021

Table 19: Commercial 5G roll-out and status by operator.
Sources: Latvian Public Broadcasting, 2022; LMT, 2021; Morris, 2022.

Testbeds, innovation hubs and networks
A testbed that has received considerable media and political attention can be found in the defence sector. The Latvian 5G military testbed began operations in November 2020 and hosted NATO's first 5G experiment testing AR/VR applications for military use in 2022 (Ministry of Defence, 2022).

5G verticals and use cases
There are 18 use cases identified in Latvia. Most Latvian verticals can be placed in the Mobility/Transport sector (see Figure 11). One example is an automated bus terminal management system currently in use at Riga's international bus terminal (LMT, 2022). However, it should be noted that the majority (12) of the use cases are not yet fully reliant on 5G but can be classed within the "4G going for 5G" category.

	Public vs private	Focus
5G Laboratory LMT MikroTik	Private	Lab for Latvian tech companies to evaluate and improve solutions
5G Cross-Border Mobility Stimulation Space	Both	Europe's first cross-border mobility simulation space
Europe's first 5G military testbed	Both	Testbed provides an R&D environment for the accelerated development of 5G-enabled military and general tech use cases, such as various sensors, defence systems, and platforms, including unstaffed solutions.

Table 20: Testbeds, innovation and networks.
Source: Data from the "Mapping 5G applications 2022 survey" (last updated 2022).

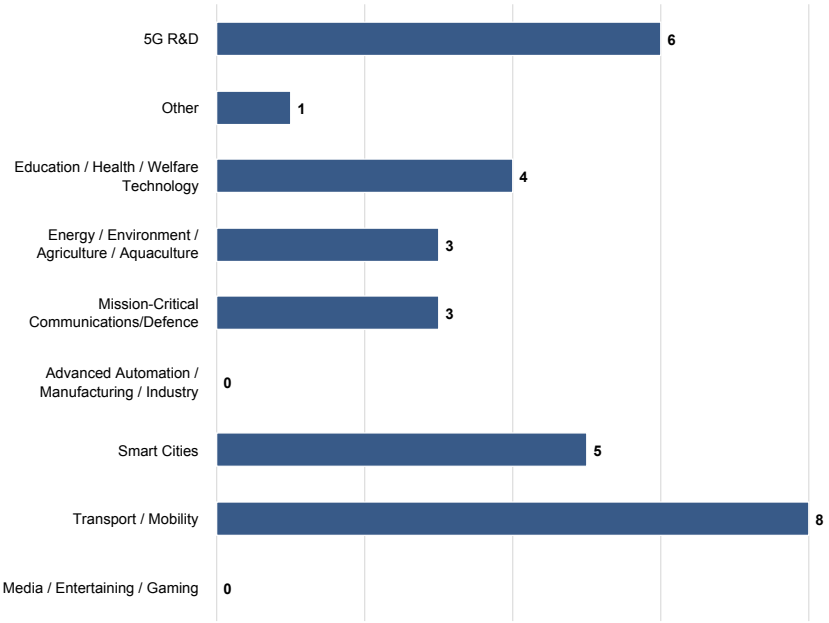


Figure 11: Verticals in Latvia across different sectors.
n=30, multiple answers possible. *Source: Data from the "Mapping 5G applications 2022 survey" (last updated 2022).*

Indicator	Latvia 2022	EU 2022
2c1 5G spectrum Assigned spectrum as a % of total harmonised 5G spectrum	63% 04 2022	56% 04 2022
2c2 5G coverage % of populated areas covered by at least one operator as reported by operators and national regulatory authorities	0% 2021	66% 2021

Table 21: Latvia's status according to international indicators.
Source: Digital Economic and Society Index 2022 (European Commission, 2022d).

Challenges and strengths

A relatively slow allocation and roll-out process has hampered the spread of 5G technology in Latvia. There is still limited spectrum availability (63% as of April 2022) which may contribute to a combination of fewer service providers and increased consumer costs leading to slower general adoption of 5G technology. The Latvian Public Utilities Commission (SPRK) set out coverage obligations to improve coverage in cities but did not extend this measure to support sparsely populated areas (Kuś and Massaro, 2022). Overall, despite some recent progress, 5G network coverage remains limited.

The importance of 5G within the defence vertical, together with hosting the 5G defence testbed on its territory, should be noted (The Baltic Times, 2022). Furthermore, Latvia's Recovery and Resilience Plan includes an investment of €12.5 million for the construction of passive infrastructure to ensure 5G coverage on the Via-Baltica corridor (European route E67, from Tallinn via Riga and Kaunas to the Lithuanian border and on to Poland), aiming to ensure 100% fibre backhaul availability along the Latvian section of the route. This 5G implementation is being accelerated in partnership with its Baltic neighbours and is a good example of cross-border co-operation processes (European Commission, 2020).

Latvia is prominent among the Baltic Countries in its dynamic approach to stakeholder engagement initiatives, such as hosting the annual Techritory forum, a Global 5G technology conference.

4.6 Lithuania

Overview key findings

Commercial Operators	Vendor Collaboration	Bands & Year of Allocation
Telia Lietuva	Ericsson	- 3,5 GHz 2022 - 700 MHz 2022
Tele 2	Nokia	- 3,5 GHz 2022 - 700 MHz 2022
Bite Lithuania	Ericsson	- 3,5 GHz 2022 - 700 MHz 2022
Roll-out Indicators	**Lithuania**	**EU**
5G spectrum: Assigned spectrum of total harmonised 5G spectrum	5% As of 04 2022	56% As of 04 2022
5G coverage: populated areas covered by at least one operator	33% In 2021	66% In 2021
Challenges and Strengths		
Slow allocation and roll-out process		

Table 22: Overview of key findings on Lithuania.
Sources: European Commission, 2022e; Pham, 2023; Telia Lietuva, 2022. 5G Data Hub

Overview commercial network roll-out and coverage

5G coverage in Lithuania is still relatively sparse, with only 33% coverage in populated areas in 2021, or approximately half of the EU average of 66% (European Commission, 2022e). Telecommunication companies are upgrading their equipment to allow for a swift introduction of 5G after the auctions have been concluded.

National policy targets on 5G

The Lithuanian government approved guidelines for the development of 5G in the Republic of Lithuania in 2020–2025. Guidelines indicate that at least one 5G network should cover one of Lithuania's largest cities (Vilnius, Kaunas, Klaipeda, Siauliai, or Panevezys) by 2022. It further states that at least one 5G network should be available in all five cities by 2023. The guidelines also introduced coverage obligations of all other urban areas and main transport routes and hubs by 2025 (European 5G Observatory, 2021a).

An October 2021 memorandum on 5G development in Lithuania also pledged that international land transport corridors Via Baltica & Rail Baltica would offer uninterrupted 5G connection services by 2025 (Lietuvos Respublikos susisiekimo ministerija, 2021).

Spectrum allocation and auctions

According to the DESI 2022 country profile, Lithuania is among the EU Member States that have assigned the least spectrum (5% compared to 56% at European level) (European Commission, 2022e). In August 2022, the auction of 5% mobile

spectrum in the 700MHz band was concluded. An additional auction for frequencies in the 3.5GHz band has also been concluded in August 2022 (TeleGeography, 2022c).

Regulation on private network or local permits for specific verticals/industries
No relevant information could be identified.

	Vendor collaboration	Roll-out status
Telia Lietuva	Ericsson	Telia Lietuva has been testing 5G in Lithuania since 2018 and has been providing commercial services in Vilnius using the 2100 MHz frequency band since January 2022. In September 2022, their 5G network reached more than half of the country's territory and 80% of its population. The company plans to cover 99% of Lithuania's territory by summer 2023.
Tele 2	Nokia	Tele 2 launched its 5G services in the Lithuanian capital of Vilnius in September 2022 and is planning on further network expansion.
Bite Lithuania	Ericsson	Bite Lithuania launched its commercial 5G network for smartphones in February 2023 and for 5G fixed wireless access broadband in October 2022.

Table 23: Commercial 5G roll-out and status by operator.
Sources: Barton, 2022; Pham, 2023; Telia Lietuva, 2022.

Testbeds, innovation hubs and networks
No relevant information could be identified.

5G verticals and use cases
Only one vertical could be identified within the context of the present study: 5G Cross border transport corridors for connected and automated mobility (CAM) in the Baltics, also known as Via-Baltica/Rail-Baltica (DIGIBYTE, 2018).

Challenges and strengths
5G technology has the potential to foster new business models and supports sustainable, inclusive development in Lithuania, improving citizens' quality of life, supporting innovation, and enabling new services and applications.

Nevertheless, several challenges can be highlighted. Lithuania's spectrum allocation lies below the EU average, having assigned only 5%, compared to the EU average of 56%. As the availability of spectrum is vital for the deployment of 5G networks, this could impact the speed and quality of 5G services.

In a small country like Lithuania, the infrastructure investment needed for the deployment of 5G networks is also a challenge, especially for smaller telecom

companies. At the same time, there is a risk that the deployment of 5G networks may aggravate existing digital divides in the country, especially in rural and remote areas (related to the excessive cost of deploying infrastructures in areas of lower population density).

Addressing these limitations will be critical to foster 5G deployment in Lithuania and increase the possibility of reaching the targets set for the Gigabit Society and the 2030 Digital Decade (European Commission, 2022e).

Indicator	Lithuania 2022	EU 2022
2c1 5G spectrum Assigned spectrum as a % of total harmonised 5G spectrum	5% 04 2022	56% 04 2022
2c2 5G coverage % of populated areas covered by at least one operator as reported by operators and national regulatory authorities	33% 2021	66% 2021

Table 24: Lithuania's status according to international indicators.
Source: Digital Economic and Society Index 2022 (European Commission, 2022e).

4.7 Norway

Overview key findings

Commercial Operators	Vendor Collaboration	Band & Year of Allocation
Telenor	Ericsson	- 700 MHz, 2019 - 2.6 GHz, 2021 - 3.6 GHz, 2021
Telia	Ericsson	- 700 MHz, 2019 - 2.6 GHz, 2021 - 3.6 GHz, 2021
Ice Norway	Nokia	- 700 MHz, 2019 - 2100 MHz, 2019 - 3.6 GHZ, 2021
Altibox	Nokia	- 2.6 GHz, 2021 - 3.6 GHz, 2021
Roll-out Indicators	**Norway**	**EU**
5G spectrum: Assigned spectrum of total harmonised 5G spectrum	67% As of 04 2022	56% As of 04 2022
5G coverage: populated areas covered by at least one operator	24% In 2021	66% In 2021
Challenges and Strengths		
Improving 5G uptake		

Table 25: Overview of key findings on Norway.
Sources: European Commission, 2022f; Ice Norway, 2022; Nkom, 2021, 2022; Nokia, 2022; Telenor, 2020; Telia, 2022a. 5G Data Hub

Overview commercial network roll-out and coverage

The Norwegian government and industry see enormous potential in the further deployment and application of 5G in leveraging innovative technologies that can revolutionise industrial processes as well as everyday life practices. The main operators are Telenor, Telia and Ice Norway. The roll-out is ongoing, supplementing the established private networks for specific verticals, as outlined below.

National policy targets on 5G

Although Norway had no national strategy targeting 5G, as of 202o, some 5G-related goals can be found in other policy documents (ITU, 2020b), for instance, the 2019 National Strategy for Artificial Intelligence stresses Norway's goal to deploy a nationwide 5G network by 2023. It further highlights the value of 5G in the development and use of IoT and advanced solutions facilitated by artificial intelligence, such as self-driving vehicles, early warning systems etc. (Norwegian Ministry of Local Government and Modernisation, 2019).

The government also sees 5G as an important tool in improving industrial processes as part of the Green Industrial Initiative (Norwegian Ministry of Trade, Industry and Fisheries, 2022).

Spectrum allocation and auctions
Norway's auction in the 700 MHz and the 2100 MHz band were completed in June 2019. In total, €74.9 million were raised. Telia, Telenor and Ice emerged victorious from the bidding. The winning bidders of the 700MHz and 2100MHz bands were entitled to a discount on their bidding price if they agreed to pursue certain objectives. For instance, Telia agreed to cover selected railway lines and Telenor to cover major roadways (GSMA, 2022b).

In 2021, auctions in the 2.6 GHz, as well as the 3.5 GHz band, were concluded, raising €49 million. Telia, Telenor, Ice Norway and Altibox were the winning bidders at this auction (Nkom, 2021).

Regulation on private network or local permits for specific verticals/industries
Several partnerships between operators and other private and public actors around the establishment of private 5G networks could be identified. The Norwegian Defence Material Agency and Telenor Norway agreed in 2022 to work together on the development of services based on 5G. This will include the establishment of a private 5G network (Telenor, 2022). Telia and Herøya Industrial Park initiated a strategic co-operation to launch a private network on the industrial spectrum 3.8-4.2 GHz. A test laboratory for 5G applications, e.g., in AI, will be housed in the industrial park (Telia, 2022a).

Recently, Norway also started to offer free private trial licences in the 3.8–4.2 GHz range (European 5G Observatory, 2022b). Based on feedback within the industry, Norway is also considering new frequency bands for mobile communications and 5G and hopes to allocate the 1500 MHz and 26 GHz bands in 2023 (Nkom, 2022a).

	Vendor collaboration	Roll-out status
Telenor	Ericsson	Telenor opened Scandinavia's first 5G pilot in November 2018. 5G became commercially available in March 2020. The goal is to have coverage all over Norway in the first half of 2024.
Telia	Ericsson	Telia began the 5G roll-out in 2018. Today two out of three Norwegians can access 5G coverage through Telia. Telia claims to be the first provider offering nationwide coverage in 2023.
Ice Norway	Nokia	Deployment is underway, with intended completion by 2026.
Altibox	Nokia	Altibox's 5G Wireless Broadband product will be available in the first half of 2023. By focusing on this technology, Altibox aims to reach the 500,000 inhabitants that live in rural areas and therefore are often too far from base stations.

Table 26: Commercial 5G roll-out and status by operator.
Sources: Altibox, 2022; Ice Norway, 2022; Telenor, 2020; Telia, 2022a.

	Public vs private	Focus
5G-VINNI	Public	Public safety and disaster recovery including drone use eHealth use cases involving remote ultrasound and asset monitoring (5G Heart) Fixed wireless Media and Entertainment
YAGO Testbed	Private	Test arena for autonomous technologies in the mobility sector
5G in Kongsberg	Private	Kongsberg is the first city where Telenor tested 5G technology and is a site for the 5G-VINNI
SINTEF ACE	Not stated	Testbed for Aquaculture Engineering tested in realistic conditions on fish farms along the coast of Trondelag.
Aurora Borealis – Intelligent Corridor	Public	40km road (E8) testbed where the Norwegian Public Roads Administration tests and develops intelligent transport systems

Table 27: Testbeds, innovation hubs and networks.
Source: Data from the "Mapping 5G applications 2022 survey" (last updated 2022).

5G verticals and use cases

Most 5G use cases in Norway are in the smart cities vertical, followed by Mobility/ Transport and Mission Critical Communications / Defence (see Figure 12). Of note is the Herøya Industry Park where, together with Telia, a number of 5G industry applications are being developed and tested, e.g. in the area of automation (Telia, 2022b).

Norway can also be considered a frontrunner in using 5G to revolutionise the maritime industry. An example in this context is the MAMIME project, the world's first maritime 5G communication project. It focuses on 4G LTE and Wifi enhancement and innovative research into 5G Massive MIMO for maritime applications. The primary objective of this project is to design a solution with a high data rate and extensive coverage for land-to-boat radio communications, utilising 5G Massive MEMO technology.

Examining the overall 5G landscape in Norway and the collected data on use cases in the country, it becomes apparent that the advanced status of the Norwegian 5G roll-out is also reflected in the technical maturity of the 5G use cases that were identified, both in terms of TRL as well as usage of 5G rather than "4G going for 5G" (see Figures 13 and 14).

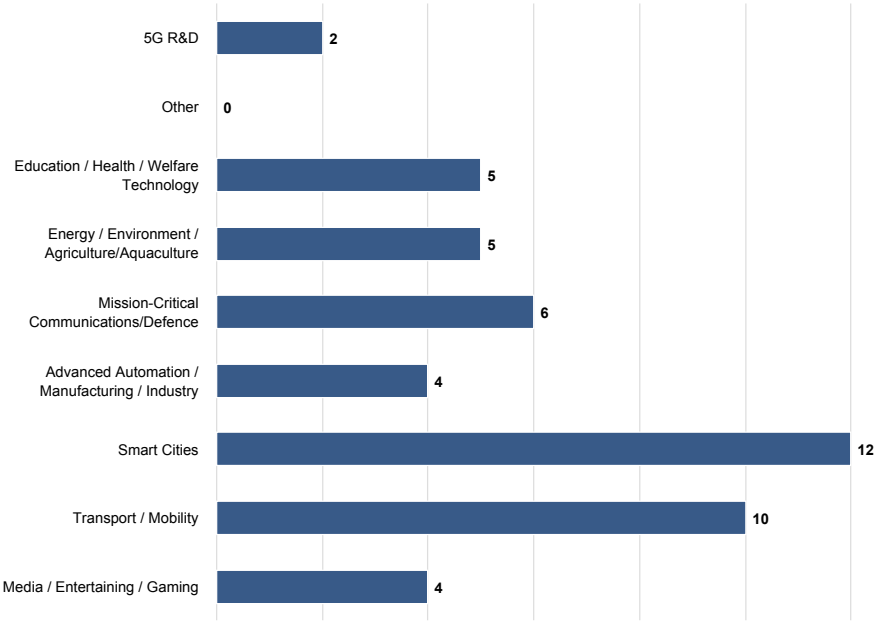


Figure 12: Verticals in Norway across different sectors.

n=48, multiple answers possible.

Source: Data from the "Mapping 5G applications 2022 survey" (last updated 2022).

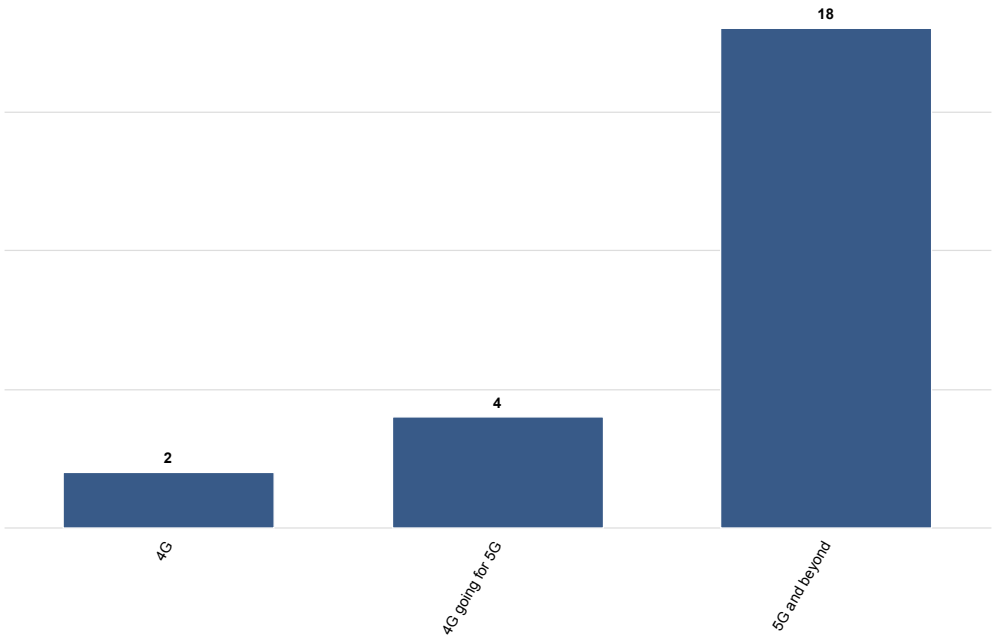


Figure 13: Technology usage/status of Norwegian 5G use cases.
Source: Data from the "Mapping 5G applications 2022 survey" (last updated 2022).

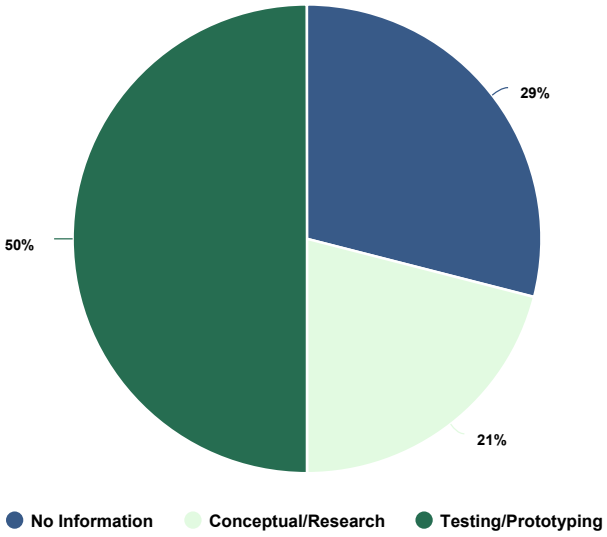


Figure 14: Development status of Norwegian use cases.
Source: Data from the "Mapping 5G applications 2022 survey" (last updated 2022).

Indicator	Norway 2022	EU 2022
2c1 5G spectrum Assigned spectrum as a % of total harmonised 5G spectrum	67% 04 2022	56% 04 2022
2c2 5G coverage % of populated areas covered by at least one operator as reported by operators and national regulatory authorities	24% 2021	66% 2021

Table 28: Norway's status according to international indicators.
Source: Digital Economic and Society Index 2022 (European Commission, 2022f).

Challenges and strengths

As in its Nordic neighbours, addressing 5G high infrastructure investments remains challenging, with roll-out in rural and remote areas and moving from 5G potential to actual business uptake both providing cases in point. While several use cases have been identified in the smart cities and mobility/transport vertical, there is still a notable discrepancy between pilot and testing initiatives and market acceptability.

In Norway, the Ministry of Local Government and Rural Development and the Ministry of Trade and Industry initiated a 5G industry forum in 2022 consisting of senior executives from several industries and the public sector to promote knowledge and best practice in the use of 5G technology and its role in efficiency, innovation, business development and improving competitiveness and exports (Nkom, 2022b).

Industry is an important sector that could potentially benefit from 5G, where advanced automation, data analytics, and machine-to-machine communication could support the development of smart factories, connected supply chains, and real-time monitoring of manufacturing processes.

4.8 Sweden

Overview key findings

Commercial Operators	Vendor Collaboration	Band & Year of Allocation
Tele 2	Nokia	- 700 MHz, 2018 - 3.5 GHz, 2021
Telenor	Ericsson	- 700 MHz, 2018 - 3.5 GHz, 2021
Three (Hi3G)	Ericsson	3.5 GHz, 2021
Telia	Ericsson	- 700MHz, 2018 - 3.5 GHz, 2021
Teracom Group	Ericsson	2.3 GHz 2021
Roll-out Indicators	**Sweden**	**EU**
5G spectrum: Assigned spectrum of total harmonised 5G spectrum	81% As of 04 2022	56% As of 04 2022
5G coverage: populated areas covered by at least one operator	18%In 2021	66%In 2021
Challenges and Strengths		
Semiconductor shortages have delayed the roll-out. High number of 5G testbeds, offering multiple options for research and industry partners to collaborate, develop and test 5G applications.		

Table 29: Overview of key findings on Sweden.
Sources: 5G Observatory, 2021; Eklund, 2021; Ericsson, 2020; European Commission, 2022g; Mobilnät.se, 2022; Tele2, 2022. 5G Data Hub

Overview commercial network roll-out and coverage

In Sweden, four operators offer commercial 5G services: Tele2, Telenor, Tre and Telia. The regulating body is Post- och Telestyrelsen (PTS). Sweden led the Nordic countries in 5G median download speeds in Q2 2022, which is partially driven by the Swedish digitalisation strategy (Kechiche, 2022). However, the country still lacks coverage. Sweden reached a population coverage of 18% in 2021 (European Commission, 2022g).

National policy targets on 5G

The Swedish government does not have specific 5G goals. The national broadband strategy states that all citizens must have access to reliable and high-quality mobile services no later than 2023. The operators have outlined their own plans in relation to 5G. For instance, Telia has a target of covering 90% of the population by 2023 and Telenor 99% of the population by 2023 (5G Nordic-Baltic Monitoring Tool workshop 2021).

Spectrum allocation and auctions

PTS auctioned the 700 MHz band in December 2018. In May 2020, Telia Sweden announced the activation of its 5G network in Stockholm, using its existing 700 MHz spectrum. At the same time, Tele2 launched its 5G network using 80 MHz of the 3.6

GHz spectrum band. In June 2020, Tre announced the commercial launch of 5G services using frequencies in the 2.6 GHz band. In October 2020, Telenor Sweden launched a commercial 5G service with 80 MHz of spectrum in the 3.7 GHz band.

In Sweden, the first stage of the 2.3 GHz and 3.5 GHz auction was initially scheduled for March 2020 but was postponed twice, finally concluding in January 2021 (5G Observatory – Quarterly Report #11).

Regulation on private network or local permits for specific verticals/industries
Like Denmark, Finland and Norway, Sweden has proposed a local licensing model for private 5G networks. In this instance, Sweden has focussed on the 3.6 GHz and 26 GHz bands (European 5G Observatory, 2022a).

	Vendor collaboration	Roll-out status
Tele 2	Nokia	At the end of 2022, Tele2's 5G network was available to 35% of the population. Tele 2's goal is to bring 5G to 90% of the Swedish population by the end of 2023. The remaining deployment is planned for 2024.
Telenor	Ericsson	Telenor launched its 5G service in 2020 and is currently expanding its 5G coverage across the country.
Three (Hi3G)		Three launched 5G in Stockholm in 2020, finalising 5G deployment on existing networks in 2022, reaching 16% of the Swedish population as of 2022. Future goals include upgrading its core network to 5G for lower latency (2022–2023), network expansion and densification (2023–2024) and rolling out network slicing to serve enterprise needs.
Telia	Ericsson	Match 5G coverage to that of the 4G network by 2025, covering over 90% of the population by 2023, extending to 90% geographical and 99% population coverage.
Teracom Group	Ericsson	Teracom AB is a state-owned service provider offering communication services to public and private critical infrastructure enterprises in Sweden. At the 2021 auction, Teracom AB won the entire 2.3 GHz band.

Table 30: Commercial 5G roll-out and status by operator.
Sources: (slamian, 2021; Mobilnät.se, 2022; Tele2, 2022.)

	Public vs private	Focus
Urban ICT Arena	Private	5G test platform that Ericsson offers to innovators and service developers in the Urban ICT Arena
ICE Data Center Testbed	Public	This testbed focuses on enabling open, secure, and vendor-neutral edge computing in a 5G net. Examples of applications: AI inference, control and automation, AR/VR-rendering, detection, gaming, IoT etc.
5G för vård och omsorg i övre Norrland 5GVO	Public	Runs from 2020–2023. Installed Telia's 5G Innovation Network at different sites: Luleå campus, Skellefteå campus, Övertorneå – Särkivaaragården, Luleå – Kronandalen care home, Skellefteå – The Great Northern (corporate hotel), Storuman – Hospital
Royal Institute of Technology	Public	Sweden's first 5G network is using a test license and serves as a testbed for developing innovative solutions and services.
Luleå University of Technology test environment	Public	The goal is to establish a research and innovation environment where companies, students and organisations can test innovations and applications.
AstaZero Borås	Public	Enable the testing of connected vehicles and associated services by offering test sites for vehicle manufacturers and other operators.
Testbed Digitalized Agriculture	Public	Create an innovation arena for co-operation, testing and development of new agricultural technology, e.g. developing decision support systems for agriculture and testing how new autonomous control and electric propulsion machine systems can be used in agriculture.
Scania 5G	Private	Three state-of-the-art mobile base stations have been installed at Scania's R&D facility in Södertälje. Support the development of, e.g. self-driving vehicles and convoy driving.
Stena Industry Innovation Lab (SII-Lab)	Private	Provides opportunities to test industrial digitalisation in future production systems. Affords the possibility to experience collaborative robots, 5G telecommunication and Virtual Reality in a work environment, such as gaming universes.
5G Innovation Hub North	Not stated	Hosts field trials and other related test cases since 2019 from sectors including healthcare, gaming, music, video conferencing, remote control, etc.
Umeå 5G	Public	Launched in 2018, five public actors joined forces to make Umeå Sweden's first 5G city offering a testbed for 5G. (Umeå Energi, Umeå Municipality, Umeå University, Umeå Science Park and Västerbotten County Council).
Dronecentersweden	Both	Testbed in Västervik, the first and only geographical UAS zone.
5G-ROUTES project	Public	An international automated mobility initiative devoted to validating 5G field trials on Connected and Automated Mobility. Cross-border use cases: automated co-operative driving, awareness driving, sensing driving, uninterrupted infotainment passenger services on the go, and multimodal services.
0Troedsson Forestry Teleoperation Lab – Testbed	Both	Addresses the key conditions for enabling autonomous forest machines, which may improve the working environment for forest machine operators and increase forestry sustainability.

Table 31: Testbeds, innovation hubs and networks.

Source: Data from the "Mapping 5G applications 2022 survey" (last updated 2022).

5G verticals and use cases

Next after Finland, Sweden is the country in which most use cases/verticals could be identified in the context of this project. In total, 43 Swedish use cases were identified and distributed across the different verticals. While Mobility/Transport use cases head the list, use cases in the field of automation/manufacturing/industry follow close behind. The third intensive case area was in the education/health and welfare vertical (see Figure 15).

Challenges and strengths

In Europe, Sweden is also considered one of the leading countries in the roll-out of 5G technology, with early investments and a dynamic ecosystem with both large companies like Ericsson driving 5G patenting in Europe (Buggenhagen and Blind, 2022) and innovative start-ups (Sifted, 2021).

Nevertheless, Sweden shares several of the main challenges of the other Nordic countries primarily linked to investment costs and geography, as manufacturers and suppliers have more interest in the roll-out of 5G in densely populated areas (cities) and less in sparsely populated rural areas.

Other challenges in the Swedish 5G roll-out can be attributed to delays due to semiconductor shortages and transport problems (Eklund, 2021). Similar to other Nordic regions, Sweden has also barred the use of 5G equipment from Huawei and ZTE because of security reasons (Blind and Niebel, 2022).

However, Sweden stands out in relation to the other countries in this survey due to its number of 5G testbeds, offering multiple options for research and industry partners to further their experience and development of 5G applications and promoting partnerships with a high TRL. Innovation hubs/ testbeds play a vital role in bringing research closer to the market. This dynamic ecosystem creates a promising shared environment fostering opportunities to develop new business models. Of note is the most recent partnership (early 2023) between Telia and Ericsson with the expressed aim of upscaling digital solutions into tangible business models. This NorthStar programme promises to spearhead 5G innovation for industrial enterprises, focussing on the automotive and transportation sectors, one of the most important verticals in the Nordic-Baltic region ("Telia och Ericsson lanserar NorthStar - nytt innovationsprogram för 5G i industrin," 2023; Tomás, 2023).

At a regional level, cross-border models for co-operation were highlighted in the 5G Monitoring tool project workshops as playing a key role in the ongoing 5G roll-out and development, especially taking into account the historical levels of shared R&D between Finland's Nokia and Sweden's Ericsson in previous mobile technology development.

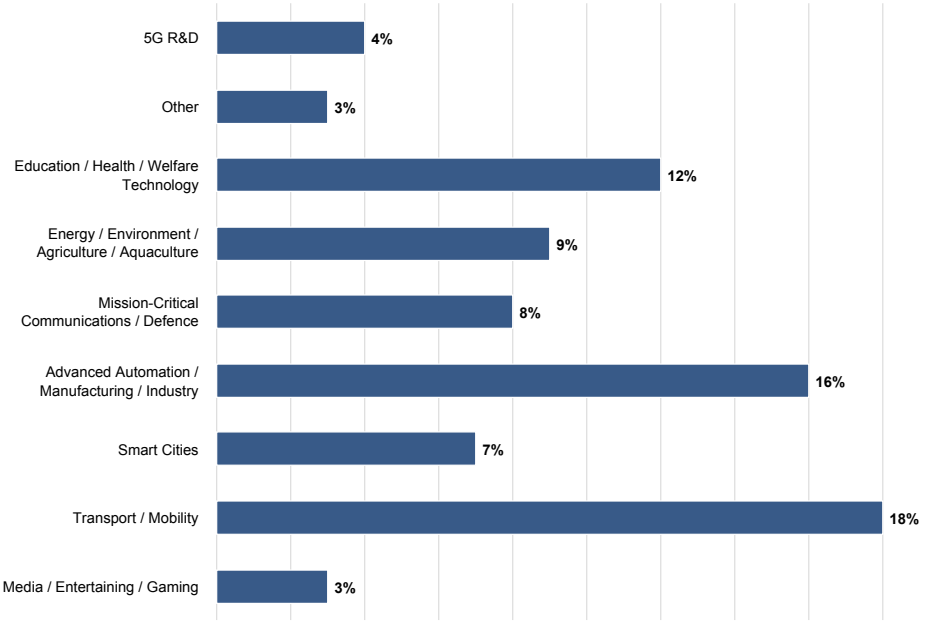


Figure 15: Use cases and verticals in Sweden.

n=80, multiple answers possible.

Source: Data from the "Mapping 5G applications 2022 survey" (last updated 2022).

Indicator	Sweden 2022	EU 2022
2c1 5G spectrum Assigned spectrum as a % of total harmonised 5G spectrum	81% 04 2022	56% 04 2022
2c2 5G coverage % of populated areas covered by at least one operator as reported by operators and national regulatory authorities	18% 2021	66% 2021

Table 32: Sweden's status according to international indicators.

Source: Digital Economic and Society Index 2022 (European Commission, 2022g).

4.9 Faroe Islands

Overview key findings

Commercial Operators	Vendor Collaboration	Spectrum & Year of Allocation
Faroese Telecom	Ericsson	2021
Challenges and Strengths		
The 5G roll-out was delayed due to a change in strategy away from partnership with Huawei		

Table 33: Overview of Key Findings for the Faroe Islands.
Sources: Duxbury, 2019; Faroese Telecom, 2021. 5G Data Hub

Overview commercial network roll-out and coverage

The Faroe Islands, an autonomous territory of the Kingdom of Denmark, are acknowledged for their good digital connectivity. In 2021, there was 4G coverage for 97.2% of the population. The roll-out for the Faroese 5G network commenced in 2021 and is scheduled to be concluded in 2023 (Ericsson, 2021).

National policy targets on 5G

As with its 4G network, the Faroe Islands pursues an ambitious plan to offer extensive and stable 5G coverage and high-speed Internet access on the islands' various transport routes as well as at sea in support of the important local fishing industry (Sharpe, 2021).

Spectrum allocation and auctions

One operator (Faroese Telecom) and Vendor (Ericsson) oversee the Faroese 5G roll-out.

	Vendor collaboration	Roll-out status
Faroese Telecom	Ericsson	Ongoing with planned completion by 2023.

Table 34: Commercial 5G roll-out and status by operator.
Source: Sharpe, 2021.

	Public vs private funding	Specific verticals?
KIMA – Public Safety Network	Private	Mission-critical-push-to-talk used by Faroe Islands' Police

Table 35: Testbeds, innovation hubs and networks.
Source: Data from the "Mapping 5G applications 2022 survey" (last updated 2022).

5G verticals and use cases

One single 5G use case could be identified in the survey conducted in the context of this project in 2022. The KIMA project is also listed above and is a privately funded project which supports the development of a local public safety network in the Faroe Islands for use by the local police force. However, it should be noted that this use

case relies on 4G for the moment, although the aim is to function on 5G in the future.

Challenges and strengths

The Faroe Islands have achieved comprehensive coverage across its 18 islands and beyond, bringing stable and fast digital connectivity to its underwater traffic links and adjacent waters. In the past, the Faroe Islands have worked with Chinese telecommunications company Huawei for the roll-out of their 4G network. In light of security concerns, the Faroe Islands withdrew from an initial plan to continue the partnership with Huawei, including its 5G roll-out. This change in plans and the need to replace Huawei equipment entailed certain political, technical, and economic challenges and delays for the Faroese roll-out process (Duxbury, 2019).

Another challenge facing the autonomous region relates to the Faroe Islands' location (remote part of the North Atlantic) and topography. Consisting of 18 separate islands, connected by bridges, tunnels and ferries, several geographical factors need to be considered in the roll-out of new digital technologies as well as the costs associated with building and maintaining the infrastructure needed for 5G networks in such a remote and sparsely populated area (Duxbury, 2019; Sharpe, 2021).

Nevertheless, the deployment of 5G networks in the Faroe Islands can offer a range of economic and social advantages, greatly enhancing the residents' quality of life. There is also potential for boosting the Islands' economy in relation to the tourism industry (offering new services) and remote work (Linda Randall et al., 2022).

4.10 Greenland

Overview key findings

Commercial Operators	Vendor Collaboration	Year of Allocation
Tusass	Ericsson	2022
Challenges and Strengths		
Providing sparsely populated areas with fast Internet connectivity Local geographical and weather conditions		

Table 36: Overview of key findings for Greenland.
Sources: Ericsson, 2022d. 5G Data Hub

Overview commercial network roll-out and coverage

Greenland is an autonomous region, part of the Kingdom of Denmark. In 2018, the last Greenlandic mobile mast was upgraded from 2G to 4G (McGwin, 2018). One year later, in 2019, Greenland's telecommunications monopoly TELE-POST, now known as Tusass, partnered with Ericsson to bring 5G technology to the region. Comparable to the situation in the Faroe Islands, the Greenlandic government chose to work with Swedish company Ericsson over the Chinese telecommunications company Huawei (Gronholdt-Pedersen, 2019). Given the fact that Greenland's population is spread over a large dispersed geographical area, Tusass has focussed primarily on bringing 5G to the larger settlements. In November 2022, the three Greenlandic towns of Sisimiut, Maniitsoq and Narsaq were the first to gain access to 5G. The roll-out process in ten other towns and settlements is still ongoing (Lindstrom, 2022).

National policy targets on 5G

In its 2018–2021 digitalisation strategy, the Government of Greenland stated its aim of developing 5G technology in Greenland in line with the goals set by the Nordic Council of Ministers (Digitaliseringsstyrelsen, 2018).

Spectrum allocation and auctions

The 5G roll-out will be implemented in its entirety by operator Tusass in partnership with Ericsson as the vendor. No further spectrum allocations or auctions are planned for the near future.

	Vendor collaboration	Roll-out status
Tusass	Ericsson	Coverage in three cities with plans to bring 5G to major towns and settlements via submarine cable access.

Table 37: Commercial 5G roll-out and status by operator.
Source: Gronholdt-Pedersen, 2019.

Testbeds, innovation hubs and networks
No relevant information could be identified.

5G verticals and use cases
No relevant information could be identified.

Challenges and strengths
Having a total population of about 57,000 people dispersed over an area measuring four times the size of France brings its own set of challenges when providing digital connectivity to all parts of the population. This is further aggravated by the environmental conditions in the Arctic, which may render the roll-out of innovative technologies more expensive and complex. The excessive cost of building and maintaining infrastructure in these areas, combined with a relatively small customer base, may hamper development.

Nevertheless, similar to the Faroe Islands, 5G technology in Greenland could offer several benefits, especially in ease of access to healthcare services through telemedicine and increased opportunities for remote work and education.

4.11 Åland

Overview key findings

Commercial Operators	Vendor Collaboration	Band & Year of Allocation
Elisa Oyj	Nokia, Ericsson, Huawei	- 723 / 768 - 778 MHz, 2017 - 3.54-3.67GHz, 2018 and in Åland: 3.54-3.64GHz, 2020 - 25.1 - 25.9 GHz, 2020
Telia Finland Oyj	Nokia, Ericsson, Huawei	- 733 / 778 - 788 MHz, 2017 - 3.41-3.54GHz, 2018 and in Åland: 3.41-3.51GHz 2020 - 25,9 - 26,7 GHz, 2020
DNA Oyj (Telenor)	Nokia, Ericsson, Huawei	- 703 - 713 / 758 - 768 MHz, 2017 - 3.67-3.8GHz, 2018 - 26.7 - 27.5 GHz, 2020
Ålcom (only Åland)	Ericsson	- 3.7-3.8 GHz, 2018

Table 38: Overview of key findings on Finland and Åland.
Sources: Ålcom, 2022; Traficom, 2023. 5G Data Hub

Overview commercial network roll-out and coverage
Åland is an autonomous region of Finland. In December 2022, Ålcom launched its 5G service to all its customers, starting in the capital of Mariehamn. Coverage is planned to expand over the coming years, reaching complete overall population coverage by 2025 (Sjöblom & Karlsson, 2022).

Spectrum allocation and auctions
In 2020, Ålcom, Elisa and Telia Finland were each granted a license in the 3.5 GHz band. This did not take place through an auction as in the other countries but by direct allocation from the Finnish Government to the three providers, two of whom had already emerged successful from the Finnish 5G auction in the 3.5 GHz band in 2018 (Ministry of Transport and Communications, 2020). The allocation of the 700 MHz band is planned to take place in the near future (Ålcom, 2022).

	Vendor collaboration	Roll-out status
Ålcom (Ålands Telekommunikation)	Ericsson	Launched 5G network in Mariehamn in December 2022. In 2023, coverage will be expanded to areas around Åland's capital, eventually including all the islands by 2025.
Elisa	Ericsson	No relevant information could be identified.
Telia	Nokia	In October 2022, Telia received criticism for not having progressed with its 5G roll-out on Åland despite having been granted a network concession by the Finnish government in 2020. According to Telia, the necessary infrastructure to expand its high-speed network in the middle bands was lacking on the islands.

Table 39: Commercial 5G roll-out and status by operator.
Sources: Ågren, 2022; Ålcom, 2022.

Testbeds, innovation hubs and networks
No relevant information could be identified.

5G verticals and use cases
For further information on 5G verticals, please see the section on Finland earlier in this report, as data on use cases from Åland was integrated there.

Challenges and strengths
Like other isolated territories, Åland stands to benefit greatly from 5G technology in areas such as innovation and sustainable socio-economic development. Access to healthcare services through telemedicine, increased opportunities for remote work, education and new tourism services are all sectors that could profit from 5G.

With an economy dominated by the maritime industry, 20% of local GDP (The Government of Åland, 2022), 5G technology can play a significant part in improving efficiency and productivity (e.g. autonomous shipping and smart Ports), as well as improving safety and environmental regulations adherence (real-time monitoring of air and water quality, noise pollution, and other environmental factors).

However, high investment costs, combined with a limited pool of specialised skills and expertise available on the islands, may prove a hindrance in 5G deployment.


5. 5G Outlook: the Nordic-Baltic Region

Overall, 180 5G activities (applications as well as testbeds and innovations hubs – Figure 16) were identified in the Nordic-Baltic region in this study. The list is not exhaustive but offers valuable insight into the Nordic-Baltic 5G ecosystem's status while identifying future market trends and remaining challenges and bottlenecks.

Contextualising the data on use cases and testbeds with status updates regarding current 5G roll-out and policy goals helps to understand better both the strengths as well as the obstacles specific to the Nordic-Baltic 5G ecosystem.

The challenges include (1) high infrastructure investment costs; (2) geographical limitations linked to the isolated character of some territories and remote rural areas in others; (3) an uneven 5G roll-out, (4) slow industrial uptake of 5G and (5) the need to carefully align regulatory framework on the deployment of 5G with the different stakeholders, including telecom operators, consumers, and government agencies.

As for the greatest strengths, (1) the Nordic-Baltic region is considered one of the most advanced regions in the world with a robust tradition and supportive environment for innovation, especially in the technology sector, and a strong education system that can supply a skilled workforce; (2) identifying diverse use cases across verticals such as the mobility and transport vertical as well as smart cities applications is now possible (3) emerging testbeds have a determining role, pushing for higher technology maturity and fostering the already existent practise of strong partnerships across government, industry, and academia, (4) there is a broader awareness of security and inclusion issues related to 5G usage; (5) there is a cognisance of the importance of Nordic-Baltic joint research/development/ co-operation as a means to accelerate the development of new applications, services, and business models towards the objective of remaining in the vanguard of 5G innovation.

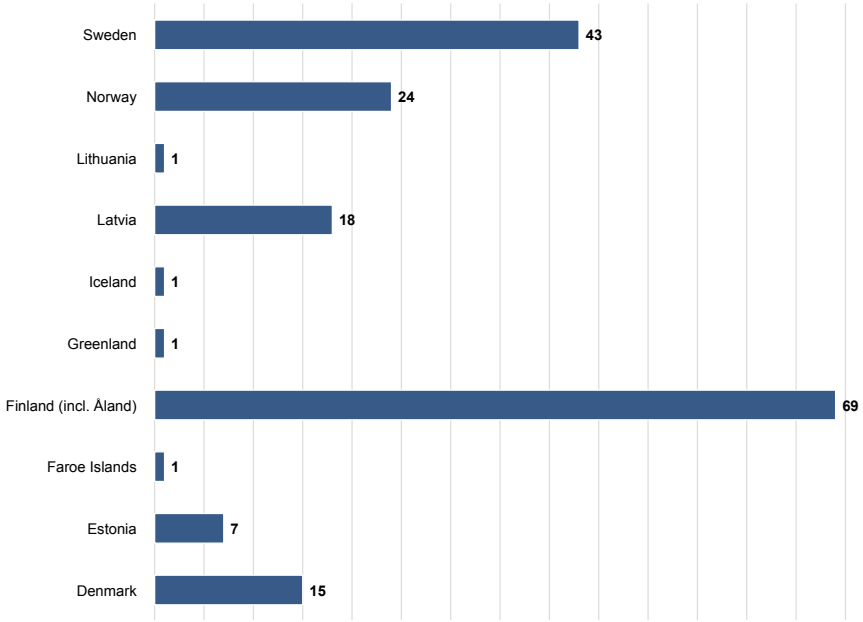


Figure 16: 5G activities across the Nordic-Baltic region.

Source: Data from the "Mapping 5G applications 2022 survey" (last updated 2022).

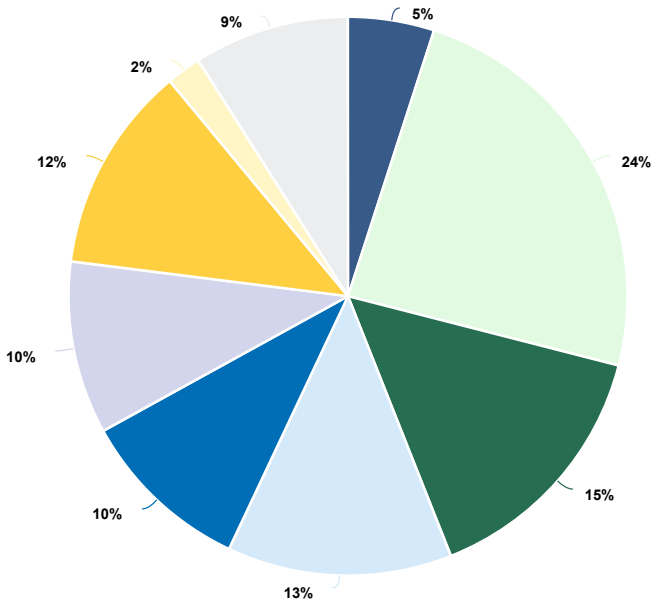


Figure 17: Overview of all 5G verticals across the region, multiple answers possible.

Source: Data from the "Mapping 5G applications 2022 survey" (last updated 2022).

- Media / Entertainment / Gaming
- Smart Cities
- Mission-Critical Communications / Defence
- Education / Health / Welfare Technology
- 5G R&D
- Transport / Mobility
- Advanced Automation / Manufactoring / Industry
- Energy / Environment / Agriculture / Aquaculture
- Other

5.1 Discussing the Obstacles

The uneven distribution of 5G activities across the region reflects the differences in the countries' 5G roll-out progress. While countries like Denmark and Finland are above the EU average in terms of 5G coverage, other countries such as Latvia, Estonia, Lithuania and Iceland find themselves still in the implementation and roll-out phase of 5G technology. The report further shows that these delays can be traced back to comparably slow spectrum allocations in some cases (see Figure 19), a lack of necessary infrastructure, as was the case for Åland, or more general accessibility challenges in rural areas, something that affected all countries surveyed here. Possible reasons for a delayed spectrum allocation and roll-out can be manifold. In Estonia, for example, a comprehensive regulatory debate on cybersecurity implications was a major factor in slowing the 5G roll-out in the country.

Additional factors affecting both roll-out and the industrial uptake of 5G in the region can be economic, political or structural in nature. While the data collected in the context of this study cannot offer an in-depth analysis of these factors, the insights presented in this report make it clear that the countries in the Nordic-Baltic region have pursued advances in the 5G sphere with varying levels of political commitment. Denmark, Finland, and Latvia can be named as examples of countries with a high degree of political investment in the technology, all having formulated 5G-specific policy goals and corresponding roadmaps. It could be argued that such approaches facilitate and foster the development of both 5G use cases and testbeds that benefit from the technology's innovative potential. The high number of Finnish 5G activities and the establishment of Europe's first 5G military testbed in Latvia can be named as two relevant examples in this regard.

Another factor exerting influence on 5G uptake is the prominence and maturity of different business sectors within a country, which in turn may accelerate engagement with and integration of 5G. As laid out in Section 2, Denmark, Finland, Norway, and Sweden are leading in terms of businesses using Artificial Intelligence or the Internet of Things. However, Lithuania and Latvia have also made great strides in this respect.

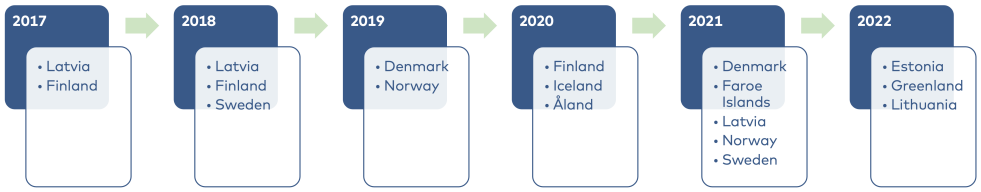


Figure 18: Overview of years in which countries concluded different 5G spectrum auctions.

5.2 Looking at the Opportunities

The landscape of 5G use cases in the Nordic-Baltic region is diverse and dynamic. Partnerships between research, industry and the public sector have led to the emergence of 5G-driven innovation projects, advancing novel solutions in different sectors ranging from more sustainable mobility to automation processes in manufacturing. Across the region, the vertical "mobility and transport" is prominent, with 78 identified 5G activities (see Figure 20). Many of the projects are not only cross-sectoral but also cross-border. An example here is the 5G-ROUTES project, involving Latvia, Estonia and Finland, promoting connected and automated mobility. The further advancement of 5G innovation will not only stimulate cross-regional co-operation but also enable a sustained approach to the challenges facing the region in areas such as sustainability and competitiveness, opening new opportunities and added value for business, employees as well as the environment. 5G's potential role in combating climate change has been subject to much debate in recent years. Some scholars have noted the predicted increase in energy demand brought about by an accelerated rollout of 5G across the globe (e.g. I. et al., 2020). It is estimated that Information and Communication Technologies (ICT) generate 2.1–3.9% of greenhouse gas emissions (Freitag et al., 2021). Others stress the positive impact that 5G-enabled smart management of resources may have on reducing society's carbon footprint by optimising usage, modelling needs and gaining a better understanding of environmental impacts (e.g. Huseien and Shah, 2021). The role of 5G in a just green transition is, therefore, a balancing act that needs thorough consideration of the potential impacts and contributions the technology can offer at an early stage of each development project. In this context, it also needs to be noted that most of the energy used and produced in the Nordic countries is today renewably sourced (Nordic Energy Research, 2021).

When examining the current development stage of Nordic-Baltic 5G applications, one finds that a considerable number are still in the testing and prototyping phase (45%), while only 6.7% have already been deployed or are currently in commercial use (see Figure 19). As experience and research in other technology sectors have shown, the establishment and continued political support for relevant testbed and innovation hub infrastructures is crucial for elevating the maturity level of emerging technologies. The availability and diversity of these structures give the region a competitive edge, helping not only local businesses and research entities to achieve progress in their 5G-related projects but also achieve higher technology maturity allowing for the deployment of their innovation. The success of Nordic-Baltic testbeds may also attract other partners from outside the region or foreign direct investment in the future.

The critical engagement that several of the challenges 5G roll-out has brought about should be highlighted. The extensive engagement with cybersecurity issues on Estonia's behalf highlights that there is both political awareness and technical expertise with regard to these. In times of intelligent connectivity, security weaknesses pose a fundamental threat to the functioning of our societies, affecting privacy and other individual freedoms, critical infrastructures, and the mundane operability of everyday services, from a smart lamp to online banking. While awareness of this topic was identified and is evident in the design of many of the identified 5G activities, a shared approach across the region could further reinforce the Nordic-Baltic cybersecurity agenda. Apart from security issues, challenges regarding equal access, particularly in the more sparsely populated areas of the

region, have come to the fore in the analysis of slowed or stagnating roll-out processes. While this points to unresolved inequalities along the urban-rural divide, it also highlights political and societal awareness of these issues and the need to address them in a timely manner.

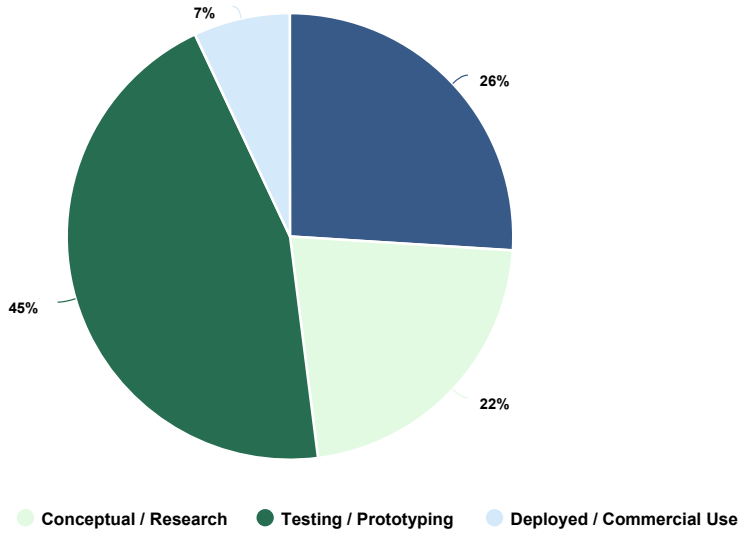
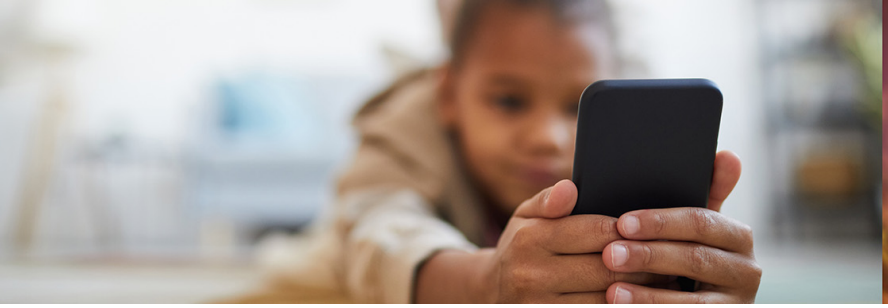
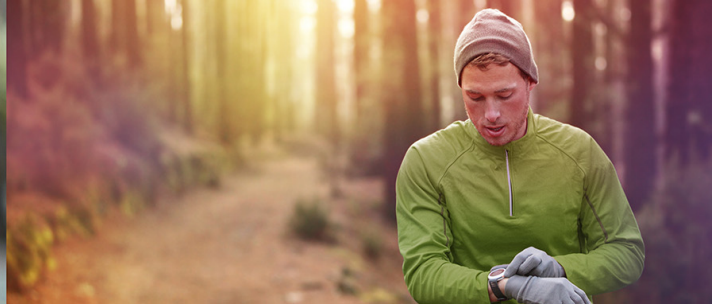


Figure 19: Development Stage of Nordic-Baltic 5G applications

Source: Data from the "Mapping 5G applications 2022 survey" (last updated 2022).

6. Conclusion

This report provides an overview of the current status of 5G roll-out and uptake in the Nordic-Baltic region. It highlights differences in roll-out progress and policy-based approaches and links these to data on 5G activities in the region, including both use cases as well as testbeds and innovation hubs. This contextualised presentation and the analysis of the project's findings allow for the identification of remaining challenges and particular strengths in the Nordic-Baltic ecosystem. The findings portray a substantial number of success stories in the form of innovative 5G-enabled solutions in verticals that will affect everyday life practices for large parts of the population in areas such as healthcare, transport, and energy. However, the analysis also highlights the need to harmonise policy approaches further to ensure equal access across the region, forming a basis for shared innovation projects, advanced integration through cooperation and equal opportunities and living standards for citizens in the Nordic-Baltic region.

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About this Publication

The Role of 5G in the Transition to a Digital and Green Economy in the Nordic and Baltic Countries: Analytic Report

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Nordregio report 2023:7

ISBN: 978-91-8001-067-2 (PDF))
ISBN: 978-91-8001-066-5 (ONLINE)
ISSN: 1403-2503 (PRINT)
ISSN: 1403-2503 (ONLINE)
http://doi.org/10.6027/R2023:7.1403-2503

Layout: Mette Agger Tang
Photos: iStock

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