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Published in:
Electric Power Systems Research

DOI:
10.1016/j.epsr.2021.107367

Published: 01/10/2021

Document Version
Publisher's PDF, also known as Version of record

Please cite the original version:
Borenius, S., Hämmäinen, H., Lehtonen, M., & Ahokangas, P. (2021). Smart grid evolution and mobile communications - Scenarios on the Finnish power grid. *Electric Power Systems Research*, *199*, Article 107367. https://doi.org/10.1016/j.epsr.2021.107367

Electric Power Systems Research 199 (2021) 107367

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

Smart grid evolution and mobile communications—Scenarios on the Finnish power grid

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ARTICLE INFO

Keywords:
Smart grid
Mobile networks
Cellular networks
Communications
3GPP
Anticipatory action learning
Scenario planning

ABSTRACT

This paper focuses on the evolution of the Finnish power grid until 2035 and the role of mobile communications networks in this evolution. It outlines alternative futures (i.e. scenarios) and identifies the role of mobile communications networks in these scenarios. The paper uses an established scenario planning process and a group of experts to determine three scenarios for the evolution of services offered to customers in a future electricity system and four scenarios describing the evolution of grid management. Finally, the role of mobile communications (cellular networks) is analyzed in each of the scenarios. Results show that mobile networks can serve as a key enabler in those scenarios where smart grid evolution would be the most transformative.

1. Introduction

Electric power grids are gradually evolving into smart grids. However, power grids still remain at the system-level primarily top-down networks for distributing electricity from large-scale generators to consumers. Nevertheless, current power grids include some flavors of dynamic meshed networks, particularly reflected in an increasing amount of intermittent distributed power generation. In the future, full-blown smart grids could become highly distributed, dynamic meshed networks. Such networks are likely to be based more on extensive large- and small-scale intermittent power generation, rather than traditional generation supplying inertia. The inertia of large rotating machines has formed the basis for maintaining power grid stability in a relatively straightforward manner. Smart grids introduce a proliferating number of active entities, including distributed generation, flexibilities to address network stability, and functionality related to the active participation of customers. Furthermore, a large number of monitoring entities is likely to be needed for compiling the operational status of a dynamic grid. These issues introduce increased complexity and stability vulnerability, thus posing a challenge for managing the grid. This challenge will increasingly be addressed using information and communications technologies [1–3].

The main driver behind digitalization of electric power grids is the move towards carbon neutrality. Smart grids are a key component in efforts to create a more sustainable energy system [4]. The evolution of the smart grid will be emphasized and accelerated by electrification of the transportation, industry, and heating sectors. Other drivers behind the digitalization of the electric power grids include not only cost pressures, which can be addressed through automatization, but also the goal of creating a closer connection with customers [5,6].

Thus, power grids are likely to enter a new era and could undergo a fundamental architectural change. The same applies to mobile communications networks, which have traditionally focused on the consumer segment, i.e. individuals using mobile phones, tablets, and PCs. This is also the case with the first fifth-generation (5G) mobile network deployments. Nevertheless, right from the beginning, 5G networks, as standardized by the 3rd Generation Partnership Project (3GPP), have targeted industrial applications in addition to the traditional consumer segment [7–11]. 3GPP has in 2020 completed the next release of the 5G network specifications, which introduces the first set of functionalities to address industrial applications, such as power grid management and control. Network deployments including these new functionalities are likely to be launched in the latter half of 2021 and will be further enhanced in subsequent specifications over the coming years. The advantages of employing mobile networks in industrial applications are similar to those in consumer applications: flexibility to provide access without the need for cables, ability to provide mobility, freedom of movement (e.g., enables machinery to rotate, as there are no cables),

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https://doi.org/10.1016/j.epsr.2021.107367
Received 29 January 2021; Received in revised form 30 April 2021; Accepted 10 May 2021
Available online 28 May 2021

and efficiencies in operational maintenance.

Electric power grids within the European Union (EU) are becoming more integrated both commercially, technically, as well as in terms of regulations and legislation. The framework for this integration will continue to be set by the EU and other European co-operation organization. Thus, developments in Europe will also highly impact the Finnish electric power grid. For example, the European Network of Transmission System Operators (ENTSO-E) and European Network of Transmission System Operators for Gas (ENTSOG) published in 2019 their 10-year scenarios in the Ten Year Network Development Plan (TYNDP) 2020 Scenario report. The TYNDP report outlines three scenarios. One of these is a bottom-up scenario based on national energy and climate plans (NECPs) created by each EU member state. This scenario should meet the target of the Paris Climate Conference (COP21, 2015) for maintaining the temperature increase below 2.0 °C compared to pre-industrial levels. The two other scenarios are top-down scenarios based on centralized and distributed generation, respectively. They are compliant with the Paris Climate Conference 1.5 °C target. In Finland, the national Transmission Operator (TSO), Fingrid, has in 2020 published its network vision focusing on the development needs of the Finnish transmission network [12]. The scenarios outlined in this network vision are partly based on the TYNDP report. Fingrid's network vision and other recent work on the evolution of the Finnish power grid are summarized in Section 2.

Much research has focused on mobile network applications for power grids. Most of this research has focused on applying mobile, or more broadly speaking, wireless technologies in specific power grid applications, such as metering, condition monitoring, power quality monitoring, and demand response management. Research has also been directed towards highly critical applications, such as power grid protection. For example, the feasibility of replacing the optical link between two line differential relays has been studied both using simulations and experimental measurements in trial environments [13,14]. The authors in [15–17] and [18] provide a more comprehensive overview of the opportunities of wireless communications in smart grids. Rivas et al. [15] discuss various communications technologies, including 5G, for smart grid fault monitoring, detection and classification. Bag et al. [16] outline utilizing 5G for sharing the load between distributed generators, power management in large microgrids, and protection applications. Reka et al [17] discuss the advantages and disadvantages of 5G in smart grids. Ghorbanian et al [17] present a broad range of communication technologies, discuss their suitability for specific power grids applications, identify relevant standards and discuss open research questions on utilizing information and communications technologies in power grids.

What to our understanding has received less focus is possible power grid futures, and approaches for integrating electric power grids and communications in each of these futures. This task is particularly challenging due to uncertainties leading to different scenarios in the evolution of future power grids and rapidly developing mobile communications technologies. Therefore, the novelty and contribution of this paper is to analyze the current and potential convergence between power grids and mobile communications in multiple, different power grid evolution scenarios created by using a formal scenario planning process. The primary research question is what are the alternative scenarios or "possible futures" for the Finnish electric power grid over the next 15 years until 2035, and what will be the role of mobile communications networks in these scenarios? Scenarios and their likelihood are dependent on country-specific issues. Thus, these issues must be taken into account when attempting to generalize to other contexts.

The rest of the paper is organized as follows. Sections 2 and 3 provide the background. Section 2 describes the status of the Finnish power grid today and highlights characteristics specific to it. Section 3 summarizes the current status of mobile networks including what is known about its planned evolution in the coming years. Section 4 describes the applied scenario planning method and analysis process. Section 5 presents the identified trends and uncertainties. Based on the trends and uncertainties, scenarios are outlined and described in Section 6. Section 7 analyzes the role of mobile communications in each of the scenarios. Finally, Section 8 provides discussion and concluding remarks.

2. The Finnish power grid today

Finland is a sparsely populated northern country with a population of 5.5 million inhabitants. Due to its relatively large land area, 304,000 square kilometers, Finland has a population density of only 18 inhabitants per square kilometer. The vast majority of the population (86%) is concentrated in urban areas, with most living in the southern part of the country. The southern and northern parts of the country have temperatures averaging 5.9 °C and -0.4 °C, respectively. In 2019, Finland's Gross Domestic Product (GDP) reached € 240,600 million (about USD 270,000 million), giving a per capita GDP of € 43,600 (about USD 49,000) [19–22].

In 2019, the total electricity consumption reached 86 TWh [23], with the industry and construction sectors comprising the largest consumers of energy, as depicted in Fig. 1. At the same time, domestic power generation rose to 66 TWh, as shown in Fig. 2 [24]. The difference (20 GWh) was covered by importing electricity, as can be seen in Fig. 3 [24]. The four nuclear power plants accounted for 35% of the total domestic power generation. Currently, one new nuclear power plant is under construction and another is being planned, with projected capacities of 16 GW and 1.2 GW, respectively [25]. Hydropower is the second most important electricity source accounting for 19% of the total power generation. The power of rivers is already to a large extent harnessed, leaving only marginal possibilities for increasing domestic hydropower generation capacity. The total electricity storage capacity of water basins in the Nordic countries is 121 TWh, most of which is located in Norway and Sweden, as the Finnish capacity comprises only 5.5 TWh [25]. Wind power accounts for 9% of the domestic power generation, though its share has been increasing. As of February 2020, there was 18.5 GW of wind power under planning – 15.8 GW onshore and 2.7 GW offshore [26]. Enhancements in the cross-border connections have increased the significance of Nordic hydropower for the Finnish electric power system [24]. Eighty-two percent of the domestic generation is carbon neutral, 51% of which is based on domestic energy sources, and 47% on renewables [24].

Northern Finland has a surplus of electricity generation, and Southern Finland has a deficit. Consequently, a strong transmission network and particularly strong north-to-south connections are important. As the national TSO, Fingrid's investments in the transmission network have been increasing and are estimated to be about € 2,000 million for the transmission network in 2021-2030. Of this amount, €

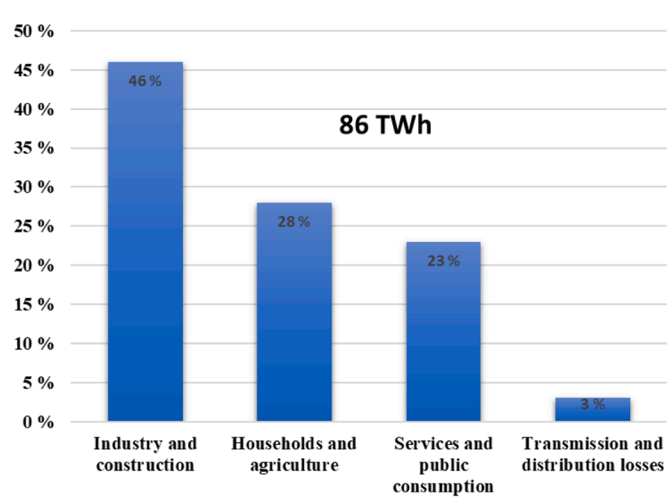

Fig. 1. Finnish Electricity consumption in 2019 [23].

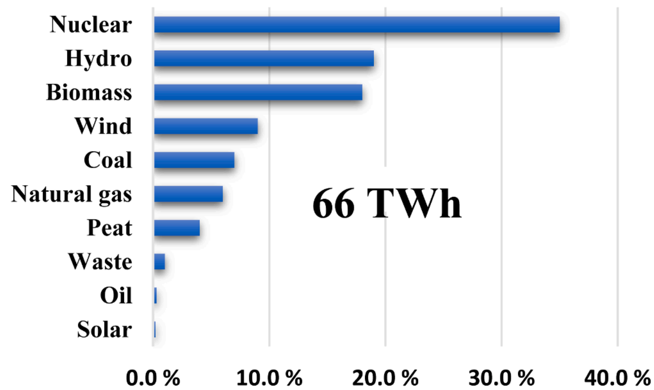

Fig. 2. Domestic power generation for Finland in 2019 by energy source [24].

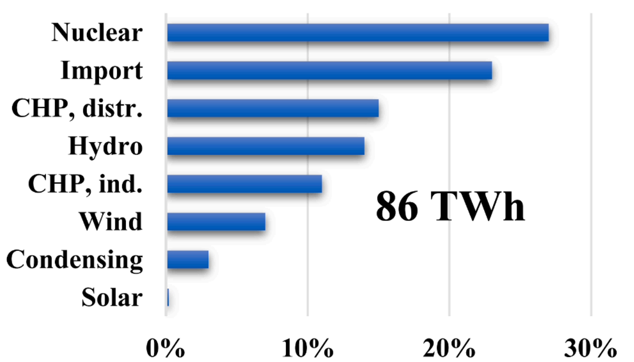

Fig. 3. Finnish energy supply in 2019 by energy type [24]. CHP, distr. = Combined Heat and Power, district heating; CHP, ind = CHP, industryHydro and condensing power have traditionally been the main sources of balancing power. The condensing power capacity has been essentially decreasing during the past years, corresponding to nearly 3 GW for the years 2015-2018 [25,28]. At the beginning of 2019, the condensing power capacity during the peak hour amounted to 1 GW [24,29].

550 million would be used to strengthen the north-to-south connections [27].

The generation capacity in Finland at the end of 2018 totalled 17.6 GW [25], of which 2.0 GW was produced by wind power. The Finnish Energy Authority [25] estimates that only 68% (11.9 GW) of the total generation capacity (17.6 GW) would be available at the peak hour during the winter season, including reserves of 700 MW [25]. It is estimated that 6% of the nominal wind power capacity (2.0 GW), i.e. 120 MW, would be available during the peak hour. The Finnish Energy Authority further estimates the peak demand during a cold winter to be 15.3 GW [25]. As the total generation capacity in Finland is 11.9 GW during that peak hour, a minimum of 3.4 GW should be covered by imports.

The Finnish power grid forms part of the synchronous inter-Nordic system. Besides Finland, the inter-Nordic system covers the Swedish and Norwegian grids, as well as the grid in eastern Denmark. The Finnish grid also has power transmission links to Sweden, Norway, Russia, and Estonia [30]. Furthermore, it is anticipated that a third 400 kV cross-border connection in the north between Sweden and Finland will be deployed by 2025. There are also plans to strengthen one of the two existing DC links in the south between Finland and Sweden [24]. There are nearly 80 Distribution System Operators (DSOs) in Finland [31], which are investing heavily in the distribution grid to replace most of the overhead lines in this geographically large country with underground cables. This effort is expected to increase the security of supply in those rural areas which have been vulnerable to storms. This investment will require about USD 8,000 million by the end of the 2020s [32]. Another characteristic of the Finnish power grid is that smart meter penetration in Finland is very high. At the end of 2016, 99.6% of the 3.4 million low voltage electricity consumption points were equipped with a smart meter [33].

Various scenarios have been developed for the Finnish power system [6,12,34–36]. Fingrid, the national TSO, published in 2020 its network vision focusing on the development needs of the Finnish 400 kV and 220 kV transmission network until 2045 [12]. This vision outlines four scenarios. Three of these are based on the three TYNDP scenarios by ENTSO-E and ENTSO-G. The scenario referred to as the “Exporting electricity” scenario provides more conservative carbon reduction targets, while the ”Wind blows across the sea” (centralized) and the “Sun and batteries”(decentralized) scenarios enable reaching more aggressive targets. The “Exporting electricity” scenario, which is based on the National Trends scenario in the TYNDP report, assumes modest progress in the electrification of the industry and transport sectors, which would allow Finland to export energy due to an increase in onshore wind power. The ”Wind blows across the sea”, which is based on the Global Ambition scenario in the TYNDP report relies on extensive onshore and offshore wind power and nuclear power. The “Sun and batteries scenario” utilizes, as the name suggests, solar power and batteries extensively and is based on the TYNDP Distributed Energy scenario. In these three scenarios, the total electricity production would remain roughly on the same level. However, in the fourth scenario, referred to as the “Climate-neutral growth” scenario, the electricity production would essentially increase driven by extensive onshore wind power. This scenario assumes that Finland would be capable of attracting essential new industrial investments.

The smart grid working group, established by The Finnish Ministry of Economic Affairs and Employment, published its final report on a flexible customer-centered electricity system in 2018 [6]. Rather than outlining multiple scenarios, the report presents one main path forward for enabling a future intelligent electricity system to improve the services offered to customers, as well as to provide customers with opportunities for participating in the electricity market. Future prospects for the distribution grid evolution in sparsely populated, declining regions has been studied by the Lappeenranta-Lahti University of Technology [34], providing projections until 2030. The study forecasts that despite a decrease in the amount of electric energy consumed in sparsely populated areas, peak powers can be expected to increase, due to the electrification of heating and transportation systems. Thus, although there will be fewer households in these relatively remote locations, they will have higher electricity needs. The Finnish National Emergency Supply Agency has recommended strategies for ensuring a stable energy supply until 2030 [35]. Its report emphasizes strong transmission links to the Nordic countries as well as strong north-south oriented domestic transmission links, as most of the power tends to be generated in the north, while most of the population lives in the south. The report also asks whether there should be separate generation reserves, apart from the regular electricity markets for crises. The Finnish industry has recently been working on energy roadmaps [36]. The Technology Industries of Finland represent the largest and most important export sector in Finland. According to their report, it would be possible to reduce CO_2 emissions by 80% from the current level of about 6 megatons. This would double the need for CO_2 neutral energy from the current level of about 12 TWh to 24 TWh by 2050. However, for this development to be viable, the electricity price should be competitive.

3. Evolution of mobile communications networks

This section provides an overview of current and forthcoming 3GPP 4G and 5G network capabilities in terms of their industrial applications and discusses the initial ideas for future 6G networks.

The 3rd Generation Partnership Project (3GPP) was established in 1998 to create 3G network standards based on Global Systems for Mobile Communications (GSM) 2G technology. 3GPP is a co-operation body of seven telecommunications standards organizations from Asia, Europe, and North America [37], referred to as 3GPP organizational partners. 3GPP's standards have been a worldwide success. 3GPP digital mobile networks technologies GSM-EDGE (2G), WCDMA (3G), TD-SCDMA (3G), LTE (4G), and 5G cover the vast majority of digital subscriptions worldwide, as can be seen in Fig. 4 [7]. These technologies allow interoperability between networks of different generations and end devices typically supporting multiple generations. For example, an end device using 4G Long Term Evolution (LTE) for data connection can also rely on 2G or 3G for a traditional circuit-switched phone call, or can rely on 3G or even 2G data connections if no 4G LTE coverage is available. As of August 2020, nearly 800 operators offer 4G networks to over 5,400 million 4G users, with 5G technologies being commercially deployed by about 118 operators in 59 countries. Although 4G networks typically have wide geographical coverage within the countries in which they have been deployed, 5G has so far been deployed only in major cities.

The standardization work of 3GPP is being carried out in releases [8, 38], though feature specifications for each generation span multiple releases, thus enhancing and stabilizing these features through multiple releases. As the specifications and feature lists are extensive, their implementation in commercial products gradually occurs over several years. Some features might not achieve market traction and are consequently not implemented in commercial products to a great extent. Specification work for two generations can occur in parallel. For example, as of today, further development of 4G LTE is ongoing in the same releases that specify 5G.

The first 5G release specification, Release 15, was created in three steps between December 2017 and March 2019. Standardization work for the subsequent release, Release 16, was completed in July 2020. Currently, during the fall of 2020, extensive standardization work is ongoing to define both Release 17 and the further evolution. Release 17 will probably be concluded during 2022. The content of Release 18 is preliminarily targeted to be defined during the first half of 2021. Fig. 5 outlines the foreseen 5G evolution in terms of 3GPP releases [8,9,11,39].

In its requirements specification, the International Telecommunications Union defines three usage scenarios for 5G [40]: (1) eMBB = enhanced Mobile Broadband, (2) URLLC = Ultra-Reliable and Low-Latency Communications, and (3) mMTC = massive Machine Type of Communications. eMBB focuses on providing fast broadband access with low 4 ms latency. Its initial focus is primarily on the consumer sector. Different business sectors and segments are referred to as "verticals" in the 3GPP context. URLLC provides very low 1 ms latency and 99.999% reliability in the radio interface, thus focusing on industrial verticals. mMTC will provide support for a large number of devices in a small area, with a target of 1 million devices per square kilometer. mMTC also focuses primarily on industrial applications.

Mobile network generations before 5G have focused on providing voice and broadband data services to the consumer segment through

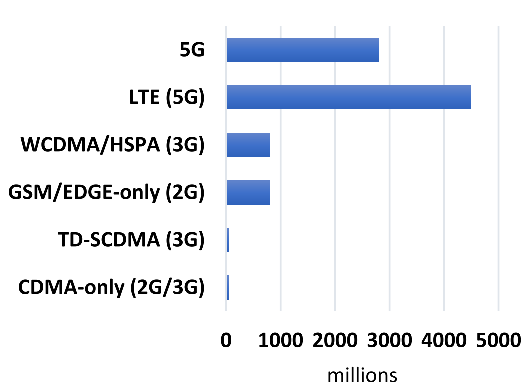

Fig 4. Projected mobile subscriptions by technology in 2025. Internet of Things (IoT) connections are not included [7].

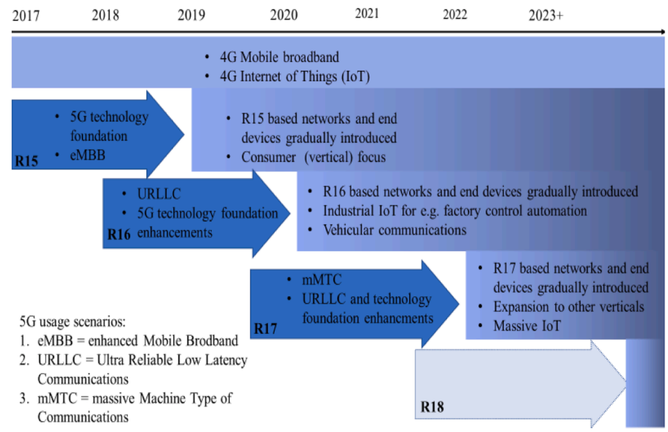

Fig 5. The 5G evolution roadmap [8,9,11,37].

mobile network operator (MNO) networks. Consumers using mobile phones and mobile network operators remain an important target for 5G. However, since its launch, 5G has also targeted industrial and business sectors, verticals, as well as new business and network deployment models [41]. In 2019, the role of the 3GPP Systems & Services Working Group 6 (SA WG 6) was explicitly expanded to cover "the standardization of new vertical applications within the 3GPP ecosystem, and also promoting the adoption of 3GPP 5G technology across a variety of industries" [42]. Earlier, it formally covered only mission-critical public safety and emergency type of applications [43].

With regards to industrial and business verticals, 3GPP has specifically focused on factory and industrial process automation, also known as the Industrial Internet of Things. Features enabling new business models and roles include network slicing and private company-specific network deployments. Network slicing refers to the capability both to separate a logical network for certain verticals, customers, and applications as well as to assign performance characteristics for the logical network to match their needs. One of the verticals identified as a future target is electric power distribution [41].

Release 15 lays the technological foundation for 5G by defining a New Radio (NR) access technology and a new Service-Based Architecture (SBA). NR enables multi-gigabit data rates and millisecond-level latencies. NR is designed to operate both on the conventional cellular spectrum (Frequency Range 1) and higher millimeter wave spectrum (Frequency Range 2), as well as to cover frequencies below 6 GHz and above 24 GHz, respectively. SBA defines architecture in terms of the software components that can be run on standard computing platforms. This provides flexibility and scalability to support various types of deployments from large mobile operator networks to small local, company-specific network deployments. Additionally, Release 15 also implements the basis and initial functionality for many of the features to be introduced or strengthened in the upcoming releases, including network slicing as well as Ultra-Reliable and Low-Latency Communications (URLLC). Release 15 also implements one of the three usage scenarios, eMBB, as it primarily targets the traditional consumer segment of mobile phone users [8–11,38,39].

Having laid the foundation for 5G in Release 15, Releases 16 and 17 shift the focus to addressing industrial and business sectors and new deployment models. These two releases aim to develop a versatile set of features over multiple releases. These features can be grouped as follows [10,11]:

- Industrial automation and process control, also known as Industrial IoT. The target is to enable plant automation and functionality comparable to fixed industrial operational technology (OT) networks by using 5G wireless networks. This will be achieved using as primary technologies URLLC, Time Sensitive Communications (TSC),

private network deployments (i.e., non-public networks, NPNs), and network slicing.
- Enhancements to 4G IoT functionality and creation of 5G native IoT solutions. The native 5G IoT solution, also known as a reduced capability NR device, NR Light or NR Lite, is targeted to applications such as industrial sensors and video surveillance, and is planned to have data rates between 4G IoT (NB-IoT, LTE-M) and "full" NR data rates.
- Location, also known as positioning, based on 5G radio signals. This could provide a location accuracy of 1-2 meters, comparable to satellite-based systems such as GPS (Global Positioning System). The advantages of 5G-based location services would be that it could eliminate the cost of the GPS receiver and potentially enable indoor coverage, depending on the deployment scenario.
- New radio (NR) unlicensed spectrum. Release 16 enables NR operation in unlicensed 5 GHz and 6 GHz bands. Co-existence with Wi-Fi is achieved by listen-before-talk (LBT) mechanisms. Release 17 will also target a higher 60 GHz unlicensed spectrum.
- Multicast and broadcast technologies enabling efficient simultaneous communication to multiple end devices. This is primarily targeted at vehicular communications, public safety, software updates, and various IoT applications.
- Network automation and data analytics will contain functionality to assist in the management of 5G networks and to allow access to external parties (e.g., verticals) to create, monitor, and optimize their network services. Analytics on network performance will be provided by a Network Data Analytics Function (NWDAF), and access to and from vertical applications will be allowed using various interfaces, including Common API Framework (CAPIF), Service Enabler Architecture Layer (SEAL), and Architecture for enabling Edge applications Network (EDGEAPP).

As the first step in Time-Sensitive Communications, Release 16 implements support for Time-Sensitive Networks (TSN), which are being developed by IEEE working group 802 [44]. TSN networks aim at providing support for critical, real-time control applications, including accurate time synchronization of switches and end devices. TSN networks are deterministic and offer "guaranteed packet transport with bounded latency, low packet delay variation, and low packet loss" [44]. In Release 16, a 5G network can appear as a TSN bridge in a TSN network, as depicted in Fig. 6 [10]. Release 17 will potentially enable 5G networks to support Time Sensitive Communications natively without reliance on TSN networks [11]. Within power grids, TSNs could provide a cost-efficient alternative to GPS. This could enable wider use of applications that depend on accurate time, such as line differential protection and Phasor Measurement Unit (PMU) applications for state estimation.

Private networks provide dedicated, organization-specific 5G network deployments within a limited geographical area [45]. As shown in Fig. 7, they can be deployed either standalone, or in conjunction and integrated with public networks. Within power grids, substations could be candidates for private 5G network deployments. They could provide a flexible platform for covering instrumentation and sensoring without the need for extensive cabling.

3GPP Releases 17 and 18 are frequently described in the research community as addressing beyond-5G features [46]. Preliminary research for the next generation, 6G, is also already ongoing. 3GPP is expected to launch a more formal study and specification work for 6G during 2025-2027 [47] . 6G would address technical shortcomings potentially left in 5G standards and implementations, as well as provide a basis for some 5G applications to reach targeted goals and full potential, enabling new applications [46,48,51].

Regarding potential shortcomings, a question mark remains concerning how well the technical integration of the three usage scenarios eMBB, URLLC, and mMTC would succeed. Bi [48] points out that current eMBB deployments mostly use a Time Division Duplex (TDD) spectrum due to the difficulty of finding 100 MHz bands in pairs. Nevertheless, for URLLC, Frequency Division Duplex (FDD) would be more beneficial as it would avoid changing turns between transmission and reception as is the case in TDD. Current mMTC deployments also in the 5G context are based on 4G technologies. Upcoming releases will show how successful these efforts will be in creating a 5G native IoT solution [48]. Jiang [47] and Bhat [49] propose that initial 6G research should consider approaches to create more versatile and flexible usage scenarios by combining features from eMBB, URLLC and mMTC.

To achieve higher speeds, 6G continues to move to higher frequencies and will continue to extensively utilize MIMO (Multiple-Input Multiple-Output) antenna technologies [50]. Initial research will focus on utilizing the so-called TeraHertz band between 300 GHz and 10 THz or even visible light in indoor scenarios. Visible Light Communications (VLC) would utilize frequencies between 430 THz and 720 THz [51,52].

5G is cloud-native and includes capabilities for edge computing. It also has features to integrate other access mechanisms, such as Wi-Fi. 6G research aims to further expand these features and ultimately transform a communications network into a seamless computing and storage platform [47]. In this platform, intelligence could be placed either in the proximity of the end device, deeper in the platform, or centrally depending on the application need. Access would be equally seamless, thus enabling new techniques, such as cell-less access and grant-free access [48,49], as well as new access networks such as satellite links [49]. Cell-less access would enable the user to connect to the network instead of to an individual cell [49], while grant-free access would, in

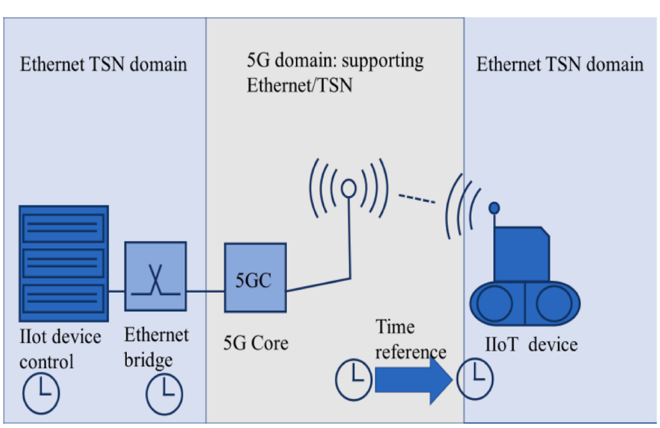

Fig. 6. 5G network as a TSN (Time Sensitive Networks) bridge in industrial applications [10].

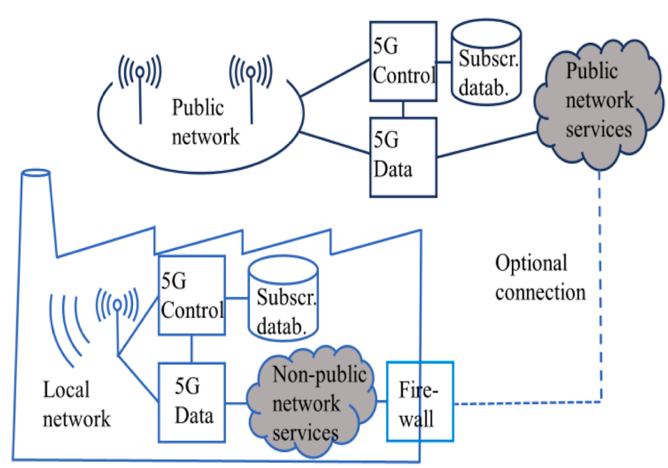

Fig. 7. Private, non-public network (NPN) deployed as an isolated network [45].

some cases, enable the user to access the network without an explicit grant from the central controlling unit. The latter could be beneficial, for example, in sensoring cases where end devices occasionally send small amounts of data [48,53].

As higher frequencies and broader bandwidths become more widely used, questions will arise concerning power consumption and cost, which must be addressed [48]. This applies both to 5G and 6G.

Finland has three public mobile network operators. Their 2G, 3G, and 4G networks have good nationwide coverage, reaching over 99% of the population [54–56]. 5G network deployments were started in early 2019 on the 3.5 GHz spectrum band [57]. Each operator has 130 MHz of the spectrum [57]. As of fall 2020, each of the 5G networks covers around 30-50 cities depending on the operator [58–60]. The same three operators acquired the 26 GHz spectrum band licenses auctioned in 2020 [61], thus allocating 800 MHz of the spectrum for each operator [61]. In 2020, 20 MHz of dedicated spectrum was allocated for private and local 4G LTE and 5G networks at the 2.3 GHz spectrum band. A similar allocation is planned for the 25 GHz spectrum band in 2021 [56, 62].

4. Research method

This research utilizes the anticipatory action learning approach [63–65] as well as Paul Schoemaker's popular scenario planning process [66,67] to generate future scenarios. Action learning focuses on conversations, in which experts from various backgrounds generate and explore the scenarios. The scenario planning process consists of 10 steps, as depicted in Fig. 8.

In this paper, we focus on the scenario generation and qualitative analysis outlined in steps 1-8 of the scenario planning process. Quantitative modeling of steps 9-10 is excluded from this work. Instead, we analyze the role of mobile networks in each of the scenarios.

Step 1 (Scope) was defined by two questions presented to the experts:

1 What are the alternative scenarios ("possible futures") for the Finnish electric power grid over the next 10-15 years (until 2030-2035), and
2 What are the key trends and uncertainties that produce these scenarios?

Key trends and uncertainties were initially identified in a half-day workshop in February 2020 among Finnish industry experts. Both trends and uncertainties are forces shaping the future. A trend was considered to be identified when the majority of the experts agreed that the force is valid with a reasonable probability. Consequently, trends are by definition present in all scenarios. Uncertainty was identified when experts were either uncertain or disagreed about the outcome of the force. Scenarios were formed by assuming different outcomes for the uncertainties.

To cover all macroeconomic aspects impacting the power grid scenarios, the workshop was divided into four parts representing different viewpoints on the forces shaping the future. These forces were identified in terms of four so-called PEST categories: (1) Political and regulatory forces, (2) Economic and industry forces, (3) Social forces, and (4) Technological forces. For each category, a coordinate system was used to plot the level of uncertainty against the importance of the force. The workshop participants indicated the level of uncertainty and importance by individually placing the forces they had identified on appropriate positions in the coordinate system.

Workshop results were elaborated and enhanced by interviewing all the experts individually following the workshop during the spring of 2020. The preliminary results were discussed and verified with the experts in three separate meetings. Based on this feedback, the final scenarios were created by the authors. Results of the preceding steps are presented in Sections 5-6. Subsequently, the authors assessed options for the role of mobile networks in these scenarios. The results of this step are presented in Section 7.

A total of 16 experts participated in the process. The experts represented the following stakeholder organizations: distribution and transmission system operators, energy suppliers, regulators, industry associations, power grid equipment manufacturers, power grid service providers, communications network manufacturers, communications network operators, electric vehicle charging service operators, as well as power systems and communications research institutes. The views expressed by the experts were their own and were not necessarily shared by their employers.

5. Trends and uncertainties

Table 1 lists the identified trends. The trends are designated by acronyms, in which the first number represents the PEST category and the last number after the letter T (denoting "Trend") indicates the relative importance given to the trend by the experts, with the number 1 being evaluated the most important. Henceforth, the names of trends and uncertainties will be placed within quotation marks to distinguish them from the names of scenarios, which will be indicated by the use of *italics*. As discussed in Section 4, the trends are forces which the majority of the experts agreed as being valid with a reasonable probability. These trends were formed by grouping similar types of forces identified by the experts during the workshop. The approximate position of each trend on the uncertainty-importance coordinate system reflects the position of the individual forces pertaining to that group. The grouping was done in an iterative process together with the experts after the workshop.

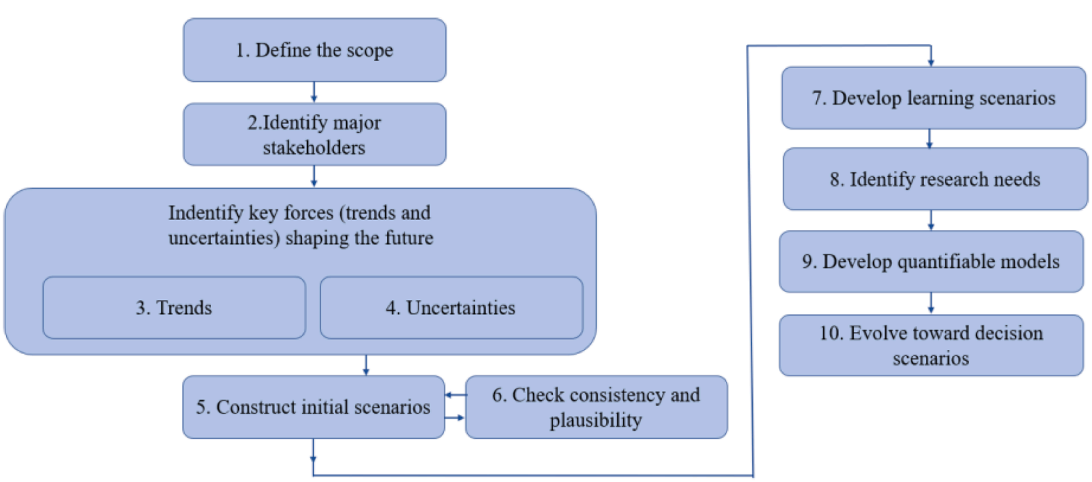

Fig. 8. The scenario planning process [66].

Table 1
Trends.

	POLITICAL AND REGULATORY TRENDS		SOCIAL TRENDS
1T1	Capex based distribution system operator (DSO) regulation will continue during the 2020s, after which the regulation model is open but will likely emphasize opex more	3T1	Increasing interest in service-based models
1T2	The amount of renewable generation will increase	3T2	Urbanization (rural areas losing people)
1T3	Increased focus and requirements on cybersecurity	3T3	Ease of use and convenience are essential to customers
1T4	Distribution system operators will remain responsible for power quality (voltage levels) in distribution networks		**TECHNOLOGICAL TRENDS**
1T5	Regulated distribution networks evolve towards being a market platform for non-regulated, competitive services. One pays for existence.	4T1	The role of different flexibilities (e.g., consumer demand response) will increase
1T6	Some increase in the role of capacity (power) pricing to improve cost-relatedness.	4T2	The role of sector integration (or sector coupling, e.g. electricity and district heating) becomes more significant
1T7	Electrification of heating and transportation sectors proceeds	4T3	Requirements for supply reliability will increase
	ECONOMIC AND INDUSTRY TRENDS	4T4	The amount of data will increase (e.g., sensoring) and will become more extensively used for power grid management
2T1	Use of electricity will increase	4T5	Role of small-scale entities in power grid management increases
2T2	The economic situation in Finland will be similar or slightly better	4T6	Usage of communications solutions increases rapidly
2T3	Consolidation will occur among distribution system operators	4T7	Decentralized production units better controlled through mobile solutions (e.g., 5G)
2T4	People are increasingly willing to pay more for sustainable solutions		

It should be noted that there remains a possibility of an unexpected, contrary outcome. Some of these contrary outcomes might have fundamental impacts on the scenarios. For example, assume that it turns out that Trend T2 “Economic situation in Finland will be similar or slightly better” is not valid. This would indicate that the Finnish economy will considerably struggle during the 15-year period, which would most likely impact the uncertainty 2U5 “Citizens in a position or willing to finance the required investments?” and potentially also 3U1 “Attitude towards climate change actions staying positive?”

Even though the trends are by definition present in all scenarios, they have different weights in different scenarios. Trends 1T2, 1T5, 2T1, 4T1, 4T2, and 4T5, at least, would indicate a major change to the past. The weight of these change trends is discussed along with the scenarios in Section 6.

Table 2 lists the identified uncertainties. The uncertainties are designated by acronyms, in which the first number indicates the PEST category and the last number after the letter U (denoting “Uncertainty”) indicates the relative importance, with the number 1 being evaluated the most important. As discussed in Section 4, uncertainties are forces for which the experts are either uncertain or disagree about the outcome of the force. Similar to the trends, the grouping was done in an iterative process together with the experts after the workshop.

Some of the uncertainties are incidents, which can be highly disruptive. These include:

Table 2
Uncertainties.

	POLITICAL AND REGULATORY UNCERTAINTIES		SOCIAL UNCERTAINTIES
1U1	Consistent implementation of legislation targeting carbon neutrality?	3U1	Attitude towards efforts to mitigate climate change staying positive?
1U2	Energy communities gaining system-level significance?		**TECHNOLOGICAL UNCERTAINTIES**
1U3	Electricity price increasing from its current relatively low level?	4U1	Increased complexity causing major disturbances?
	ECONOMIC AND INDUSTRY UNCERTAINTIES	4U2	Cybersecurity breaches causing major disturbances?
2U1	Essential new innovative services and service platforms emerging?	4U3	Essential evolution towards networks of automatized, distributed entities?
2U2	New disruptive entrants entering the market?	4U4	Essential development of feasible large-scale electricity storage solutions (e.g., power-to-x)?
2U3	Controllable bulk generation capacity increasing?	4U5	Grid supporting capabilities required from renewable generation (e.g., batteries in combination with solar panels)?
2U4	A new, cost-effective large-scale balancing power solution emerging?	4U6	Cost of electricity production continues to decrease (e.g., solar panels in combination with batteries)?
2U5	Citizens are able or willing to finance required investments?		
2U6	Electricity use by industry increasing?		

- Consistent implementation of legislation targeting carbon neutrality? (1U1)
- Attitude towards climate change actions remain positive? (3U1)
- Increased complexity causing major disturbances? (4U1)
- Cybersecurity breaches causing major disturbances? (4U2)

Regarding the two first uncertainties, it can be expected that there will be multiple elections in Finland and other European Union countries by 2035. The sentiment which currently sees global warning as a severe, human-made problem might change. There are political forces and parties which dispute this, and new ones might emerge. The two latter uncertainties are related to the increasing amount of communications and information technology in power grids. This complexity makes grid management more vulnerable to technical problems and cybersecurity attacks. A long-lasting blackout covering major urban areas could lead both the electorate and politicians to re-assess power grid development directions. Due to the disruptive nature of these uncertainties, they are excluded from the scenarios presented in Section 6, though their potential impact on the likelihood of the scenarios will be discussed.

To understand the interrelationships between the uncertainties and to ensure the consistency of the scenarios, a dependency matrix [66] was constructed from the uncertainties, as shown in Table 3. A plus sign in the cross-section between two uncertainties indicates that answering “yes” to one of the uncertainties, increases the likelihood of a “yes” answer to the other uncertainty. Conversely, a minus sign (-) decreases the probability, while a zero (0) indicates no relationship, and a question mark (?) indicates an indeterminate relationship between the uncertainties. For example, the cross-section of 1U2 and 1U3 shows a plus sign, indicating that energy communities are likely to be more popular if electricity prices were at higher levels for a longer period. One of the fundamental reasons for establishing energy communities would be to become more self-sufficient, to maintain affordable electricity prices, and to introduce new technologies and services. The latter is indicated by a plus sign in the cross-section of 1U2 and 2U1 “Essential new innovative services and service platforms emerging?”. On the other

Table 3
Dependencies between uncertainties.

	1U2	1U3	2U1	2U2	2U3	2U4	2U5	2U6	4U3	4U4	4U5	4U6
1U2	1	++	++	++	?	?	-	?	++	++	-	++
1U3		1	++	++	-	-	-	-	?	?	?	–
2U1			1	++	?	?	-	?	?	?	?	?
2U2				1	?	?	-	?	?	?	?	?
2U3					1	+	?	+	?	?	-	?
2U4						1	?	+	?	+	–	?
2U5							1	+	?	?	?	++
2U6								1	?	?	?	+
4U3									1	?	+	?
4U4										1	–	?
4U5											1	-
4U6												1

hand, the cross-section of 1U2 and 2U5 is marked with a minus sign, indicating that energy communities would become more popular if citizens were not able or willing to finance required investments in the power grid.

6. Scenarios

After several iterations together with the experts, scenarios were created using two methods: (1) clustering important dependent uncertainties, and (2) crossing the outcomes of two important reasonably independent uncertainties [66]. The first method resulted in three scenarios designated as the "Service leapfrog" perspective (Fig. 9), while the second method resulted in four scenarios, classified as the "Grid-level generation capacity and balancing power" perspective (Fig. 10).

6.1. The service leapfrog perspective

The "Service leapfrog" perspective is comprised of three scenarios: Scenario A1 Current grid with technically mandatory enhancements, Scenario A2 Current grid with some essential, new innovative services, and Scenario A3 New holistic service experience. In Scenario A3, the outcome of the following uncertainties is assumed to be "yes":

- Energy communities gaining system-level significance? (1U2)
- Electricity price increasing from its current relatively low level? (1U3)
- Essential new innovative services and service platforms emerging? (2U1)
- New disruptive entrants entering the market? (2U2)
- Essential evolution towards networks of automatized, distributed entities? (4U3)
- Essential development of feasible large-scale electricity storage solutions (e.g. power-to-x)? (4U4)
- Cost of electricity production continues to decrease (e.g., solar panels in combination with batteries)? (4U6).

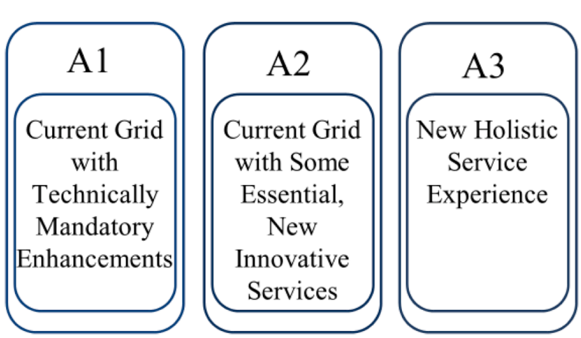

Fig. 9. Scenarios comprising the Service leapfrog perspective.

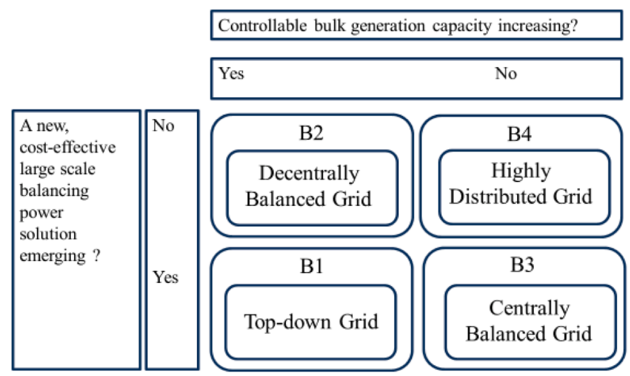

Fig. 10. Scenarios comprising the Grid-level generation capacity and balancing power perspective.

In Scenario A3 *New holistic service experience*, the users would have an easy-to-use application to manage the temperature and lighting of their apartments and houses, thus enabling them to buy these as services or "circumstances" instead of electricity. The application would holistically optimize, based on user preferences and electricity price, the circumstances inside all the premises owned by the user. It would also seamlessly integrate charging and discharging of the user's electric vehicles and manage local generation and storage on all the user's properties. The application could include a mobile app user interface for providing a superior end-user experience. Development towards Scenario A3 could be accelerated by new, major entrants emerging onto the Finnish electricity market. These entrants could include major European energy companies (e.g., E.ON, EDF) or entrants originating from outside the established electricity business. Currently, European energy companies are showing interest in expanding their portfolios [68,69], while global giants, such as Google, Amazon, and Tesla, are likewise showing interest in introducing housing and transportation solutions [70,71,72]. In urban areas, since most of the residents live in apartment buildings as opposed to detached houses, apartment buildings could become natural energy communities in the future. On the other hand, it is difficult for a community living in an apartment building to acquire and maintain the competence to establish the required technical solutions and operate the energy community. Instead, it would be more credible and effective to buy the service from a major service provider. These service providers could also be active in balancing power markets and providing flexibilities to the transmission system operator. Furthermore, increasing electricity prices could be one factor driving customers to seek more innovative and holistic solutions.

Scenario A1 *Current grid with technically mandatory enhancements* is the other extreme: the outcome of the above-listed uncertainties is "no". In this scenario, the current grid and its existing business models would remain relatively unchanged with only mandatory technical enhancements to cope with the increased use of intermittent energy resources and decreased inertia. Finally, Scenario A2 *Current grid with some essential, new innovative services* is a middle-of-the-road scenario between the two extremes.

Section 5 identified major change trends, such as 1T2 "Amount of renewable generation will increase". Even though all trends are by definition present in all scenarios, change trends appear strongest in Scenario A3 *New holistic service experience*. If Trend 3T1 "Increasing interest in service-based models" is strong, the likelihood of Scenarios A2 and A3 would increase. On the other hand, the relatively short time frame of 15 years might limit large-scale deployment of fundamentally new service solutions. Section 4 listed some highly disruptive uncertainties, such as 4U1 "Increased complexity causing major disturbances?". If disruptive outcomes materialize, they would probably increase the preference for maintaining the status quo, thus leading to only very limited, mandatory changes. In the case of the "Service leapfrog" perspective, this would lead to A1 *Current grid with technically mandatory enhancements*.

6.2. The "Grid-level generation capacity and balancing power" perspective

The "Grid-level generation capacity and balancing power" perspective was created by crossing Uncertainties 2U3 "Controllable bulk generation capacity increasing?" and 2U4 "A new, cost-effective large-scale balancing power solution emerging?". This resulted in four scenarios (Fig. 10): Scenario B1 *Top-down grid,* Scenario B2 *Decentrally balanced grid,* Scenario B3 *Centrally balanced grid,* and Scenario B4 *Highly distributed grid.*

In Finland, controllable bulk generation could potentially be increased based on nuclear power, small modular nuclear power plants, or Power-to-x/x-to-power technologies. Given current plans and ongoing construction, nuclear power would seem to be one obvious choice, as nuclear power can also be considered carbon neutral. Teollisuuden Voima's Olkiluoto 3 reactor is under construction and Fennovoima's Hanhikivi 1 is in the planning phase [25]. Olkiluoto 3 would have a capacity of 1.6 GW and Hanhikivi 1 a capacity of 1.2 GW. During the 15-year scenario planning period, small modular nuclear power plants (SMRs) or even fusion power might also have some early proof-of-concept deployments [73,74]. A third option might be to implement large-scale power-to-x/x-to-power in combination with large wind farms in high voltage networks [75].

Power-to-x/x-to-power might also enable longer-term storage of electric energy, which could potentially form the basis for a new large-scale balancing power solution. Another large-scale balancing power option would involve increasing bulk generation capacity, as well as sector integration between district heating and electric power system (Trend 4T2). In case of sufficient bulk generation, one could operate larger generators on constant, high levels and utilize heat storage in the district heating systems to accommodate fluctuations in electricity demand. Extensive electrification of the industry (Uncertainty 2U6) could create new opportunities to utilize large industrial loads as a balancing solution.

Import capacity, applicable for both bulk generation and balancing power, will increase to 5.5 GW by 2025 [28]. As mentioned in Section 2, by that time, the third AC transmission connection, with a capacity of 800 MW, would be operational between Sweden and Finland [25]. Simultaneously, the transmission networks to and from Central Europe will be strengthened and the European electricity market will become further integrated [28,76]. This is an opportunity, as it alleviates the challenge caused by a lack of domestic bulk and balancing power capacity. On the other hand, Central Europe is certainly interested in Nordic hydropower as a balancing power solution. Thus, the political question concerning the importance of self-sufficiency remains under discussion.

In Scenario B1 *Top-down grid*, both controllable bulk domestic generation and domestic balancing power capacity would be roughly adequate. Consequently, one would not have a technical need to implement complicated and costly large-scale demand response solutions for maintaining grid stability.

In Scenario B2 *Decentrally balanced grid*, domestic controllable bulk generation would be roughly adequate. Thus, the grid would be less strained than in Scenario B4. Distributed balancing solutions in the form of demand response would be extensively implemented to replace those condensing power plants that can be expected to be closed down. Many of these demand response solutions would be based on aggregating numerous small resources. Imports would also play a role in maintaining a power balance. In this scenario, the need to import electricity would be less than that in scenario B4. Consequently, this would increase the overall reliability of the grid. In Scenario B3 *Centrally balanced grid,* the domestic balancing power would be roughly adequate, though domestic bulk generation would be expected to be insufficient. Compared to Scenario B2, the balancing solution in Scenario B3 would be relatively easy to manage, as one would not need to aggregate the balancing power from numerous very small resources. On the other hand, balancing actions would be needed relatively frequently due to the lack of controllable bulk generation capacity. The driver for the flexibility needed in Scenarios B2 and B3 is slightly different. In Scenario B2, flexibilities are needed to address a shorter-term imbalance caused by intermittent generation, while Scenario B3 would require these flexibilities to address a temporary shortage in bulk generation.

Scenario B4 *Highly distributed grid* presents challenges in terms of the adequacy of both domestic controllable bulk generation capacity and domestic balancing power. To ensure power balance and grid stability, extensive imports of both bulk and balancing power would be needed. On the coldest winter days, the whole Nordic grid might be strained [28], potentially requiring imports from Central Europe and extensive demand response solutions. The question remains whether market mechanisms would be sufficient to establish the demand response solutions or whether this would require command-and-control or regulation measures. In this scenario, consumers might seek more independence from the grid to ensure service reliability and more affordable prices by implementing local generation solutions, combined with storage capabilities or by establishing energy communities.

Change trends, such as 1T2 "Amount of renewable generation will increase", are strongly present in Scenarios B2 *Decentrally balanced grid* and B3 *Centrally balanced grid*, and even more strongly in Scenario B4 *Highly distributed grid*. If ongoing and planned nuclear power investments materialize as planned, and possibly some new ones are initiated, this would increase the likelihood of Scenarios B1 and B2. If there is a breakthrough in large-scale commercial power-to-x and x-to-power deployments within the 15-year time frame of this study, that would increase the likelihood of Scenarios B1 and B3. Such a breakthrough, in combination with large-scale wind turbine deployments, would increase the likelihood of Scenarios B1 and B2, as it could also comprise a source of controllable bulk generation capacity. The likelihood of Scenario B1 would also increase in the case of additional nuclear bulk generation capacity in combination with district heating as a flexibility to provide a large-scale balancing solution.

As in the case of the "Service leapfrog" perspective, if some of the disruptive uncertainty outcomes listed in Section 5 materialize, they would probably increase willingness to rely on proven solutions and a high level of self-sufficiency. In the case of the "Grid-level generation capacity and balancing power" perspective, this would indicate Scenario B1 *Top-down grid*.

7. Role of mobile networks in the scenarios

Following the creation of the scenarios, the role of mobile communications networks was assessed in each of the scenarios. Table 4 summarizes the role of mobile communications networks in the scenarios. As shown in the table, mobile communications are a crucial key enabler in some of the scenarios, since these scenarios would be difficult to

Table 4
Summary of the role of mobile networks.

	SCENARIO	ROLE OF MOBILE NETWORKS
A1	*Current grid with technically mandatory enhancements*	An additional communications channel option
A2	*Current grid with some essential, new innovative services*	An important enabler. This scenario is supported by the use of mobile cloud communications.
A3	*New holistic service experience*	A key enabler. This scenario requires extensive use of mobile cloud communications. Promotes disruption of business models.
B1	*Top-down grid*	An additional communications channel option
B2	*Decentrally balanced grid*	An important enabler. This scenario requires extensive use of mobile communications.
B3	*Centrally balanced grid*	An important enabler. This scenario requires extensive use of mobile communications.
B4	*Highly distributed grid*	A key enabler. This scenario requires extensive use of mobile communications, including the use in the most critical applications, such as protection.

implement without extensive use of mobile communications. Depending on the scenarios, either the connectivity or the cloud computing aspect of mobile communications is emphasized, while other scenarios utilize mobile communications just to provide an additional connectivity option, which is particularly convenient for cases involving retrofitting.

Scenario A3 is enabled by extensive use of communications and information technologies in a disruptive manner, while Scenarios A1 and A2 are based on gradual evolution from both the technical and business perspectives. Scenario A3 requires mobile networks in combination with cloud technologies. Cloud technologies would enable the creation of energy applications for consumers. In Scenario A3, the cloud is likely to be the dominant component potentially disrupting existing business models. Major cloud service providers are repositioning themselves with regards to mobile networks by integrating “5G as a feature” to their offering or looking at close co-operation with telecom operators. This poses a challenge, particularly for mobile network suppliers, who are investing heavily in their cloud services. [77–80]

In Scenario B1, communications technologies would be moderately used in a relatively straightforward manner to replace point-to-point connections and to increase visibility and controllability. Security would be addressed through dedicated communications channels, such as Virtual Private Networks (VPNs) and network slicing, as well as strong authentication provided by 5G end devices. Typical communication architecture solutions would consist of two domains: packet-switched networks and mobile networks. Packet-switched networks, such as IP/MLPS networks, are used to connect operation centers and primary substations. Mobile networks are used both for providing a communications channel to the required distribution network automation, which is relatively limited compared to Scenarios B2-B4, as well as for reading smart meters. In Scenario B1, mobile communications would provide connectivity for essential secondary substations or distribution transformer stations enabling monitoring and non-real-time control. Mobile networks could potentially also provide backup connections for primary substations. Well-established point-to-point connection solutions, such as Optical Ground Wires (OPGWs) in high voltage lines, would continue to play an essential role, for example, in line differential relay applications. The same would apply to Power Line Communications (PLC) as a last-mile solution for smart meter reading. Furthermore, cloud technologies would be used to a limited extent for extending the computing capacity of central operation centers.

Compared to Scenario B1, Scenarios B2 and B3 have a greater need for communications and information technology support for grid operations, both to improve the visibility needed to address the increased vulnerability and to manage the flexibilities. Scenario B2 would utilize mobile communications as a means to aggregate the extensive and numerous flexibilities. Mobile networks are particularly suitable for such retrofit cases due to their straightforward deployment without fixed cabling. Cloud networking would be used to address the distributed computing needs caused by aggregation of the flexibilities. Compared to Scenario B2, Scenario B3 has more consolidated flexibility sources. Although these must be used more frequently due to insufficient bulk generation, the required communications solutions would not be as extensive as in Scenario B2.

Scenario B4 *Highly distributed grid* very much differs from the current Finnish power grid, which is still predominantly top-down and relies on large synchronous generators and Nordic hydro-based balancing power. Scenario B4 extensively utilizes communications and information technologies to maintain oversight, supervision, and management capabilities, as well as to interconnect all distributed entities. In Scenario B4, large-scale sensoring is widely deployed to enable situational awareness, control capabilities are extended deep into the distribution network, and automatization of the distribution grid accelerates and includes new solutions. Some of these, such as line differential protection, require very low latencies and high reliability. Being agnostic to the power flow direction, line differential relays are suited for addressing the complex and varying fault current introduced by extensive distributed generation. Thus, Scenario B4 would clearly benefit from all three 5G generic service categories: eMBB and mMTC for monitoring, eMBB for close-to-real-time grid control, and URLLC for real-time grid control. Potential communications solutions could include (a) power grid specific mobile network slices for covering extensive geographical areas, and (b) substation-specific private mobile network deployments. These network slices would be parameterized to provide required service levels for very different service needs: large-scale monitoring and supervision, close-to-real-time control, and real-time control. Network slicing could also utilize Time-Sensitive Communications services and provide accurate timing for power grid devices, such as Phasor Measurement Units (PMUs). In contrast, substation-specific private mobile networks would enable extensive retrofit instrumentation within a limited geographical area. These wireless solutions, similar to factory installations, would provide deterministic communications and supply accurate timing to all active devices. Cloud-based data storage would allow all applications to operate based on the latest status information. Cloud edge would be deployed locally (e.g., at substation sites) to enable local processing for providing extremely low round trip times, while still being integrated into the overall cloud. All these mobile technologies would also be applicable in Scenarios B2 and B3, albeit to a lesser extent.

Fig. 11 outlines a potential high-level architecture for Scenario B4 *Highly distributed grid.* In this architecture, substations evolve into interacting computing platforms comprising a mesh network. They utilize commoditized computing hardware to run control and monitoring functions. These control and monitoring functions interact with power grid devices, such as merging units and switches. This arrangement is similar to the Software-Defined Networking (SDN) principle utilized, for example, in 5G networks [9]. Such an arrangement enables efficient management, as new functionality can be more readily added or existing updated. These “software-defined substations” form part of the edge cloud and interact with other substations over the mobile cloud to implement grid-level functionality. Each of the “software defined substations” utilizes a private mobile network for interconnectivity within the substation, as well as a wider mobile cloud to monitor and control the distribution grid.

Table 5 summarizes the extent of digitalization, as well as main communication and information technology capabilities envisioned in Scenarios B1-B4.

Scenarios A3 *New holistic service experience* and B4 *Highly distributed grid* utilize communication and information technology capabilities most intensively but for different reasons and to some extent with an emphasis on different technologies. Scenario A3 is consumer-centric, as it provides consumers with an easy way to manage and optimize their services related to heat, light, and transportation. Thus, the consumer

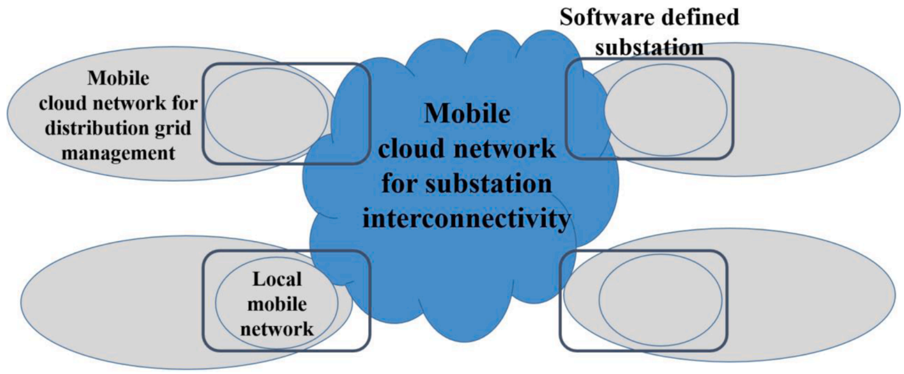

Fig. 11. Potential architecture for Scenario B4 *Highly distributed grid.*

Table 5
The extent of digitalization and communication technologies in the "grid-level generation capacity and balancing power" perspective.

	B1	B2	B3	B4
Wireless solutions used in grid monitoring applications	++	+++	++	++++
Wireless solutions used in non-real-time grid control applications	+	+++	++	++++
Wireless solutions used in the most critical real-time grid control applications	0	+	+	+++

can utilize the same means as they use in other daily activities, such as the managing of their finances or entertainment needs. Cloud and mobile app technologies are the key technologies for implementing such services. Furthermore, intensive, customer-focused digitalization paves the way for new entrants to introduce totally new business models. In contrast, Scenario B4 is grid management-centric, since it uses automation extensively for real-time grid balance management and for providing an overview of a highly complex system. For managing this complexity, proactive real-time system state forecasting would be extensively used to identify upcoming grid stability issues and to propose solutions to address these. The required communications infrastructure investment and operational costs in Scenario B4 would be significant due to the size of the distribution grids. Consequently, the outcome of the uncertainty 2U5 "Citizens are able or willing to finance required investments?" impacts essentially Scenario B4. As stated in Section 3, the research on 6G networks is in the very early stages. Some of the themes of that research, such as the possibility of combining functionality from different service categories in a flexible manner, cell-less access and grant-free access, are potentially very relevant to power grids. For example, combining URLLC and mMTC functionality could enable ultra-low latency access to numerous sensoring devices for real-time control. Cell-less access could enable flexible usage of different access networks, such as satellite links, while grant-free access could enable efficient, large-scale low-power sensoring. Unlike Scenarios A3 and B4, Scenarios A1 *Current grid with technically mandatory enhancements* and B1 *Top-down grid* exploit communication and information technology capabilities the least. Mobile communications offer an alternative communications channel, which is particularly compelling in cases requiring retrofitting. Again, the reasons are different: Scenario A1 envisions no consumer demand for new services, while Scenario B1 would require no additional complex management capabilities, nor would it introduce any increased costs as well.

8. Concluding remarks

8.1. Discussion

In all scenarios identified in this paper, power grids and communications can be expected to become more tightly integrated. Digitalization in industrial applications is progressing, but at an uneven pace in different industries [81]. A digitalization index was introduced by McKinsey&Company [81]for industries in the United States. The index shows that the electric power industry is one of the industries that could benefit most from digitalization. This would apply both in terms of (a) managing the physical grid and its assets and (b) engaging more deeply with the customers. This resonates well with the scenarios B2-B4 (Grid level generation capacity and balancing power perspective) and scenarios A2-A3 (Service leapfrog perspective), respectively.

The power grid and communications industries both deal with networked infrastructures. Thus, going forward, similarities could also be expected in the business model evolution of these two industries. Power grids and communications both include operations that are regulated natural monopolies. Power grid distribution and transmission is an even stricter natural monopoly, since communications often includes a viable choice, particularly in the access network. In the communications industry, the EU's net neutrality rules introduced in 2015 stipulate the separation between (1) regulated, monopolistic bit transmission and (2) content, application, and services carried on top of transmission [82]. In power grids, the EU's Energy Packages have, since 1996, started to separate regulated electricity transmission and distribution from energy sales [83].

In the communications industry, one could say that the liberalization took place "despite the regulator" during the 1990s and early 2000s, due to the wide deployment of the TCP/IP protocol and the advent of the Internet. This was followed by innovative start-ups providing new services and applications. Gradually, these start-ups grew to be giants. Subsequently, cloud-based, virtualized applications emerged. Despite their efforts, the role of traditional telecom operators was mostly limited to being "bit pipes". In the electricity industry, the evolution has been the other way around. The separation was enforced by regulation. Even though the electric energy sector has made efforts to develop new business models and service concepts, so far we have not seen a similar breakthrough as has occurred in the communications industry. Nevertheless, virtual energy storage offered by some energy companies is an example of a new, innovative service concept. This new concept allows the consumer to "store" electricity produced, for example, by solar panels in the grid and to use it later. This could be seen as conceptually analogous to the Internet's cloud storage. Another analogy could be found in the evolution of network architecture. The electric power grid is becoming more meshed and dynamic, a phenomenon closely resembling the emergence of the Internet more than twenty years ago.

8.2. Summary

The novelty and contribution of this paper is to analyze the current and potential convergence between power grids and mobile communications in multiple, different power grid evolution scenarios created by using a formal scenario planning process. This process resulted in two scenario perspectives: (1) the service or customer-centric perspective and (2) grid management perspective. One aspect impacting the service and customer-centric scenarios (A1-A3) is the strategy adopted by global giants, or to-be-giants, and their interest in the Finnish electricity market. Evolution of controllable bulk generation capabilities and a possible breakthrough in large-scale power-to-x/x-to-power deployments could influence the likelihood of grid management related scenarios (B1-B4) and the nature of the grid management challenge. Furthermore, the scenario planning process revealed some highly disruptive, black swan type of developments. If some of these materialize, they will make some scenarios more likely than others. Possible disruptive developments could include radically decreasing support for climate change actions due to unpredicted events, such as long-term financial difficulties, or blackouts caused by the increased grid management challenge or cybersecurity attacks.

Mobile communications and cloud computing are important enablers in evolutionary scenarios A2, B2 and B3, and key enablers in the two most transformative scenarios A3 (*The new holistic service experience)* and B4 (*The highly distributed grid)*. In these scenarios, mobile communications offer a flexible, cost-effective way to rapidly increase and improve connectivity within the power grid. If mobile network product implementations can meet the challenging reliability targets required in current and future 3GPP specifications, mobile communications can be used even for the most critical applications, such as grid protection. In the customer-centric scenarios A2-A3, cloud computing offers the framework for providing new services. In the grid management scenarios B2-B4, cloud computing offers the framework for distributed computing solutions needed to address both heavily increasing computing needs and low latencies. The scenarios revealed important directions for further research, such as evaluating the scenarios in terms of the increased costs and the potential opportunities to create more focused applications for power grids by merging functionality from currently specified 5G service categories. Furthermore, upcoming heterogeneous access technologies, such as WiFi and satellite links, open up new possibilities to power grids that have both large geographical coverage in often remote places, as well as a high concentration of active devices, as is the case with major substations.

These scenarios and their likelihood are dependent on country-specific issues. Currently, it appears that the controllable bulk generation capacity in Finland could be increasing due to the addition of new nuclear power plants. Furthermore, it seems there will be an essential expansion in wind power capacity. Due to ongoing investments in transmission and distribution infrastructure, the grid can be expected to remain strong. In terms of the balancing power, increasing integration of European power grids can result in increased competition for nearby Nordic hydropower. Finland's small market size might impact the interest of global giants to introduce new services. If mobile communications networks in Finland continue to evolve and remain strong, it would also pave the way for more extensive use of mobile communications, even in the most critical applications reflected in the evolutionary (A2, B2, and B3) and the most transformative (A3 and B4) scenarios.

CRediT authorship contribution statement

Seppo Borenius: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – original draft, Visualization, Project administration. **Heikki Hämmäinen:** Methodology, Formal analysis, Resources, Writing – review & editing. **Matti Lehtonen:** Supervision, Resources, Writing – review & editing. **Petri Ahokangas:** Formal analysis, Writing – review & editing.

Declaration of Competing Interest

None.

Acknowledegements

This work was supported in part by the Finnish public funding agency for research, Business Finland under the project “5G VIIMA”, grant number 6430/31/2018. 5G VIIMA is part of 5G Test Network Finland (5GTNF).

References

[1] CEN-CENELEC-ETSI Smart Grid Coordination Group, Smart grid reference architecture, November 2012.
[2] M. Uslar, S. Rohjans, C. Neureiter, et al., Applying the Smart Grid Architecture Model for Designing and Validating System-of-Systems in the Power and Energy Domain: A European Perspective, Energies 12 (2019) 258.
[3] Y. Xu, P. Ahokangas, J.-N. Louis, E. Pongrácz, Electricity market empowered by artificial intelligence: a platform approach, Energies 12 (2019) 4128.
[4] ENTSOG and ENTSO-E, TYNDP Scenario report, June 2020.
[5] European Commission, Joint Research Center (JRC): Global Energy and Climate Outlook 2019: electrification for the low-carbon transition, 2020.
[6] Ministry of Economic Affairs and Employment:, Final report of the Smart Grid Working Group, 2018, 24 October.
[7] Global mobile Suppliers Association (GSA), Evolution from LTE to 5G, August 2020.
[8] The 3rd Generation Partnership Project (3GPP), Releases. Available: www.3gpp.org/specifications/67-releases. Accessed: 10.6.2020.
[9] Qualcomm, Future of 5G - Building a unified, more capable 5G air interface for the next decade and beyond, February 2020.
[10] Ericsson:, 5G New Radio Evolution, Ericsson Technol. Rev. 2 (2020).
[11] Nokia, 5G Releases 16 and 17 in 3GPP White Paper, 2020.
[12] Fingrid, Verkkovision skenaarioluonnokset (Draft scenarios for the network vision), 28.8. 2020.
[13] G. Wikström, J. Torsner, J. Kronander, O. Al-Saadeh, F. Chernogorov, G. Bag, J. Neander, K. Landernäs, P. Hovila, Wireless protection of power grids over a 5G Network, IEEE PES GTD Asia (2019).
[14] P. Hovila, P. Syväluoma, H. Kokkoniemi-Tarkkanen, S. Horsmanheimo, S. Borenius, M.A. Uusitalo, Zexian 5G Networks enabling new smart grid protection solutions, in: 25th International Conference on Electricity Distribution CIRED, 2019, 3-6 June.
[15] A.E.L. Rivas, T. Abrão, Faults in smart grid systems: monitoring, detection and classification, Elsevier Electr. Power Syst. Res. 189 (2020).
[16] G. Bag, L. Thrybom, P. Hovila, Challenges and opportunities of 5G in power grids, in: 24th International Conference on Electricity Distribution CIRED, 2017, 12-15 June.
[17] S.R. S, T. Dragicevic, S.R. Sahaya Pierluigi Siano, S.R.S. Prabaharan, Future generation 5GWireless networks for smart grid: a comprehensive review, Energies (2019), 4 June.
[18] M. Ghorbanian, S.H. Dolatabadi, M.M.P. Siano, Communication in smart grids: a comprehensive review on the existing and future communication and information infrastructures, IEEE Syst. J. 13 (NO. 4) (2019). December.
[19] Statistics Finland, Population. Available: www.stat.fi/til/vrm_en.html. Accessed 24.8. 2020.
[20] National Land Survey of Finland, Pinta-alat kunnittain, Surf. Community (2020), 1.1.
[21] Statitics Finland, National accounts. Available: www.stat.fi/tup/suoluk/suoluk_kansantalous_en.html. Accessed: 24.8. 2020.
[22] Statistics Finland, Ilmasto – Vuositilastot, Climate -Yearly statistics). Available: www.ilmatieteenlaitos.fi/vuositilastot. Accessed 24.8. 2020.
[23] Tilastokeskus (Statistics Finland), Total energy consumption. Available: www.stat.fi/tup/suoluk/suoluk_energia_en.html. Accessed 24.8. 2020.
[24] Energiateollisuusry, Energiavuosi 2019, Sähkö, (Finnish Energy: Energy year 2019, Electricity), 3.1.2020. Available: energia.fi/files/4360/Sahkovuosi_2019_mediakuvat.pdf, Accessed: 25.8.2020.
[25] Energiavirasto, Sähkön toimitusvarmuus vuonna 2019, (Finnish Energy Authority: Power Supply Security in 2019), 28.11. 2019.
[26] Finnish Windpower Association, Windpower Projects in Finland - Projects under planning, February 2020. Available: tuulivoimayhdistys.fi/en/wind-power-in-finland/projects-under-planning. Accessed 25.8.2020.
[27] Fingrid, Fingrid to invest a record EUR 2 billion in the main grid, 27.11. 2020. Available: www.fingrid.fi/en/pages/news/news/2020/fingrid-to-invest-a-record-eur-2-billion-in-the-main-grid/. Accessed 26.8.2020.
[28] J. Ruusunen, Sähkötehon riittävyys, Huoltovarmuuden uudet kysymykset energiamurroksessa, (Sufficiency of electric power - Security of supply in the energy transition, Fingrid (2019), 17.4.
[29] Tilastokeskus (Statistics Finland), Electricity generation capacity in peak load period in the beginning of the year 2019. Available: www.stat.fi/til/ehk/2018/04/ehk_2018_04_2019-03-28_kuv_019_en.html. Accessed 26.8.2020.
[30] Fingrid, Electricity system of Finland. Available: www.fingrid.fi/en/grid/power-transmission/electricity-system-of-finland/. Accessed: 26.8. 2020.
[31] Energiavirasto, Verkkotoiminnan luvanvaraisuus, (Finnish Energy Authority: Grid operations licences). Available: energiavirasto.fi/verkkotoiminnan-luvanvaraisuus. Accessed 26.8. 2020.
[32] Finnish Energy, Towards a smart energy system. Available: energia.fi/en/advocacy/energy_policy/energy_networks. Accessed 26.8. 2020.

[33] T. elinkeinoministeriö, Seuraavan sukupolven älykkäiden sähkömittareiden vähimmäistoiminnallisuudet (Ministry of Economic Affairs and Employment, Smart Grid Working Group: Minimum requirements for the next generation smart meters), 15.12. 2017.
[34] Lappeenranta-Lahti University of Technology: Electricity customer and electricity distribution network 2030, 31 March 2019.
[35] National Emergency Supply Agency, Huoltovarmuus energiamurroksessa (Security of Supply in the Energy Transition), 29 May 2019.
[36] Technology industries of Finland, Teknologiateollisuuden vähähiilitiekartta 2035 (Low carbon roadmap until 2035 by Technology Industrioes of Finland), 8.6. 2020.
[37] The 3rd Generation Partnership Project (3GPP), About 3GPP, 2020. Available: www.3gpp.org/about-3gpp. Accessed 8.9.2020.
[38] The 3rd Generation Partnership Project (3GPP): 3GPP features and study items, 2020. Available: www.3gpp.org/DynaReport/FeatureListFrameSet.htm. Accessed 8.9.2020.
[39] ATIS, 5G Standards Developments in 3GPP Release 16 and Beyond, September 2020.
[40] International Telecommunications Union (ITU), Report ITU-R M.2410-0, 2017. November.
[41] The 3rd Generation Partnership Project (3GPP):, TR 22.804 V16.3.0, 2020. July.
[42] The 3rd Generation Partnership Project (3GPP), 3GPP SA6 accelerates work on new verticals!, June 7, 2019. Available: www.3gpp.org/news-events/2045-sa6_verticals. Accessed 8.9.2020.
[43] The 3rd Generation Partnership Project (3GPP), Mission Critical Services in 3GPP, June 20, 2017. Available: www.3gpp.org/news-events/3gpp-news/1875-mc_services. Accessed 8.9.2020.
[44] IEEE 802.1, Time-Sensitive Networking (TSN) Task Group. Available: 1.ieee802.org/tsn/. Accessed 8.9. 2020.
[45] 5G Alliance for Connected Industries and Automation (ACIA), 5G Non-Public Networks for Industrial Scenarios, White paper, July 2019.
[46] T. Taleb, R.L. Aguiar, I.G.B. Yahia, et al., White Paper on 6G Networking, 6G Res. Vis. 6 (2020). University of Ouluhttp://urn.fi/urn:isbn:9789526226842.
[47] W. Jiang, B. Han, M.A. Habibi, et al., The road towards 6G: a comprehensive survey, IEEE Open Access J. Commun. Soc. 2 (2021).
[48] Q. Bi, Ten Trends in the Cellular Industry and an Outlook on 6G, IEEE Commun. Mag. Vol. 57 (No. 12) (2019). December.
[49] J.R. Bhat, S.A. Alqahtani, 6G Ecosystem: current status and future perspective, IEEE Access 9 (2021).
[50] H. Tataria, M. Shafi, A.F. Molisch, 6G wireless systems: Vision, requirements, challenges, inasights, and opportunities, Proc. IEEE (2021). February.
[51] M. Giordani, M. Polese, M. Mezzavilla, S. Rangan, M. Zorzi, Toward 6G networks: use cases and technologies, IEEE Commun. Mag. 58 (No. 3) (2020). March.
[52] M. Matthaiou, O. Yurdunsen, H.Q. Ngo, The road to 6G: then physical layer challenges for communications engineers, IEEE Commun. Mag. 59 (No. 1) (2021). January.
[53] E. Peltonen, M. Bennis, M. Capobianco, M. Debbah, et al., 6G White Paper on Edge Intelligence, (6G Research Visions, No. 8), Univ. Oulu (2020). http://urn.fi/urn:isbn:9789526226774.
[54] Finnish Transport and Communications Agency Traficom, Frequencies and license holders of public mobile networks, 29.10. 2020. Available: www.traficom.fi/en/communications/communications-networks/frequencies-and-license-holders-public-mobile-networks. Accessed 14.9.2020.
[55] Finnish Transport and Communications Agency Traficom, Mobile network coverage, 6.7.20. Available: www.traficom.fi/en/communications/broadband-and-telephone/mobile-network-coverage. Accessed 14.9. 2020.
[56] H. Himmanen, Paikalliset 5G-verkot (Local 5G-networks), Finn. Transp. Commun. Agency Traficom (2020), 5.11. Available: www.traficom.fi/sites/default/files/media/file/Heidi%20Himmanen_Paikalliset%205G%20verkot%20.pdf. Accessed 14.9.2020.
[57] S. Wirén, Finland's 5G spectrum regulatory status, Minist. Transp. Commun. (2018). December 18 Available: www.oulu.fi/sites/default/files/events/Sini%20Wir%C3%A9n.pdf. Accessed 14.9.2020.
[58] Telia, Missä 5G-verkko kuuluu? (What is the 5G coverage area?). Available: www.telia.fi/5g/5g-verkko-laajenee. Accessed 14.9. 2020.
[59] Elisa, Elisan 5G laajenee jatkuvasti (Elisa's 5G network expands continuously). Available: /elisa.fi/5g/5g-verkko. Accessed 14.9. 2020.
[60] DNA, Jo liki kolmannes suomalaisista DNA:n 5G-verkon piirissä – näin verkko laajenee vuonna 2021 (Already close to one third of the population has 5 G coverage). Available: corporate.dna.fi/lehdistotiedotteet?type=stt2&id=69895825&scrollTo=UJpEOgFgPw1f. Accessed 14.9.2020.
[61] Ministry of Transport and Communications, 5G spectrum auction concluded, 8.6. 2020. Available: valtioneuvosto.fi/-/5g-taajuuksien-huutokauppa-paattyi?languageId=en_US. Accessed 15.9.2020.
[62] Finnish Transport and Communications Agency Traficom, Use of the frequency band 2300 - 2320 MHz, 13.11. 2020. Available: www.traficom.fi/en/communications/communications-networks/use-frequency-band-2300-2320-mhz. Accessed 16.9.2020.
[63] T. Stevenson, T: Anticipatory action learning: Conversations about the future, Futures 34 (2012) 417–425.
[64] S. Inayatullah, Causal layered analysis. Poststructuralism as method, Futures 30 (1998) 815–829.
[65] S. Inayatullah, Anticipatory action learning: Theory and practice, Futures 38 (2005) 656–666.
[66] P.J.H. Schoemaker, Scenario planning: a tool for strategic thinking, Sloan Manage. Rev./Winter (1995).
[67] M. Amer, T.U. Daim, A. Jetter, A review of scenario planning, Futures (2012). Elsevier.
[68] Reuters, France's EDF buys UK electric vehicle infrastructure firm Pivot Power, November 4, 2019. Available: www.reuters.com/article/us-edf-electric-pivot/frances-edf-buys-uk-electric-vehicle-infrastructure-firm-pivot-power-idUSKBN1XE0NS. Acceesed12.6.2020.
[69] Meister, EON unveils electric vehicle collaboration with ALD Automotive, 13.2. 2019. Available: meisterproject.eu /eon-unveils-electric-vehicle-collaboration-with-ald-automotive/. Accessed 12.6.2020.
[70] Electrek, Tesla smart home HVAC: Elon Musk considers the new product again, March 24,2020. Available: electrek.co/2020/03/24/tesla-smart-home-hvac-elon-musk-considers-new-product/. Accessed 12.6.2020.
[71] Wall Street Journal, Google, Amazon Seek Foothold in Electricity as Home Automation Grows, January 27, 2019. Available: www.wsj.com/articles/google-amazon-seek-foothold-in-electricity-as-home-automation-grows-11548604800. Accessed 12.6.2020.
[72] Forbes, Amazon and google launch secret plot to power your home, February 27, 2019. Available: www.forbes.com/sites/jonmarkman/2019/02/27/amazon-and-google-launch-secret-plot-to-power-your-home/#40b332a06aa8. Accessed 12.6.2020.
[73] Worlds Nuclear Association, Small nuclear power reactors, March 2020. Available: www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/small-nuclear-power-reactors.aspx. Accessed 16.6.2020.
[74] ITER, Building ITER, 29.2.2020. Available: www.iter.org/construction/construction. Accessed 16.6.2020.
[75] H. Laaksonen, Sähköjärjestelmä murroksessa – miten käy kuluttajan, tuottajan ja sähköverkon haltijan?, (Electric power system in transition – what does happens to the consumer, the producer and the grid owener), Univ. Vaasa 14 (2018), 11.
[76] J. Ruusunen, Huoltovarmuus ja energia (Security of suplly and energy), Fingrid (2020), 30.3.
[77] Forbes, 5G: the next battleground for microsoft and google, April 6, 2020. Available: www.forbes.com/sites/maribellopez/2020/04/06/5g-the-next-battleground-for-microsoft-and-google/?sh=3bc6271a55fe. Accessed 17.6.2020.
[78] Lightreading, Public cloud providers seek closer collaboration with telcos, September 28,2020. Available: www.lightreading.com/public-cloud-providers-seek-closer-collaboration-with-telcos/d/d-id/764266. Accessed 17.6.2020.
[79] Ericsson, Cloud infrastructure. Available: www.ericsson.com/en/portfolio/digital-services/cloud-infrastructure. Accessed 21.9.2020.
[80] Nokia, Nokia dynamic enterprise services. Available: www.nokia.com/networks/dynamic-enterprise-services/cloud-services/. Accessed 22.9. 2020.
[81] McKinsey Global Institute, Digital America: A tale of the Haves and Have-Mores, December 2015.
[82] BEREC, Berec guidelines on the implementation by national regulators of european net neutrality rules, August 1026, 2000.
[83] European Union, Internal energy market, February 2020. Available: www.europarl.europa.eu/factsheets/en/sheet/45/internal-energy-market. Accessed 8.6.2020.