5G Solutions: Opportunities and New Business Models for Energy and Mobility

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About SPARCS

Sustainable energy Positive & zero cARbon CommunitieS demonstrates and validates technically and socioeconomically viable and replicable, innovative solutions for rolling out smart, integrated positive energy systems for the transition to a citizen centred zero carbon & resource efficient economy. SPARCS facilitates the participation of buildings to the energy market enabling new services and a virtual power plant concept, creating VirtualPositiveEnergy communities as energy democratic playground (positive energy districts can exchange energy with energy entities located outside the district). Seven cities will demonstrate 100+ actions turning buildings, blocks, and districts into energy prosumers. Impacts span economic growth, improved quality of life, and environmental benefits towards the EC policy framework for climate and energy, the SET plan and UN Sustainable Development goals. SPARCS co-creation brings together citizens, companies, research organizations, city planning and decision making entities, transforming cities to carbon-free inclusive communities. Lighthouse cities Espoo (FI) and Leipzig (DE) implement large demonstrations. Fellow cities Reykjavik (IS), Maia (PT), Lviv (UA), Kifissia (EL) and Kladno (CZ) prepare replication with hands-on feasibility studies. SPARCS identifies bankable actions to accelerate market uptake, pioneers innovative, exploitable governance and business models boosting the transformation processes, joint procurement procedures and citizen engaging mechanisms in an overarching city planning instrument toward the bold City Vision 2050. SPARCS engages 30 partners from 8 EU Member States (FI, DE, PT, CY, EL, BE, CZ, IT) and 2 non-EU countries (UA, IS), representing key stakeholders within the value chain of urban challenges and smart, sustainable cities bringing together three distinct but also overlapping knowledge areas: (i) City Energy Systems, (ii) ICT and Interoperability, (iii) Business Innovation and Market Knowledge.

Partners

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1. INTRODUCTION

The development of smart city solutions is a central theme within the SPARCS project, the Espoo development strategy, and the transformation towards carbon-neutrality in general. These smart city solutions aim towards the improvement of city functions, such as healthcare, security, and energy, while providing a foundation for sustainable digital services. This development process requires an expanded telecommunications infrastructure within the urban environment, as the capacity of current mobile networks is insufficient for the substantial increase of communication needed as smart city solutions increase in scale. [1] The research and development (R&D) activities to further the take-up of 5G, and 5G-linked services, can be a key enabler for future smart city development.

5G can provide a resilient network with low latency and high bandwidth for mobile users, while a local small cell network can enable scaling up to a large quantity of users within a more limited urban area. [1], [2] Edge computing can enable the distribution of computing and storage infrastructure closer to the user, providing even lower latency and higher scalability for local smart infrastructure solutions. In addition, 5G can enable the development of new network services for public entities, companies, network operators and citizens within e.g., data as a business and network slicing. [1] The new data services provide a new problem for smart cities to solve: The impartial ownership of data to provide unbiased sale and sharing for different actors, while protecting the right for privacy.

Different development and research projects within Finland and the City of Espoo have been implementing innovative pilots in the field of 5G. These pilots are testing 5G communication, physical small cell infrastructure and connected operation models needed for a smart city. These development projects include LuxTurrim5G, piloting a 5G small cell infrastructure within an urban environment, and Neutral Host Pilot, piloting the connected operation models and data services.

To aid in assessing the role of 5G within smart city development activities in Espoo, the Espoo SPARCS project team prepared this report to investigate the opportunities of 5G for energy and mobility, the key themes of the project. The main questions that this report aims to assess are as follows: How crucial will 5G be in the development of smart city services in Espoo, what kind of opportunities can 5G provide within Espoo when compared to current mobile network infrastructure, how can 5G technology aid in the implementation of the Espoo Story, and how will the ecosystems around 5G need to be developed to gain the desired benefits of the technological advancement?

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2. Relevance of 5G in SPARCS

This section will explain the relevance of 5G within SPARCS activities. This will be done via a detailed look into the different actions and plans in the grant agreement and further deliverables, with a focus on Kera due to other relevant ongoing and finalized projects within the demonstration area. Within the Grant Agreement, the Kera demonstration area is explained as follows:

> *"The goal of the demonstration block is to act as a testbed for co-creation and infrastructure building towards a resilient, sustainable and smart energy positive area. Infra solutions will include a bidirectional electricity grid, 5G platform, emission-free energy, and open district heating system (heating energy consumers acting as prosumers). Kera is also planned to become a testbed for a 5G network based on sensors and antennas installed in lampposts and already being tested in the northern parts of the area."*

As can be seen, 5G has been specifically mentioned as a possible building block for Kera to emerge as a resilient, sustainable, and smart Positive Energy District (PED) in the future. The possibilities of 5G within Kera is looked at in intervention E12 – ICT for positive energy blocks within the Kera interventions and is closely linked to two actions: E12-1, looking into 5G and smart infrastructure and E12-2, looking into 5G and mobility.

Figure 1 below shows the detailed plan devised to meet action E12-1 from deliverable D3.1. The action focuses on opportunities offered by 5G networks towards smart infrastructure solutions in Kera and elsewhere. The aim is to investigate and document these opportunities for possible future use locally, nationally, and internationally.

Action E12-1	**Smart infrastructure 5G. Investigating opportunities offered by the Kera digital platform and local district 5G network for management of the smart power grid, optimization, bi-directional energy flows, energy demand side management and demand flexibility.**
Detailed plan	• Investigate and document current 5G projects in Kera. • Identify opportunities for synergies in energy efficiency, DSM, prosumer. transactions and innovative business models. • Map and engage key stakeholders. • Document findings, report and communicate.
Targeted outcome	Energy performance optimisation requires automation and smart solutions to ensure energy savings, cost effectiveness and reliable operation. 5G infrastructure facilitates smart energy.
Roles and responsibilities	ESP: Main responsibility. Stakeholders
Schedule	M15 Current projects documented M25 Opportunities identified, stakeholders mapped and engaged M30 Findings reported
KPIs	Number of new solutions with 5G utilisation

Figure 1: Detailed plan of action E12-1

Figure 2 below shows the detailed plan devised to meet action E12-2 from deliverable D3.1. The action focuses on opportunities offered by 5G networks towards smart mobility solutions in Kera and elsewhere. The aim is to investigate and document these

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opportunities for possible future use locally, nationally, and internationally. This document provides a theoretical viewpoint, answering a portion of the questions raised in Figure 2. Discussions between the SPARCS project team and Kera area development partners are presented in a separate document, focusing on a 5G and mobility survey devised during the project. V2G and charging infrastructure requirements are inspected in more detail within actions E2-1 and E18-1.

Action E12-2	5G as service enabler. Developing new service models for autonomous transport and e-mobility linked to the local 5G network, solutions enabling the use of car batteries as energy reserve and the operation of autonomous transport. (ESP, stakeholders)
Detailed plan	Identify smart infrastructure requirements for autonomous transport and e-mobility. Open discussion with smart city Kera area development, relevant stakeholders and ongoing projects developing autonomous transportation and 5G technologies in Kera (including LuxTurrim5G+ / Neutral Host Pilot -project; Six Cities: Low-carbon transport in mobility hubs -project). Estimate car battery capacity available for energy reserves in different scenarios.
Targeted outcome	Car batteries and smart charging can improve power balance and reduce emissions and costs. 5G technologies can support the use and operation of autonomous transportation and enable e-mobility in local networks.
Roles and responsibilities	ESP: Main responsibility.
Schedule	M3-12 Opening discussion with relevant stakeholders. M12-36 Assessment of car battery solutions. Assessment of local 5G network in the operation of autonomous transportation.

Figure 2: Detailed plan of action E12-2

Action E12-1 will focus on the opportunities offered by 5G towards a more intelligent and optimized power grid, while also mapping the key stakeholders of future development activities. In turn, action E12-2 will focus on autonomous transport, e-mobility, and Vehicle-to-Grid (V2G) solutions. Both actions aim to prove that 5G technology can enable new opportunities within these themes. To achieve these aims, this report will provide a literature review, examples of current projects and solutions, and possible opportunities within Kera and Espoo.

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3. The Role of 5G in Smart City Development: Energy

As this report focuses on the opportunities provided by 5G to smart city development, a look into the technological advancements provided by 5G towards this transition is needed. As noted in the grant agreement, SPARCS will specifically focus on the energy and mobility sectors. This section will provide a look into the energy sector, while the next section will focus on mobility. For the energy sector, the role of 5G in developing smart grid solutions for the transition towards a smart bidirectional energy grid was determined to be the focus of this study.

3.1 5G and the smart grid

The power grid has traditionally been a top-down system, where electricity is generated upstream in large scale power plants and sold downstream to the consumer according to their consumption. However, the integration of renewables into the current power grid in addition to other smart solutions require the improvement of the grid itself into a more dynamic and complex system, with bi-directional functionalities to facilitate energy sales from consumers back to the grid [3]. 5G could aid in enhancing the current power grid to a smart system. In addition, the electrification of the transport, industrial and heating sectors will drive a large increase in grid usage, with widely differing use conditions compared to the traditional system. For example, Huawei defines the future of the smart grid via three key challenges and opportunities [4]:

- *"New energy: The large-scale deployment of renewable energy brings new challenges to the operation and management of power grids. The intermittent and random power generation of renewable energy brings difficulties to load balancing and operational control."*
- *"New users: The rapid development of electric vehicles increases requirements for available charging capacity."*
- *"New requirements: New devices and new scenarios require higher quality of consumption. For example, some high-tech digital devices require zero interruption of power supply. In addition, requirements for asset utilization efficiency are gradually increasing from the perspective of power grid operation."*

Within report [5], an analysis on the importance of mobile communication technologies to the Finnish power grid is explained under different scenarios. Mobile networks are seen as a key enabler in two of the seven scenarios, and an important enabler in three of the seven scenarios. So, mobile communications are seen as an enabler in five of the seven scenarios in total. However, this report does not differentiate between 5G and previous communication systems in this analysis. Within [6], six advantages of 5G for smart grids are explained, reliable and fast bidirectional communication for the control of renewables, data monitoring and visualization on a constant pace, real-time time-critical computing, fully automated power networks, edge computing for increased efficiency and increased network security.

According to [7], communication services within a smart grid can be divided between two categories, control and collection. The control category includes services that help control grid functions, such as grid protection, automation, load control and inspection [7]. In

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turn, collection means collection, metering, and monitoring of power system data. The report also provides examples of most promising applications for 5G, including power distribution automation, accurate load shedding, transmission line inspection, intelligent patrols, and electricity consumption information collection. In addition to this report, [8] notes that precise monitoring and control are the main enablers of new communication technologies within the smart grid. The report notes that new communication solutions in the distribution grid are important within the sectors of automated meter reading, Demand Side Management (DSM), the monitoring and control of distributed resources and EV charging. In the transmission grid, the report notes that solutions will focus on time-critical protection and control. Historically, both wired and wireless communication solutions have been used. Within [9], differential protection, distributed energy resources, microgrids, advanced metering, distributed feeder automation and drone solutions are marked as the most promising services for 5G usage. Within [10], possible 5G use cases are divided between three service clusters, identified here as scenarios. The high-capacity business cluster contains user integrated load forecasting and power grid operation state perception, while the high bandwidth service cluster contains photovoltaic forecasting and real-time monitoring of High Definition (HD) imaging. Thirdly, the low latency service cluster contains real-time frequency modulation of demand-side resources and precise control of participating resources.

Network slicing is an integral new feature of 5G for smart grids. Network slices are defined as multiple virtual networks with differing requirements, situated within a single physical network [11]. 3GPP has defined four standardized slice types, Enhanced Mobile Broad Band (eMBB), Ultra-reliable and Low Latency Communications (URLLC), Massive Internet of Things (mIoT) and Vehicle to Everything (V2X). The power sector has services in three of these four standardized slices, excluding V2X [9], [10]. This report also notes other possible sections of a smart grid 5G architecture, 5G LAN, 5G-based time synchronization, and differentiated isolation. Within [10], the heterogenous network technology, large-scale MIMO, green communication technology and millimeter wave communication are specified as key technological aspects of 5G for smart grids.

From the information gathered from the previously mentioned reports, a shortlist of identified use cases of 5G within smart grids can be devised. This shortlist can be seen in Table 1 below.

Use Case	User	Additional Information
Distribution automation	Distribution System Operator (DSO)	5G can be utilized to monitor and automatically control equipment and loads connected to the grid widely and on an ultra-low latency
Grid protection	Distribution System Operator (DSO), Transmission System Operator (TSO)	5G can provide guaranteed low latency for automated fault location, isolation, and grid protection.

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Predictive Grid Maintenance	Utility Company, System Operators (DSO and TSO)	5G can provide opportunities for utilizing real-time data and drones in maintenance operations
Load Balancing, Control and Forecasting of renewables	Energy Community Operator, Utility Company	Increase of renewable generation leads into a more complicated grid where the number of producers grows significantly and energy flows bidirectionally. 5G can aid in the control, monitoring and forecasting of these assets while ensuring reliable communication from these assets themselves.
Enhanced Use of Data and Smart Devices such as Smart Meters	Residents, Utility Companies, Distribution System Operator (DSO), Service Providers	5G can ensure high capacity while the number of smart devices and the amount of data increases. For example, 5G can aid in providing more value from the smart meters utilized in Finland by providing real-time information to consumers and creating new data-based services.

Table 1: 5G use cases within the smart infrastructure segment

As mentioned previously in this section, smart grids can be seen as an enabler for many of the smart and sustainable solutions researched in SPARCS and beyond. However, this will create several challenges for the grid to beat, such as the increased number of generation units due to decentralization, bi-directional electricity flows due to new prosumer-based business models and more complex generation and consumption patterns due to intermittent generation and DSM measures [3]. This added complexity will require a grid with interwoven information technologies and solutions to provide better control and measurement of grid condition while providing quick fault location in a more complex environment. In turn, more accurate and faster communication solutions need to be implemented to accommodate this change [3], as the volume of smart devices collecting, monitoring, analyzing, and sharing data increases substantially. The utility companies, being the main stakeholders in the construction and operation of the current energy system, will increasingly utilize this data to enhance their own operative services and services towards their customers [12]. Several of the use cases noted in Table 1 provide examples on the services that are made possible towards these providers.

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Residents can also gain value from the enhanced operation of smart meters, which in turn accommodate the increase of P2P trading opportunities, thus leading to a possibility of residents becoming prosumers instead of solely consumers of energy. This will most probably lead to an increased number of people who sell energy back to the grid while continuing to purchase energy from traditional utilities when needed. This development is expected to happen both in electricity and in heating grids, where consumers can increasingly sell waste heat back to the utilities as future technologies aid in easier waste heat utilization.

It must be noted that measuring grid condition through smart metering is already possible today with current network solutions, as smart meters within a static power grid most often do not require the low-latency solutions provided by 5G [13]. Currently, 99.6% of the consumption points within the Finnish low voltage distribution network are already equipped with smart meters that operate without the aid of 5G [5]. Most often, these meters use either Power Line Communication (PLC) or mobile network solutions for data transfer [14]. However, as the grid grows to be increasingly smarter by time, the current solutions will not suffice as the amount of communicating parts of the grid increases and new innovative services are implemented [5].

In addition, 5G will provide increased reliability and security to the grid in case of faults caused by technical issues or cyberattacks [13]. 5G provides three key benefits to achieve more reliable communication. Firstly, it utilizes User Plane Function (UPF) to increase reliability in data transfer and enable data processing at the edge of the network [3]. Secondly, 5G provides a new radio interface with better reliability and shorter delays, with Ultra-Reliable and low-latency communications (URLLC) as a specific service to provide reliable communication to critical services ([15]; [16]; [17]). To provide these differing services, 5G utilizes network slicing as a solution to guarantee the performance levels needed for different services [18].

For prosumers, 5G could enable more reliable P2P or DR solutions for reliable and transparent trading of energy or grid balance control. In addition, data service providers can bring additional value to the system through real-time consumption, production and weather data and prediction services for better management of the microgrid [19]. An example of these 5G-assisted microgrids is the Siemens campus microgrid in Vienna [20].

Energy performance optimization of buildings is heavily connected to the enhanced usage of data and the internet-of-things (IoT) advancement. In this context optimization would mean adjusting the usage of energy resources via e.g., improved energy efficiency, DSM, and electrification in the residential sector [21]. These solutions can contain several different improvements from retrofitting to smart lighting, but from the aspect of 5G the most interesting improvements are new advanced technologies to make better usage of metering data and improvements in M2M communications for reliable communication between a massive number of devices. To enable new advancements in city planning, 5G could advance the evolution of digital twins, enabling better visualization through VR (Virtual Reality), real-time cross-party communication within an ecosystem or automated twin-to-twin (T2T) processes [22]. 5G could accommodate the emergence of massive IoT through the enablement of mMTC (massive machine type communications) [23], enabling these smart city services.

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4. THE ROLE OF 5G IN SMART CITY DEVELOPMENT: MOBILITY

The current development activities within the mobility sector are aiming towards a more sustainable transport system. The main aims in sustainable transport include the increased use of active modes of transport, public transport, and alternative fuels. This section assesses the role of 5G within the themes of autonomous transport and Vehicle-to-Grid (V2G), which can aid in both altering the local modal split towards more sustainable habits and increase the use of alternative fuels via the increased adoption of e-mobility solutions.

Helsinki Regional Transport Authority (HSL) reports the modal split for the whole capital region in regular intervals. The last assessment on local mobility habits was completed in 2018, and the next assessment is carried out during 2023. The modal split for Espoo is presented in Figure 3 below [24]. HSL aims to increase the use of public transport by 70% (in passenger numbers) between 2021 and 2025 [25]. 5G, as a supportive communication technology, can aid in the implementation of automatic and autonomous public transport. This, in turn, can create new last-mile transport solutions and aid in making public transport more interesting in comparison to using a personal vehicle.

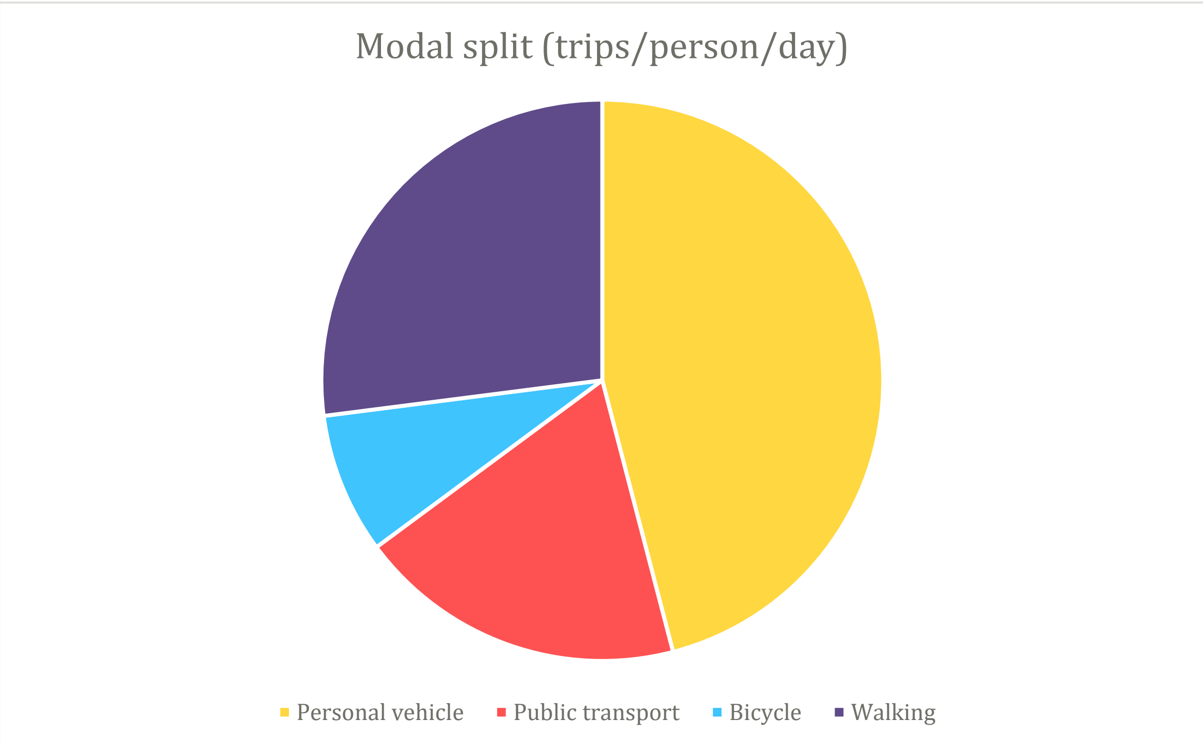

Figure 3: Modal split for Espoo (trips/person/day)

The use of alternative fuels has steadily increased within the Finnish transport system especially through the increased use of Electric Vehicles (EV's), and the number of EV's is expected to reach 600 000 by 2030 as envisioned by the Ministry of Transportation and Communications [26]. In August of 2023, 36% of registered new vehicles were fully electric. For the first time in Finnish history, the share of newly registered EV's surpassed

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the share of petrol-based vehicles [27]. This spike is most likely temporary due to delays in deliveries and discounts of certain models, but is still indicative of the trend at large. 5G, as a supportive communication technology, can aid in the implementation of V2G at a large scale, while accommodating the ever-increasing number of EV's and related devices.

4.1 Communication Technologies for Smart Mobility

To fully understand the possibilities of 5G within the themes of autonomous transport and V2G, a look into the communication technologies within the smart transport sector is needed. As the transport system moves towards becoming more sustainable and safer, the use of communication systems for safety and system optimization increases. Thus, the vehicle of the future can be seen as a platform for digital solutions that enhance its communications with the outside world, otherwise known as Vehicle-to-Everything (V2X) solutions. The 3GPP divides V2X between four different sections, known as [28]:

- *Vehicle-to-Vehicle (V2V)*
- *Vehicle-to-Infrastructure (V2I)*
- *Vehicle-to-Pedestrian (V2P)*
- *Vehicle-to-Network (V2N)*

Currently, vehicles already rely on digital communications to provide on-ride comfort and safety to drivers. Cars sense the surrounding world and communicate with several different sources, such as road maps, traffic updates and weather data, to aid in navigation and control. These solutions are already functional today with current systems, but the lower latency and higher capacity of new communication technologies can enhance these systems even further. This will slowly move transportation from automated safety features such as lane assist and cruise control to full automation, as automated solutions gain further features in predicting and surviving unexpected situations. More information about vehicular safety systems in relation to autonomous transport can be found in section 4.2.

To provide an initial overview of the communication systems used for this digital enhancement of transportation, a table of the most prominent communication systems was devised (see Table 2). This table was divided between intra-vehicular sensing systems, short-range communications, and medium- to long-range communications.

Application/Range	Technologies
Intra-vehicular sensing	Camera-based sensing
	Radio Detection and Ranging (RADAR)
	Light Detection and Ranging (LIDAR)
	Ultrasonic sensing
Short-range communications	Bluetooth and Bluetooth Low Energy (BLE)
	ZigBee

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	Ultra-wideband (UWB)
Medium- to long-range communications	Communications falling under the 802.11p standard, such as Dedicated Short-Range Communications (DSRC) in the U.S. and ITS-G5 in Europe
	Cellular Vehicle-to-Everything (C-V2X)
	5G New Radio Vehicle-to-Everything (5G-NR V2X)

Table 2: Communication technologies within the transport sector

Intra-vehicular sensing systems are the main systems that enhance the current vehicle to a sensor platform, while enabling automation via the collection and analysis of the data collected by these systems. These sensors allow vehicles to observe the surrounding world, provide information, make plans and decisions according to this collected information, control vehicular functions accordingly and to interface with the components of the vehicle itself according to the provided information [29], [30].

Short-range communication technologies include intra-vehicular communication systems between sensors and different vehicular functions, in-car infotainment, and other short-range applications such as positioning [29]. Most often, these technologies do not meet the stringent safety requirements for critical V2X functions, but they can provide opportunities in lessening the wiring between less critical sensor systems and the vehicle, while providing additional features. In addition, they are not functional for V2V, V2I or V2P communications due to their relatively low range. Thus, the V2X system also contains medium- and long-range communication solutions [29], [30]. These solutions can handle the V2V, V2P and V2I side of necessary communications, while also providing the necessary network infrastructure for the highly critical transport sector. C-V2X and 5G-NR V2X are also the communication technologies where 5G has the most impact, as they work either based on or in parallel with mobile technologies [30]. Use cases for the different communication technologies are presented in Table 3 below.

Technology	Use Case
Camera-based sensing	Environmental detection, driver assistance
Radio Detection and Ranging (RADAR)	Environmental detection, driver assistance
Light Detection and Ranging (LIDAR)	Environmental detection, driver assistance
Ultrasonic sensing	Sensing at short distances in low speeds
Bluetooth and Bluetooth Low Energy (BLE)	Infotainment, wireless connection of less critical sensors to vehicle systems to reduce wiring

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ZigBee	Connection of less critical sensors to vehicle systems to reduce wiring
Ultra-wideband (UWB)	Vehicular localisation and positioning
Communications falling under the 802.11p standard, such as Dedicated Short-Range Communications (DSRC) in the U.S. and ITS-G5 in Europe	V2V, V2P and V2I communication within close proximity. For example, safety warnings, alerts, and traffic light operation
Cellular Vehicle-to-Everything (C-V2X)	V2N communication, long-range sharing of critical information, infotainment
5G New Radio Vehicle-to-Everything (5G-NR V2X)	V2N communication, long-range sharing of critical information, infotainment

Table 3: Use cases of different communication technologies

The final aim of V2X is to move towards a fully autonomous vehicle, which does not need a human driver for its operations. The next sections will investigate the role of 5G in both the transformation towards autonomous vehicles and the enhancement of EV charging infrastructure.

4.2 5G and the Autonomous Vehicle

As the communication systems of the mobility sector develop, the traditional automobile will move towards an Autonomous Vehicle (AV). By 2040, AVs are expected to reach more than 26% of new car sales globally [31]. Currently AVs are in the pilot phase, and several pilots and research activities have been commenced and completed in Espoo as well. S-Group, a Finnish company on the retail and service sector, has commenced a pilot on autonomous last-mile deliveries from retail locations within Espoo via a robotic platform developed by Starship Technologies [32]. Due to the success of the original pilot project, S-Group continued the autonomous deliveries during the summer of 2023, and expanded the service to neighboring cities [33]. The City of Espoo, in the low-emission transport within mobility hubs (VÄHILI) project, commissioned several feasibility studies on autonomous buses as a part of the Espoo public transport system. The reports identified the most feasible transport routes for autonomous buses within different city districts and provided a roadmap for future implementation of autonomous buses [34], [35]. The reports were produced by Roboride OY and Sitowise.

The automotive industry can receive an integral boost from 5G in its attempts to enhance communication for the enablement of autonomous vehicles. 5G can provide several benefits to autonomous transport due to its lower latency, higher capacity, and additional services. AV's can benefit from network slicing, edge computing and big data solutions, to provide safe, connected and reliable communication services. Historically, automation in transport has been divided between six different levels as follows [29]:

- *L0: No automation*
- *L1: Driver assistance*
- *L2: Partial automation*
- *L3: Conditional automation*

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- *L4: High automation*
- *L5: Full automation*

In the first level of automation, the vehicle assists the driver either in steering or braking/acceleration, without taking full control of driving responsibilities. Examples of Level 1 automation include adaptive cruise control and lane assistance. The second level of automation is slightly more complicated, as advanced driving assistance can take over multiple tasks from the driver in specific scenarios, such as highway driving. However, the driver must still be ready to take control of the vehicle at all times. As such, the second level of automation still requires human engagement. Both of these levels are available in current production vehicles.

Currently, some stakeholders within the automotive industry have developed level 3 automation systems, but national regulation still remains a major blockade for global implementation. The two highest levels of automation, L4 and L5, are still under development, and implementation is expected to rise slowly as markets and regulators accommodate to technological advancements. Looking at these six levels of automation and the rate of achievement, the first two levels have already been achieved without significant 5G penetration. However, further levels will likely require enhanced communication techniques due to an increasing need for sensor data, which 5G can aid in. Higher level of automation will require V2V and V2I communication for sensing, co-operated driving, platooning and safety enhancements. These use cases can already be implemented via LTE networks, but 5G will enhance the use of these solutions in high-density areas.

For example, the German telecommunication company Deutsche Telekom AG plans to install a 5G network on all key transport routes under its service [36]. According to the provider, this 5G network will help in making fully automated transportation a reality in the future. A main enhancing component that Deutsche Telekom mentions is the opportunity for remote control if automated solutions reach an unexpected situation that they cannot solve on their own [36]. Without 5G, the response times and resources of the mobile networks will not be enough for reliable remotely controlled options. As with the energy sector, network slicing is also seen as an integral part of 5G for autonomous transport [36]. Within network slicing, the 3GPP has secured a slice for V2X solutions, ensuring that critical information gets transferred reliably. Telekom predicts that this combined with edge computing solutions ensures that sensors fitted within cars can reliably communicate not only with the network, but with the local infrastructure as well, thus ensuring that automated cars gain information on out-of-sight obstacles to enable faster speeds and better flow of traffic.

Benefit	Additional Information
Remote Control	5G can provide an opportunity for remote control of autonomous vehicles in real-time if unknown situations occur.

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Fast and reliable transfer of time-critical information	Via the utilization of network slicing and edge computing, the V2X slice can ensure the transfer of time-critical information between the vehicle and the infrastructure, network and other vehicles reliably to enable better traffic flow
Control of a large amount of assets	As the number of smart smart assets producing, controlling, monitoring and transferring data within the transportation network increases, 5G can provide the means of scaling up mobile communications to meet the increased demand.
Network slicing	Within network slicing, multiple virtual networks can be provided on a shared network infrastructure. Each slice can have a separately defined topology, reliability needs and security level, among others. Thus, separate slices can be dedicated to sectors and services which require high reliability and ultra-low latency, such as autonomous mobility.
Edge computing	Within edge computing, data is processed closer to the data sources themselves, utilizing a more decentralized IT network instead of the traditional data center -based solution. Processing data and providing services on the edge instead of transmitting it to the center can aid in e.g. reliability and latency.

Table 4: Benefits of 5G for smart mobility

Discussions remain on how integral 5G really is in kick-starting automation within the transport sector. According to some experts, 5G might only become crucial decades from now when a critical mass of automated vehicles is reached. Before that, LTE based solutions combined with industry-wide standards can already be suitable for laying the foundations for a 5G-based large-scale system [30]. However, it must be noted that planning of products and infrastructure within the automotive and telecommunication sectors is a long-term investment, and work to achieve the critical mass of 5G-connected vehicles and 5G infrastructure must start decades before large-scale automation becomes a reality. Thus, the automotive industry is constantly working on developing more connected vehicles together with telecom providers to ensure that they are available for consumers when needed. For example, Audi has announced that they will bring 5G-connected vehicles to their lineup in 2024 in collaboration with Verizon [37], GM has collaborated with AT&T to bring 5G connectivity to Chevrolet, Cadillac and GMC vehicles by 2024 [38] and Volvo Cars together with Ericsson have tested 5G network capabilities in cross-border vehicular handovers in the 5GCroCo project [39].

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4.3 5G and Vehicle-to-Grid

The electrification of mobility is seen as a key reason for the future reduction of transport sector carbon emissions. The Finnish Ministry of Transport and Communications predicts that 600 000 EV's will be on the Finnish roads by 2030 [40]. For efficient implementation of eVs into the current power system, further work in the optimization of the grid and DSM solutions needs to be done [41]. This vehicle-based DSM is known as Vehicle-to-Grid (V2G). V2G, as a concept, means the use of electric vehicles as storage for the larger electricity grid. This means that EVs could optimize recharging procedures and provide electricity back to the grid when needed. EV owners can then be compensated for the provision of these services.

So far, the amount of research articles related to the use of 5G or related technologies within V2G solutions has been low. Oftentimes, the role of 5G within V2G has been deemed small, as V2G does not have the low latency requirement that autonomous vehicles require [41], [42]. However, the opportunities of 5G for mM2M solutions are deemed beneficial for V2G [42]. As EV fleets scale up, 5G can ensure reliable communication [43]. In article [41], the different communication requirements for V2G systems are analyzed. This article notes past research on the same issue but indicates that current state-of-the-art research mostly centralizes on communication within the charging station and does not consider communication needs for mobile EVs. This research often focuses on vehicle-to-infrastructure communication (V2I) and autonomous vehicles (AV's), which do not consider grid connection as extensively as other issues, such as safety. This article also provides an example on the communication requirements of smart charging solutions for demand side management (DSM).

Several articles provide information on using network slicing in providing more efficient EV charging services for different user segments [44], [45], [46]. The aim of network slicing in this case is to provide allocated resources to different smart grid applications, including V2G, to guarantee the provision of needed services constantly.

In addition to network slicing, several articles also investigate the use of edge computing to ensure low-latency communication for eV's in all parts of the grid [44], [47]. The aim of edge computing in this case is to ensure the availability of processing power nearby the EV users themselves, thus providing lower latency communication due to the lesser use of central resources. Edge computing is proposed as an interesting innovation for EV's due to the high mobility of the vehicles themselves, in addition to the EV-situated computing power needed to make decisions on charging and discharging based on user preferences and grid condition. These decisions also need to be made in real-time due to the nature of electricity as a commodity, thus providing a need to construct a communication network that minimizes delay in V2G communication. In addition to edge computing, where the data is processed right at the devices themselves or very close physically, the benefits of fog computing, an intermediary level between the edge and the cloud, is also researched in several articles [48], [49], [50].

From the analyzed research, an intent to overlook V2G when piloting 5G solutions for mobility can be seen, as V2X and autonomous mobility are much more viable options for research in the sphere of 5G and mobility. However, the role of 5G within the enhancement of V2G communications can be substantial as the number of eVs in circulation increases. Still, the full role of 5G is only seen as the implementation of the V2G services continues.

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5. STAKEHOLDERS WITHIN A 5G ECOSYSTEM

As per the detailed plans of actions E12-1 and E12-2, key stakeholders within a 5G ecosystem related to smart infrastructure and mobility will be mapped. These stakeholders are mapped in the tables below, and the work was done according to the completed literature review. The 5G Infrastructure Association (5G-IA) has published a white paper on 5G ecosystems [51]. Within this report, target stakeholders of the 5G Infrastructure Public-Private Partnership (5G-PPP) are revealed. These are divided between policy makers and financing bodies, standards and open-source organizations, verticals, 5G-related organizations, vertical associations, 5G industry and research, and 5G complementary industry. Relevant stakeholders have been added to the tables below. The report notes that no singular 5G ecosystem exists. Instead, ecosystems are divided and interconnecting depending on the point of view. 5G-IA explains two different ecosystems as follows [51]:

- *“The 5G provisioning ecosystem encompasses those roles and actors who take part in developing, delivering, and providing 5G services.”*
- *“The 5G vertical ecosystem black boxes the 5G provisioning ecosystem and focuses on other actors who work closely together as part of vertical industries. While roles and actors from the telecommunication sector are still present in this ecosystem, the emphasis is on yet other roles which apply 5G services in their value creation and can be domain specific.”*

Vertical ecosystems are often divided by market, encompassing a group of stakeholders specializing on a shared market or niche across industry lines. Verticals could include sectors such as agriculture, healthcare, energy and smart cities. The stakeholders identified within this report can be assumed to fall under either one or both identified ecosystem types.

Within report [52], the main stakeholders and relationships of a 5G V2X ecosystem are mapped. The report mentions road infrastructure operators, the 5G industry, standardization organizations, policy makers, the automotive industry, and users. Within report [53], a business model for a V2X ecosystem was analyzed, together with relevant stakeholders. The article identifies network infrastructure providers, mobile network operators (MNO’s), cloud service providers, original equipment manufacturers (OEM’s), automotive dealers, drivers, and municipalities. Within the State-of-Art report of the Neutral Host Pilot consortium [13], several different business models within a future smart city ecosystem are provided. These include possible actors within these business models as well. The business models of “A data user of location data” and “a data supplier of pedestrian and bicyclist information” were deemed to be the most related to a 5G V2X ecosystem. Within these two business models, the report identified cloud platform providers, the automotive industry, municipalities, application developers, on-demand service providers, fleet logistics management suppliers, consumers, and research centers.

A decision was made to divide the stakeholders mentioned in the last paragraph as follows: infrastructure operators, industry and research, policymakers and standardization, service providers and users. Table 5 below shows the identified stakeholders.

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5G and Smart Transport Ecosystem	
Infrastructure operators	Road infrastructure
	Public transport infrastructure
	5G Network infrastructure, MNO's
Industry and research	Telecom industry
	Automotive industry
	OEM's
	Research institutions
	Universities
	Electronics industry
	IT providers
	Technology and connectivity providers
Policymakers and standardization	Finnish Transport Infrastructure Agency
	Traficom
	Ministry of Transport and Communications
	Municipalities
	Standardization organizations (3GPP, ETSI, IETF, IRTF, IEEE, ISO…)
Service providers	Cloud service providers
	Automotive dealers
	Insurance
	Driver assistance
	Application developers
	On-demand services
	Fleet logistics management
	Transport and logistics services
Users	Drivers
	Vehicle owners
	Passengers
	Pedestrians
	Consumers
	Public safety
	Municipalities (smart cities)

Table 5: Stakeholders related to 5G and smart transport.

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In the next table, this same analysis is done on smart infrastructure and 5G. Within report [54], stakeholders involved in smart metering adoption within the energy sector are identified. These include power distribution providers, power suppliers, consumers, regulatory authorities, producers, and the power market. In turn, report [55] investigates stakeholders' perspectives on energy flexible buildings. These use cases can be looked into as possible stakeholders within a smart infrastructure ecosystem. The report identifies building managers, occupants, energy suppliers, aggregators, technology providers, building energy analytics and consulting, regulatory authorities, and industrial consumers. A compilation of the identified stakeholders for smart infrastructure can be seen in Table 6 below.

5G and Smart Transport Ecosystem	
Infrastructure operators	Energy infrastructure (production, transmission, and distribution)
	5G Network infrastructure, MNO's
Industry and research	Telecom industry
	Energy industry (generation, supply, sales)
	Construction
	Electronics industry
	IT providers
	Technology and connectivity providers
Policymakers and standardization	Energy authority
	Ministry of Economic Affairs and Employment of Finland
	Municipalities
	Research institutions
	Universities
	Standardization organizations (3GPP, ETSI, IETF, IRTF, IEEE, ISO…)
Service providers	Demand response services
	Virtual Power Plant services
	Aggregator services
	Smart home services
	Energy sales and market services
	Automation
	Analytics services
	Consultancies
Users	Industrial consumers
	Prosumers

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	Building Managers
	Occupants

Table 6: Stakeholders related to 5G and smart infrastructure.

These two tables give an idea of what stakeholders are needed to fully develop and implement 5G-based mobility and energy solutions. All or most of these stakeholders need to be around the same table to enable the development process towards concrete solutions, as infrastructure providers need services to be implemented to ensure profits from constructed new and innovative infrastructure, and service providers need to ensure the availability of infrastructure to reduce risks on developing their services.

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6. Opportunities Provided By 5G in Espoo

As a background on 5G and its benefits compared to previous solutions has already been provided in previous sections, this section will focus on service opportunities made possible by 5G technology, related research projects and the smart city transformation. These opportunities will be linked to the Espoo city strategy as well. This section will give a broad overview, while the next section will incorporate the objectives of Kera development in the investigation.

6.1 The City Context

Espoo, a lighthouse city within the SPARCS project together with Leipzig, is the second largest city in Finland after its close neighbor Helsinki. Espoo comprises the capital region area of Finland together with the aforementioned Helsinki, Vantaa and Kauniainen. Espoo does not have a single city center. Instead, Espoo consists of five area centers: Leppävaara, Tapiola, Matinkylä-Olari, Espoonlahti and Espoon keskus. The demo areas of SPARCS, Sello, Kera and Lippulaiva are contained within two of these area centers, Leppävaara and Espoonlahti.

Figure 4: The Sello shopping center within Leppävaara

Figure 5: The Espoonlahti area before the construction of the new Lippulaiva shopping mall began

The Espoo city strategy, also known as the Espoo story, sets the city vision for four-year increments at a time. The newest Espoo story was accepted in October of 2021, and will run until 2025. To ensure that implementing 5G solutions provides quantifiable benefits to the city, careful consideration of the links between the solutions and the city strategy is needed. Some of the connected themes within the story are mentioned below [56]:

- Espoo is a responsible pioneer:
  - "Being a pioneer involves utilizing research and international experience, organizing experiments and knowing how to deal with possible failures. We develop Espoo in an economically, environmentally, socially and culturally sustainable manner."
- Espoo is the top city for culture and education in Finland
  - "We will support the development of university campuses into strong innovation and competence clusters. In addition to Otaniemi, campus

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development efforts will focus on Leppävaara and Kivenlahti. In all these areas, we will set special goals for partnership activities related to city vitality and urban development."

- Espoo provides services together with the entire Espoo community:
    - "In Espoo, services will be provided by the entire city community, not just the city organisation. Companies, organisations and other communities will be part of the innovative urban ecosystem and service provision. We will promote the implementation of the City as a Service multi-provider model."
    - "The development of services will be characterized by creative enthusiasm, the breaking of various boundaries and the strengthening of vitality, also with the help of technological development, art, top-level sports and business cooperation."
    - "We will develop management based on information, data analysis and effectiveness. Espoo and its partners will actively utilise digitalisation, robotics, artificial intelligence and other technologies throughout the operating processes. We will promote social innovations, resident-, customer- and partnership-based activities, effective service provision, improved productivity as well as cost savings. With the help of digitalisation, we will increase the openness of our activities, develop new platform solutions and speed up service processes. We will also take into account those who are unable to use digital services."
    - "Espoo will collect information material for use by its own administration, residents, customers and partners to support the systematic sustainable development of different areas. This will be developed into Espoo's area model, in which we digitally present the facts and illustrate the current situation of an area, the changes enabled by approved plans, the planned investments and changes in the service network as well as the longer-term target."
- Espoo is an internationally attractive capital of entrepreneurship and innovation
    - "Espoo will strengthen its position as the internationally most interesting and attractive centre of innovation in Northern Europe in relation to competence, science, art and economy. Our partners – Aalto University, VTT Technical Research Centre of Finland and businesses in particular – will play a key role in this."
- Espoo is an attractive city close to nature and a safe place to live:
    - "Sustainable and intelligent urban solutions will make daily life and mobility smoother. All Espoo residents will have good opportunities to make sustainable choices in their daily lives and make a difference in their local environment."
    - "Transport emissions will be reduced. Our efforts will be seen, among other things, in the improved conditions for public transport, walking and cycling and, with regard to private cars, in the rapidly increasing use of electric cars. The safety of people's daily lives will be improved through

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multidisciplinary cooperation to ensure that Espoo is the safest city in Finland."

- Espoo will achieve carbon neutrality by 2030:
    - "Espoo will actively combat climate change, strengthen biodiversity and achieve carbon neutrality by 2030. Espoo will adapt to the impacts of climate change. Cooperation with universities, research organisations, innovation activities and businesses will generate solutions with a significant carbon handprint that will help tackle the global climate challenge. Espoo will promote new solutions for local energy production and examine the possibility of placing a small nuclear power plant in the city's area. A roadmap for combating climate change will be drawn up for the city to describe the City of Espoo's own activities and the cooperation with partners and residents to achieve the goal of carbon neutrality."

6.2 The Kera Context

The SPARCS demonstration site of Kera currently houses industrial buildings due to be demolished and replaced by residential and mixed-use buildings for about 14 000 residents. The current property owners include companies such as S-Group and Nokia, with involvement and interest in the ICT sector. The site will undergo a city planning process, new zoning, purchase by real estate developers and subsequently emerging as a modern and vibrant district with excellent train connections to other Espoo districts and the neighboring cities of Kauniainen, Helsinki and Kirkkonummi.

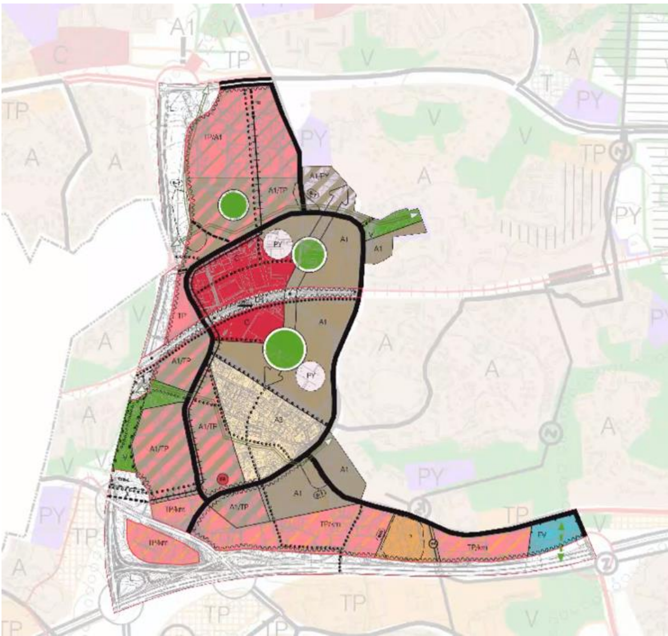

Figure 6: Zoning of Kera

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The city council has set a target for Kera to serve as a front runner on smart ICT solutions and circular economy, and there are several co-creation projects to engage stakeholders in this development. In the latest developments towards a more sustainable Kera, a Kera sustainability commitment was accepted as an addition to the Kera land use agreement [57]. The aim of this commitment is to ensure that the actors joining the Kera development activities will adhere to the city goals related to sustainable development.

The largest plot, owned by S-Group, is located on the south side of the railway, and it is expected that these properties will be demolished and plots subsequently sold. Nokia owns properties on the north side, close to the Nokia Headquarters area north of Kera. The company still has an incentive of involvement in Kera, as it could serve as housing for staff, and a showcase of smart city infrastructure like 5G smart poles. A smart pole pilot environment has already been implemented within the Nokia headquarter sector of Kera in the LuxTurrim5G project (see section 6.3.1).

6.3 Kera – LuxTurrim5G/Neutral Host Pilot

Within Kera, a consortium led by Nokia has developed small cell -based 5G infrastructure integrated to the urban infrastructure in lampposts and bus stops. Connected to this infrastructure, a separate project has been looking into the possibilities of data marketplaces and neutral hosts.

The 5G project within Kera has been divided to two different sections: LuxTurrim5G and LuxTurrim5G+, focusing on designing the local 5G pilot network and the 5G light poles with accompanying modules for different applications, and Neutral Host Pilot, which investigates the ownership structure of the 5G network and the accompanying data platform and data marketplace. Both projects will end during 2021, and their results in relation to smart infrastructure and mobility will be documented in this section. A more detailed overview can be found on documents of the projects themselves from the project webpage [58].

6.3.1 LuxTurrim5G and LuxTurrim5G+

The aim of the LuxTurrim5G project was to develop a 5G network based on light poles with integrated devices, such as sensors, antennas, and screens. The project aimed to tackle the challenge of developing digital service infrastructure that can deal with the increased traffic volume and new digital services that will be implemented in a smart city environment [1].

The project began in 2017 with an aim of developing a smart light pole with an integrated 5G small cell, and in June 2021 the first pre-commercial product version of the 5G smart pole was released [59]. Different versions of the smart pole were created to meet differing needs between cities, thus creating a whole smart pole product family. The poles were modularly designed to fit the needs and requirements of different customers [59]. These modules could include air quality and weather sensors, video cameras, positioning devices and radar. Several of these modules could be of use in the smart mobility or smart infrastructure sectors. A pilot environment featuring smart poles, smart bus stops, and IoT devices was also implemented by the project consortium in Kera. This environment can be seen in Figure 7 below.

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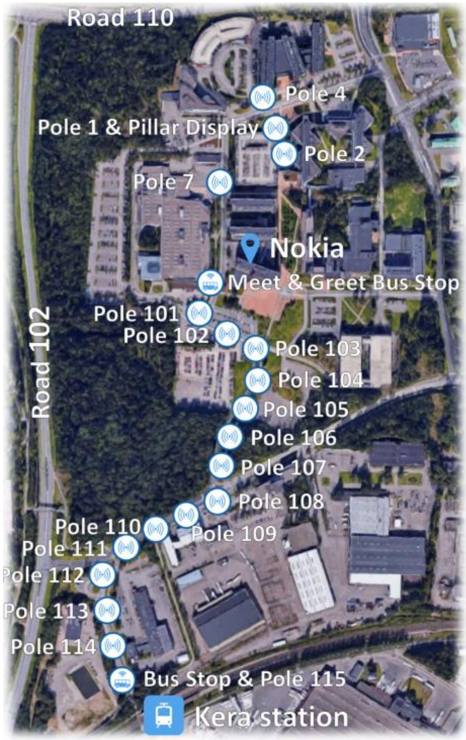

Figure 7: The Kera smart pole pilot environment [58]

In addition to the concrete modules mentioned above, the project also looked at solutions and use cases where these modules could be utilized in. For example, L7 Drive, a power electronics cleantech company, focused on analysing the use of the power backup systems of the smart poles for grid optimization [60], and the formation of a Virtual Power plant (VPP) from these systems [61]. Vaisala investigated air quality and weather monitoring using sensors embedded within the smart poles [62], and defined increasing renewable energy usage as a key megatrend in the drive towards applying these solutions. Rumble tools investigated drone solutions connected to the poles [63], while Teleste focused on public safety and security [64]. Agora networks investigated the opportunities of 24/7 parcel delivery kiosks in last-mile logistics [65]. City design opportunities were also investigated, with a focus on data usage for optimization, 3D-modelled city design and a constantly updated digital twin of the pilot area [66].

6.3.2 Neutral Host Pilot

The second side of the LuxTurrim5G project package, Neutral Host Pilot, aimed to look at operational models and data platforms for local 5G networks, with a focus on transparency, openness, and a sharing economy. The Neutral Host refers to the service provider of the network itself, which was defined in the State-of-the-Art analysis as "a service provider that builds and operates an integrated technology platform that is solely for sharing purposes". From this definition, the analysis states that a neutral host "offers continuous services for customers in the area of its operations, constructs, maintains and

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develops the infrastructure together with key partners to meet the needs of customers, consolidates required technological components in one uniform environment and seeks opportunities to gather as many participants to the platform as possible to meet economies of scale" [13].

The Neutral Host Pilot project has investigated the current situation in different industries and possible services that could be provided with the aforementioned solution and smart city design. This project can provide numerous insights on the possible business cases possible through the use of the local 5G network and the planned business models. In the identified service opportunities of the project, five different clusters were identified, being city monitoring, transport and mobility, culture, safety and emergency and public maintenance. All five of these clusters contain opportunities that are interesting for either the energy or the mobility sector, or both simultaneously. The project also aimed to visualize the data marketplace concept within Kera and the stakeholders within the concept.

6.4 The Opportunities

Next, a look into the different opportunities made possible by 5G is given. Separate sections will explain the opportunities found in the Neutral Host Pilot and Smart and Clean Kera projects, both of which are related to the Kera demonstration area.

6.4.1 Neutral Host Pilot

A very detailed overlook on different services, and connected operation models, that are made possible by a local 5G network can be found in the Neutral Host Pilot state-of-the-art analysis [13]. As previously said, this analysis divides the possible services into five clusters:

- City monitoring, containing surveillance and monitoring services for awareness of city condition.
- Transport and mobility, for contemplating the needs of different transport sectors.
- Culture, enriching public spaces and enhancing citizen engagement.
- Safety and emergency, containing services for operators such as the police, paramedics, and the fire department with an intent to increase citizens safety.
- Public maintenance, to improve urban spaces and city operations.

Out of these service clusters, transport and mobility is analyzed under its own section, but all of the other service clusters have services that can be beneficial for smart energy infrastructure as well. This report will aim to divide services mentioned under the different clusters according to their value proposition for the energy sector.

a) Energy

From the service clusters identified within the Neutral Host Pilot project, the most beneficial services for the energy sector were collected within Table 7. The collected services fall under multiple themes, such as enhanced use of data, energy guidance and

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knowledge sharing, efficiency measures and maintenance. Each service and their value proposition for the energy sector is explained in the table below.

Service	Add. Info	Value Proposition for Energy
Open City Data	Sharing data between stakeholders in real time on a digital platform	Sharing data between actors, and using shared data to enhance operations
Open Weather Data	Open access to real time weather data	The use of weather data in enhancing production predictions
Local Weather Monitoring	Provide data on weather conditions from specific city areas	Optimization of local renewable generation
Tailored Information	Provide citizens with information relevant to them by utilizing different interfaces	Provide relevant information on energy for local citizens
Crowd Flow Optimization	Smart sensors can provide data to optimize crowd flows	Optimizing crowd flows for energy efficiency
Emission Sensing	Monitoring local air quality in real time	Monitoring effects of energy solutions on local air quality
Smart Hubs	A hub with internet connection, smart lighting and charging	Smart hubs can integrate renewable solutions
Smart Lighting	Environmentally or otherwise digitally controlled lighting	Smart control of lighting can enhance energy efficiency
Data As Art	Data can be used to create art installations in the city. Participatory processes can be included in this so that citizens can contribute	The visualization of the energy transition, making local energy visually appeasing and thus more desirable for citizens

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Smart Forum	Open spaces for citizen engagement, combined with digital solutions that enhance the physical experience	Energy guidance, citizen engagement on renewable energy
Augmented Reality Learning	Augmented reality can aid in providing information for education in open spaces	Energy guidance activities
Context-based Realtime Information	Real time information based on the surrounding context	Visualization of the energy transition, providing information on local energy solutions
City Issue Report System	A digital platform for reporting city issues to relevant authorities	Reporting of issues related to energy
Citizen Engagement Platform	A participatory platform for the citizens, to provide feedback	Providing feedback on urban energy solutions
City's Digital Twin	A digital twin of the city for monitoring in real time	Real time energy optimization
Drone Services	The use of drones for different services, such as predictive maintenance	Predictive maintenance

Table 7: Service opportunities identified within the Neutral Host Pilot project, with a link to energy

As can be seen in Table 7, multiple service opportunities in multiple service clusters within the NHP project can provide value for the energy sector. These opportunities are related to the sharing of data, optimization of energy services, provision of information and guidance, monitoring, and visualization. These services partly correlate with the opportunities found in section 3 of the report. The correlating opportunities include ones related to the real-time control of renewables, data monitoring and visualization, and drone services. However, the services identified here don't include the control of time-critical grid services that can utilize URLLC network slice, such as grid protection. This is probably because grid control needs to work at a higher level, communicating across the grid in different urban and rural areas. However, the infrastructure piloted within these projects could be used to relay information about the grid between stakeholders, thus serving as an enhancement to more large-scale control services utilizing 5G.

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In addition, many of the services identified within Table 7 can largely be seen to have secondary uses within the energy sector while focusing on other services. Thus, these services are also not critical for the functions of smart energy infrastructure, and can be seen more as auxiliary services. These services include tailored information, smart hubs, data as art, smart forums, and the citizen engagement platform. The energy sector can participate in these services, but their implementation will need interest from other sectors as well.

b) Mobility

From the service clusters identified within the Neutral Host Pilot project, the most beneficial services for the mobility sector were collected within Table 8. The collected services fall under a single service cluster within the NHP state-of-art report, but encompass several different themes, such as monitoring, navigation, drone services and information provision. Each service is explained in the table below, with the "Add. Info" column providing more information on their value proposition for mobility.

Service	Add. Info
Crowd Flow Tracking	Real-time monitoring of people flow for optimizing commuting within public spaces
Digital Tourism Navigation	Real-time informational and navigational maps for tourists
Guidance Drones	Drones that provide navigational guidance to citizens
Commuting Signs and Notifications	Dynamic digital interfaces that provide real-time notifications to commuting citizens
Mobility as a Service (MaaS)	A platform that connects different transportation solutions in a single digital application

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Parking Spaces Location and Availability	Provision of information about available parking spaces via cameras or sensors
Wireless Charging for Vehicles	Spaces assigned to charge citizens' electric vehicles
Smart Parking Payment	Service to let drivers pay tolls or parking meter fees automatically using cameras or RFID tag detection
E-Bikes and E-Scooters Parking Areas	Assign parking areas for e-bikes and e-scooters to reduce congestion and clutter in public spaces
Autonomous Public Transport	Automated public transportation within urban areas
Emergency Traffic Lights Management	Prioritize certain vehicle segments via smart traffic management
Bus Stops as a Service Station	Integrate other services, such as bike parking, gardens and drones, to a bus stop
Operational Status as a Lighting Color Code	Color codes at bus stops to indicate operational status
Guidance Services	Use of different urban infrastructure to provide guidance to commuters

Table 8: Service opportunities identified within the Neutral Host Pilot project, with a link to mobility

As can be seen in Table 8, the NHP project identified numerous service opportunities, several of which have links to city services as well. Public spaces can gain value from

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guidance services and parking solutions, while public and emergency transport can gain value from smart traffic lights and bus stops, autonomous public transport, and MaaS.

6.4.2 Smart and Clean Kera

Kera has been developed with an aim to become a global example of a smart and sustainable city district. The aim of the already concluded Smart and Clean Kera project was to aid in this development. Within the theme of smart infrastructure, this project focused on renewable solutions and energy system optimization, with digital solutions as an overarching theme that was looked upon when finding the most feasible solutions. To achieve this, the project team procured a report to identify the foundations of a local energy ecosystem. [67] The table below shows the prioritized concepts found on page 51 of the report, and prioritizes them based on their connections to the 5G technology based on the literature review process (bolded).

Local Energy Production	Energy distribution and measurement	Energy recovery and storage	Services	Use	Overarching Themes
Solar electricity	**Smart Grid**	**Local electricity storages/batteries**	Energy-as-a-service	**Demand Side Management**	Reserve Power
Ground-source heat pumps (300m)	**Smart meters (15 min intervals)**	Waste heat	**Demand Side Management**	**Smart Infrastructure and IoT**	Net-Zero Energy Buildings
Water-to-air heat pumps	District Cooling Network	Power-to-X solutions	**Virtual Power Plants**	**Apartment-based circumstantial control**	**Energy simulation/Digital Twin/Optimization**
Deep wells (2km)	**Microgrids**		**Local trading of energy**	**A district energy market**	**5G sensors and data platform**
Geothermal heat (7km)	**Separated Kera electricity grid**				**Building energy management systems**
					KeraHUB/Other Kera development platform

Table 9: Identified concepts of a smart energy positive system in Kera

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6.4.3 Current Services and 5G opportunities

In this section, an analysis is provided on current local services connected to the identified 5G opportunities. The aim is to assess how 5G can enhance the operation of state-of-the-art solutions. This section will focus on mobility solutions. In Table 10 below, current solutions related to the identified 5G services are revealed, in addition to the value proposition of 5G as a technology.

Service	Implementation status and added value from 5G infrastructure
Crowd Flow Tracking	Crowd flow services are already readily available for buildings and other indoor areas as a part of various access control services. Crowd flow can also be measured via mobile network data. For example, Helsinki Regional Transport Authority (HSL) collaborated with Telia in assessing crowd flows to analyze needs in feeder bus traffic for the Espoo metro extension [68]. 5G infrastructure could aid in more real-time and precise people flow tracking of open urban areas, while edge computing solutions can aid in assessing data at the source. For example, Aalto University has implemented a people flow pilot at their university campus in Otaniemi, Espoo. This pilot utilizes lidar technology and edge computing to measure the mobility of people at the campus center, focusing on sustainable mobility modes. Wifi-positioning is used for indoor areas [69].
Digital Tourism Navigation	There is no information of real-time tourist maps in current implementation. Currently, smart tourism activities in the Helsinki region focus on knowledge-based management and better use of connected data [70]. 5G can aid in expanding data services to real-time navigation and guidance.
Guidance Drones	Currently, drone services are in pilot phases of implementation. Espoo is one of the first municipalities in Finland where drones are used in environmental protection services. The City of Espoo operates a remotely controlled drone for inspection and mapping activities [71]. 5G can aid in expanding drone services, and implementing fully autonomous solutions. For example, in the LuxTurrim5G pilot environment, Rumble Tools has piloted the use of docking stations connected to a small cell 5G

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	network to facilitate the use of autonomous drones in smart city services [63].
Commuting Signs and Notifications	Notification boards with regularly updated information are already in use within Espoo. These can provide information of weather, news, and future events. For example, the Espoo City Library co-operates with iDiD to provide dissemination services via digital notification boards [72]. The local public transport authority HSL provides on-the-go passenger information on certain bus routes, including estimated travel time to the routes next stops and terminus. The aim of HSL is to expand the provision of real-time and personified data to local commuters [73]. Local citizens and businesses can also provide information on public transport timetables on their own devices or notification boards via a HSL-provided service. This service includes current disruptions in traffic [74]. Notification solutions are already in frequent use, but 5G can aid in more efficient operation and provide service guarantees especially in on-the-go operations.
Mobility as a Service (MaaS)	A MaaS application known as Whim provides this service within the Helsinki capital region [75]. MaaS services can benefit from 5G by accommodating more expansive operation via higher capacity and lower latency. In addition, 5G-enhanced autonomous mobility can provide new opportunities for MaaS providers.
Parking Spaces Location and Availability	Parking applications, such as Easypark, provide information on the availability of parking spaces within Helsinki based on collected data. The use of 5G infrastructure can enhance this data towards an accurate real-time system.
Wireless Charging for Vehicles	Destia, a Finnish contractor of infrastructure construction, has began a wireless charging pilot in Vantaa, Finland together with Electreon [76]. 5G can aid in increasing capacity of charging systems, and providing real-time information to optimize charging on the go between a fleet of vehicles.

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Smart Parking Payment	Several parking areas within the Helsinki capital region utilize automatic payment solutions [77], [78], [79]. Urban 5G infrastructure can extend these solutions further to paid public parking spaces.
E-Bikes and E-Scooters Parking Areas	Helsinki designates restricted areas and parking spaces for e-scooters within the most congested public spaces, such as the city center [80]. Parking of e-scooters is monitored via photographs provided by the rider after the end of each trip. Within Espoo, work on regulating e-scooters has focused on implementing speed limits and time restrictions together with service providers [81]. Urban 5G infrastructure can enable the automated inspection of e-scooter parking.
Autonomous Public Transport	Automated public transportation solutions have reached pilot and research phases within Espoo [33], [82]. 5G can be integral in the implementation of autonomous public transport at a larger scale due to the needs of low latency and reliability.
Emergency Traffic Lights Management	Prioritized traffic lights for public transport have been implemented in Espoo since the JENKA project, ending in 2010 [83]. Prioritized traffic lights for emergency traffic have been implemented via the HALI-system, utilized in 20% of Finland's traffic lights with full implementation devised in 2023 [84]. The HALI system utilizes the mobile network, thus gaining value from the faster 5G network.
Bus Stops as a Service Station	Smart bus stops integrating other services, such as security solutions, have been piloted within the LuxTurrim5G project in Espoo [85].
Operational Status as a Lighting Color Code	There is no information on bus stops with color coding as indicator of operational status in the Helsinki capital region.
Guidance Services	Examples of current guidance services have been explained in previous parts of this table, such as 'Commuting Signs and Notifications'. Currently, guidance is provided with solutions such as notification boards, physical signs, or mobile applications.

Table 10: Service implementation status and 5G opportunities

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6.5 5G Projects and Ecosystems Beyond Kera

This section will look at other relevant 5G projects and ecosystems to compliment the information provided from the LuxTurrim5G and Neutral Host Pilot projects. A focus is on projects within Finland and the EU due to the similarities in legislation. The aim of this report is not to provide an all-encompassing list of relevant projects, but to guide the reader to sources that can give more information to the interested.

6.5.1 5G Test Network Finland

5G Test Network Finland (5GTNF) was an open innovation ecosystem that aimed to support 5G research, validation, product development and company experimentation. The ecosystem contained both platform-level research activities and solutions, and pilot activities within industry verticals. Ecosystem partners included research institutions, universities, public entities, and private partners. Local test sites in Espoo, Helsinki, Oulu, Tampere, Turku, Ylivieska and Kuopio were implemented, mostly as test networks for educational entities. Within Espoo, implemented test networks focus on the Aalto University campus area in Otaniemi. 5GTNF provides a list of connected research projects for further review. However, several included project webpages do not function presumably due to concluded activities. [86]

6.5.2 Traficom and 5G Momentum

The Finnish Transport and Communications Agency Traficom has implemented an ecosystem under the name of 5G Momentum, aiming to promote collaboration towards new trials and solutions within the 5G research space. Within ecosystem activities, Traficom offers 5G-themed events, information sharing and support in implementation of activities, especially regarding technology and regulation. [87]

As part of the agency's 5G activities, Traficom provides a list of 5G and 6G projects on the agency webpage. Due to the interests of the agency itself, most listed projects fall under the domain of rail transport, drones, ports and shipping, and road transport. Traficom also provides a list of finished 5G-related projects. [88]

6.5.3 Business Finland Funding for Leading Companies and Ecosystems

Business Finland provides funding for leading companies and ecosystems across industry lines through the so called Veturi initiative. The aim of the initiative is to increase research, development, and innovation investments in Finland and to increase productivity and sustainability across the implemented ecosystems [89].

Within the Business Finland Veturi initiative, three company-lead programmes have direct connections to 5G technology development. Nokia leads two different ecosystems focusing on industrial 5G and edge computing research and development, with over 200 ecosystem partners [90]. Within Nokia's Veturi programme 'Unlocking industrial 5G', the ecosystem aims to speed up development and investments into research of 5G solutions, build analytics, artificial intelligence (AI) and visualization driven operability solutions to

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support industrial 5G, and develop joint solutions through co-innovation between the ecosystem partners [91]. Within Nokia's Veturi programme 'Competitive Edge', the ecosystem aims to increase sustainability, competitiveness and scalability of digital infrastructure through edge and cloud computing solutions, and develop joint solutions through co-innovation between the ecosystem partners [92]. In addition to Nokia's Veturi programmes, Business Finland has funded a programme focusing on seamless and secure connectivity led by Bittium. The programme focuses on secure encryption technologies, secure connectivity for security-critical applications, developing end-to-end information security in different verticals, sensor fusion development, new operating models and new technologies, solutions and services [93].

6.5.4 5G Infrastructure Public-Private-Partnership

The 5G Infrastructure Public Private Partnership (5G PPP) is a joint initiative between the European Commission and European ICT industry. The initiative is currently in its third phase of projects. The aim of the partnership is to secure Europe's leadership in the field of next generation communication technologies, especially in areas where local competence is deemed strong, or areas with high market potential. The 5G PPP names smart cities, e-health, intelligent transport, education, entertainment and media as key markets of interest. Key challenges for 5G PPP are as follows [94]:

- *"Providing 1000 times higher wireless area capacity and more varied service capabilities compared to 2010."*
- *"Saving up to 90% of energy per service provided. The main focus will be in mobile communication networks where the dominating energy consumption comes from the radio access network."*
- *"Reducing the average service creation time cycle from 90 hours to 90 minutes."*
- *"Creating a secure, reliable and dependable Internet with a "zero perceived" downtime for services provision."*
- *"Facilitating very dense deployments of wireless communication links to connect over 7 trillion wireless devices serving over 7 billion people."*
- *"Ensuring for everyone and everywhere the access to a wider panel of services and applications at lower cost."*

All projects funded under 5G PPP supervision can be found on the initiative webpages. The last 19 projects have been funded under calls "ICT-41-2020 - 5G innovations for verticals with third party services" and "ICT-52-2020 - Smart Connectivity beyond 5G". Projects where expected to commence in January 2021 and run for three years.

6.5.5 6G Flagship

The University of Oulu coordinates 6G Flagship, a 6G research, development and innovation ecosystem. The ecosystem is funded by the University and the Research Council of Finland. The programme is a part of the Finnish government's national research spearhead programme for the years 2018-2026. The goals of the flagship programme are as follows [95]:

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- *Enable economic growth and support companies in identifying new services and business models via carrying out technological and system-level pilots.*
- *Create a nationwide test network and environment for 6G applications.*
- *Gain understanding of selected key vertical applications within a 6G ecosystem, being health, energy, automotive and industry verticals.*
- *Be a leader in crafting the 6G vision.*

Currently, thirteen white papers have been completed by experts under 6G Flagship facilitation. In addition, the programme releases 6G talks, a video series on the future of communication technologies.

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7. CONCLUSION

The SPARCS project aimed to assess the relevance of 5G within the energy and mobility sectors. Within the energy sector, a focus on the development of smart grids including optimization solutions, bi-directional energy flows and demand side management was chosen, while the mobility section focused on autonomous mobility and Vehicle-to-Grid (V2G).

The current energy transition leads to the utilization of new more intermittent energy solutions, a large-scale addition of new users, and new requirements for grid stability. This leads to the implementation of new and enhanced smart infrastructure, such as smarter energy grids, requiring enhanced use of data and new smart solutions to ensure reliable operation. This requires new solutions for communication within the energy sector, of which 5G is one opportunity. 5G can enhance the grid in the themes of grid control and data collection. This includes use cases in enhanced grid protection, distribution automation and the control and forecasting of renewable production. The opportunities that 5G provides for drone services can also aid in grid inspection and maintenance. The main question that remains is if enhanced mobile communications are a requirement for a fairly static infrastructure sector. Still, 5G has clear benefits when the number of smart devices that provide data to utilities, service providers, and consumers increases substantially, and opportunities in network slicing provide dedicated channels for integral safety operations via the Ultra Reliable Low Latency Communications (URLLC) slice.

Within the mobility sector, the development of autonomous mobility will require enhanced communication solutions from intra-vehicle sensing systems all the way to long-range communication between the vehicles and everything around them, known as Vehicle-to-Everything (V2X). 5G is an enabler to this long-range communication section of autonomous transport development. For the foreseeable future, autonomous vehicles will need an opportunity for human control in unexpected situations. Without proper communication solutions, this human control needs to be provided on-site. Another opportunity that 5G provides is network slicing, where a dedicated slice of the 5G network is provided for V2X communications to ensure the reliable exchange of operation-integral data. As with the energy sector, 5G provides the most benefits as a critical mass of autonomous vehicles is reached and the rate of data collection and exchange has increased rapidly. Still, the development of new products and infrastructure within the telecommunications and automotive sectors is a long process, and thus stakeholders in both fields have already begun working on the needed enhancements.

So far, the amount of research on the opportunities of 5G within Vehicle-to-Grid (V2G) solutions has been low. However, some research has still been made within this field. Oftentimes, the role of 5G within V2G has been deemed quite low, as V2G does not have the low latency requirement that autonomous vehicles require. However, the opportunities of 5G for mM2M and mIoT solutions are deemed beneficial for V2G. As EV fleets scale up, 5G can ensure reliable communication. Still, current state-of-the-art research mostly centralizes on communication within the charging station, and does not consider communication needs for mobile EV's. This research often focuses on vehicle-to-infrastructure communication (V2I) and autonomous vehicles (AV's), which do not consider grid connection as extensively as other issues, such as safety. Within 5G, network slicing can be used to provide reliable communication solutions to the charging

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infrastructure as the number of chargers increases. In addition to network slicing, the added possibilities of edge computing as a 5G service can provide the processing power needed nearby the EV users. Edge computing is proposed as an interesting innovation for EV's due to the high mobility of the vehicles themselves, in addition to the EV-situated computing power needed to make decisions on charging and discharging based on user preferences and grid condition. These decisions also need to be made in real-time due to the nature of electricity trade, thus providing a need to construct a communication network that minimizes delay in V2G communication.

As work has already been done on the implementation of 5G infrastructure for smart city solutions within Espoo, a look into the results provided by this work was deemed necessary. The different service opportunities and use cases identified within these projects was chosen as a possible link between this report and the previous work. The Neutral Host Pilot (NHP) project has identified different service clusters that utilize a local small cell 5G network, with examples of different services given under each cluster. This report identified current providers that already provide these services within the city limits, and identify the value that a 5G network can provide to these actors. The role and opportunities of 5G will be clarified as service providers increasingly make use of this technology and its opportunities.

This report identifies the role of 5G within the Espoo city strategy, including links between 5G technology and the Espoo story. In addition, current 5G projects within the Kera demonstration area in Espoo are analyzed, and projects beyond Kera are identified. Kera continues to be an interesting area for 5G development activities due to local stakeholders' interest and the local pilot environment. Several projects and ecosystems can provide additional information on 5G and related issues, while ecosystems have already been built around the development of the next stage of mobile communication technology, 6G.

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