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Do Not Reinvent the Wheel: A Checklist for Developing National 5G Strategies

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Abstract: Digital transformation is taking place across all levels of governance, from small businesses to governments. If the seed of digital transformation is data, then reliable connectivity is the nourishing soil that data need to prosper. With digital transformation, billions of connections require more broadband. In response to this need, some countries are preparing national 5G strategies, as 5G technology has been identified as a significant driver of the digital economy. In this study, 16 national 5G strategies have been systematically and comprehensively analyzed, and a checklist has been developed to formulate national 5G strategies and policies. The checklist can be used by policymakers, especially in developing countries, to guide the preparation of national 5G strategies and policies. Of course, each country's national strategy will differ regarding resources, culture, etc. It is hoped that this checklist may speed up the preparation process by providing a baseline during the strategy formulation phase and make the process more efficient by incorporating lessons learned, especially for developing countries.

Keywords: national strategy; 5G; national 5G strategy; strategic management; technology management



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1. Introduction

The fourth industrial revolution makes many sectors more competitive while contributing to the economy. The revolution requires an accelerated digital transformation, entailing emerging technologies, including the Internet of Things (IoT), augmented and virtual reality (AR/VR), robotics, cloud computing, and many more. The full potential of these technologies depends on connectivity [1]. Billions of information exchanges between machines and sensors are expected, requiring ever-increasing broadband. Since fifth-generation cellular network technology (5G) is the core infrastructure of the fourth industrial revolution [2], it can be inferred that the more 5G technology is generalized, the faster the revolution's effects will be. Compared to previous mobile communications technologies, 5G provides higher data rates, lower latency, and incredible connectivity, enabling the Internet of Things applications [3,4]. Aside from the manufacturing industry, particularly during the COVID-19 pandemic, countries have realized that online education, remote work models, and telemedicine are not long-term needs.

The importance of communication infrastructures for the sustainability of economic activities has become more evident, and connectivity to the Internet is necessary [5–7]. Institutions and organizations are trying new ways to run their operations smoothly; some have courageously tried out-of-the-box solutions using 5G technologies [8,9]. Today's connectivity requirements, and those of the future, will depend on developing the 5G infrastructure, as it provides broader bandwidth with reduced latency, thereby enabling connectivity among more devices than ever [10]. In this regard, 5G can accelerate national economic growth, but it requires comprehensive planning considering the positive and negative consequences of 5G technologies. Some countries have begun this comprehensive planning, and some are implementing their plans.

Especially after 2014, 5G-related research has gradually increased, but almost all of these studies focus on the technical aspects of 5G [11]. Although there are some studies in the literature about national 5G strategies, they mainly focus on individual countries. Reviews of multiple national strategies are limited, and few studies specifically focus on developing countries (details will be presented in part 2.2. of the article). In deploying 5G technologies, clarifying the strategic direction and country policy is as essential as meeting the technical requirements. Considering the crucial and catalytic role of 5G in the fourth industrial revolution and the need to help countries implement better strategies, this paper examined the employed strategies. This examination aims to (i) present shared or differing approaches to 5G strategies, (ii) provide policymakers and decision-makers with 5G strategy benchmarks, and (iii) provide recommendations for strategies to be developed or updated.

Therefore, the research questions that guide our research are as follows:

- What policy areas are prioritized in national 5G strategies?
- Is it possible to create a list of issues that need to be addressed in national 5G strategies? Can policymakers (especially in developing countries) be supported in this way?

The structure of this paper, which aims to help policymakers design 5G strategies to develop technological products and services, is outlined as follows. Section 2 provides the conceptual framework, encompassing the literature review and methodology. Sections 3 and 4 delve into the data analysis, findings, and discussions. Finally, Section 5 presents the conclusions and future research directions.

2. Conceptual Framework

2.1. Fifth-Generation Cellular Network Technology

2.1.1. Development and Concept of 5G

Radio access technologies have addressed the communication needs of different generations via diverse improvements over history. Here, 5G is the fifth generation of cellular network technology. The first generation represents the transmission of analog voices, while the second generation represents the shift from analog to digital and data transmission in formats such as voice and SMS. In the third generation, data transmission sped up, and the ecosystem first experienced mobile broadband [12]. As the volume of data to be transferred increased, fourth-generation radio access technologies became more widespread [13]. For instance, the number of cellular IoT connections, 1.6 billion in 2020, is expected to reach 5.4 billion in 2026 with a compound annual growth rate (CAGR) of 23% [14].

Fifth-generation cellular network technology is a game-changer. It enables more connected devices at a higher speed, with less latency and energy consumption. It is a software-intensive connection technology accessed by adding new hardware and a frequency band [15]. It also provides machine–machine and machine–person communication services in addition to interpersonal communication.

In 2019, 52% of all connections were 4G, 23% 2G, and 25% 3G. However, this distribution is expected to change by 2025 to 56.6% for 4G, 20.2% for 5G, 18.2% for 3G, and 0.1% for 2G [16]. Although the share of 5G will increase considerably soon, it will become an integrated configuration with 4G. Thus, the complementary positioning of 4G and 5G is critical for an efficient 5G ecosystem [17].

2.1.2. Components and Distinct Features of 5G

Now, 5G is defined by international organizations as a set of standardized features recognized by the ITU (International Telecommunication Union) under the Third-Generation Partnership Project (3GPP); 3GPP is an umbrella term for several standard organizations that develop protocols for mobile telecommunications [18]. Fifth-generation cellular network technology consists of “advanced mobile broadband (eMBB)”, “massive machine-type communication (mMTC)”, and “ultra-reliable and low-latency communication (URLLC)”. eMBB is utilized for applications like video streaming and augmented reality, which de-

mand high data throughput. mMTC is employed for smart city and IoT applications, necessitating low data rates and energy consumption across numerous devices. Meanwhile, URLLC is deployed in critical applications like self-driving cars, where high reliability and low latency are paramount [19]. With these components, the speed capacity of 4G is 1 Gbps compared to 20 Gbps for 5G. The connection latency is 10 milliseconds (ms) in 4G compared to 1 ms in 5G, which means that while 4G can support 100,000 connections per Km², 5G can support one million low-speed connections [20]. These improvements will foster the development and adoption of new products and services, which can contribute significantly to the efficiencies of various sectors and the growth of digital economies.

There are three new significant components of 5G that 4G cannot offer. These new 5G components meet the requirements of diverse application types and increase the efficiency and productivity of vertical industries. To meet the growth of the digital economy globally, 5G was designed. Fifth-generation technologies that offer advantages over 4G are network functions virtualization (NFV), software-defined networking (SDN), and network slicing, which is a method of creating multiple unique logical and virtualized networks over a single multi-domain infrastructure [13,21–23]. Other beneficial 5G technologies include millimeter waves for speed and bandwidth, small cells to accelerate distribution and increase speed, massive multiple-input and multiple-output (MIMO) to increase capacity, and beamforming technologies to improve spectrum efficiency and user experience [23–25]. In short, 5G technologies are revolutionary as they transform vertical industries when utilized in conjunction with 4G networks [26]. On the other hand, there are significant challenges for 5G deployment, such as infrastructure investments, network security, standards, regulations, sustainability cybersecurity, etc. [11,27].

2.1.3. Fifth-Generation Cellular Network Technology and Verticals

Fifth-generation cellular network technology will contribute to enabling digital economy growth with diverse applications in vertical sectors by providing some requirements in terms of latency, bandwidth, and reliability [28]. Since a reliable, high-speed, and up-to-date network infrastructure is a critical requirement for digital economy growth [29], countries that seek the immediate benefits of 5G opportunities in vertical industries must rapidly make trials in vertical industries that meet the needs of today and are adaptable to the needs of tomorrow. As of March 2021, 258 trials had been conducted in 31 countries, 81% of which were European Union (EU) Member States and the UK. Others were conducted in Russia, San Marino, Norway, Turkey, and Switzerland. Most of these vertical industry applications were in media and entertainment, transportation, and the automotive industry [30]. There are different requirements for the various vertical industries. In this context, 5G technologies will have different effects with diverse use cases in sectors such as industry, mobility, smart cities, media and entertainment, health, education, and agriculture. Table 1 summarizes 5G use case applications that can be utilized in relevant sectors and their potential impact upon adoption.

Table 1. Technologies in verticals and their implications [1,31–34].

Verticals	Use Cases	Implications
Industry	Enhanced predictive maintenance, remote maintenance, smart factory, digital twins, cyber-physical systems, M2M communication	Safer human–robot collaboration and more flexible, efficient, safe production
Mobility	Vehicles, roads, infrastructure, lights, etc. that are connected with one other, autonomous vehicles, smart traffic management, logistics management	Reduction of traffic accidents, better driving safety and control, emission reduction, smart traffic management, more controllable supply chain operations
Smart Cities	Smart environmental applications, smart waste management, smart energy management	More effective disaster mitigation, more efficient resource utilization, better waste management

Table 1. Cont.

Verticals	Use Cases	Implications
Media and Entertainment	Online AR/VR games, voice communication with avatars, ultra-high-definition (resolution) contents	Faster and higher quality content delivery, improved user experience
Health	5G-connected ambulances, remote diagnostics, remote surgery (tele-surgery), industrial robotics applications	More efficient critical healthcare services to remote locations, improving effective diagnostics and patient care, better senior and home care processes
Education	Education and training with customized content, virtual classrooms offered with virtual reality and augmented reality	More versatile learning models (tactile, exploratory learning, remote, etc.)
Agriculture and Environment	Data collection of soil moisture, fertilizer level, disease status, and pest control requirements with IoT and remote intervention	Reducing greenhouse gases, higher quality agricultural production, and sustainable resource management

2.1.4. Fifth-Generation Cellular Network Technology Ecosystem

To achieve the full benefits of 5G technologies, multiple stakeholders must coordinate and cooperate to accelerate the adoption of those technologies. The ecosystem includes several stakeholders, including the government, which makes the regulations and tenders; the operators who supply the service; the technology suppliers who develop the technology; and the firms and individuals that utilize those technologies. Fifth-generation technologies are expected to have disruptive effects, especially in digital transformations for companies, regulations for governments, and business models for operators [3]. The positive and negative consequences of 5G technologies will differ for each party, as shown in Table 2. Investment costs pose significant uncertainty for both MNOs and technology suppliers, while governments face the challenge of regulating and determining appropriate revenues. However, 5G offers MNOs new business opportunities, provides technology suppliers with opportunities for technology development, and presents governments with opportunities for technological advancement and strengthening the digital economy. Technology users, on the other hand, improve customer experiences by bearing service costs and have the opportunity to see the benefits of use cases.

Table 2. The positive and negative consequences of 5G for ecosystem stakeholders [3,17,35–37].

Positive Benefit/Advantages	Stakeholders and Their Roles	Negative Outcomes/Obstacle
✓ Potential to be a leader in what? ✓ Local development of products and services ✓ Frequent auction revenues ✓ Increased contributions to GDP ✓ Stronger digital economy	Government Coordinate and Organize 5G Initiatives	✓ Risk of cybersecurity failures ✓ Risk adversity of Mobile Network Operators (MNO) ✓ Prohibitive costs ✓ Prohibitive technical complexity ✓ Ambiguous regulations
✓ Access to new service areas ✓ Access to new customers ✓ Access to new connected devices	The Mobile Network Operators (MNOs) Service Delivery	✓ Multiple uncertainties about the ecosystem ✓ Prohibitive infrastructure costs ✓ Challenges of a dense deployment infrastructure ✓ Uncertainties regarding return on investment, asset costs ✓ Private 5G operators ✓ Uncertainty regarding demand for services ✓ Prohibitive technical complexity

Table 2. Cont.

Positive Benefit/Advantages	Stakeholders and Their Roles	Negative Outcomes/Obstacle
✓ Improved user experience ✓ Better process management	Technology Users Use of Services	✓ Prohibitive service usage costs ✓ Uncertainty regarding demand for services ✓ Difficulty timing investments
✓ Creation of new production areas ✓ Improved competitive advantage	Technology Suppliers Production of Technologies	✓ Prohibitive investment costs

The 5G applications, which typically start with early government investments [17], are disseminated through additional investments of operators, spectrum allocations, and the presentation of solutions suitable for industry needs. Private sector investments increase by establishing a regulatory environment and increased demand by sectors and users. In short, achieving the potential benefits of 5G requires the cooperation and collaboration of many parties focused on defined strategic priorities. On the other hand, it is also stated that the ecosystem is cautious about 5G technologies due to the immaturity of the 5G market and many uncertainties [38].

2.2. Why Are National 5G Strategies Necessary?

Porter states, “National prosperity is created, not inherited.” in his “The Competitive Advantage of Nations” study. He specifies that the most effective way for countries to do this is by determining and implementing strategies to create a competitive advantage. Evaluating countries’ competitiveness by comparing their industries’ innovation rate to their technological developments and examining their relation with technological infrastructure is critical to understanding where a country stands and how to improve its competitiveness in the future [39]. Therefore, developing and implementing strategies for all domains of developing technologies, such as national 5G strategies, are prioritized for countries. Bauer stated that technology policies should be reconsidered to make investments in the right direction and to increase innovation throughout the country [40].

Therefore, 5G can catalyze innovation by enabling billions of devices to connect instantly on a high-powered infrastructure [41], offering citizens a more prosperous, intelligent, and comfortable life and new work opportunities. It will create a new generation in wireless communication and become the primary technological key to the digital transformation of developed societies and economies [42]. Therefore, countries are designing plans for 5G deployment to contribute to developing their economies and advancing in global competition. However, it is vital that these strategies come in the form of long-term national-level planning. In this regard, the current national and international landscapes can be thoroughly analyzed, and strategies can be developed according to each country’s opportunities and strengths. One of the essential considerations in building strategies is to consider any lessons learned. Understanding how different applications work under other conditions will help minimize potential cost losses when implementing a strategy and ensure the process is carried out efficiently. As a result, these new opportunities may be capitalized upon in the best way, as seen in Japan and Korea [43]. This study aims to provide valuable insights for countries developing their 5G strategies by presenting lessons learned and a comprehensive checklist.

The literature contains numerous studies examining country-based 5G policies and strategies. South Korea, a leader in 5G technology, is among the most extensively studied countries [27]. This success has been achieved with users’ positive attitudes towards 5G and MNOs’ strategic approaches to the issue [44,45]. Mostly, commitment and the robust and consistent role of the Korean government unite the ecosystem, encourage doing business together (companies, institutes, MNOs, academia, etc.), and support R&D [44,46–48]. The articles examining China’s 5G policies are more about the importance of user-oriented [49] and mission-oriented [50] strategies and the impact of policies, especially on operators’

firm value [38]. The European Union's 5G policy reviews generally argue context [51], leadership vs. non-proactive roles of the EU [4,48], and 5G-related innovation policies [52]. In addition to examining country-based 5G policies in the literature, multiple national strategies are also examined, albeit to a limited extent. Regarding 5G policies, Forge and Vu conducted an extensive study on developing countries by examining five countries, and India's strategies were also examined [17,53]. In this study, we increase the number of countries whose national 5G strategy is examined, and the recommendations are presented holistically as a checklist.

2.3. Methodology and Review of Selected National 5G Strategies

This research is exploratory. It employs an exploratory approach and utilizes document analysis, a qualitative research method that follows systematic stages, including document identification, cataloging, and subsequent data analysis [54]. The primary source for collecting detailed information on national 5G strategies was the official websites of government institutions in respective countries. Mostly, these websites contain summaries of national 5G strategies, and the documents are readily available for download. National 5G strategy documents from 16 countries were accessible, and analyses were conducted based on these documents. The properties of these reports are outlined in Table A1, which includes data such as Country, Name of Strategy/Policy, Year of publishing, Government institution, and Vision statement or Strategic objectives. This paper aims to address the questions posed in the introduction section through an analysis of these documents.

When examining the strategy documents of 16 countries, it became apparent that these countries could be categorized into three distinct groups. According to the "Economies by per capita GNI", only India is in the Lower-Middle Income category and developing country. All other countries in categories 1, 2, and 3 are developed countries in the high-income category [55,56]. Consequently, instead of conducting individual assessments for each country, the focus shifted towards making broader comments, inferences, and evaluations based on these categories. The categorization was established by considering the G7 and G20 countries, representing most of the world's largest economies.

The first category involved examining countries within the G7 that had strategy documents (South Korea was included in this category due to its prominence in 5G research, and the EU was included due to the increase in the data set and for its importance). Therefore, the USA, South Korea, Germany, France, the United Kingdom, and the EU were included in this category. These countries' strategies will benefit developing countries in terms of lessons learned [17]. Furthermore, it is necessary to understand the strategies of these countries to ascertain areas that can create a competitive edge for other countries [17].

The second category encompassed Australia, India, and Spain within the G20 or those participating in discussions as guests. Thus, Category 1 countries have the opportunity to experience 5G before others. Therefore, the reason for choosing Category 2 countries is to understand the path followed by countries with large economies that are not in Category 1 yet have dedicated 5G strategies.

Finally, other countries with national 5G Strategies, which are Austria, Hungary, Denmark, Luxembourg, Netherlands, Finland, and Singapore, were classified under category 3. The reason for including these countries in this study is to highlight how nations with fewer resources approach the issue, providing inspiration for developing countries. To clarify some areas of focus, it is helpful to understand Category 1 countries' 5G strategies, benchmark the practices of other countries, and review the considerations in developing 5G strategies for all reviewed countries. Rather than jumping into the implementation of disjointed 5G infrastructure strengthening actions, it is recommended that countries take an analytical look at how both leading countries in 5G technologies and other countries with fewer resources to invest have developed and implemented their national 5G strategies. These lessons learned from global and national experiences can accelerate the development of more achievable strategies [17]. This study offers a benchmarking opportunity and a summary of the experiences of countries leading in 5G technologies.

While our examination focuses on countries that have published their national 5G strategies, it is essential to note that the absence of such a strategy in a country does not necessarily indicate a lack of 5G-related initiatives or efforts being undertaken. For example, Italy has been the leading country in completing procedures for the transition to 5G, allocating top bands and starting trials [57]. Canada supports the development of testing environments where large companies such as Ericsson and IBM Canada are in charge of developing 5G technologies and applications, with small companies, academics, and NGOs participating [58].

Although China and Japan have not published their national 5G strategies, it is necessary to make a separate note of their efforts and initiatives related to 5G. China's strategy for 5G is included in "The 13th Five-Year Plan for Economic and Social Development of The People's Republic of China". It addresses 5G in the "strategic emerging industry" category [59]. China's strategy prioritizes such noteworthy issues as strengthening research in essential technologies required for 5G mobile networks and ultra-broadband applications, increasing commercial applications of 5G technology, and systems' cyber security. The 5G trials in vertical industries were carried out by the IMT-2020 (5G) promotion group, founded in 2013 by the Chinese Ministry of Industry and Information Technology, the National Development and Reform Commission, and the Ministry of Science and Technology [60]. Japan found the expansion of fiber optics to be an essential strategic advantage for 5G. The 5G trials are conducted with the participation of many stakeholders, including various operators, led by the Ministry of Internal Affairs and Communications (MIC) [61]. Similarly, many other countries have no 5G-related strategy, but this should not imply that there are no 5G initiatives in those countries. For example, a strategy document for 5G and beyond technologies is being developed in Turkey, and work is progressing with a non-profit structure called the 5GTR Forum, which includes participation by operators, companies, and academia. In addition, test environments are offered for 5G trials in Turkey [62].

3. Findings and Lessons Learned

In this study, the strategic frameworks within national 5G strategy documents have been examined. The strategic framework reviews comprise introductory information (identity tag), strategic vision, the strategy's structure (priority areas or pillars), and the objectives and strategies themselves [63].

3.1. Introductory Information (Identity Tag)

In general, the studies on strategies were completed in Category 1 and 2 countries between 2016–2018 and in Category 3 countries between 2017–2019, and strategies were developed by government authorities that conducted digital transformation, technology, communication, and innovation studies in their countries [2,42,57,64–76].

3.2. Vision Statements

Vision statements are expressions that contain the reasons for their existence in general, paint an inspiring picture of the future, and direct stakeholders to work toward the vision and create passion for it. The vision statements of Category 1 countries generally focus on striving to bring their country to the forefront (Table A1). More specifically, in these countries, phrases such as "the best in the world" [2], "Superiority" [64], "a lead market" [65], and "global leader" [68] are included in the vision statements. This is unsurprising given their current status and the size of the 5G investments in these countries.

The vision statements of Category 2 countries, on the other hand, seem to be built on competition with phrases such as being among the most advanced countries in developing 5G technologies [42], being an important innovator and technology supplier at the global level [70], and being at the forefront of benefiting from 5G across the economy [69].

In Category 3 countries, vision statements are designed as targets for global or regional impact. For example, on a global scale, the Australian Government Department of Communications and the Arts and Digitaliz aims to become a 5G leader in Europe [69,72]. Within a

regional context, some focus on domestic impacts within the country, such as the Danish Energy Agency and The Ministry of State Department of Media Telecommunications and Digital Policy aiming to provide the best conditions for citizens, businesses, and the public sector to use 5G [67,73].

3.3. Priority Areas—Pillars

Each national 5G strategy involves many components with unique goals and strategies. Structured strategies, built around focus areas (or pillars), provide a holistic perspective of how the components come together and make the strategic objectives easier to understand. Many countries have developed their strategies in this way.

In nearly all countries' documents, pillars related to the technical requirements of 5G, such as regulation, infrastructure, and spectrum, along with those associated with the demonstration of 5G technology through use cases, are highlighted. It can be said that this emphasis on pillar dimensions is more pronounced in the second and third category groups. Different countries from different categories have addressed aspects related to the development of the national ecosystem, such as talent development, governance, investment, and foundation. Additionally, emphasis on the international ecosystem is observed in some countries of the first and second categories (see Table 3) [2,42,57,64–76]. The pillars in this review are categorized as “regulations and spectrum management”, “infrastructure”, “5G and verticals”, “national ecosystem”, and “international collaborations and standardization”. In Section 3.4, goals and strategies are presented under these categories.

Table 3. Summary of priority areas (pillars) in national 5G Strategies.

Section Mapping	Priority Areas	Category 1					Category 2					Category 3					
		USA	South Korea	Germany	France	United Kingdom	EU	Australia	India	Spain	Austria	Hungary	Denmark	Luxembourg	Netherland	Finland	Singapore
Section 3.4.1.	Regulations	✓				✓		✓	✓	✓		✓	✓	✓	✓	✓	✓
	Spectrum	✓		✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Section 3.4.2.	Infrastructure	✓		✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓		
Section 3.4.3.	Use Cases			✓	✓		✓		✓	✓	✓	✓	✓	✓	✓	✓	✓
Section 3.4.4.	Acceptance, Talent Development								✓			✓					✓
	Governance& Cooperation			✓	✓	✓				✓		✓		✓	✓	✓	
	Foundation		✓														✓
	Institutional Improvements		✓														
	Investment		✓													✓	
Section 3.4.5.	International Collaborations, Standards			✓		✓	✓		✓	✓							
	Overseas Expansion		✓														

The ✓ symbol denotes the presence of the respective priority area in the specified countries 5G strategy.

3.4. Goals and Strategies

The goals and strategies specified in the national 5G strategy documents are exhaustively discussed in this section. The following findings were obtained by examining goals and strategies according to groups of countries.

3.4.1. Regulations and Spectrum Management

Regulation and spectrum are defined by Sgora as essential pieces of the 5G puzzle [77]. The timely deployment of 5G and regulations are prerequisites for increasing technological diffusion and for maximizing the benefit of 5G to the economy at the national level [53,77]. At this point, countries face spectrum allocation, which contains amount, band type, usage scenarios, pricing models, and regulations about facilitating technologies, encouraging facilitating 5G investments via tax advantages and supports. In other words, the speed, accessibility, and quality of 5G services depend on policies and regulations that facilitate timely access to the appropriate amount and type of affordable spectrum under proper conditions. Variations in the quantity of the spectrum allocated and the prices drive the potential to differentiate 5G services between countries and directly impact the competitiveness of national economies [78]. Therefore, frequency allocation methods, the license period, and pricing should be conducted suitably [79]. Measures must be taken to ensure the most efficient spectrum use backed by regulations. The other critical point is the governments' views on earning money from 5G, such as frequency fees [17,45]. Although governments in previous generations may have earned income through tenders, this should not be expected in 5G investments. It is vital to handle the government's spectrum licensing regime.

When the national 5G strategies were examined, it was seen that all strategy documents included spectrum management-related targets. These spectrum policies are related to pushing into the marketplace [64], harmonizing at the global level [71,75], determining pioneer spectrum bands [57], and spectrum sharing models [67].

Many national 5G strategies include the development of regulations to disseminate 5G technology utilization. The primary purpose of the regulatory goals in almost all countries is to establish flexible, low administrative burdens and predictable regulatory frameworks that are most suitable for 5G and will support these technologies most effectively [71,74]. These regulations should also provide the test frequencies for the spread of 5G pilot applications and reduce uncertainty to investment [66,73].

Another crucial issue stated in the national 5G strategies is that fees for using frequencies are low to encourage investments and spread use cases [67]. Although governments in previous generations may have earned income through tenders, this should not be expected in 5G investments [72,78]. Small cell usage, spectrum sharing, network slicing, and cybersecurity are other issues related to regulations mentioned in national 5G strategies [42,57,66,70,73–75].

Although private 5G networks are an essential important issue, they have not been included in national strategies except for a few countries [42,57,66,70,73–75]. Despite that, the private networks sector, which has the highest growth rate in the telecommunications sector, is projected to reach USD 60 billion by 2025 [80]. With private networks, the network provider can be a cellular operator or the corporate customer itself. Private 5G networks are expected to be pivotal in developing the 5G ecosystem [17]. Private 5G networks are currently available in countries such as Belgium, China, Finland, Germany, Spain, Taiwan, and Japan [81].

3.4.2. Infrastructure

GSMA summarized the necessity of infrastructure investments as a vicious circle: no infrastructure, no use case innovation, and no monetization potential [82]. The 5G technologies require intensive infrastructure investment, with a heterogeneous technology environment such as networks, small cells, devices, etc. [37]. Although it has been demonstrated that infrastructure costs have decreased significantly with software-defined networks (SDNs) with network function virtualization (NFV) [83], it is a fact that it still requires intensive infrastructure investments. On the other hand, infrastructure investments are a prerequisite for implementing use cases for the vertical sector and developing innovation and technological products and services. Hence, the scale economy approach should be internalized for network infrastructure [37]. Although some MNOs are willing to invest in 5G, they are cautious about investment due to their decreasing income and

belief that they have not yet received returns on their investments in 4G [37,45]. Therefore, strategies to encourage operator investments are indispensable.

The expansion of fiber optic networks is considered to play a vital role in developing 5G technologies [57,72]. Additionally, the development of fiber optical networks is strongly related to 5G technologies [84]. In addition to making infrastructure investments for 5G technologies and expanding fiber optic networks, preparing environments that will facilitate technology development is an issue that needs to be considered in infrastructure. For instance, regulatory sandbox applications can be an example because technology developers seek to create technologies and spend their resources effectively. Sometimes, regulatory change can obstruct efficiency. On the other hand, the government tends to follow improvements for regulations, which is generally in the role of following. An experimental regulation zone (regulatory sandboxes) may help boost the manufacturing of technological products and services [85].

3.4.3. Verticals and 5G

Through the utilization of vertical industry applications, countries aim to see the potential gains of 5G technology for various sectors by providing economies of scale, comprehending their specific needs, and adeptly strategizing resource planning. These applications are crucial for assessing the required bandwidth and quantity, planning investments accordingly [69], understanding business plans that vary by sector [70], and comprehending dynamics before extending to other verticals. Additionally, these trials facilitate the enhancement of awareness among potential stakeholders. The fifth-generation networks, in addition to the first four generations of wireless networks, support the transition of vertical industries to the digital realm. These applications also provide the opportunity to compare the advantages of technologies such as 4G, LTE, and 5G. In summary, use cases enable us to operate with a “learn-as-we-go” approach [70] and harbor significant potential for fostering innovation.

Trials are typically conducted to advance developments such as creating immersive content, smart factories, autonomous vehicles, smart cities, and digital healthcare. Countries are improving their capabilities in V2X, connected robots, drones, wearable devices, VR, AR devices, and edge computing through these enhancements.

Countries are implementing vertical sector applications through various projects. For instance, France has executed use cases with the participation of an international stakeholder (UTAC CERAM), providing test services for the automotive industry and involving operators (Orange and Bouygues Telecom) to develop applications such as mobile data transfer, information provision, entertainment, team building, and extended sensors [66]. Details about the vertical sector applications implemented by countries are available; however, deductions are presented instead of providing these details. Firstly, vertical industry applications are selected in line with strategic priorities, and countries’ use cases may differ. When examining countries’ 5G strategies, it is observed that the focused sectors in vertical sector applications are generally in the areas of Industry 4.0, mobility, health, and smart cities [2,57,71,72]. Also, there are different prioritizations, e.g., using robots in South Korea, media and immersive content in France, banking and railways in India, tourism in Spain, energy in Germany, autonomous maritime transport in Finland, etc. Selected use cases should be tested with eMBB, mMTC, and uRLLC. The location, scope, and duration of trials should be determined based on their purpose. Partnerships (local partnerships, MNOs, etc.) should be established for trials, bringing together local authorities, operators, equipment suppliers, vertical sector stakeholders, and start-ups. Relevant data should be collected during the trial period, and financial support mechanisms supporting trials should be defined.

Technology development firms seek to create technologies, but they also want to spend their resources effectively in a field that is highly subject to regulatory change. Conversely, the government typically emphasizes manufacturing technological products and services in the relevant field, which tends to follow regulatory developments. As a solution, an

experimental regulation zone may be useful to boost the manufacturing of technological products and services, and 5G technologies are capital-intensive technologies. Enterprise-level investments in this industry to create new goods will be very costly. Therefore, it is vital to establish shared working areas and test vertical industry applications. For precisely these reasons, countries have prioritized regulatory sandbox applications. For instance, financial guidelines for Digital Test Beds for Automated and Connected Driving have been published in Germany, supporting technology testing in urban test beds. Austria has implemented the “Austria Creating 5G Test Beds and Sandboxes” application [65].

3.4.4. National Ecosystem

The somewhat socialization of 5G technologies, characterized by their highly technical and complex features and substantial investment requirements, can be assumed as one of the primary prerequisites for their adoption. Although vertical industries use cases serve this purpose, they are not sufficient. Countries aware of this reality have identified the “national ecosystem” dimension in their strategies and have set various goals for establishing an ecosystem that involves government, private sector, academia, technology users, infrastructure providers, and end users [53].

Countries often establish various working groups, committees, or forums to formulate strategies, conduct work, or organize efforts to develop a national ecosystem. Examples of such environments include the “5G Strategy Committee” in South Korea [2], the “5G Dialogue Forum” in Germany [65], the “Communications Challenge Group” in the UK [74,86], the “5GPP” in the European Union [57], and the “5G High-Level Forum” in India [70].

At this level, the goal of enhancing awareness frequently emerges. Countries have set various objectives to increase 5G awareness among the public and within industries. Typically, the aim is to raise awareness by implementing these technologies in public services. Services provided by the government, such as municipal services [66,68], public administration [71], and healthcare services in public areas prone to improvement (5G+ Live Projects) [2], are intended to be supported by 5G technologies. In summary, the expansion of applications in the public sector is a chosen strategy for spreading 5G applications [64,66,87].

National strategies exist to maximize awareness, such as organizing conferences (Future Industrial Communication) [65], hosting global events [70], conducting workshops for announcing best practices [73], and creating websites (The Laajakaistainfo.fi) [75]. National strategies also involve organized competitions [2,71] and award ceremonies [73] to contribute to visibility and, particularly, to encourage young individuals. In addition to raising awareness, strategies exist to elevate awareness to a capacity-building level in certain groups (such as youth, employees, etc.). Initiatives include providing education for “Digital gap reduction”, establishing master’s programs [2], intensive capacity development programs for workforce enhancement, and preparing young individuals for digital jobs [73,76]. Moreover, specific examples include establishing theme parks for 5G technologies, implementing AR-supported applications, and conducting interactive concerts [2].

While strategies to increase awareness at the “national ecosystem” level are essential, the emphasis lies in creating environments that foster collaboration among ecosystem stakeholders. It is assumed that this will lead to advantages in technology development. Various structures, such as establishing “Plattform for 5G” and “Agency for Digitalization”, have been implemented. Corresponding strategies have been adopted [64,71,76] for parties to establish win–win collaborations [2], enhance technology development, and increase academic collaborations [65]. In particular, collaborations have been encouraged in areas such as equipment production, new space activities, satellites, and 5G and Beyond Technologies [68,71,73]. Incentive mechanisms are generally supported by financial tools, and various funds supporting these initiatives have been established [57,66,68,72]. Academic studies also emphasize the importance of creating funds to support R&D efforts [66,68]. The most notable example is the formation of the 5G PPP, which aims to increase R&D activities in 5G technologies, foster collaborations, and support projects within this framework. It is

a joint initiative of the European Commission and communications technology industries created for 5G research [57].

All these implementations aim to increase visibility, enhance collaborations, and particularly encourage the adoption of business models that contribute to the productivity of SMEs [2,64,66].

3.4.5. International Collaborations and Standardization

Global collaborations and common standards are crucial for the compatibility and interoperability of technologies. They help to clarify the need for technology regulation and make international trade easier. Participation in standard studies with patent pools is essential. By increasing the patents based on the standards, countries may expect increased revenues from license fees. If patents obtained through technology development are included in the standards, the patents become standard essential patents (SEPs). Thus, those who want to produce products in accordance with the standards can produce products with a license. Therefore, active participation in the standard development process and forming expert groups on this subject are also priorities for countries [76]. Teece also mentions the importance of patent ownership in technological leadership, so determining strategies for SEPs may be useful [86]. In addition, global competition and cooperation strategies are significant for national strategies [27]. Strategies related to participation in standardization efforts are generally prioritized in Category 1 and 2 countries [2,71].

4. Discussion: A Recommended National 5G Strategy Development Checklist

When the findings of the strategy review are brought together, there are three primary phases for developing national 5G strategy studies: (1) preparation and landscape analysis, (2) building strategies, and (3) developing a monitoring and evaluation framework [63,87]. The checklist questions recommended for evaluation in each phase are provided in Table 4.

These analyses serve as a prerequisite for the proper formulation of strategies. It is observed that in national strategies, these analyses encompass aspects such as existing infrastructure, conducted 5G trials, current testbed and trials programs, responsible and relevant organizations, evaluation of existing spectrum, and global benchmark studies [42,72,74,76]. Therefore, considering national strategies and strategic management dynamics, the questions in this checklist phase have been formulated to cover benchmarking, stakeholder analysis, the role of government, PESTLE, and SWOT analyses.

This study explicitly examines the strategic framework of national 5G strategies, as detailed in Section 3. In nearly all national documents, priority sectors/focus areas have been identified, and vision and strategic objectives have been outlined (see Table A1). Therefore, the first three questions of the “Building Strategies” phase are proposed to be related to the identification of priority sectors, vision, and the determination of strategic objectives. The fourth question pertains to identifying strategies to achieve strategic objectives aligned with the vision. Since evaluating strategies under five pillars is recommended, the fourth question is divided into five subgroups and formulated according to pillar dimensions. The questions in the “Regulations and Spectrum Management” pillar are mainly concerned with identifying the government’s role and responsibilities. This question list encompasses issues found in the literature, such as Spectrum and price policy [53], fee policy [45], and private 5G [17]. The scope of the “Infrastructure” pillar encompasses significant infrastructure investments. Hence, the questions in this pillar focus on fiber optics, sandboxes, and encouraging stakeholders to invest. In the literature on 5G strategies, topics such as incentivizing investment by MNOs and the roles of governments are among the most discussed [84]. The third pillar, “5G and Verticals”, encompasses questions related to identifying priority sectors or areas and testbeds. The “National Ecosystem” pillar focuses on providing environments to enhance collaboration with stakeholders, determining funding mechanisms, establishing competency and awareness development programs, defining the scope of R&D activities, and evaluating technologies beyond 5G. In the final pillar,

“International Collaborations and Standardization”, it is recommended that the country assess its participation in standards and patent activities.

The final phase in strategy studies is “Aligning Strategies with Other National Strategies and Developing Monitoring and Evaluation Framework”. In this phase, assessing the alignment of prepared strategies with other national strategies is recommended. Additionally, establishing a structure to monitor, report, and undertake necessary revisions to the strategy is suggested. For instance, the “5G+ Strategy Committee”, co-chaired by the Minister of Science and ICT and a private sector expert, was established for this purpose in Korea. This committee reports progress to other ministries, evaluates investment and implementation plans, and resolves public complaints. The working group of this committee includes representatives from other ministries, private sector entities, ICT companies, Mobile Network Operators (MNOs), academia, researchers, and user groups. It is planned to monitor implementation progress through monthly meetings with the Deputy Minister of ICT Policy and quarterly “5G+ Strategy Review Meetings” with the Ministry of Science and ICT [2].

Table 4. A recommended national 5G strategy development checklist.

National 5G Strategy Development Checklist	
Phase 1. Preparation and Landscape Analysis	
1.1	Has the need for a 5G strategy at the national level been announced to stakeholders? Is this strategy owned and directed by the government?
1.2	Has an international benchmarking study been completed?
1.3	Has the legal framework for 5G technologies been analyzed, and have the legal requirements been determined?
1.4	Have analyses like PESTLE (political, economic, social, technical, legal, and environmental) and SWOT (strengths, weaknesses, opportunities, threats) been conducted to determine the current situation for the country with regard to the dissemination of 5G technologies in the country? (infrastructure, human resources, suppliers, operators, vertical industries’ needs, etc.)
1.5	Have the stakeholders actively disseminating 5G technologies been identified and analyzed?
Phase 2. Building Strategies	
2.1	Have the focus areas or sectors that will create the country’s best competitive advantage been ascertained by consulting with stakeholders? Have the needs of stakeholders been identified?
2.2	Does the country have a cohesive approach explaining why the expansion of 5G technologies is essential, what purpose it serves, and what the strategy’s vision is?
2.3	To achieve the vision, are there clear objectives, targets, and performance indicators with clear designations concerning who is responsible? Have they been developed considering international lessons and the current local situation?
2.4	In developing objectives and strategies, did the framework encompass all the relevant strategies designed by building those for priority areas?
2.4.1. Regulations and Spectrum Management	
✓	Have the institutions clarified the details of spectrum management? Is the completion schedule for all other goals and strategies aligned with the spectrum development schedule?
✓	Has the country’s infrastructure financing policy been determined?
✓	Have the fees for the frequency policy been determined? Is the government ready for a paradigm shift in the widespread use of 5G technologies?
✓	Have regulatory goals been defined by examining factors like investment incentives, tax exemptions, private 5G networks, the usage of standard hardware, etc.?
✓	Has a flexible regulatory framework with low administrative burdens been evaluated for pilot applications?
✓	Have regulations been determined for small cell usage, spectrum sharing, network slicing, and cybersecurity?
✓	Is private 5G a priority need for the relevant country?

Table 4. Cont.

National 5G Strategy Development Checklist	
2.4.2. Infrastructure	
✓	Have the fiber optic network expansion plans been evaluated and harmonized with other national strategies?
✓	Have mechanisms been established to encourage operators to invest in the 5G infrastructure?
✓	Has the link between regulation and technological development been assessed by creating a regulatory sandbox or alternative solution?
✓	Have priority investment areas been determined and investment plans made to disseminate 5G technologies?
2.4.3. 5G and Verticals	
✓	Are there any centers working on testing vertical industry applications? If not, how will they be established?
✓	There are diverse existing 5G use cases across many sectors. Have any prioritization studies been conducted for sectors where applications can create a competitive advantage for the relevant country?
2.4.4. National Ecosystem	
✓	Associations like 5GPP and 5G Observatory will increase and extend national and international projects and use cases and adopt 5G technologies. Organizations like these will accelerate the production of technologies. Has this issue been discussed with stakeholders, and is such an organization needed?
✓	Have support programs for R&D and commercialization been established for the development of technologies?
✓	Have strategies been determined to create collaboration opportunities for technology development?
✓	One of the challenges with 5G technology is that it is new [17], and its applications and consequences should be explained to both industries and people. Have strategies for conveying the potential impacts of vertical industries on enterprises and citizens and increasing competencies been discussed?
✓	Non-terrestrial networks, low-altitude and high-altitude satellites, and high-altitude platform station (HAPS) technologies can make internet access possible worldwide. These technologies are developing gradually, and many initiatives like SpaceX and Amazon's Kuiper project are underway. It is critical to establish strategies based on assessing these developments and their impacts. Has the relevant country assessed its standing about improving access to the Internet?
✓	Do the country's R&D studies and 5G strategies address technologies within and beyond the scope of 5G?
2.4.5. International Collaborations and Standardization	
✓	Is participation in the standards a priority for the relevant country, and can competence be developed in this respect?
Phase 3. Aligning Strategies with Other National Strategies and Developing Monitoring and Evaluation Frameworks	
3.1.	Are the country's 5G strategies aligned with other strategy documents? Do the responsibilities of stakeholders overlap?
3.2.	Is there a current organizational structure that can conduct, monitor, and report on the progress of the strategy and the relationships among different actions in the strategy?

5. Conclusions and Future Directions

The paper's originality lies in its comprehensive examination of perspectives outlined in national 5G strategies juxtaposed with existing literature, contributing to theoretical understanding and practical applications. With limited literature examining countries' 5G strategies and no study providing a structured list of recommendations for 5G national strategies, this research fills a significant gap. A checklist is presented with the analyses made within the research questions' framework. Its contribution has the potential to profoundly influence the developmental trajectory and economic prosperity of developing nations through the early adoption of 5G technology [54].

This study examined 16 national 5G strategies and proposed that 5G national strategies be managed in three phases. These phases are structured as follows: (i) assessing the current state of affairs regarding 5G technologies, (ii) identifying the desired direction for 5G technologies and formulating strategies to achieve this direction, and (iii) monitoring the identified strategies and making revisions as necessary. It is recommended that the strategies should be evaluated within the framework of five prominent pillars: regulations and spectrum management, infrastructure, 5G and verticals, national ecosystem, and international collaborations and standardization.

While the checklist's value proposition is "facilitation", specific considerations must be taken into account in its application. Firstly, although this checklist was prepared for use by all countries, each country's strategies will differ according to its current circumstances, resources, priorities, cultures, and international relations.

Secondly, this checklist presents a comprehensive set of topics recommended for national 5G strategy evaluation. Although low-income and medium-income countries are likely to be somewhat different from high-income countries [17], the topics/issues to be addressed in national 5G strategies and strategies according to the country's resources remain the same. With this study, a checklist has been proposed that can serve as a starting point for developing national 5G strategies. In particular, developing countries' strategy preparation phase will be shortened by presenting the practices of countries that have holistic strategies. Therefore, the difference between countries will lie in the strategies they adopt. For instance, while a developed country may devise a strategy related to technology development, a developing country may focus on technology transfer. That is, the evaluation question in the checklist remains the same; the answer varies based on the country's current situation and priorities.

Thirdly, national strategies are not required to address every question in the checklist. Indeed, Table 3 illustrates that countries have developed strategies with varying priorities. Therefore, strategies can be formulated according to each country's priorities and resources.

Fourthly, while some countries may not have a national 5G strategy, they may still conduct 5G trials, endeavor to establish a national ecosystem, and prioritize technology development efforts. For instance, thirty European countries have devised an allocation schedule for specific frequencies and allocated certain frequencies for 5G [88]. While some of these allocations align with national strategies, others do not due to a lack of national strategy. Thus, it is hoped that this study will also serve as a checklist for such countries.

Although this article proposed an in-depth strategic view for national 5G strategies, it did not include the indicators required to follow them. Future research should focus on the monitoring and evaluation phase of national 5G strategies. Additionally, it is recommended for future researchers to analyze the practices of countries regarding 5G and prepare a list accordingly. In this way, the difference between what is intended and what is achieved will be revealed, and more realistic goals can be determined. Some studies already state that 5G-related strategies should be re-evaluated considering current developments [48].

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Appendix A

Table A1. National 5G Strategies.

	#	Country	Document Name	Year	Publishing Organization	Vision Statement/Strategic Objectives
Category 1	1	USA	5G FAST Plan	2018	Federal Communications Commission	A plan to facilitate America's superiority in 5G technology.
	2	South Korea	5G+ Strategy to Realize Innovative Growth	2018	The Government of the Republic of Korea	Now, the time calls for Korea to concentrate its national capacity on 5G to leap from being the world's first to the world's best.
	3	Germany	5G Strategy for Germany	2016	The Federal Government	A scheme to promote the development of Germany to become a lead market for 5G networks and applications.
	4	France	5G An Ambitious Roadmap for France	2018	Digital Secretary of State	• Launch several 5G pilot projects immediately in a variety of regions • Be home to the world's first 5G applications in industrial sectors • In 2020: 5G frequencies allocated and a commercial rollout in at least one major city • In 2025: 5G coverage of all the main transport routes
	5	United Kingdom	Next Generation Mobile Technologies: A 5G Strategy for the UK	2017	Department of Culture Media& Sport, HM Treasury	UK to be a global leader in the next generation of mobile technology—5G.
	6	EU	5G for Europe: An Action Plan	2016	European Commission	Keeping Europe ahead in the 5G race.
Category 2	7	Australia	5G—Enabling the future economy	2017	Australian Government Department of Communications and the Arts	To create an environment that allows Australia's telecommunications industry to be at the forefront of seizing the benefits of 5G across the economy.
	8	India	Making India 5G Ready	2018	The Steering Committee	The 5G technology has the potential to usher in a significant societal transformation in India by enabling a rapid expansion of the role of information technology across manufacturing, educational, healthcare, agricultural, financial, and social sectors. India must embrace this opportunity by deploying 5G networks early, efficiently, and pervasively, as well as emerge as a significant innovator and technology supplier at the global level. Emphasis should be placed on 5G touching the lives of rural and weaker economic segments to make it a genuinely inclusive technology.
	9	Spain	Spain's 5G National Plan 2018–2020	2018	Ministry of Energy, Tourism and Digital Agenda	The 5G National Plan is to place Spain amongst the most advanced countries in developing this new technology so that, by the time 5G reaches its technological and commercial maturity point, Spain may be ready to harness all the opportunities arising from this technological paradigm.

Table A1. Cont.

Category 3	#	Country	Document Name	Year	Publishing Organization	Vision Statement/Strategic Objectives
	10	Austria	5G Strategy: Austria's way to become a 5G pioneer in Europe	2018	Federal Ministry for Transport and Innovation and Technology	To become a 5G pioneer in Europe and to be ranked among the top 3 digitization countries within the EU and among the top 10 countries worldwide.
	11	Hungary	The 5G Strategy of Hungary	2017	Ministry for Innovation and Technology and 5G Coalition (5GC)	Hungary has become one of the European centers for 5G developments, enhancing the country's competitiveness and innovation potential and supporting the digital transformation of business.
	12	Denmark	5G Action Plan for Denmark	2019	Danish Energy Agency	For Denmark to be at the forefront in rolling out and using the 5G network . . . we must have the best conditions for citizens, enterprises, and the public sector to use 5G.
	13	Luxembourg	5G strategy for Luxembourg	2018	The Ministry of State Department of Media Telecommunications and Digital Policy	The rollout and adoption of 5G have the potential to create long-term socio-economic benefits for the whole of the country and its economy; 5G also has real potential to improve the lives of citizens.
	14	Netherlands	Connectivity Action Plan	2018	Ministry of Economic Affairs and Climate Policy	The Dutch Government is aiming for high-quality connectivity that can serve a wide variety of demands and is available anytime, everywhere, and at competitive rates.
	15	Finland	Turning Finland into the world leader in communications networks–Digital infrastructure strategy 2025	2018	The Finnish Ministry of Transport and Communications	Turning Finland into the world leader in communications networks
	16	Singapore	Policy For Fifth-Generation (5G) Mobile Networks and Services in Singapore	2019	Info-Communications Media Development Authority Policy	Singapore is to have a thriving Digital Economy where every business is a digital business, every worker is empowered by tech, and every citizen is a connected citizen. World-class connectivity infrastructure, both wired and wireless, will be needed to realize this vision. 5G, touted to be the next quantum leap in mobile technology, will be vital in supporting Singapore's effort to attain this vision. In this regard, IMDA envisages Singapore as a global front-runner for innovation in secure and resilient 5G applications and services. IMDA's 5G strategy will go beyond the pervasive deployment of 5G infrastructure and focus on growing the 5G innovation ecosystem.

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