Draft Report

5G-MOBIX: CAM Deployment Study

Assessing CAM and the 5G Infrastructure Investment Delta in European Border Corridors

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- CONFIDENTIAL -

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Contents

1 MANAGEMENT SUMMARY 4

2 INTRODUCTION 5

2.1 CONTEXT 5
2.2 5G-MOBIX CONCEPT AND APPROACH 8

3 OBJECTIVES AND METHODOLOGY 9

3.1 OBJECTIVES / PURPOSE 9
3.2 OVERALL APPROACH 9
3.3 STAKEHOLDERS IDENTIFIED 11
3.4 DATA COLLECTION METHODOLOGY 12
3.4.1 Interviews and Questionnaire 12
3.4.2 Industry Research and Publications 13
3.5 DATA PROCESSING METHODOLOGY 13
3.5.1 CAM Connectivity Requirements 14
3.5.2 Radio Network Planning methodology 19
3.5.3 Costing delta calculation 26
3.5.4 Traffic Forecasting 30
3.6 LIMITATIONS 33

4 RESULTS – 5G FOR CAM DEPLOYMENT 35

4.1 OVERVIEW 35
4.2 CAM SERVICES AND DETAILED REQUIREMENTS 35
4.3 PROJECTED VEHICULAR TRAFFIC 37
4.4 PROJECTED DATA TRAFFIC 38
4.4.1 CBC PT-ES 39
4.4.2 CBC GR-TR 40
4.4.3 CBC DE-NL 40
4.4.4 CBC FI-NO 41
4.4.5 CBC ES-FR 42
4.5 EXISTING OR PLANNED 5G INFRASTRUCTURE 43
4.5.1 Network and Roadside Infrastructure and CAM 43
4.5.2 Road Coverage Obligations 48
4.6 NETWORK PLANNING FOR 5G FOR CAM DEPLOYMENT 51
4.6.1 CBC PT-ES 54
4.6.2 CBC GR-TR 64
4.6.3 CBC DE-NL 71
4.6.4 CBC FI-NO 80
4.6.5 CBC ES-FR 90
4.7 DEPLOYMENT COST DELTA FOR CONNECTIVITY INVESTMENTS 102
4.7.1 CBC PT-ES 104
4.7.2 CBC GR-TR 106
4.7.3 CBC DE-NL 108
4.7.4 CBC FI-NO 110

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.

4.7.5 *CBC ES-FR* ... *112*
4.7.6 *Multi-access Edge Computing (MEC)* ... *114*
4.7.7 *Roadside Infrastructure Deployment Delta* ... *115*
4.8 Steps and timelines for 5G RAN deployment ... 116
4.9 Qualitative Insights from Interviews ... 117
4.9.1 *Regulatory Issues* ... *118*
4.9.2 *Automotive Industry and Suppliers* ... *118*
4.9.3 *Mobile Network Operators* ... *120*
4.9.4 *Road Operators* ... *121*
4.9.5 *Other* ... *121*

5 KEY FINDINGS ... 122

5.1 Traffic Characteristics (RQ1) ... 122
5.2 CAM Requirements (RQ2) ... 123
5.3 Investment Plans (RQ3) ... 123
5.4 5G Infrastructure Deployment Delta (RQ4) ... 124
5.5 Market Implications (RQ5) ... 124
5.6 Long-term Implications towards 2030 (RQ6) ... 125

6 APPENDICES ... 134

APPENDIX A ... 135

A.1 Cost Calculation Model ... 135
A.2 Traffic Forecast Model ... 135
A.3 Questionnaires ... 135

APPENDIX B ... 136

B.1 Company Profile ... 136
B.2 Indices / Glossary / Abbreviations ... 139

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1 Management Summary

The main objective of this 5G-MOBIX Deployment Study is the estimation of 5G infrastructure investments required for connected, automated mobility (CAM) in five European cross-border corridors (CBCs). In particular, the study should give an indication to policy makers, private and public investors, and relevant industries of the investment delta of planned/ existing to required infrastructure based on the demands of connected, automated vehicles.

Key inputs for this study have been collected in stakeholder interviews with mobile network operators, road operators, 5G equipment vendors and the automotive industry. Complemented by extensive industry research and 5G MOBIX expertise these inputs allowed us to derive estimations about existing and planned infrastructure, its costs as well the expected CAM cellular capacity demand for 5G. The study focuses on the years 2023 and 2025. In all CBCs, the existing RAN infrastructure is insufficient due to white spots, i.e., cellular coverage gaps. Further, currently planned investments focus on upgrades of existing sites, rather than deployment of new sites, so most of the white spots are expected to persist.

Further, nominal radio planning across the CBCs estimated the provided capacity in two 5G deployment scenarios representing two commonly used 5G-bands for road coverage, i.e., 700 MHz and 3500 MHz. In addition, the radio planning provided the bill of quantity for the radio access network (RAN) needed to provide seamless coverage with a minimum signal strength and reliability across all CBCs for each of the deployment scenarios.

Based on these estimations, the study provides insights as to the additional 5G RAN investments required for 9 different traffic scenarios. We see that 700 MHz 5G deployment is expected to provide sufficient capacity in 4 out 5 CBCs in 2023 and in 3 out of 5 CBCs in 2025. Further, we see that 3500 MHz 5G deployment provides sufficient capacity in all CBCs until at least 2025.

With respect to the costs, our results indicate that required 5G RAN investments for CAM range from around 700k EUR in well-developed CBCs or those with low expected CAM traffic up to 3.7 mEUR for those CBCs that are expected to require dense mid-band (3500 MHz) deployment due to high expected capacity demand from connected, automated cars (CAVs).

Further, we see that regulatory road coverage obligations tied to 5G spectrum licenses appear to be a leading driver in 5G deployment along rural motorways in Europe. Besides that, interview partners from various industries have underlined that uncertainty with respect to technological standards, infrastructure deployment, cellular requirements of CAVs and business models are hindering investments. A unified pan-European approach to covering key transport corridors with clear specifications of capacity, latency, reliability and signal strength as well as cross-industry agreement on technological standardization could solve these issues and thus lead to market growth in the CAM sector and eliminate inefficient investments.

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2 Introduction

2.1 Context

Connected, automated driving use cases are evolving at an ever-accelerating speed. While these use cases come with challenging connectivity requirements, 5G cellular technology is deployed at the right time to fulfil these requirements – at least in metropolitan centres. In rural areas, the deployment of new technology tends to occur slower than elsewhere, due to lower population densities and thus, lower commercial investment incentives for mobile network operators (MNOs). In many European countries, border areas tend to fall into this category. Yet, the implications of insufficient cellular infrastructure along motorways across European borders could be quite detrimental for connected, automated cross-border traffic.

5G MOBIX is an international project consisting of 58 partners with the objective to develop and test automated vehicle functionalities using 5G core technological innovations along multiple cross-border corridors and urban trial sites, under conditions of regular vehicular traffic, network coverage, service demand, as well as considering the inherently distinct legal, business and social local aspects. The project evaluates benefits in the CAM context as well as defining deployment scenarios and identifying and responding to standardisation and spectrum gaps[1].

Within this context, the 5G-MOBIX Deployment Study aims to assess the connectivity demands of connected, automated mobility (CAM)[2] and the corresponding 5G infrastructure investment delta in five European cross-border corridors (CBCs). The objective is to provide an indication to policy makers, private and public investors, and relevant industries of the potential dimensions of additional infrastructure needed to provide sufficient and reliable 5G capacity and coverage based on the demands of connected, automated vehicles.

To this end, the report set out to provide answers to the following research questions (RQ).

- **RQ1:** What are the **traffic characteristics** that would be expected for 2023 and 2025?
- **RQ2:** What are the **exact needs of CAM services at border areas** and the CAM use-cases' detailed requirements?
- **RQ3:** What are the **already planned investments in physical & digital infrastructure** to be deployed in the Cross Border areas?
- **RQ4:** What is the **deployment "delta" between currently planned investments** and the necessary investments to deliver full coverage for the CAM use-cases?

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[1] For more information, please refer to chapter 2.3 5G-MOBIX concept and approach or the 5G-MOBIX website (www.5g-mobix.com).

[2] CAM data traffic is defined as traffic generated by CAVs with automation level 3, 4 or 5 as defined by the SAE and transported over a cellular network.

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- **RQ5:** What is necessary with regards to networking, preparation for market and business risks, enablers, market analysis, and **competitive intelligence**?
- **RQ6:** What are any **assumptions and projections** that can be made **towards 2030**?

First (RQ1), the study aims to identify the traffic characteristics that can be expected for 2023 and 2025 along the five CBCs. This includes estimating the projected CAM vehicle fleet penetration rate in each market, as well as yearly CAM market shares. Based on these figures, the study aims to estimate the amount of 5G traffic to be expected, differentiating 5G “background” traffic (i.e., traffic generated by non-IoT subscribers) from CAM-generated data traffic.

Second (RQ2), the study estimates the connectivity demand of CAM services along the CBCs based on the use cases' detailed requirements (as provided by deliverables D2.1 “*5G-enabled CCAM use cases specifications*”, November, 2019, D5.1, "*Evaluation Methodology and Plan*" February 2020, and D6.2 “*Plan and preliminary report on the business models for cross border 5G deployment enabling CCAM*”, October 2020 within the 5G MOBIX project[3]). These shall indicate potential gaps in projected services & coverage and estimated service needs.

Thirdly (RQ3), this report includes the results from industry surveys across nine European countries (Portugal, Spain, Greece, Turkey, Germany, Netherlands, Finland, Norway and France) to understand the already planned investments in cellular infrastructure along the CBCs.

Fourth (RQ4), based on a nominal high-level radio frequency planning exercise, the study aims to identify the necessary investments to deliver full coverage for the CAM use cases' connectivity demands. Comparing this to the already planned infrastructure investments, will provide an understanding the so-called infrastructure investment delta for the years 2023 and 2025. In addition to this, the study shows the generic steps and timelines of 5G RAN base station deployment.

Fifth (RQ5), based on the insights from extensive research and industry surveys, the study sheds light on necessities with regards to networking, market and business risks and competitive intelligence.

Finally (RQ6), based on the synthesized insights from the previous RQs, the study derives assumptions and projections for 5G-enabled CAM in European CBCs towards 2030.

In order to provide answers to the questions listed above, Detecon followed a comprehensive approach of multiple phases including key stakeholder interviews from various industries, desk research, a nominal radio planning, high-level capacity planning, developing road and data traffic forecast models as well as estimation models for the RAN

[3] All referenced 5G-MOBIX deliverables and reports can be found under: https://www.5g-mobix.com/resources/deliverables

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deployment costs covering two 5G common deployment scenarios for the years 2023 and 2025.

Geographically, the scope of this study covers the following five European cross-border corridors (CBCs):

A ~40 km section (20 km on each side of the border) of each of the following five CBCs was assessed as part of this study (illustrated in Figure 1). The list below includes the two-letter country code, names of prominent border towns and larger cities connected by the corridor.

- **ES-PT:** Tui/Valenca (Vigo – Porto)
- **GR-TR:** Kipoi/Ipsala (Alexandroupoli – Kesan)
- **DE-NL:** Veldhuizen (Emmerich – Arnhem)
- **FI-NO:** Kilpisjärvi (Skibotn – Muonio)
- **ES-FR:** Le Perthus (Figueres – Perpignan)

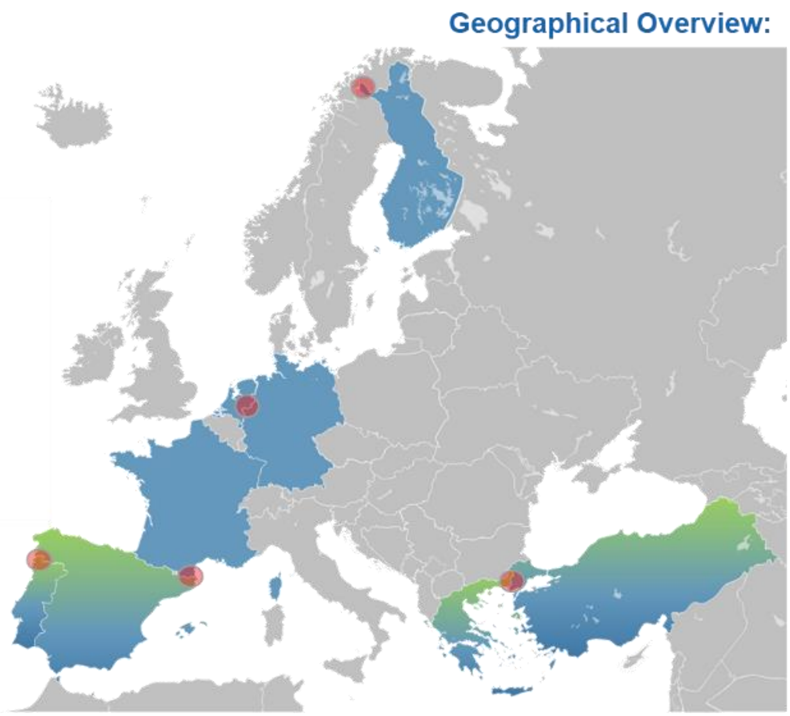

Figure 1: Geographical scope overview

The report is structured as follows. The following chapter 3 describes the key objectives and the applied methodology. Chapter 4 presents the results of the study for all five cross-border corridors. Chapter 5 presents key findings and conclusions based on the results and points out areas to be explored by further studies. The appendices to this report contain supporting material, such as the calculation and forecast models and more detailed results.

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2.2 5G-MOBIX Concept and Approach

The 5G-MOBIX consortium played a crucial role in the successful completion of this study. It currently consists of 58 partners from various countries and industries and supported the study with valuable technical expertise, insights from the trial sites and its extended stakeholder network across Europe.

5G-MOBIX aims to showcase the added value of 5G technology for advanced CAM use cases and validate the viability of the technology to bring automated driving to the next level of vehicle automation (SAE L4 and above). To do this, 5G-MOBIX will demonstrate the potential of different 5G features on real European roads and highways and create and use sustainable business models to develop 5G corridors. 5G-MOBIX will also utilize and upgrade existing key assets (infrastructure, vehicles, components) and the smooth operation and co-existence of 5G within complex cross-border environments.

5G-MOBIX will execute CAM trials along cross-border (x-border) and urban corridors using 5G core technological innovations to qualify the 5G infrastructure and evaluate its benefits in the CAM context. The study will also define deployment scenarios and identify and respond to standardisation and spectrum gaps.

5G-MOBIX has defined critical CAM scenarios, based on the input of multiple European stakeholders, needing advanced connectivity provided by 5G, and the required features to enable some advanced CAM use cases. The matching of these advanced CAM use cases and the expected benefits of 5G is currently being tested in trials on the 5G-MOBIX 5G corridors in different EU countries as well as in Turkey, China and Korea.

The trials will also allow 5G-MOBIX to conduct evaluations and impact assessments and to define business impacts and cost/benefit analysis. As a result of these evaluations and international consultations with the public and industry stakeholders, 5G-MOBIX will identify new business opportunities for the 5G enabled CAM and propose recommendations and options for its deployment.

5G-MOBIX has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement **No. 825496**. Detecon has been subcontracted by 5G-MOBIX – represented by AEVAC – to carry out this deployment study which falls under the 5G-MOBIX exploitation work.

3 Objectives and Methodology

3.1 Objectives / Purpose

This report provides a detailed estimation of the 5G RAN for CAM infrastructure investment delta along five European cross-border corridors. To perform this estimation, it is necessary to forecast the future road traffic characteristics, cellular capacity demand generated by connected, automated vehicles (CAVs), the infrastructure needed and the costs for 5G RAN deployment. Alongside the qualitative output of the stakeholder interviews and additional research, **the report thus provides an indication of the 5G for CAM infrastructure investment delta** (compared to existing infrastructure and investments already planned to accommodate non-CAV traffic) and sheds light upon the current key challenges mobile network operators, road operators and the automotive industry are facing in terms of driving the deployment of CAM across Europe's borders.

3.2 Overall Approach

In order to investigate the research questions at the core of this study and to successfully assess the 5G infrastructure investment delta or "gaps" along the CBCs, a multi-faceted approach has been used.

Based on the underlying assumptions that the investment gap is caused by the fact that expected demand for 5G services will increase along the identified high-way corridors and the corresponding expectation, that the infrastructure will not be deployed in a sufficient scale the key variable is the so-called investment delta. The key steps of the approach are shown below in Figure 2 and the two underlying key assumptions are shown in Figure 3.

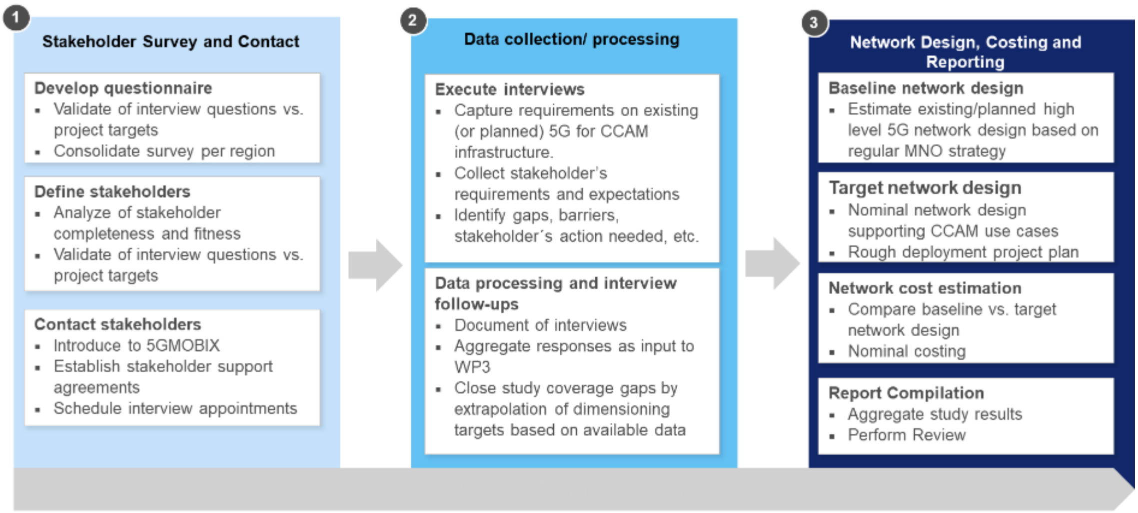

Figure 2: Overall approach

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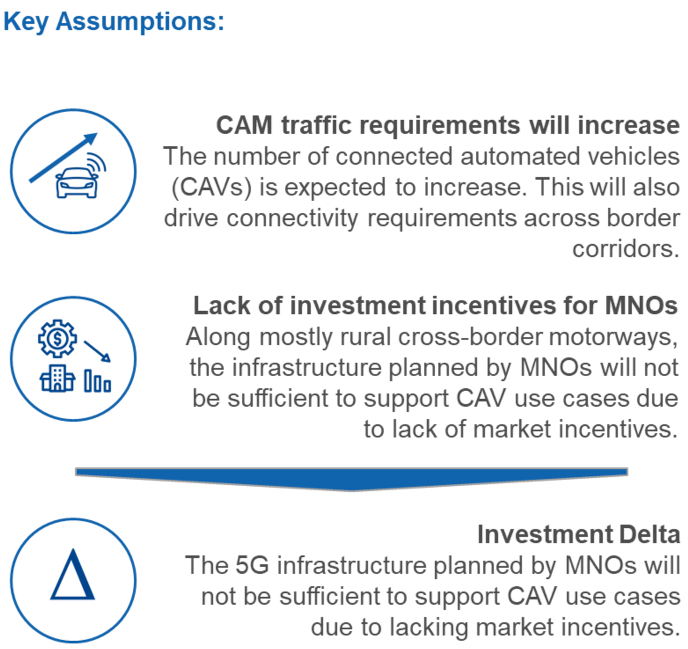

Figure 3: Key assumptions

The investment delta (RQ 4):

The key methodology to calculate the investment delta is to subtract the cost of the planned or already existing 5G deployment (RQ3) from the cost of the 5G deployment which would be needed to enable CAM traffic, as depicted in Figure 4. The information about the planned or existing 5G deployment is based mainly on the conducted interviews with the operators which provide relevant services in the corridors (e.g., road operators, MNOs etc.) and our own research into the road coverage obligations which were presented by each regulatory authority alongside the 5G auctions. On the other hand, the information about the needed 5G deployment is based on the radio and network planning exercise as part of this project, interviews with automotive manufacturers and the MNOs.

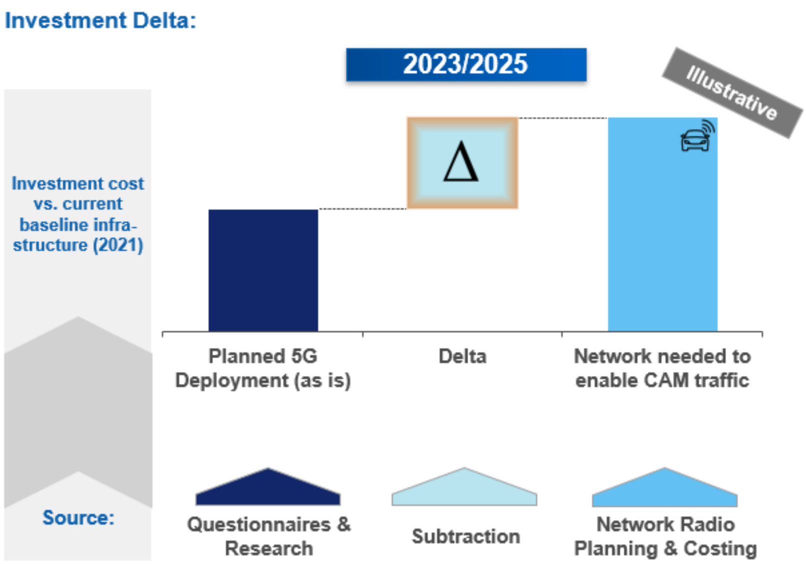

Figure 4: Investment delta

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The investment delta is calculated for two realistic deployment scenarios: 700 MHz coverage with sufficiently reliable signal strengths and 3500 MHz coverage with sufficiently reliable signal strengths. Once the capacity of the first low-band scenario is exceeded by the projected demand, the goal would be to deploy more capacity in the higher band.

RAN Radio Planning

In terms of cellular layers, this study focuses on a pure cellular network-based (Uu) radio interface due to several reasons. According to the results from our discussions and interviews with the responsible road operators, wide-spread deployment of C-V2X roadside units (RSUs) along the specified corridors is not to be expected prior to 2025. Further, in line with the level of detail aimed for within this study, calculating the C-V2X RSU investment delta is a relatively straightforward calculation that depends on the RSU equipment cost, installation services and the expected average inter-RSU distance. This basic calculation has been covered in chapter 4.7.6. to provide a high-level cost indication. Furthermore, there are various 5G architectures that could be deployed along European motorways[4], covering all different types of RAN network architectures would go beyond the scope of this study. In addition, to fulfil the use case requirements as outlined in chapters 3.5.2 and 4.6., 5G macro-layer deployment appears to be one the most likely deployment scenarios[5].

3.3 Stakeholders Identified

This study significantly relied on interviews with industry representatives. We reached out to all relevant stakeholders in the assessed CBCs. Within the course of this study, we interviewed:

- 17 mobile network operators
- 12 road operators
- 7 car manufacturers, vendors and industry representatives and experts.

There are three different types of questionnaires that were used within this study, one for each of the groups listed above (please refer to the Appendix, 6A.3, for examples of the full questionnaires). The MNO questionnaire inquired about characteristics of the existing and planned mobile network infrastructure along the CBCs, the costs for different network elements (such as RAN active and passive equipment, fiberization, MEC DCs) as well as data traffic information and forecasts and more general views on the role of CAM for MNOs. Similarly, the RO questionnaire inquired about existing and planned road-related

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[4] 5GPPP, *View on 5G Architecture*, 2019, https://5g-ppp.eu/wp-content/uploads/2019/07/5G-PPP-5G-Architecture-White-Paper_v3.0_PublicConsultation.pdf

[5] For further information on different V2I RAN deployment options, please refer to: Ricardo Energy & Environment, *Cost Analysis of V2I Deployment*, 2020, https://5gaa.org/wp-content/uploads/2020/09/5GAA_Ricardo-Study-V2I-Cost-Analysis_Final_110820.pdf

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infrastructure (such as C-V2X roadside units and optical fiber), the characteristics of current vehicular traffic and forecasts (if available) as well as the ROs view on CAM in general. The third questionnaire for the automotive industry was focusing on sales forecasts of CAVs, technical aspects of the on-board equipment with respect to cellular connectivity as well as general views on CAM and mobile network infrastructure along roads.

The received interview responses differed in terms of detail and comprehensiveness and ranged from only verbal comments and statements to full responses to the questionnaires in written form.

The results of these interviews represent the inputs for CAM requirements (chapter 3.5.1), the traffic forecasting (chapter 3.5.4), the existing 5G infrastructure (chapter 4.5), and the cost results (chapter 4.7). Further insights are documented in chapter 4.9 (Qualitative Insights from Interviews).

3.4 Data collection Methodology

The data collection methodology relies on four primary sources:

- Interviews/discussions with and questionnaire responses from industry representatives and experts
- Industry research and publications
- 5G-MOBIX expertise, stakeholder network and previous project results as well as technical inputs
- Detecon expertise and previous project experience

3.4.1 Interviews and Questionnaire

Prior to defining the stakeholder ecosystem, we defined the questionnaires and the inputs that are necessary for our analysis. In order to define the stakeholder ecosystem, we thoroughly assessed the CBCs and the organizations operating along the highways as well as relevant manufacturers. The approach included the following steps:

Questionnaire development

- Review of the questionnaire as pre-developed and provided by 5G-MOBIX and its project partners. The questionnaire was submitted to Detecon in a very mature format, based on the previous work conducted within the 5G-MOBIX project.
- Validation of interview questions in alignment with the study objectives
- Consolidation of the survey per region

Stakeholder definition

- Identification of relevant stakeholders. This exercise was significantly supported by 5G-MOBIX due to its vast network of 58 partners representing all relevant industries in various European countries.
- Analysis of stakeholder completeness and fitness.
- Validation of interview stakeholders in alignment with the study objectives.

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Stakeholder contacting

- Introduction to 5G-MOBIX and the objectives of the deployment study
- Establishment of stakeholder support agreements as well as non-disclosure agreements
- Scheduling interview appointments

All these steps were taken in preparation to the expert interviews which were conducted with various stakeholders from different industries in all nine target countries.

Expert Interviews

- Mobile Network Operators
- Internet Service Providers
- ITS Providers & Operators
- Road Authorities
- Automotive OEM
- Tier 1 Suppliers
- Industry Associations

3.4.2 Industry Research and Publications

To complement the results from the interviews, the project team also conducted extensive research of existing industry publications.

Industry Research & Publications:

- Studies
- Whitepapers
- Project Results

By established Stakeholders:

- Next Generation Mobile Networks Alliance
- Global TD-LTE Initiative
- 5G Automotive Association
- 3rd Generation Partnership Project
- GSMA

3.5 Data Processing Methodology

This section describes how the collected data was processed and how the results were derived subsequently. It is separated into four sub-sections dealing with different methods applied within the study.

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3.5.1 CAM Connectivity Requirements

The following section presents the use cases and user stories which were taken into consideration when deriving the general CAM connectivity requirements as inputs for the 5G radio and capacity planning. Based on comprehensive discussions with 5G-MOBIX trial site leaders and technical experts as well as subject matter experts outside of 5G-MOBIX, we derived estimated CAM connectivity requirements for different future scenarios (see results in chapter 3.5.1).

Note: all use case descriptions below are based on 5G-MOBIX deliverable 2.1.

The table below, which has been provided as a direct input from the 5G-MOBIX consortium, summarizes the requirements (E2E latency, vehicle bit rates, max. velocity of the use case and the required reliability) from the individual user stories on an aggregated use case level.

Use cases requirements assumptions:

Parameter	Advanced Driving	Platooning	Extended Sensors	Remote Driving	Vehicle QoS Support
E2E Latency	< 50 ms	< 50 ms	< 100 ms	< 50 ms	< 1000 ms
Vehicle bit rate	40 kbps	30 Mbps (DL/UL)	20 Mbps (DL/UL)	36 Mbps (UL)	1 Mbps
Mobility	up to 100 km/h	up to 80 km/h	up to 100 km/h	20 km/h	up to 100 km/h
Reliability	99,99%	99,99%	99,99%	99,99%	99,99%

Table 1: 5G-MOBIX Key Use Case Requirements

3.5.1.1 5G-MOBIX User Story Requirements

This section briefly describers each 5G-MOBIX user story that provided inputs to derive the CAM connectivity requirements and its connectivity requirements (bit rates in uplink and downlink).

In all user stories the required E2E latency was 50 ms or higher. Thus, we applied a 50 ms E2E latency requirement throughout the study.

Advanced Driving:

Each vehicle and/or Roadside Unit (RSU) shares data obtained from its local sensors with vehicles in proximity, thus allowing vehicles to coordinate their trajectories or manoeuvres. In addition, each vehicle shares its driving intention with vehicles in proximity. The benefits of this use case group are safer traveling, collision avoidance, and improved traffic efficiency)

- CCA: Cooperative collision avoidance
  The Vehicle A will make itself 'visible' and known to other traffic participants and to the infrastructure for Edge Computing through C-ITS messaging via 5G networks, and Cellular V2X (C-V2X) communication. The Vehicle B will submit similar

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information of its presence, speed and direction of movement to Vehicle A and infrastructure as described above. Hence the ‘Edge Cloud’ infrastructure facilities can perform calculations and offload from the vehicles to the infrastructure and then return the suggested manoeuvring messages.

- Peak Requirements:
  - Downlink: 20 Mbps
  - Uplink: 20 Mbps

- LaneMerge: Complex manoeuvres in cross-border settings: lane merge for automated vehicles
  - This scenario manages the situation where automated vehicles are in a lane merge scenario, analysing the traffic flow of the target lane. In this way, the system can detect existing vehicles including their lane position, acceleration, speed, size, etc. providing an extended perception layer, which is considered by the automated vehicle to determine the best merge manoeuvre according to the current situation.
  - Peak Requirements:
    - Downlink: 20 Mbps
    - Uplink: 25 Mbps

- Overtaking: Complex manoeuvres in cross-border settings: automated overtaking
  When an automated vehicle needs to overtake a vehicle that precedes it, additional information provided by communication technologies will drastically improve and complement the information provided by its sensor constellation.
  - Peak Requirements:
    - Downlink: 20 Mbps
    - Uplink: 25 Mbps

- AssInfrastructure: Infrastructure -assisted advanced driving
  The principal behind Infrastructure assisted advanced driving is that the Vehicles send their information (e.g., location, speed) to road entities, such as Multi-access Edge Computing data centres (MECs), which will then process the data with data from other sources like RSUs or other vehicles to give the vehicles “instructions” how to handle certain situations when they come up.
  - Peak Requirements:
    - Downlink: 20 Mbps
    - Uplink: 30 Mbps

- AutoShut: Automated shuttle driving across borders
  This use case covers two possible scenarios. The first is, the EV Autonomous shuttle is able to receive information coming from other actors (like a Vulnerable Road User) and adapt its behaviour according to specific needs. In the second one is described under “Remote Driving: BCrossing: Automated shuttle RD across borders”.
  - Requirements:
    - Downlink: 30 – 36 Mbps
    - Uplink: 36 Mbps

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Vehicles Platooning:

Vehicles Platooning enables the vehicles to dynamically form a group travelling together. All the vehicles in the platoon receive periodic data from the leading vehicle, in order to carry on platoon operations. This information allows the distance between vehicles to become extremely small, i.e., the gap distance translated to time can be very low (sub second). Platooning applications may allow the vehicles following to be autonomously driven.

- SeeWhatISee: Platooning with "see what I see" functionality in cross-border settings
  Observing that there is at least another vehicle on a road, which does not involve intersections and merging with other lanes for a certain time, the two or more vehicles on the move will decide to form a platoon. In the platoon, while one of the vehicles take on the role of the leader, which may or may not have an active driver depending on the SAE level of the vehicle itself, the rest of the vehicles may be controlled automatically by the movements of the leading vehicle.
  - Requirements:
    - Downlink: 30 Mbps
    - Uplink: 30 Mbps

- AsseRSU: eRSU-assisted platooning
  Vehicles in platoons are not only connected to each other but RSUs can help them communicate by processing the data and adding more information from additional sources.
  - Requirements:
    - Downlink: 30 Mbps
    - Uplink: 30 Mbps

Extended Sensors

Extended Sensors enable the exchange of raw or processed data gathered through local sensors or live video data among vehicles, RSUs, devices of pedestrians and V2X application servers. The vehicles can enhance the perception of their environment beyond what their own sensors can detect and have a more holistic view of the local situation.

- HDMaps: Complex manoeuvres in cross-border settings: HDMaps
  This use case focusses on the capability of automated vehicles and road-side infrastructure to detect changes in the road and the HD-Map used for driving, and in sending these changes to the ITS-Centre in order to centralise and broadcast this information to the other approaching vehicles.
  - Requirements:
    - Downlink: 20 Mbps
    - Uplink: 20 Mbps

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- AssBCrossing: Extended sensors for assisted border-crossing
  While crossing the border, a vehicle can send information about its passengers and other relevant data to homogenize the traffic near borders.
  - Requirements:
    - Downlink: 20 Mbps
    - Uplink: 30 Mbps

- TruckRouting: Extended sensors for assisted border-crossing
  While crossing the border, a vehicle can send information about its cargo and other relevant information to homogenize the traffic near borders.
  - Requirements:
    - Downlink: 10 Mbps
    - Uplink: 36 Mbps

- EDM: EDM-enabled ES with surround view generation
  Lack of environment information is caused when the view of the vehicle sensor is obstructed by objects, limited by weather conditions, or not covering a specific area. To mitigate the lack of environment information, vehicles share extracts ROIs (regions of interest) from their Local Dynamic Maps (LDMs) and/or sensor raw data and the eRSU shares its Edged Dynamic Map (EDM). This EDM is created by e.g., the RSU when it processes all data which it gets from vehicles or other sensors and generates an image of the traffic including driving instructions.
  - Requirements:
    - Downlink: 30 Mbps
    - Uplink: 30 Mbps

- EdgeProcessing: Extended sensors with redundant Edge processing
  To shorten response delay and to avoid moving tremendous data from the automated vehicle through core network, it is essential to move computational resources closer to where the data is generated. In practice, data can be gathered and processed at edge computing nodes located in wireless access networks.
  - Requirements:
    - Downlink: 20 Mbps
    - Uplink: 20 Mbps

- CPM: Extended sensors with CPM messages
  In this use case, vehicles and roadside unit (RSU) exchange information in real time to enhance their perception of the environment. CPE can improve the safety of AD vehicles and traffic flow by providing better anticipation, which in turn increases energy efficiency and reduces the carbon footprint. CPE can aid in the coordinated control of vehicles as in cooperative collision avoidance or cooperative manoeuvre such as lane change, merge and diverge. By connecting to existing C-ITS and traffic management road-side information systems, and by exploiting sources from legacy traffic that are available in the cellular network, it can further improve the traffic flow.
  - Requirements:
    - Downlink: 25 Mbps

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- Uplink: 25 Mbps

Remote Driving (RD):

Remote Driving enables a remote driver or a V2X application to operate a remote vehicle for those passengers who cannot drive themselves or a remote vehicle located in dangerous environments. For a case where variation is limited, and routes are predictable, such as public transportation, driving based on cloud computing can be used. In addition, access to cloud-based back-end service platform can be considered for this use case group.

- BCrossing: Automated shuttle RD across borders
  The EV autonomous vehicle is driving following a predefined route, and suddenly an obstacle appears in its path blocking the original route. In this situation, an operator is alarmed, and he/she is able to remotely take the control of the EV autonomous vehicle or issue a set of new navigation commands in order to handle a new route.
  - Requirements:
    - Downlink: 20 Mbps
    - Uplink: 30 Mbps

- 5GPositioning: Remote driving using 5G positioning
  In situation where the AD vehicle is unable to automatically drive further (due to a failure or unexpected driving condition), a remote operator takes over control of the vehicle and drives it to a point where AD can be resumed. As an example, this can be in situations like border control, construction zones and inclement weather. To tele-operate a vehicle, the data from multiple sensors should stream their information (synchronised and with low latency) to the operator and at the same time have low latency in the control task of manoeuvring the vehicle in real time.
  - Requirements:
    - Downlink: 36 Mbps
    - Uplink: 36 Mbps

- RedundantNE: Remote driving in a redundant network environment:
  Remote driving of a high automation vehicle occurs when the vehicle is remotely controlled, by a human operator, and in some cases a cloud-based application within the domain of a Remote Operations Centre. A number of business-, socially- or safety-inspired scenarios may motivate remote driving of autonomous vehicles. E.g.:
  - Facilitating cloud-driven autonomous shuttles or public transportation services with predefined routes and stops;
  - Providing remote driving services for individuals who are unable or unlicensed to drive (e.g., youth, elderly, disabled persons etc.)
  - Providing a fall-back driving solution for autonomous vehicles which have encountered unfamiliar navigation environments or developed some faults;

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- Providing a solution for autonomous vehicle fleet owners to remotely-control their assets (e.g., delivering/retrieving rental)
    - Requirements:
        - Downlink: 36 Mbps
        - Uplink: 36 Mbps

Vehicle QoS Support:

Vehicle quality of service support enables a V2X application to be timely notified of expected or estimated change of quality of service before actual change occurs and to enable the 3GPP System to modify the quality of service in line with V2X application's quality of service needs. Based on the quality-of-service information, the V2X application can adapt behaviour to 3GPP System's conditions. The benefits of this use case group are offerings of smoother user experience of service.

- Public Transport: Public transport, HD media services and video surveillance: The objective of this use case is to provide real time connected services to the public transport fleets. According to this approach, users will be able to enjoy different multimedia services while travelling in the public transport, including high bandwidth data consumption applications as well. On the other hand, the public transport vehicle will be equipped with a 4K Camera in order to be able to remotely access the video stream for Control Centre management and monitoring tasks. Added to this, in vehicle sensor data will be sent to the ITS Centre in order to update the HD maps of other vehicles around, helping to improve the execution of autonomous driving manoeuvres in terms of safety and comfort.
    - Requirements:
        - Downlink: 20 Mbps
        - Uplink: 25 Mbps

3.5.2 Radio Network Planning methodology

3.5.2.1 Radio Planning

One of the key objectives of this study is to assess the amount of additional investments required to deploy 5G NR infrastructure in order to enable the provisioning of the set of the defined C-V2X use cases (hereinafter – 5G NR V2X) along five European CBCs. This amount of additional investments is defined as the 5G infrastructure investment delta.

The 5G investment delta should be defined based on the information about existing/already planned 5G NR network infrastructure and the infrastructure, required to support 5G NR V2X services. Further, we assume a non-standalone architecture as we are not expecting standalone architectures prior to 2023.

When assessing 20 km CBCs (per country), the radio access network (RAN) represents the key cost driver of the cellular network infrastructure as the costs scale with the CAM requirements. Existing sites in these CBCs have backhaul with fiber connectivity, costs for fiber backhaul of new sites are considered. Costs of the core and transport network or interconnection costs are general costs of the network assuming the impact of CAM services negligible in these CBCs.

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The number of sites required to be built or to be upgraded to 5G NR represents the main input for the cost modelling. In turn, the number of sites can be obtained as the outcome of the **nominal radio planning**.

Cellular network planning process can be divided into two stages:

- nominal planning
- detailed planning

In general, during this nominal planning, the network structure and preliminary locations of base stations (sites) are selected, the coverage area is calculated, a frequency-territorial plan is developed, the plan is adapted to the conditions of frequency restrictions by the special services, service areas are formed, and intra-system interference is evaluated.

And at the stage of the detailed planning, the following steps are carried out: binding to the grid of the nominal plan, choosing the exact location of the antennas, spatial separation of the antennas, choosing the power supply of the base stations, and choosing the transport network.

As the goal of this study is not the implementation of a real network deployment, but the assessment of the amount of additional investments required to enable 5G NR V2X services along the CBCs, a **simplified nominal radio planning is executed** in order **to derive the estimated number of sites** to be potentially built to support 5G NR V2X services along the corridors.

Figure 5 shows a specific network structure proposed for seamless and reliable coverage of all CBCs considering 5G NR V2X services reliability requirements (see the column “reliability” in Table 1 (5G-MOBIX Key Use Case Requirements) and 3GPP recommendations[6].

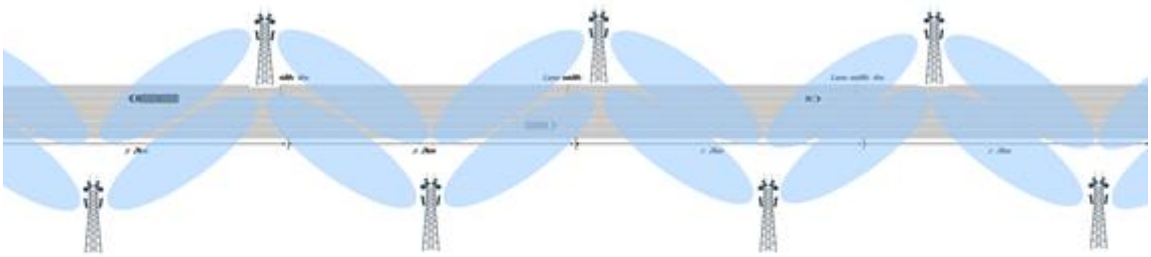

Figure 5: Target radio network structure

In summary, the simplified nominal radio planning for this study includes:

- simulation of coverage of the existing base stations

[6] 3GPP TR 38.913 v.16 00 «Technical Specification Group Radio Access Network Study on Scenarios and Requirements for Next Generation Access Technologies» (namely, but not limited to: Highway scenario, High speed, and Rural)

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- Identification of existing coverage gaps
- Identification of indicative locations for additional base stations to enable seamless coverage with V2X services required quality characteristics and based on the proposed network structure (see Figure.6) with a minimum signal of - 80 dBm
- coverage area simulation for additional base stations and the whole network
- calculation of number of base stations to be added into existing network

All radio planning has been executed with the ATDI HTZ Communications tool. HTZ Communications offers advanced radio network planning and optimisation capabilities for almost every technology allowing users to plan, evaluate and optimise radio networks.[7]

The inputs for the simplified nominal radio planning are the following:

- Frequency bands (NR operating bands in FR1 (410 MHz – 7125 MHz)) are presented in Table 2.

Spectrum scenario	**NR *operating band***	**Uplink (UL) *operating band BS receive / UE transmit*** $F_{UL,low}$ – $F_{UL,high}$	**Downlink (DL) *operating band BS transmit / UE receive*** $F_{DL,low}$ – $F_{DL,high}$	**Band width, MHz**	**Duplex mode**
Scenario 700	n28	703 MHz – 748 MHz	758 MHz – 803 MHz	10	FDD
Scenario 3500	n78	3300 MHz – 3800 MHz	3300 MHz – 3800 MHz	100	TDD

Table 2: Spectrum scenarios

Coverage simulation parameters

Scenario 700

Base station parameters:

- Nominal power: 43.01 dBm
- Antenna gain: 15.10 dBi
- MIMO: 2T / 4R
- Antenna height: 25 m
- Antenna azimuth for existing antennas (3 sectors): 120 degrees spacing (0, 120, 240 degree)

[7] ATDI, HTZ Communications v23.1.1 x64, 2021, https://atdi.com/htz-communications/

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- Antenna azimuth for new antennas (2 sectors): along the road, approx. 120 degrees spacing)
- Antenna tilt: - 3 deg
- Cable loses: Tx/Rx losses: 1.5 dB

On-board unit (OBU) parameters:

- Nominal power: 23dBm
- Gain: 0 dBi
- Losses: 0 dBi
- MIMO: 1T / 2R
- Antenna height: 1,5 m

5G MOBIX Key Use Case Requirements

- See Table 1 (5G MOBIX Key Use Case Requirements)

Scenario 3500

Base station parameters:

- Nominal power: 50 dBm
- Antenna gain: 15.10 dBi
- MIMO: 8T / 8R
- Antenna height: 25 m
- Antenna azimuth for existing antennas (3 sectors): 120 degrees spacing (0, 120, 240 degree)
- Antenna azimuth for new antennas (2 sectors): along the road, approx. 120 degrees spacing)
- Antenna tilt: - 3 deg
- Cable loses: Tx/Rx losses: 1.5 dB
- DL / UL = 80 / 20

OBU parameters:

- Nominal power: 23dBm
- Gain: 0 dBi
- Losses: 0 dBi
- MIMO: 1T / 2R
- Antenna height: 1,5 m

5G MOBIX Key Use Case Requirements

- See the table 2: 5G MOBIX Key Use Case Requirements

Outputs of the radio planning are the following:

- 5G NR coverage maps per corridor:
  - Existing sites only
  - Existing sites 5G NR @700 MHz coverage simulation
  - Existing + New sites 5G NR @700 MHz coverage simulation
  - Existing sites 5G NR @3500 MHz coverage simulation

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    - Existing + New sites 5G NR @3500 MHz coverage simulation
- Number of existing sites to be upgraded:
    - to 5G NR @700 MHz per country in the corridor.
    - to 5G NR @3500 MHz per country in the corridor.
- Number of new sites to be built:
    - 5G NR @700 MHz per country in the corridor.
    - 5G NR @3500 MHz per country in the corridor.

3.5.2.2 Capacity Planning

For the calculation of the required capacity of a gNodeB the data amount or data rate is one of the baseline figures.

Each of 5G-MOBIX Use Cases (UCs) has its own pre-defined requirements for the supported data-rate per vehicle in the Uplink (UL) and in the Downlink (DL), in Mbps. Therefore, we define the gNodeB capacity as the data rate which the gNodeB can provide for the DL and for the UL, for all the connected devices to that gNodeB.

Maximum capacity refers to the maximum data rate (maximum throughput) which the gNodeB can provide.

Any cellular network provides a certain capacity which is defined by the “Shannon-Hartley Capacity Theorem” (aka “Shannon’s Law”, depicted in Figure 6) and defined as the absolute channel capacity limit we currently know from physics:

This capacity relationship can be stated as:

$$C = W \log_2 \left(1 + \frac{S}{N}\right)$$

C = capacity of the channel (bit/s)

S = average received signal power

N = the average noise power

W = bandwidth (Hertz)

Figure 6: Shannon-Hartley Capacity Theorem

In other words, for a cellular network like 5G, which consists of cells of limited bandwidth and defines channels towards the users the entire cell capacity is shared between all the (active) users within a cell, based on service demands and on pathloss situation / channel quality of the individual users.

Within this study calculation, a sector is defined as the minimum serving unit within the base station and we’re calculating the maximum capacity of the sector. Sector angle is 120 degrees.

Capacity calculation formula

There is no special formula defining a gNodeB maximum throughput, which is why for the simplified capacity calculation we’re using the formula for the Supported max data rate for

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DL/UL from [8] with the assumption that in case of 1 UE in ideal conditions in the sector the formula provides us the UL and DL throughput from the gNodeB perspective.

The approximate data rate for a given number of aggregated carriers in a band or band combination is computed as follows in Figure 7.[7]

$$\text{Data rate (Mbps)} = 10^{-6} \times \sum_{j=1}^{J} \left(v_{Layers}^{(j)} \times Q_m^{(j)} \times f^{(j)} \times R_{max} \times \frac{N_{PRB}^{BW(j),\mu} \times 12}{T_S^{\mu}} \times \left(1 - OH^{(j)}\right) \right)$$

Figure 7: Throughput calculation

wherein

J is the number of aggregated component carriers in a band or band combination

R_{max}= 948/1024

For the j-th CC,

$v_{Layers}^{(j)}$ is the maximum number of supported layers given by higher layer parameter *maxNumberMIMO-LayersPDSCH* for downlink and maximum of higher layer parameters *maxNumberMIMO-LayersCB-PUSCH* and *maxNumberMIMO-LayersNonCB-PUSCH* for uplink.

$Q_m^{(j)}$ is the maximum supported modulation order given by higher layer parameter *supportedModulationOrderDL* for downlink and higher layer parameter *supportedModulationOrderUL* for uplink.

$f^{(j)}$ is the scaling factor given by higher layer parameter *scalingFactor* and can take the values 1, 0.8, 0.75, and 0.4.

μ is the numerology (as defined in TS 38.211 [2])

$T_S^{\mu}$is the average OFDM symbol duration in a subframe for numerology, i.e., $T_S^{\mu}=\frac{10^{-3}}{14\times 2^{\mu}}$. Note that normal cyclic prefix is assumed.

$N_{PRB}^{BW(j),\mu}$is the maximum RB allocation in bandwidth with numerology, as defined in 5.3 TS 38.101-1 [3] and 5.3 TS 38.101-2 [4], where the UE supported maximum bandwidth in a given band or band combination.

$OH^{(j)}$is the overhead and takes the following values

0.14, for frequency range FR1 for DL

0.18, for frequency range FR2 for DL

[8]Shannon–Hartley theorem: https://en.wikipedia.org/wiki/Shannon%E2%80%93Hartley_theorem
[7]Formula source: ETSI, 5G NR User Equipment (UE) radio access capabilities (3GPP TS 38.306 version 15.3.0 Release 15), https://www.etsi.org/deliver/etsi_ts/138300_138399/138306/15.03.00_60/ts_138306v150300p.pdf

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0.08, for frequency range FR1 for UL

0.10, for frequency range FR2 for UL

FR1 – Frequency bands below 6GHz

FR2 – Frequency bands above 24GHz

Assumptions

- Theoretical maximum capacity is calculated
- Maximum capacity means maximum data rate (maximum throughput) which a sector of a gNodeB can provide
- A combination of modulation & numerology is assumed as providing the highest possible capacity throughput

Inputs

- Spectrum scenarios (see Table 2) `
- Capacity calculation parameters for each spectrum scenario:

For the Scenario 700

- Parameters for the throughput calculation formula (see Figure 7):
  - Number of aggregated component carriers: 1
  - Maximum number of supported MIMO layers: 2
  - Modulation: 256 QAM
  - Scaling factor: 1
  - Numerology: 2
  - m: 15 kHz
  - NbwPRB: 52
- Traffic distribution:
  - eMBB: 50%
  - URLLC: 50%
- Use-case scenario profiles (see Table 1)

For the Scenario 3500:

- Parameters for the throughput calculation formula (see Figure 7)
  - Number of aggregated component carriers: 1
  - Maximum number of supported MIMO layers: 8
  - Modulation: 256 QAM
  - Scaling factor: 1
  - Numerology: 0
  - m: 60 kHz
  - NbwPRB: 135
  - DL / UL = 80 / 20
- Traffic distribution:
  - eMBB: 50%
  - URLLC: 50%

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- Use-case scenario profiles (see Table 1)

Output of capacity modelling following:

- Approximate maximum capacity of the 5G NR base station sector for:
  - Scenario 700
  - Scenario 3500
- Capacity assessment depending on the set of use cases for:
  - Scenario 700
  - Scenario 3500

3.5.3 Costing delta calculation

In order to arrive at the network infrastructure investment delta, the following approach was used. On the one hand, the Bill of Quantity (BoQ) inputs from the radio planning, i.e., the number of new base stations and 5G upgrades to existing base stations required (see chapter 4.5.2), represent one starting point for the cost calculation. Based on interviews, extensive industry research and the evaluation of regulatory coverage obligations, we estimate the number of new base stations and 5G upgrades that MNOs are planning to deploy by 2023 and 2025, i.e., the already planned BoQ. Comparing the two (radio planning and MNO plans + existing infrastructure) yields the delta BoQ of additionally required new base stations and upgrades of active equipment to 5G.

On the other hand, the survey conducted within this study, industry research and Detecon's in-depth market experience provide the inputs for the cost catalogue. This cost catalogue includes the average estimated costs for the most critical cost drivers in 5G RAN deployment.

The delta BoQ is then multiplied by the cost catalogue in order to arrive at the 5G RAN infrastructure investment cost delta for each CBC, for 2023 and 2025 and for both deployment scenarios (700 MHz and 3500 MHz). This is done for capital expenses (CAPEX) and operational expenses (OPEX).

It is important to stress, that these results represent estimates. We assume that costs may vary by as much as **+/- 20%** within one country from operator to operator. This variance is caused by individual negotiations between equipment vendors, deployment service providers and MNOs as well as site-specific cost drivers such as rental agreements, topographical challenges or property prices.

In summary (as visualized in Figure 8):

BoQ Inputs

- The currently **existing RAN infrastructure** provides the baseline.
- The **radio planning** provides the necessary additional number of 5G base stations and upgrades.
- The interviews and coverage obligations (where applicable) provide insights into the **planned 5G deployment.**
- Subtracting the needed upgrades and base stations from what is actually planned by 2023 yields **the BoQ.**

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Cost Catalogue Inputs

- Research (reports, previous experience) and interviews provide the inputs for the cost catalogue (CAPEX & OPEX, see chapter 4.7). Key sources included:
    - **Interview partners:** Multiple MNOs provided real cost figures for 5G equipment and passive infrastructure costs. To protect the confidentiality of the information, we cannot disclose which MNOs provided cost figures.
    - **5G-MOBIX:** Deliverable D6.1 has extensively reviewed various resources and summarized information about 5G costs on a global scale.[9]
    - **Detecon's project experience:** Detecon brings extensive experience in supporting MNOs working with telco equipment vendors across the whole world. Therefore, Detecon subject matter experts have a solid understanding of the prices of 4G/5G equipment and passive RAN infrastructure.
    - **Federal Communications Commission (FCC)**: The US-American FCC has financed extensive research by Widelity, INC on costs of telecommunications equipment.[10]
    - **Extrapolation:** Finally, where no empirical data points were available, price level extrapolation was applied using gross domestic product (GDP) based on purchasing power parity (PPP) from the World Bank.[11]

Calculation

- The **bill of quantity** (BoQ) is then multiplied with the cost catalogue.

Results

- The results are CAPEX and OPEX for each CBC.

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[9] 5G-MOBIX, D6.1, Plan and preliminary report on the deployment options for 5G technologies for CCAM, 30.10.2020, https://www.5g-mobix.com/resources/deliverables

[10] Federal Communications Commission/Widelity Inc., DA 21-355, 25.03.2021, https://ecfsapi.fcc.gov/file/03250783705361/DA-21-355A1.pdf

[11] World Bank, World Development Indicators, 2021, https://databank.worldbank.org/source/world-development-indicators

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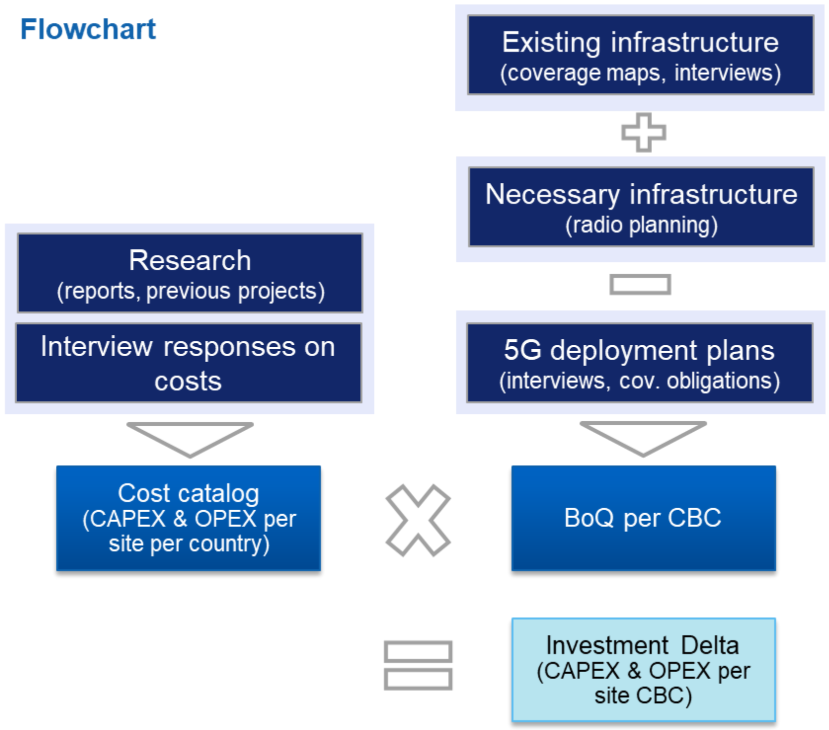

Figure 8: Costing methodology flowchart

In line with the radio planning, the following two scenarios for the Costing Delta Calculation are considered in the study:

- Scenario 700: 5G NR network at 700 MHz;
- Scenario 3500: 5G NR network at 3500 MHz;

mm-Wave or 26 GHz small cell deployment have not been considered within this study, as it is considered extremely unlikely that any MNOs will upgrade or deploy any base stations with such equipment in the assessed areas. This assumption has been confirmed by all interviewed MNOs.

The investment Delta relates to the RAN Infrastructure Delta through the Cost Model as follows:

RAN Infrastructure Delta -> Cost model -> Investment Delta

where

RAN Infrastructure Delta = RAN Infrastructure required - (RAN Infrastructure existing + RAN infrastructure planned)

And the «RAN infrastructure» equals to the number of sites (base stations) and upgrades (required & planned only).

Hence:

- *RAN Infrastructure existing* is the number of existing sites;
- *RAN Infrastructure required* is the number of sites and upgrades, which should be added in the network to enable 5G NR-V2X services along the corridors according to the defined use-cases requirements

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- *RAN Infrastructure planned* is the number of sites and upgrades that are planned (voluntarily or by obligation)

Assumptions

- Only RAN-related costs are considered. Costs for any transport- and core network-related equipment have not been considered in this study as they cannot be properly evaluated. This is largely due to the fact that deriving the share of the overall network architecture costs of the assessed 20 km stretches of highways (i.e., 1 – 10 RAN base stations) requires extensive critical information from mobile network operators and complicated calculations based on national and local subscriber and data traffic figures.
- Spectrum license fees are not included as distributing the fees paid for spectrum in a national award onto a RAN network on a 40 km stretch of a highway would represent a high level of inaccuracy and negligible value added.
- We exclude non-network-related operational costs such as marketing, sales or billing as this study is not a commercial analysis.
- We exclude costs for organizational process harmonization needed for the reduction of network hand-over times between operators. These vary greatly depending on the network design and equipment of network operators, their current status of cooperation as well as negotiations.
- Costs for local MEC data centres have been excluded from the investment delta but covered in chapter 4.7.6 from a general perspective. This is primarily due to the fact that the majority of the MNOs did not indicate any intentions to deploy local MEC data centres along the CBCs or rural highways in general. More information can be found in the results section, chapter 4.7.6.

3.5.3.1 Cost drivers

As mentioned above within the radio planning section, the RAN is the key element of the cellular network infrastructure and the main cost driver.

Therefore, within this study we consider the following cost catalogue which consists of the base-station related cost elements:

CAPEX:

- Active:
  - Hardware
  - Hardware Installation
  - Antenna & Cabling
  - Antenna & Cabling Services
- Passive:
  - Microwave Repeater incl. Services
  - 30 m mast construction
  - Foundation (30 m)
  - Base station building permit fee
  - Emergency power supply cost
  - Fibre to new RAN site & backhaul interface

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OPEX:

- Software license fee per year
- Electricity costs
- Site rental fees
- Maintenance fees
- Interconnection fees

3.5.4 Traffic Forecasting

This section describes the methodology that was used to forecast 5G data and vehicular road traffic characteristics.

3.5.4.1 5G Background Traffic

There is no publicly available information on the amount of network traffic per base stations in the corridors assessed within this study. Only a limited number of MNOs provided information about the experienced throughput of their base stations along the corridors.

Therefore, to understand the relative share of CAM-related data traffic caused by legacy vehicles in the same corridor, we assume a constant average bitrate per legacy vehicle[12] based on typical end-user behaviour of about 160 kbps. This bitrate is based on a combined usage basket of several end-user applications, such as a navigation and a music application. Bitrates are based on market leading applications.[13] This assumption has been validated by mobile RAN experts in the interviews conducted within the survey as part of this study.

In combination with the available road traffic information and forecasts[14][15] as well as predictions about 5G subscriber numbers[16] in the different countries, we can calculate the estimated number of 5G subscribers along the corridor and the traffic generated by those subscribers.

These estimates (which can be found in the traffic forecast model, see Annex chapter 6A.2) are roughly in line with the information about current experienced throughput provided by the MNOs. In all cases, the estimated throughput was negligible compared to the CAM-generated data traffic.

3.5.4.2 Road Traffic and CAM Data Traffic Forecasting

Legacy Road Traffic

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[12] Within this report, legacy vehicles are defined as all vehicles below level 3 automation (SAE). d

[13] This bitrate is based on a combined usage basket of several end-user applications, such as a navigation and a music application. Bitrates are based on market leading applications.

[14] OMDIA, "*Network Traffic Forecast: 2019–24*", April 2020

[15] Analysys Mason, *"Wireless network traffic worldwide: forecasts and analysis 2020–2025"*, July 2020

[16] ITU, "*Mobile Subscription and Revenue Forecast: 2020–25*", September 2020

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The legacy road traffic data and forecasts (please refer to the respective results section in chapter 3.5.4.2) are based on information provided by the responsible road operators along the corridors (please refer to the traffic forecast model in 6A.2).

Approach

- Vehicles crossing the border per day:
    - To estimate the number of vehicles crossing the border on an average day, we used public vehicle counter data from road operators & authorities as well as information from interviews with road operators. Except for the Greek and Dutch road operators responsible for the examined highways (who ignored our requests), we interviewed all responsible road operators (12 in total). Additionally, the following publicly accessible sources were used:
        - ES-PT:
            - Spanish Ministry of Public Works and Transport, https://www.mitma.gob.es/
        - GR-TR:
            - Türkiye Cumhuriyeti Ticaret Bakanligi, "Kara Kapılarına ve Araç Türlerine Göre Araç Giriş-Çıkış Sayıları"; https://ticaret.gov.tr/istatistikler/bakanlik-istatistikleri/gumruk-istatistikleri/dis-ticaret-verileri
        - DE-NL:
            - Counter Elten A3 (BASt; 2019; https://www.bast.de/BASt_2017/DE/Verkehrstechnik/Fachthemen/v2-verkehrszaehlung/Aktuell/zaehl_aktuell_node.html)
        - FI-NO:
            - Data in Finland taken from automatic traffic detection point 1447 near the customs, Finnish Transport Agency (Valya), https://vayla.fi/en/transport-network/data/open-data/road-network/tms-data
        - ES-FR:
            - Spanish Ministry of Public Works and Transport, https://www.mitma.gob.es/
- Data was then distributed across 24 hours to get an hourly average
- Based on research we derived a factor of 2 in order to arrive at peak hourly traffic
- To understand what share of the traffic lies within the serving area of each base station, we divided the peak hourly traffic (number of vehicles) by the average speed (km/h) and then multiplied it with the average RAN inter-site distance (ISD).

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$$\frac{(Peak\ hourly\ traffic\ \#/h)}{Velocity\ (\frac{km}{h})} * ISD\ (km) = road\ traffic\ per\ base\ station\ (\#\ of\ vehicles)$$

- This exercise has been done for all vehicle types and for three different traffic scenarios. Then we multiplied the road traffic per base station with the average expected bit rates per vehicle type. This yields the overall capacity demand from CAM
- Background traffic is calculated based on legacy vehicles and assumed bit rates per legacy vehicles of 160 kbps.

CAM Road Traffic

The CAV/CAM (defined within this report as all vehicles with automation levels of SAE level 3 and above) traffic forecasts are based on the following approach:

1. Several research and industry publications provide forecasts on the number of connected automated vehicle (CAV) sales for different years and with different specifications and definitions. The following reports provide inputs to the estimations for CAM traffic in the defined CBCs
    a. OICA, Registrations or Sales of New Vehicles, 2021, https://www.oica.net/category/sales-statistics/
    b. ACEA, Vehicles in use Europe, January 2021, https://www.acea.auto/publication/report-vehicles-in-use-europe-january-2021/
    c. Schaeffler Gruppe; IHS https://www.schaeffler.com/remotemedien/media/_shared_media_rwd/08_investor_relations/presentations/20200910_schaeffler_adapting_our_structures_presentation_commented_slides.pdf
    d. KPMG, 2020_KPMG_Autonomous_Vehicles_Readiness_Index, https://assets.kpmg/content/dam/kpmg/es/pdf/2020/07/2020_KPMG_Autonomous_Vehicles_Readiness_Index.pdf
    e. McKinsey, Private autonomous vehicles: The other side of the robo-taxi story, 2020, https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/private-autonomous-vehicles-the-other-side-of-the-robo-taxi-story
    f. Deloitte, Future of Automotive Sales and Aftersales, 2020, https://www2.deloitte.com/content/dam/Deloitte/global/Documents/Consumer-Business/gx-deloitte-future-of-automotive-sales-aftersales.pdf
2. The ACEA (see source b. above) provides figures on the overall number of vehicles on the country level as well as the average fleet age.
3. When accumulating the yearly CAV figures and taking into consideration the industry's predictions about the countries' CAM adaptability as well as the average vehicular fleet age, it is possible to derive an estimation of the share of CAVs of the total fleet.

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4. This CAV share can then be used as a factor on the forecasts cross-border traffic numbers in order to understand the number of CAVs passing through the CBC per day and per hour. For further details please refer to the Excel-model attached to this document (see Appendix 6A.2).

3.5.4.3 Key Assumptions for the Traffic Forecasts

- No legal barriers in selling and operating level 3+ (SAE) cars as interference from legal and governing bodies cannot be properly forecasted within the scope of this study.
- We assume shares of vehicle types to remain constant because they have been relatively stable over the past years, and it would go beyond the scope of this study to forecast dynamic shares of vehicle types until 2025.
- We assume the average age of the overall vehicle fleet to remain constant as this factor is rather static and not expected to change significantly until 2025.
- We assume the vehicle age in CBCs to be the same as on the national level, as there is no data on vehicle ages for the assessed CBCs to our knowledge.
- We assume different CAV adoption rates in different countries based on average vehicle fleet age, GDP per capita and KPMG's 2020 Autonomous Vehicles Readiness Index.[17]
- We assume the overall fleet size to remain constant until 2025 across the country selection as these are highly saturated markets.
- We assume no effects of semiconductor shortages limiting supply for car manufacturers to an extent that would affect the CAV traffic forecasts, largely due to the unpredictability of this recent phenomenon. Predicting these effects would go beyond the scope of this study.
- We assume road traffic at peak hours to be twice the average daily traffic per hour, in line with statistics and research (e.g., UK department of transport: Traffic distribution by time of day[18]).
- We assume legacy vehicles produce a DL traffic of about 160 kbps and insignificant uplink traffic. This reflects the continuous usage of apps likely to be used on end-user devices while driving. This approach is entirely based on estimates by subject matter experts due to the absence of reliable empirical data.

3.6 Limitations

There are some limitations to the methodology applied within this study.

- Reliability on voluntary participation of key stakeholders and sharing of information

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[17] KPMG, 2020 Autonomous Vehicles Readiness Index, 2020, https://assets.kpmg/content/dam/kpmg/it/pdf/2020/07/2020-autonomous-vehicles-readiness-index.pdf

[18] Department of Transport, "Statistics and data about the vehicle miles travelled by vehicle type, road category and region.", 2021: www.gov.uk/government/organisations/department-for-transport/series/road-traffic-statistics

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- Information about the existing network infrastructure is combined from the different sources (public crowd sources, interviews, publications), but it cannot be considered as exhaustive since in many cases sensitive information, in particular the coordinates of sites, is not published or provided. Hence, the radio planning provides an indicative picture.
- Not all the approached stakeholders were able to provide information due to its sensitivity and confidentiality (questionaries were declined), some of the approached stakeholders did not provide any feedback

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4 Results – 5G for CAM Deployment

4.1 Overview

To account for high levels of uncertainty associated with predictive forecasts, we have developed nine scenarios that represent a combination of deviations from our best estimates. These nine scenarios are the result of a combination of two factors, the estimated continuous bit rate per CAV and the overall road traffic density. For each of the two factors, we have defined three sub-scenarios: low, medium and high. The different combinations of both sub-scenarios (3x3) create nine scenarios in total. The low bit rate per CAV scenario represents a scenario in which CAVs create low cellular data traffic as per the applied use cases, while a high bit rate scenario represents CAVs applying more demanding use cases and therefore higher bit rates.

Further, based on the radio planning, we analyse two realistic 5G RAN deployment scenarios, one in the 700 MHz band and one in the 3500 MHz band.

All results focus on the years 2023 and 2025 as per the defined time scope of the study. Unless MNOs plan to (or are obliged to) deploy additional infrastructure or upgrade existing infrastructure in between the two years (i.e., in 2024 or 2025), the investment delta remains the same for both years.

4.2 CAM Services and Detailed Requirements

To derive the overall capacity requirements of CAM in the selected CBCs, it is important to understand the required connectivity of individual CAVs. It is difficult to derive and predict these figures for a number of reasons. First, wide-spread serial production and usage of CAVs according to the definition applied in this report (SAE level 3 and up) is only expected to begin next year, so there are no representative empirical sources of CAV connectivity requirements in a cross-border highway scenario[19]. Second, different car manufacturers are expected to use different equipment and various technologies (e.g., cameras, LIDAR, RADAR and more) with different data volumes and varying extents of reliance on cellular connectivity.[20] This effectively results in a traffic mix consisting of different CAVs with very distinct connectivity requirements. Third, CAV on-board software is under continuous development and while this may result in increased data efficiency it may also result in increased data volumes. At this point, it is impossible to predict which

[19] GSMA, Connecting Vehicles Today and in the 5G Era with C-V2X, 2019, https://www.gsma.com/iot/resources/connecting-vehicles-today-and-in-the-5g-era-with-c-v2x/

[20] 5GAA, Tele-Operated Driving (ToD): Use Cases and Technical Requirements, 2020, https://5gaa.org/news/tele-operated-driving-tod-use-cases-and-technical-requirements/

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implication outweighs the other. This list could be continued; however, it showcases that for this study an assumption- and scenario-based approach was needed.

Table 3 shows the vehicular bit rate assumptions that were used for three different vehicular data traffic scenarios (Mbps on top, GB/h at the bottom). These assumptions are based on approximations formed from a combination of different sets of C-V2X use cases from the 5G-MOBIX project as described in Table 1 in sub-chapter 3.5.1. Validated by multiple subject matter experts, the three scenarios below were designed to mitigate the uncertainty with respect to the future 5G connectivity requirements of CAV on-board equipment. The differentiation by vehicle types is based on the fact, that some use cases are applicable to certain types of vehicles only. The values in Table 3 represent average bit rates per second (and data usage per hour) that reflect assumptions about a CAV drive over a cross-border highway.

	Downlink				Uplink			
	Vehicle type				Vehicle type			
Mbps	Passenger	Transport Vans	Shuttle Buses	Trucks	Passenger	Transport Vans	Shuttle Bus	Trucks
high bit rate	45	45	36	51	22,5	22,5	36	58,65
medium bit rate	15	15	12	17	7,5	7,5	12	19,55
low bit rate	7,5	7,5	6	8,5	3,75	3,75	6	9,77
	Vehicle type				Vehicle type			
GB/h	Passenger	Transport Van	Shuttle Buses	Truck	Passenger	Transport Van	Shuttle Bus	Truck
high bit rate	20,25	20,25	16,2	22,95	10,12	10,12	16,2	26,39
medium bit rate	6,75	6,75	5,4	7,65	3,37	3,37	5,4	8,79
low bit rate	3,37	3,37	2,7	3,82	1,68	1,68	2,7	4,39

Table 3: Vehicular bit rate assumptions

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4.3 Projected Vehicular Traffic

As illustrated in Figure 9, the German-Dutch corridor and the Spanish-French corridor see the highest daily vehicular road traffic. The traffic along the Finnish-Norwegian corridor is by far the lowest with less than 700 vehicles per day. Shuttle buses account for only a maximum of 1% of the traffic. This is including long- and short-distance public transportation autobuses.

We have considered four different vehicle types[21] within this study:

- Passenger vehicles,
- Transport vans,
- (shuttle) Buses and
- Trucks.

Due to lack of more specific data in the CBCs, we assume that the national-level share of overall vehicles in use is the same as on cross-border highways. Thus, trucks and transport vans may be slightly underrepresented.

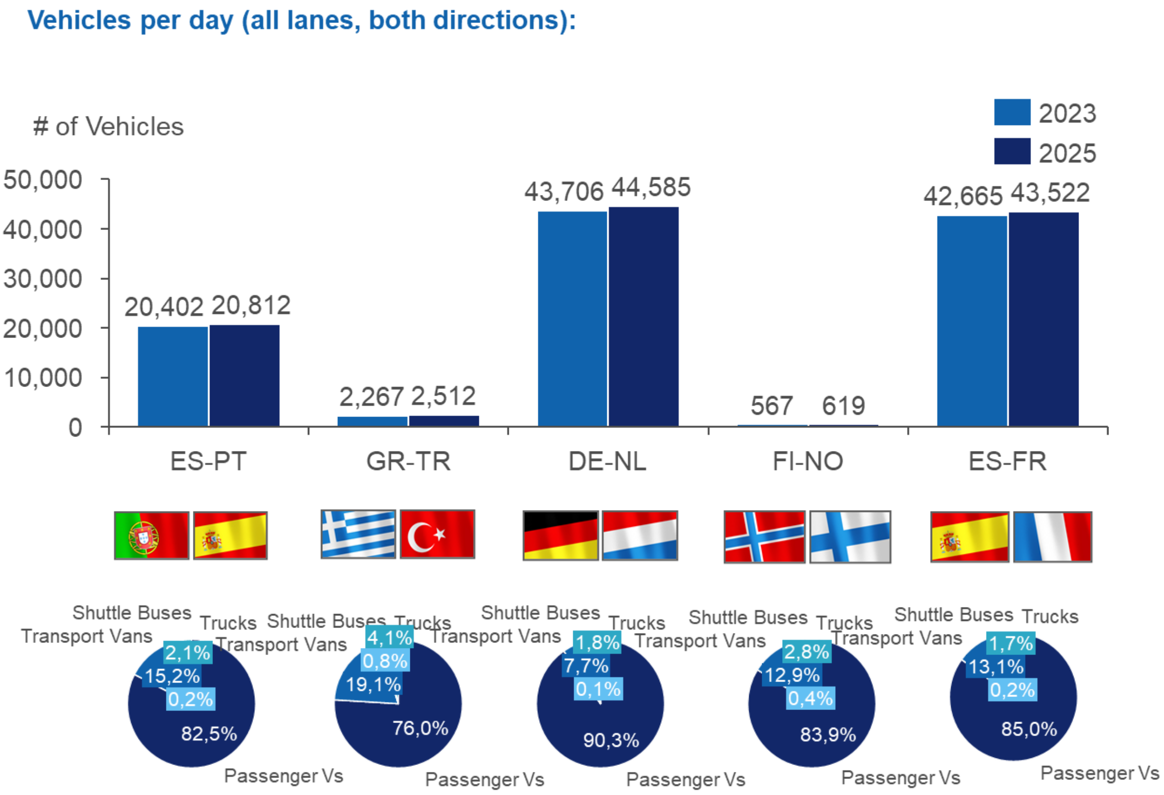

Figure 9: Traffic forecast and vehicle type shares by CBC

In some countries, the forecasts suggest much faster adoption rates of connected, automated vehicles, as depicted in Figure 10. This is partially caused by the vehicle

[21] Following ACEA definitions.

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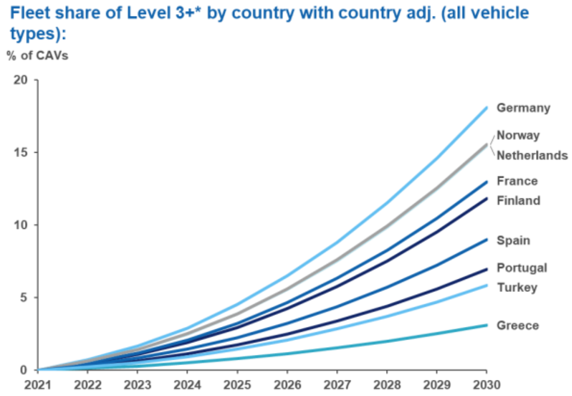
"churn" rate, the rate at which old vehicles are replaced by new ones. This is reflected in the overall vehicle fleet age.[22]



	2021	2022	**2023**	2024	**2025**	2026	2027	2028	2029	2030
Finland	0,00%	0,48%	1,08%	1,90%	2,95%	4,23%	5,76%	7,53%	9,54%	11,81%
France	0,00%	0,53%	1,18%	2,08%	3,23%	4,64%	6,32%	8,26%	10,47%	12,96%
Germany	0,00%	0,73%	1,65%	2,90%	4,51%	6,48%	8,81%	11,52%	14,60%	18,08%
Greece	0,00%	0,13%	0,28%	0,50%	0,78%	1,12%	1,52%	1,98%	2,51%	3,11%
Nether-lands	0,00%	0,63%	1,41%	2,48%	3,86%	5,54%	7,53%	9,85%	12,49%	15,46%
Norway	0,00%	0,63%	1,42%	2,50%	3,88%	5,58%	7,59%	9,92%	12,58%	15,57%
Portugal	0,00%	0,28%	0,63%	1,11%	1,73%	2,49%	3,38%	4,42%	5,61%	6,94%
Spain	0,00%	0,36%	0,82%	1,44%	2,24%	3,22%	4,38%	5,72%	7,25%	8,98%
Turkey	0,00%	0,24%	0,53%	0,94%	1,46%	2,09%	2,84%	3,72%	4,71%	5,84%

Source: Detecon Analysis; ACEA; OICA; McKinsey; Deloitte
Within this study, CAVs & CAM are defined as level 3-5 as per SAE definitions.

Figure 10: Fleet share forecasts of level 3+ by country

4.4 Projected Data Traffic

The following sub-chapters present the capacity results for 2023 and 2025 for each of the corridors. For detailed figures of road traffic and CAM data traffic in the CBCs up to 2030 please refer to the Traffic Forecast Model (see Appendix 6A.2).

The figure below illustrates the summarized results for the most likely scenario (MVMB) from this section (see Figure 11) for both 5G deployment scenarios. The left side shows the first deployment scenario (700 MHz), the right side shows the mid-band deployment scenario (3500 MHz). For each CBC (illustrated by the corresponding country flags), we performed a check on whether the deployment scenario (for each, 700 MHz and 3500 MHz) would be sufficient to support the CAM data traffic in each analysed year (2023 & 2025). A green circle indicates a sufficient capacity, whereas a red dot indicates that the 700 MHz / 3500 MHz deployment scenario would be insufficient, and a higher spectrum band deployment scenario would be needed to provide sufficient capacity for the expected traffic. The applied traffic scenario for this summary table is medium vehicular traffic and medium vehicle bit rate scenario (MVMB).

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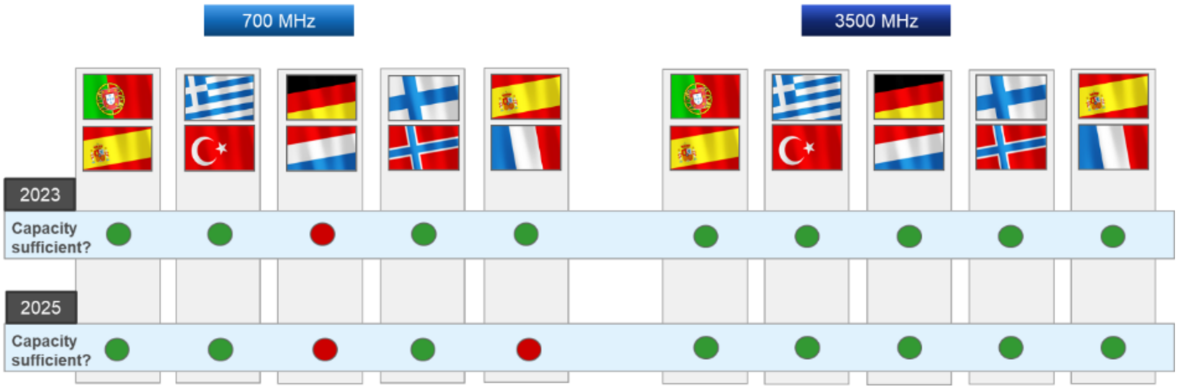

Figure 11: Overview of capacity sufficiency in both scenarios (MVMB scenario)

The results for each CBC and all nine assessed traffic scenarios and both 5G deployment scenarios (700 MHz & 3500 MHz) can be found in the following sub-sections.

4.4.1 CBC PT-ES

Along the Portuguese-Spanish CBC the 700 MHz deployment scenario would be sufficient in all analysed scenarios in both target years. The same applies to the 3500 MHz deployment scenario coverage, as depicted in Figure 12.

700 MHz

ScenarioID	Scenario Name	Capacity (2023)	Capacity (2025)
HVHB	High vehicular traffic & high bit-rate	●	●
MVHB	Medium vehicular traffic & high bit-rate	●	●
LVHB	Low vehicular traffic & high bit-rate	●	●
HVMB	High vehicular traffic & medium bit-rate	●	●
MVMB	Medium vehicular traffic & medium bit-rate	●	●
LVMB	Low vehicular traffic & medium bit-rate	●	●
HVLB	High vehicular traffic & low bit-rate	●	●
MVLB	Medium vehicular traffic & low bit-rate	●	●
LVLB	Low vehicular traffic & low bit-rate	●	●

3500 MHz

ScenarioID	Scenario Name	Capacity (2023)	Capacity (2025)
HVHB	High vehicular traffic & high bit-rate	●	●
MVHB	Medium vehicular traffic & high bit-rate	●	●
LVHB	Low vehicular traffic & high bit-rate	●	●
HVMB	High vehicular traffic & medium bit-rate	●	●
MVMB	Medium vehicular traffic & medium bit-rate	●	●
LVMB	Low vehicular traffic & medium bit-rate	●	●
HVLB	High vehicular traffic & low bit-rate	●	●
MVLB	Medium vehicular traffic & low bit-rate	●	●
LVLB	Low vehicular traffic & low bit-rate	●	●

Figure 12: CBC PT-ES capacity-fit

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4.4.2 CBC GR-TR

Along the Greek-Turkish CBC the 700 MHz deployment scenario would be sufficient in all analysed scenarios in both target years. The same applies to the 3500 MHz deployment scenario, as depicted in Figure 13.

700 MHz

ScenarioID	Scenario Name	Capacity (2023)	Capacity (2025)
HVHB	High vehicular traffic & high bit-rate	●	●
MVHB	Medium vehicular traffic & high bit-rate	●	●
LVHB	Low vehicular traffic & high bit-rate	●	●
HVMB	High vehicular traffic & medium bit-rate	●	●
MVMB	Medium vehicular traffic & medium bit-rate	●	●
LVMB	Low vehicular traffic & medium bit-rate	●	●
HVLB	High vehicular traffic & low bit-rate	●	●
MVLB	Medium vehicular traffic & low bit-rate	●	●
LVLB	Low vehicular traffic & low bit-rate	●	●

3500 MHz

ScenarioID	Scenario Name	Capacity (2023)	Capacity (2025)
HVHB	High vehicular traffic & high bit-rate	●	●
MVHB	Medium vehicular traffic & high bit-rate	●	●
LVHB	Low vehicular traffic & high bit-rate	●	●
HVMB	High vehicular traffic & medium bit-rate	●	●
MVMB	Medium vehicular traffic & medium bit-rate	●	●
LVMB	Low vehicular traffic & medium bit-rate	●	●
HVLB	High vehicular traffic & low bit-rate	●	●
MVLB	Medium vehicular traffic & low bit-rate	●	●
LVLB	Low vehicular traffic & low bit-rate	●	●

Figure 13: CBC PT-ES capacity-fit

4.4.3 CBC DE-NL

In the German-Dutch corridor, the capacity provided in the 700 MHz deployment scenario would reach its limits (i.e., the maximum capacity or throughput per base station) in the high-vehicular traffic & high bit rate scenario in 2023. In 2025, the scenarios HVHB, MVHB and HVMB would exceed the 700 MHz deployment scenario's capacity. 3500 MHz would provide sufficient capacity for all scenarios (depicted in Figure 14).

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700 MHz

ScenarioID	Scenario Name	Capacity (2023)	Capacity (2025)
HVHB	High vehicular traffic & high bit-rate	🔴	🔴
MVHB	Medium vehicular traffic & high bit-rate	🟢	🔴
LVHB	Low vehicular traffic & high bit-rate	🟢	🟢
HVMB	High vehicular traffic & medium bit-rate	🟢	🔴
MVMB	Medium vehicular traffic & medium bit-rate	🟢	🟢
LVMB	Low vehicular traffic & medium bit-rate	🟢	🟢
HVLB	High vehicular traffic & low bit-rate	🟢	🟢
MVLB	Medium vehicular traffic & low bit-rate	🟢	🟢
LVLB	Low vehicular traffic & low bit-rate	🟢	🟢

3500 MHz

ScenarioID	Scenario Name	Capacity (2023)	Capacity (2025)
HVHB	High vehicular traffic & high bit-rate	🟢	🟢
MVHB	Medium vehicular traffic & high bit-rate	🟢	🟢
LVHB	Low vehicular traffic & high bit-rate	🟢	🟢
HVMB	High vehicular traffic & medium bit-rate	🟢	🟢
MVMB	Medium vehicular traffic & medium bit-rate	🟢	🟢
LVMB	Low vehicular traffic & medium bit-rate	🟢	🟢
HVLB	High vehicular traffic & low bit-rate	🟢	🟢
MVLB	Medium vehicular traffic & low bit-rate	🟢	🟢
LVLB	Low vehicular traffic & low bit-rate	🟢	🟢

Figure 14: CBC DE-NL capacity fit

4.4.4 CBC FI-NO

Along the Finnish-Norwegian CBC the 700 MHz deployment scenario would be sufficient in all analysed scenarios in both target years. The same applies to the 3500 MHz deployment scenario, as depicted in Figure 12.

700 MHz

ScenarioID	Scenario Name	Capacity (2023)	Capacity (2025)
HVHB	High vehicular traffic & high bit-rate	🟢	🟢
MVHB	Medium vehicular traffic & high bit-rate	🟢	🟢
LVHB	Low vehicular traffic & high bit-rate	🟢	🟢
HVMB	High vehicular traffic & medium bit-rate	🟢	🟢
MVMB	Medium vehicular traffic & medium bit-rate	🟢	🟢
LVMB	Low vehicular traffic & medium bit-rate	🟢	🟢
HVLB	High vehicular traffic & low bit-rate	🟢	🟢
MVLB	Medium vehicular traffic & low bit-rate	🟢	🟢
LVLB	Low vehicular traffic & low bit-rate	🟢	🟢

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3500 MHz

ScenarioID	Scenario Name	Capacity (2023)	Capacity (2025)
HVHB	High vehicular traffic & high bit-rate	🟢	🟢
MVHB	Medium vehicular traffic & high bit-rate	🟢	🟢
LVHB	Low vehicular traffic & high bit-rate	🟢	🟢
HVMB	High vehicular traffic & medium bit-rate	🟢	🟢
MVMB	Medium vehicular traffic & medium bit-rate	🟢	🟢
LVMB	Low vehicular traffic & medium bit-rate	🟢	🟢
HVLB	High vehicular traffic & low bit-rate	🟢	🟢
MVLB	Medium vehicular traffic & low bit-rate	🟢	🟢
LVLB	Low vehicular traffic & low bit-rate	🟢	🟢

Figure 15: CBC FI-NO capacity fit

4.4.5 CBC ES-FR

In the Spanish-French CBC two connectivity demand scenarios may exceed the capacity provided in the 700 MHz deployment scenario by 2025. The 3500 MHz deployment scenario would provide sufficient capacity in all scenarios and beyond 2025 (depicted in Figure 16).

700 MHz

ScenarioID	Scenario Name	Capacity (2023)	Capacity (2025)
HVHB	High vehicular traffic & high bit-rate	🟢	🔴
MVHB	Medium vehicular traffic & high bit-rate	🟢	🔴
LVHB	Low vehicular traffic & high bit-rate	🟢	🟢
HVMB	High vehicular traffic & medium bit-rate	🟢	🟢
MVMB	Medium vehicular traffic & medium bit-rate	🟢	🟢
LVMB	Low vehicular traffic & medium bit-rate	🟢	🟢
HVLB	High vehicular traffic & low bit-rate	🟢	🟢
MVLB	Medium vehicular traffic & low bit-rate	🟢	🟢
LVLB	Low vehicular traffic & low bit-rate	🟢	🟢

3500 MHz

ScenarioID	Scenario Name	Capacity (2023)	Capacity (2025)
HVHB	High vehicular traffic & high bit-rate	🟢	🟢
MVHB	Medium vehicular traffic & high bit-rate	🟢	🟢
LVHB	Low vehicular traffic & high bit-rate	🟢	🟢
HVMB	High vehicular traffic & medium bit-rate	🟢	🟢
MVMB	Medium vehicular traffic & medium bit-rate	🟢	🟢
LVMB	Low vehicular traffic & medium bit-rate	🟢	🟢
HVLB	High vehicular traffic & low bit-rate	🟢	🟢
MVLB	Medium vehicular traffic & low bit-rate	🟢	🟢
LVLB	Low vehicular traffic & low bit-rate	🟢	🟢

Figure 16: CBC ES-FR capacity fit

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4.5 Existing or Planned 5G infrastructure

Information about existing or planned 5G infrastructure and potential deployment plans is gathered from official public sources (as referenced in each of the CBC sub-chapters in 4.6) and from the interviews with the relevant stakeholders (i.e., mainly MNOs and ROs). The interview results are presented in the following sub-section (4.5.1). These results are complemented by the results of a screening of 5G road coverage obligations in the assessed countries (see 4.5.2).

4.5.1 Network and Roadside Infrastructure and CAM

The main source of the information on the existing network and roadside infrastructure consists of the results from the interviews with MNOs and ROs in each country of the CBCs of this study.

4.5.1.1 CBC PT-ES

Mobile network infrastructure and MNO perspective

According to interviews with MNOs In **Portugal,** all types of bands (800MHz-2600MHz) are available, hence many sites can be used for 5G, but depending on the existing infrastructure sites capacity. At the moment, MNOs are upgrading capacity between the central unit (CU) and Core to achieve more than 1Gbps per site, needed for 5G.

In terms of architecture MNOs are deploying 5G (NSA) but due to delays in the license award process they are not allowed to commercially provide it (at the moment of the interview) and SA will not be available until 2023, possibly by even 2025. 5G specific features like network slicing are very important but there are currently no precise plans on how to exactly use it.

According to some of the MNOs interviewed the end-to-end (E2E) latency requirements which were presented in the study, 50ms are too high for connected, automated driving. But <10ms (according to the interview partner a more plausible threshold for connected, automated driving) is critical and to achieve it they would need more local MEC DCs, but there are pilot networks with 5G (NSA) where 15ms is achieved, with stand-alone networks (SA) probably be even lower values can be achieved.

Roadside infrastructure and Road Operator's perspective

According to a Portuguese RO, establishing CAM and the corresponding infrastructure is important, yet there is too much uncertainty in the market for CAM traffic in Portugal and Europe (technical architecture, business models, who provides 5G connectivity, who pays for SIMs, etc.). Therefore, the RO has not yet formed concrete plans for its own role in CAM traffic.

At the locations where the Portuguese RO operates ducts there is a public offer for managed ducts. A 100% subsidiary of the operator manages the telecommunications network and rents the ducts and dark fibre to the market (but only for the Portuguese side). But besides the ducts for the fibre the rest falls under the task area of the MNOs.

In Spain, a Spanish RO responsible for the ES-PT corridor i**s** currently exploring options with various mobile operators for different RSU deployment scenario. So far, no RSUs have been deployed and there are no specific plans for deployment. When RSU

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deployment becomes viable, the Spanish RO plans to closely cooperate with the mobile network operators. So far, the plan is to just provide optical fibre for the MNOs' operations. According to the Spanish RO, all base stations along the corridor are connected via fibre and the fibre is rented to the operators.

The major obstacles according to the Spanish RO are the high investment costs for RSU infrastructure deployment. Furthermore, 5G spectrum licenses are exclusively available to mobile operators.

4.5.1.2 CBC GR-TR

Mobile network infrastructure and MNO vision

According to Greek MNOs, the key band for 5G deployment along the corridors will be 700 MHz. Currently, there are no specific plans to deploy 5G in any higher bands across this highway. Standalone 5G architecture is not expected prior to 2023. No further statements have been collected regarding CAM from Greek MNOs.

Roadside infrastructure and Road Operator's vision

No information was provided by Greek ROs.

With respect to CAM, there are ongoing collaborations between the government and the responsible road operator for a C-ITS pilot in Istanbul. 6-7 services are going to be provided there – all for urban needs. It will be a single project covering about 20 km of the road. In case of positive results, RSU deployment will be expanded to more regions. Currently, the project focus on the RSU's interface in ITS-G5. Average distance in between RSUs is about 300m according to the RSU vendor (a Turkish company).

4.5.1.3 CBC DE-NL

Mobile network infrastructure and MNO vision

According to **a Dutch MNO**, CAM is inevitable in the next years. But to enable it there is a sufficient communication infrastructure needed which is not yet available. Particularly crowded, urban places will require strong connectivity to enable CAM traffic.

Looking at the CBC, one of the biggest problems is the network hand-over. At the moment there are several minutes of interrupted mobile connection when the borders are crossed. With new technologies this can be decreased to 10-30 seconds, but an entirely seamless setup isn't realistic. One solution could be roaming technology, but it will need at least a few years and a lot of work to enable it (under the precondition that roaming agreements between MNOs are not an obstacle).

Another problem is the capacity requirements. Bitrates of up to 50 Mbps won't be supported unless very large investments take place. Particularly high uplink capacities will require additional base stations.

According to **another Dutch MNO,** the Netherlands are already 90% covered with 5G, within the next 1-2 years the goal is to cover the whole country. But the challenge is that at the moment there is only the 700MHz spectrum available.

According to the MNO, the auction for the 3.6GHz spectrum is supposed to take place next year. Further, the MNO stated that the latency of 5G would not be that different from

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4G and the actual key advantage of 5G is E-UTRAN New Radio – Dual Connectivity (ENDC), so it's possible to let secondary nodes connect to one main node in the same network, thereby providing low experienced latencies and less connectivity interruptions. In conclusion, deploying just 5G alongside the highways may not provide a latency that low.

One of the **German MNO**s mentioned that until the higher CAM levels are reached (and personnel costs can be reduced) there is no real business case for MNOs to upgrade their infrastructure near the highways. According to the MNO most of the revenues profit come from mobile contracts for cell phones and near the assessed CBCs, population densities are too low to form a business case. For automotive manufacturers it's even less practical to invest in the network infrastructure.

Besides that, the interviews suggested that at the moment 700 MHz deployments will be sufficient for the next few years (at least until 2025).

The enablement of hand-over in border corridors was mentioned as the crucial part to enable CAM traffic along the CBC.

Roadside infrastructure and Road Operator's vision

No information was provided from **Dutch road operators**.

In Germany, the responsible **road operator** is planning to significantly expand the usage of ITS-G5 RSUs, however, most stations will be mobile (e.g., at temporary construction sites) and only few stationary. Within the time scope of this study, it wasn't possible to acquire more specific information about the CBC from the RO. Besides that, the RO stated that they are already working on projects to develop connected and automated driving in Germany and testing it on test-tracks and the public Autobahn/highway.

The current use cases of the increased connectivity and data amount are at the moment "working around construction sites" on the German Autobahn/highway and in the future to record and process the traffic situation to improve the efficiency of the Autobahn/highway.

More use cases are not possible at the moment due to German/European "Data Protection Laws". The goal in the next years is to build a digital twin of the German traffic system to enable and establish connected and automated driving.

4.5.1.4 CBC FI-NO

Mobile network infrastructure and MNO vision

According to a large Norwegian MNO, particularly for rural areas the 700MHz band is the most probable. 700MHz will be the primary band for 5G or at least the planning is, at the moment, limited to 700MHz. Ideally with SA, without any 4G anchoring. The 5G terminal penetration in Norway is below 15%. So, to use it for 5G only would be an inefficient use of resources. Until the 5G penetration has grown it should be possible to pay for a 4G+5G combination with the 5G performance.

In the FI-NO corridor there are existing sites which do not cover any dense areas. These were not planned for CAM traffic, yet all sites along the corridors are candidates for 5G upgrades.

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According to information gathered from the **Finnish** MNOs, there is no 5G yet, but all the existing sites are candidates for 5G upgrade and 700MHz will be the primary band for 5G there.

Roadside infrastructure and Road Operator's vision

The responsible **Finnish RO** stated that there is a G5 ITS equipped test road in Muonio based on Aurora project. Muonio is further South from this corridor. This project was done 2018. Further, according to the RO, the E8 (VT 21 in Finland) was undergoing a major improvement project 2107-2018 with a total budget of 25 million €. This represents a major investment into a road with such low vehicular traffic volumes. Thus, there are no plans for improvement projects for the E8 planned within the next years.

The **Norwegian RO** stated that currently RSUs are only deployed for testing purposes and that those are equipped with ITS-G5 interfaces. Along the CBC, there are currently four such testing RSUs. At the moment, there are no plans to expand RSU deployment along the specified corridor. Furthermore, the RO is expecting first CAM traffic around 2023.

4.5.1.5 CBC ES-FR

Mobile network infrastructure and MNO vision

A French MNO informed us that due to Arcep's (the French telecoms regulatory authority) road coverage obligations, the CBC specified within the 5G MOBIX deployment study, has to be covered with 4G or 5G by 2025 (with the specifications of 100 mb/s DL and <10ms latency), therefore the MNO is going to upgrade their base stations. Besides that, the MNO is not planning to deploy any RSUs. As RSUs don't need SIM cards to work, there is no perceived business model for MNOs. Yet, there are already close to 200 RSUs deployed in France (within European or French projects).

Further, the MNO hypothesized that France may see an interest in deploying RSUs because 80% of the French Highway is owned by private road operators.

The MNO stated that the costs for new 5G base stations vary significantly depending on local factors. As 5G NSA needs to be connected to the 4G core EPC, upgrading an existing 2/3/4G installation with 5G (adding 5G antennas & upgrading several other parts) is probably one of the most used ways by operators to deploy 5G during the NSA phase.

According to the operator, like everywhere else, there's currently no network handover improvement at the borders. For the MNOs, there's currently no financial incentive to tackle this problem. Another issue is that achieving a seamless handover implies the interconnection of operator's core networks (LTE S10 interface). This connection has been standardized but has not been a priority feature in MNO requests. It has probably not undergone a lot of operators testing and implementations could therefore need a bit more of a lead time.

With respect to roaming agreements, they are mostly slow to follow technology evolution. Roaming agreements for VoLTE – a well-established service – have been signed only recently by a certain number of operators.

According to **another French MNO**, there are road coverage obligations related to 5G licences. MNOs should cover the main motorways by the end of 2027 for the main roads.

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Operators are working on the precise planning. Further, the second interviewed French MNO stated that 5G deployment will primarily happen via upgrades of existing sites to 5G rather than the deployment of entirely new sites.

With respect to the CBC ES-FR, the second French MNO pointed out an important issue at the border crossing area – operators are actually obliged to maintain a coverage gap at the border crossing zone in order to avoid interference with radio signal from base stations of the operator from the other countries.

Regarding the CAM use cases, the second French MNO in general sees that many of them could be delivered already now with 4G.

Currently, the French MNOs are at the stage of evaluation. The management appears to be undecided, and some parts of the management are not keen to invest in 5G for CAM because it's too costly and there is no clear business case.

For the **Spanish MNOs'** views please see the section CBC PT-ES 434.5.1.1 above.

Roadside infrastructure and Road Operator's vision

In Spain, a **Spanish RO responsible for the ES-FR** corridor, is not directly working with the French Road operator on the other side of the ES-FR corridor. This is caused by different configurations of the 5G connectivity compared to the French Network which make it hard to cooperate.

The **border corridor between Figueres and Perpignan (ES-FR)** is part of the 5GMED program. At the moment **the infrastructure is being deployed (cameras, MECs etc.)** by a telecom equipment vendor who also provides the RSUs (C-V2X) within the 5GMED program.

As of now, **the Spanish RO** (operating along the ES-FR CBC) does not have specific plans for RSU deployment along the corridor as the business model for road operators remains unclear. Within the CEF2 programs, these business models are under investigation, however, focusing on connected driving excluding automated driving. It is unclear what kind of services can be offered in the next 3 years, but different options are currently being explored.

A **French RO** responsible for the ES-FR corridor has not deployed RSUs on the part of the road defined by this deployment study because Renault & Peugeot are located next to Paris and all the trials are located mostly there.

At the moment the number amounts to 53 RSUs installed, but by 2023 50 new ones will be installed. If C-V2X would be required, then only one chip should be replaced, the RSUs are compatible. The French RO is not planning to deploy private networks, but, according to them this is a responsibility of MNOs. Besides that, the RO supports in hybrid communications: short-range + long-range connectivity is seen as complementary.

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4.5.2 Road Coverage Obligations

According to official public sources as well as stakeholder interviews, many countries of the CBCs of this study have imposed road coverage obligations along with the 5G spectrum licenses. At the same time, in a few countries there are no road coverage obligations (yet).

The road coverage obligations for 5G are expected to have a significant impact on the deployment, particularly along highways in rural areas. This is validated from MNOs across Europe. This section summarizes the 5G road coverage obligations for the countries of the assessed CBCs.

4.5.2.1 Road Coverage Obligations in Portugal[23]

The obligations in Portugal specify no transmission rate or latency but a percentage of the highway which shall be covered by 5G.

By the year 2025, 95% of each Portuguese highway should be covered with 5G.

The Portuguese side of the specified CBC will probably be covered with 5G by 2025 (not guaranteed).

4.5.2.2 Road Coverage Obligations in Spain[24]

In Spain, 700 MHz license holders are obliged to cover all roads that were examined within this study (AP-7, AP-9 and A-55) with a minimum signal of -118 dBm and 90% probability by the end of 2022. Further, by the end of 2022, the country's main airports (ten), ports (three), railway stations (six) and highways (eight) should also have coverage in this band.

4.5.2.3 Road Coverage Obligations in Greece[25]

The Greek obligations depend on the frequency bands acquired by the operator.

The 700 MHz license holder has to cover 95% of all motorways within 3 years.

3.4 -3.8 GHz the license holder has to cover most of the Greek Motorways (including E90/A2) within 3 years and all within 6 years. Accordingly, the specified border will probably be covered with 5G within 3 years (not guaranteed).

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[23]ANACOM, Conditions of the auction for 5G and other relevant bands, 2020:

https://www.anacom.pt/render.jsp?contentId=1574207

[24] Gobierno de Espana, Ministerio de Asuntos Económicos y Transformación Digital, BOE-A-2021-9060, https://www.boe.es/diario_boe/txt.php?id=BOE-A-2021-9060

[25]5G Observatory, “Quarterly Report 11”, 2021:

http://5gobservatory.eu/wp-content/uploads/2021/04/90013-5G-Observatory-Quarterly-report-11-2.pdf

This study has received funding from the **European Union’s Horizon 2020 research and innovation programme** under grant agreement No. 825496.

4.5.2.4 Road Coverage Obligations in Turkey[26]

Turkey has not yet awarded 5G licenses and MNOs are therefore not obliged to adhere to any road coverage obligations.

4.5.2.5 Road Coverage Obligations in France[27]

The French obligations are not displayed as a percentage but a number of kilometres which should be covered.

By 2025, 16.642 km of the French Highway (that is more than the actual highway length) and by 2027 54.913 km of the main roads should be covered with 5G. Both milestones include 100mb/s transmission rate and <10ms latency.

The specified border can be expected to be covered with 5G by 2025.

4.5.2.6 Road Coverage Obligations in Germany[28]

The Bundesnetzagentur created a comprehensive catalogue of obligations to ensure wide-ranging 5G coverage on German roads and especially motorways.

The key obligation is that all German Motorways have to fulfil a transmission rate of at least 100mb/s and a maximum latency of 10ms by the year 2022.

The specified border can be expected to be covered with 5G by 2022.

4.5.2.7 Road Coverage Obligations in Netherlands[29]

The Netherlands imposed no obligations specifically targeting roads or highways. Their obligations cover a percentage of each municipality.

The license holder has to achieve 98% area coverage of all municipalities nationwide, with a minimum speed of 100mb/s at the network edge until 2022. However, this effectively includes most highways.

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[26] ITU, "5G Country Profile Turkey", 2020: https://www.itu.int/en/ITU-D/Regional-Presence/Europe/Documents/Events/2020/5G_EUR_CIS/5G_Turkey-final.pdf

nperf, „Türk Telekom Mobile 3G/4G/5G coverage map, Turkey", 2021:

https://www.nperf.com/en/map/TR/-/164410.Trk-Telekom-Mobile/signal/

[27] CMS, "5G Regulation and Law in France", 2021:

https://cms.law/en/int/expert-guides/cms-expert-guide-to-5g-regulation-and-law/france

[28] Bundesnetzagentur, "determinations and rules in detail (award rules) and on the determinations and rules for conduct of the proceedings (auction rules) to award spectrum in the 2 GHz and 3.6 GHz bands.", 2018: https://www.bundesnetzagentur.de/

[29] CMS, "5G Regulation and Law in the Netherlands", 2021:

https://cms.law/en/int/expert-guides/cms-expert-guide-to-5g-regulation-and-law/netherlands

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.

4.5.2.8 Road Coverage Obligations in Finland[30]

There are no road coverage obligations tied to 5G licenses in Finland.

4.5.2.9 Road Coverage Obligations in Norway[31]

20-year license holders in the 700 MHz band must provide mobile broadband access to 40% of population within five years.

A license fee reduction from the total fee was proposed to operators who agreed to coverage obligations:

- Telenor was assigned 2x10 MHz spectrum in the 700 MHz band subject to the coverage obligation on main highways (including "European roads and the coastal road from Mo i Rana to Bodo").
- Telia was assigned 2x10 MHz spectrum in the 700 MHz band subject to the coverage obligation on designated railway sections.

[30]LVM, "Finland's 5G spectrum regulatory status", 2018:

https://www.oulu.fi/sites/default/files/events/Sini%20Wir%C3%A9n.pdf

[31]5G Observatory, "Nkom announces results of 7000MHz, 2100 MHz spectrum auction in Norway", 2019:

https://5gobservatory.eu/nkom-announces-results-of-700mhz-2100mhz-spectrum-auction-in-norway/

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4.6 Network Planning for 5G for CAM deployment

Figure 17 shows the key steps which were executed for each CBC in accordance with the Radio Network Planning methodology, described in the chapter 3.5.2.

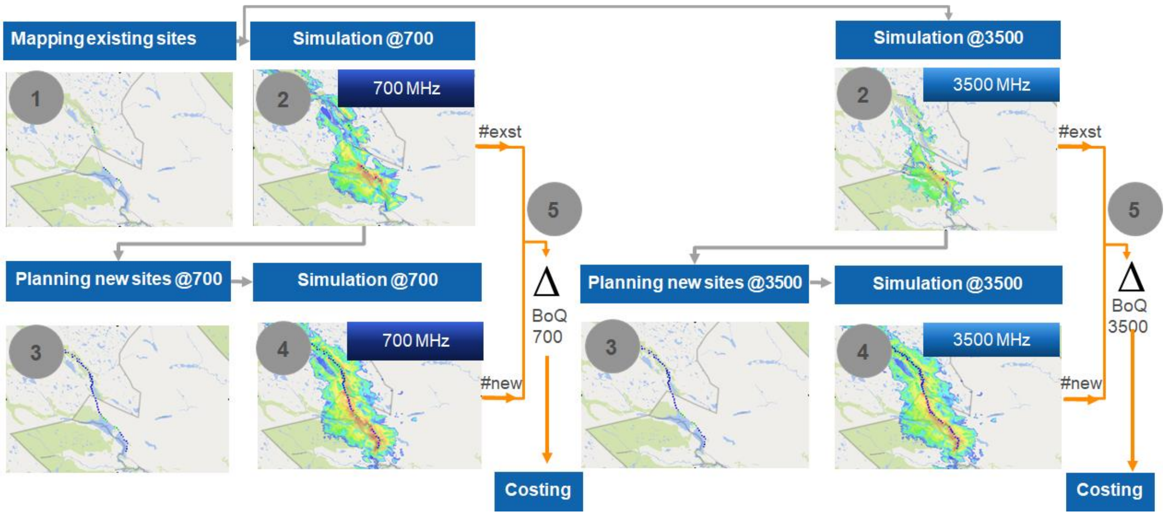

Figure 17: Key steps of the nominal radio planning

For the simulation purposes input parameters defined in the section 3.5.2.1 were used. They are summarized in the Table 4.

TX / RX parameters				
	gNodeB		OBU	
Parameter	**Frequency band**		**Frequency band**	
	700 MHz FDD	3500 MHz TDD	700 MHz FDD	3500 MHz TDD
Bandwidth	10 MHz	100 MHz	10 MHz	100 MHz
Antenna array	2T4R	8T8R	1T2R	1T2R
Power	43.01	50 dBm	23 dBm	23 dBm
Antenna gain	15.1 dBi	24.4 dBi	0 dBi	0 dBi
Antenna height	25 m	25 m	1.5 m	1.5 m
Antenna azimuth for existing	120 degrees spacing	120 degrees spacing	n/a	n/a

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antennas (3 sectors)	(0, 120, 240 degree)	(0, 120, 240 degree)		
Antenna azimuth for new antennas (2 sectors)	along the road, 120 degrees spacing	along the road, 120 degrees spacing	n/a	n/a
Antenna tilt:	- 3 deg	- 3 deg	n/a	n/a
Cable loss	1.5 dB	1.5 dB	0 dBi	0 dBi

Table 4: Key parameters for radio coverage simulation

The analysis of the coverage simulation results was based on two key parameters:

- Presence of coverage gaps - zones with no coverage
- Reference Signal Received Power (RSPR)

Presence of **gap in coverage** does not allow to have a seamless and continuous connectivity along the whole vehicle path, which is why it is critical to identify the gaps and cover them with the appropriate gNodeB sector.

RSRP is the average power value of the received pilot signals (reference signal) or the level of the received signal from the base station, that is RSPR shows the signal strength received from the base station at given point of space.

Throughput (capacity) depends on the signal-to-noise ratio. Hence, the stronger the signal, the higher the signal-to-noise ratio which results in a possibility to use a higher modulation scheme leading to a higher spectral efficiency and, subsequently, to a higher overall sector throughput.

Also, a stronger signal has greater noise proof, which is expressed in higher reliability and stability of communication quality.

The strongest signal can be reached at the central area of the base station due to low propagation loss as well as low interference.

Therefore, due to high throughput (up to 30 Mbps in UL) and reliability (99.99%) requirements we plan our network according to the strongest signal (best signal) which is reflected in -60 dBm and normally presented at the central area of the base station.

Thus, RSRP values and correspondent colour coding used on the coverage maps are presented in the Table 5

RSRP	Interpretation	Colour code
- 60 dBm	Excellent	Brown orange

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- 72 dBm	Very good	Orange
- 90 dBm	Good	Green
-111 dBm	Low	Light-blue
122 dBm	Poor	Dark blue

Table 5: RSRP values and its interpretation

The planning and decision-making process for additional sites (add/do not add a site) looked as follows:

- On the 1st step existing sites were mapped into the planning tool.
- On the 2nd step 5G NR@700 MHz and 5G NR@3500 MHz coverage was simulated for the existing sites only.
- The network coverage was analysed for the presence/absence of gaps in coverage and, if there were gaps, a new site(s) was(were) added in accordance with the target structure (Figure 5: Target radio network structure) on the 3rd step. The overall rule which is used for the target network planning is to minimize potential costs for the 5G network deployment by reuse of all the unique existing sites and to consider building new ones only if it's necessary.
- After that, on the 4th step, the entire network was analysed against the gaps and by RSRP level. And if there were zones between two neighbouring sites with RSRP below - 60 dBm, planning adjustments were made in order to have seamless around - 60 dBm along the CBC (sites were moved closer to each other or the new ones were added).
- On the 5th step number of additional sites were calculated and provided as the input for the cost model.

The radio network (target network) obtained in this way is a dense **basic network** to serve CAM traffic. This **basic network enables** seamless 5G coverage and continuous connectivity required to serve the defined CAM use-cases (in terms of signal and reliability) along the selected stretch of the CBC. This basic network has a capacity, and the capacity was calculated **separately** against different uses case requirements (i.e., the bit rates, see chapters 3.5.1 and 3.5.2.2 for the methodology and chapter 4.4 for the results).

In general, the capacity is limited by physical parameters - primarily the bandwidth of a frequency band (10 MHz bandwidth for 700 MHz frequency band and 100 MHz bandwidth for 3500 MHz frequency band). Thus, potential upgrades of the network capacity are possible by:

- expansion of the band by adding adjacent sections of the spectrum in the same band (if any)
- adding new frequency bands and building a multi-layer network (e.g., 700 MHz + 3500 MHz).

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4.6.1 CBC PT-ES

Corridor overview

Cross-border corridor **ES-PT Minho/Mino** is the European route 1 (E 1) - European long-distance connection that runs from the port of Larne in Northern Ireland via Dublin and Valença to Seville in Spain (see Figure 18).

Within this study a ~40 km strip (~20 km in each country) of the highway' southern part on the west coast of Spain and Portugal was assessed.

Figure 18: Cross-border corridor ES-PT Minho/Mino

Existing sites and 5G NR coverage simulation

Based on the Information about the existing sites taken from the available public sources (http://cellmaper.net/, https://antenasgsm.com/) and information from the local stakeholders, the map of existing site is depicted below in Figure 19:

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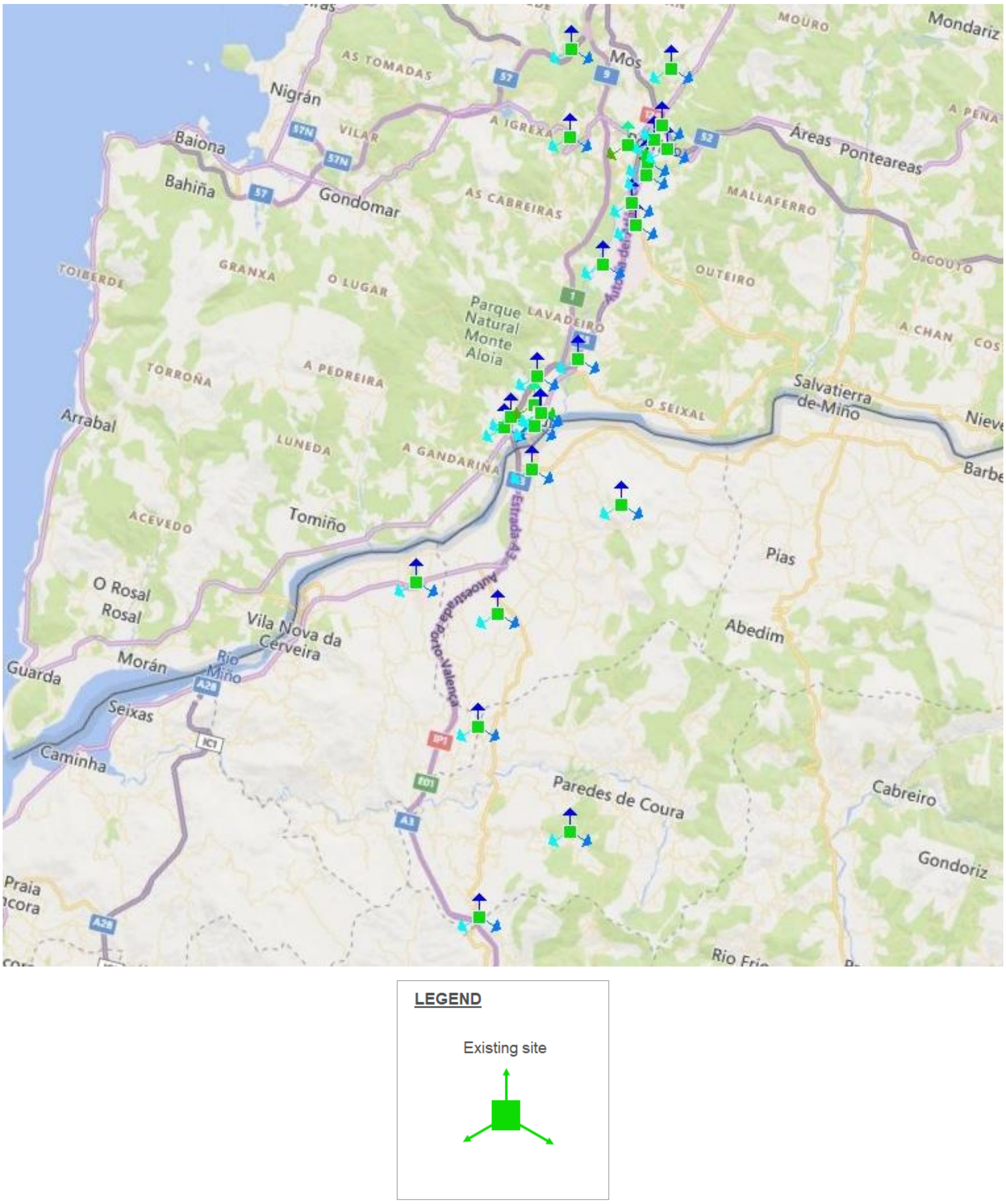

Figure 19: Existing sites in the area of ES-PT Minho/Mino CBC

It's important to note, that the Portuguese stretch of the CBC is characterized by a long mountainous area on the south.

On the Spanish part of the CBC there are many sites located closer to the parallel highway (AP-55), but not along the AP-9 (which is the continuation of the E1 on the Spanish territory), as well as most of the sites on the Spanish territory are in the settlements along the AP-9 highway.

Network coverage of the existing sites only was simulated and depicted below:

- on the Figure 20 for the 700 MHz FDD

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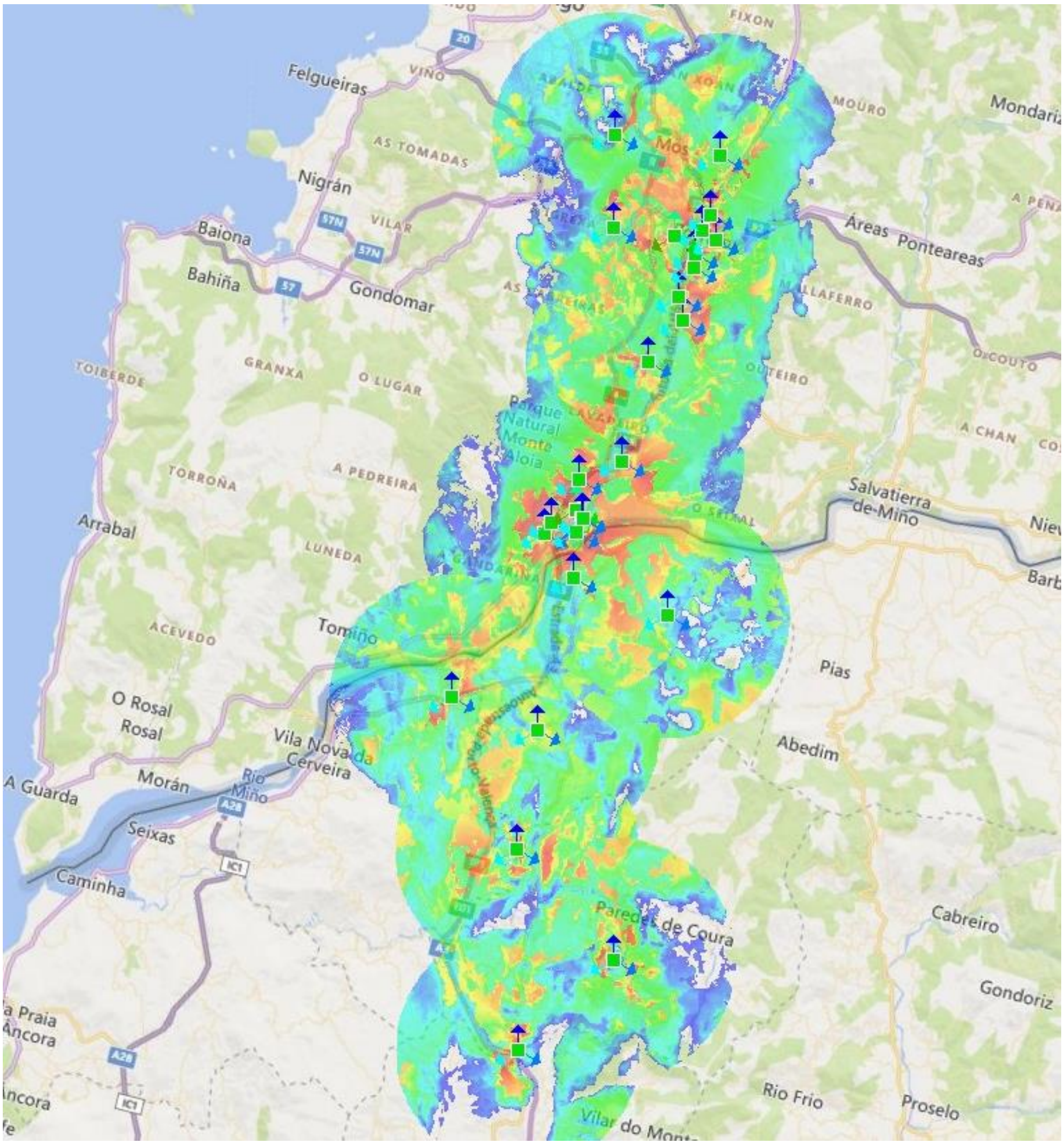
- on the Figure 21 for the 3500 MHz TDD



LEGEND

Existing site

RSRP	Interpretation	Color code
- 60 dBm	Excellent	Brown orange
- 72 dBm	Very good	Orange
- 90 dBm	Good	Green
-111 dBm	Low	Light-blue
122 dBm	Poor	Dark blue

Figure 20: Existing sites in the area of ES-PT Minho/Mino CBC, 5G NR 700 MHz FDD radio coverage simulation

Simulation of 700 MHz network coverage (based on the existing sites only) shows that:

- the CBC is assumed to be mostly covered with good signal (RSRP is between -90 dBm and -70 dBm)

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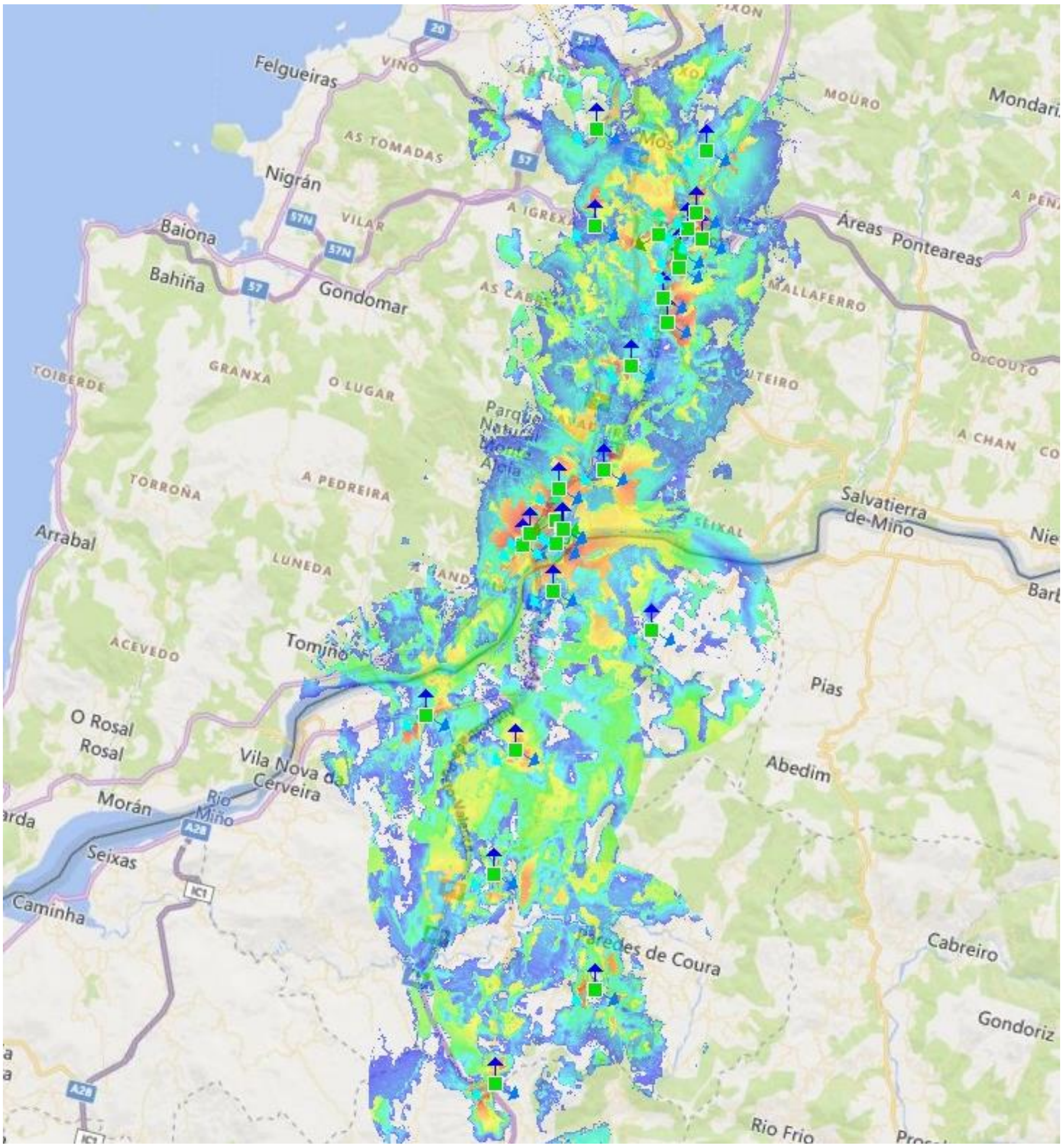
- the border area (bridges across the river Minho and adjacent parts of the cities Minho and Tui) is assumed to be covered with excellent signal (RSRP is about -60 dBm) as well as the part of the road closed to Mos at the northern end of the corridor in Spain.
- there are almost no coverage gaps along the given stretch of CBC.



LEGEND

Existing site

RSRP	Interpretation	Color code
- 60 dBm	Excellent	Brown orange
- 72 dBm	Very good	Orange
- 90 dBm	Good	Green
-111 dBm	Low	Light-blue
122 dBm	Poor	Dark blue

Figure 21: Existing sites in the area of ES-PT Minho/Mino CBC, 5G NR 3500 MHz TDD radio coverage simulation

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Simulation of 3500 MHz coverage based on the existing only sites shows that:

- the CBC is covered, but the signal is low (RSRP is about –111 dBm)
- although the border area is supposed to be covered with the good and excellent signal (RSRP is about -72 dBm -60 dBm)
- at the same time many coverage gaps are presented

Target network nominal planning and coverage simulation

700 MHz FDD target network nominal planning and coverage simulation

- there are almost no coverage gaps along the given stretch of CBC.

Figure 22 shows the existing site locations and indicative locations for the new sites, required to get the seamless 5G coverage with almost continuous RSRP level around -60 dBm to - 70 dBm along the CBC at 700 MHz.

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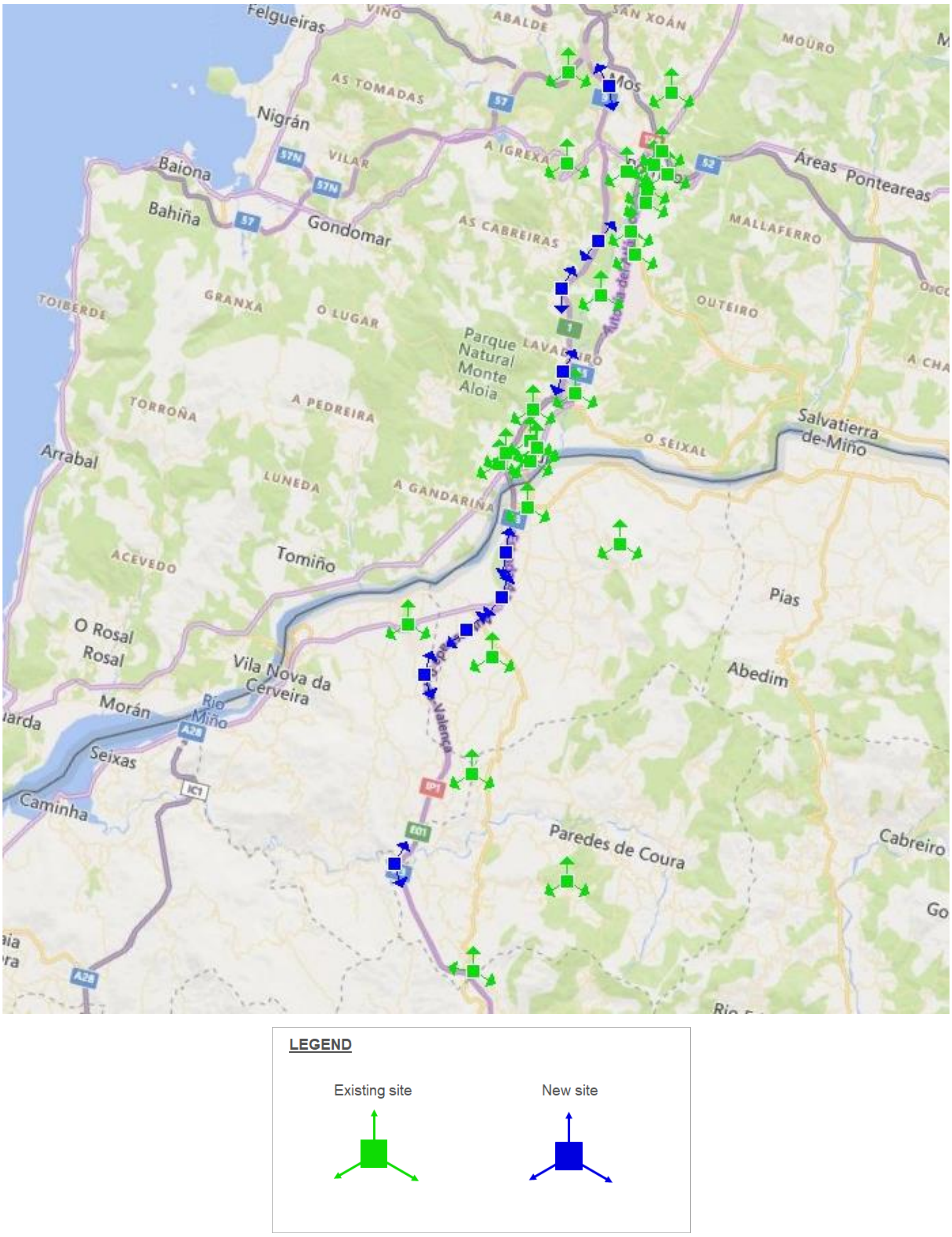

Figure 22: Existing and new sites in the area of ES-PT Minho/Mino CBC, 5G NR 700 MHz FDD

Figure 23 shows the results of the coverage simulation for the radio network based on the existing and the new sites, required to get the seamless 5G coverage with almost continuous RSRP level around -60 dBm to - 70 dBm along the CBC at 700 MHz.

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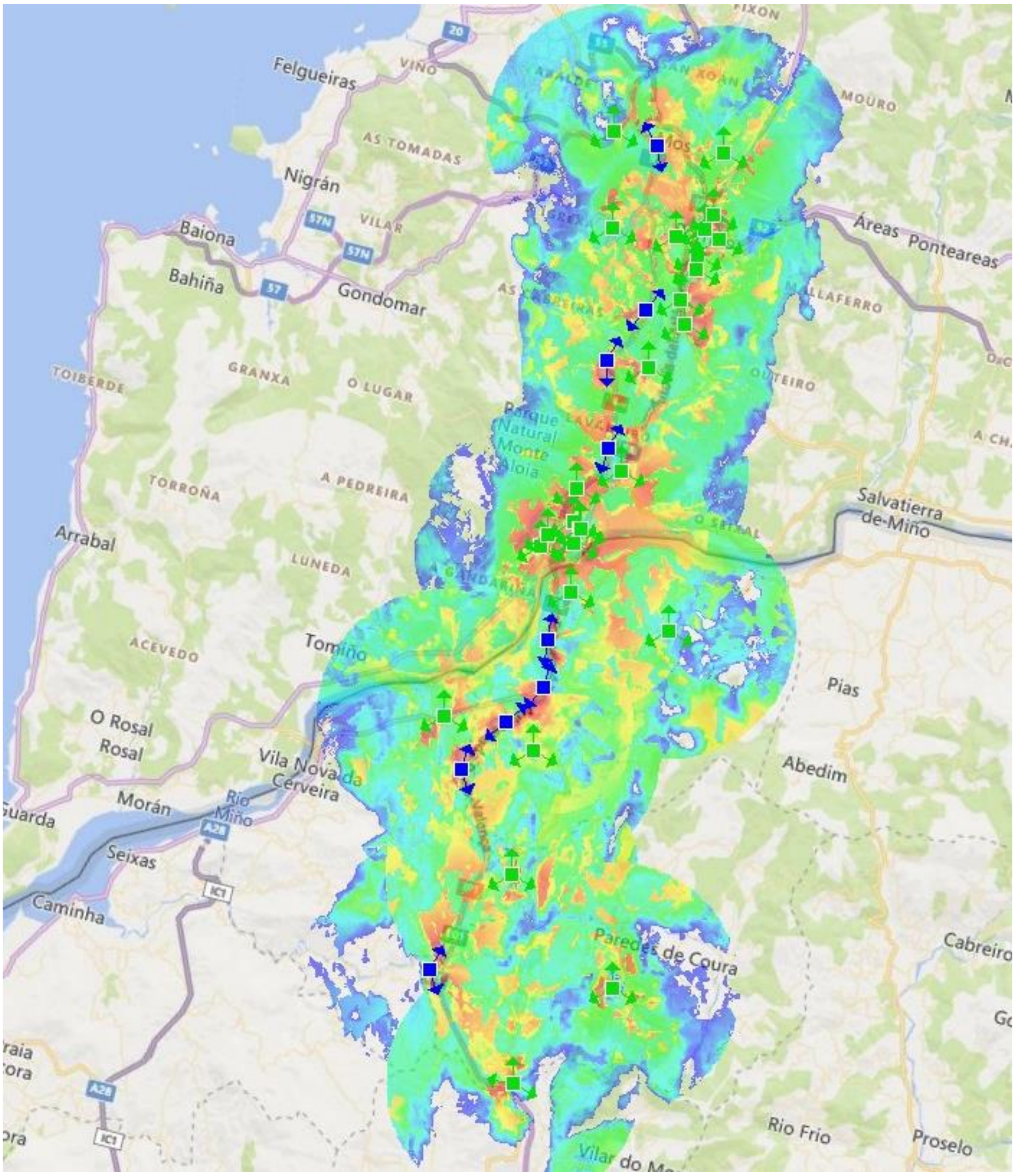

LEGEND

Existing site New site

RSRP	Interpretation	Color code
- 60 dBm	Excellent	Brown orange
- 72 dBm	Very good	Orange
- 90 dBm	Good	Green
-111 dBm	Low	Light-blue
122 dBm	Poor	Dark blue

Figure 23: Existing and new sites in the area of ES-PT Minho/Mino CBC, 5G NR 700 MHz FDD radio coverage simulation

Simulation of coverage of the existing and newly added sites shows no gaps and RSRP at about -60 dBm – - 70 dBm along all the stretch of the corridor.

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Thus, in order to provide the basic coverage of the CBC with the 5G NR @ 700MHz in accordance with the Use-cases requirements (seamless 5G network along the selected CBC stretch) following actions are required in RAN domain.

- Existing sites could be upgraded to 5G:
  - 13 existing should be upgraded on the Spanish side
  - 3 existing should be upgraded on the Portuguese side
- 11 new sites should be added and distributed along the road in order to provide seamless coverage:
  - 6 new sites should be built along the Spanish stretch of the corridor
  - 5 new sites should be built along the Portuguese stretch of the corridor

3500 MHz TDD target network nominal planning and coverage simulation

Figure 24 shows the locations of existing sites and indicative locations for the new sites, required to get the seamless 5G coverage with almost continuous RSRP levels around -60 dBm to - 70 dBm along the CBC at 3500 MHz.

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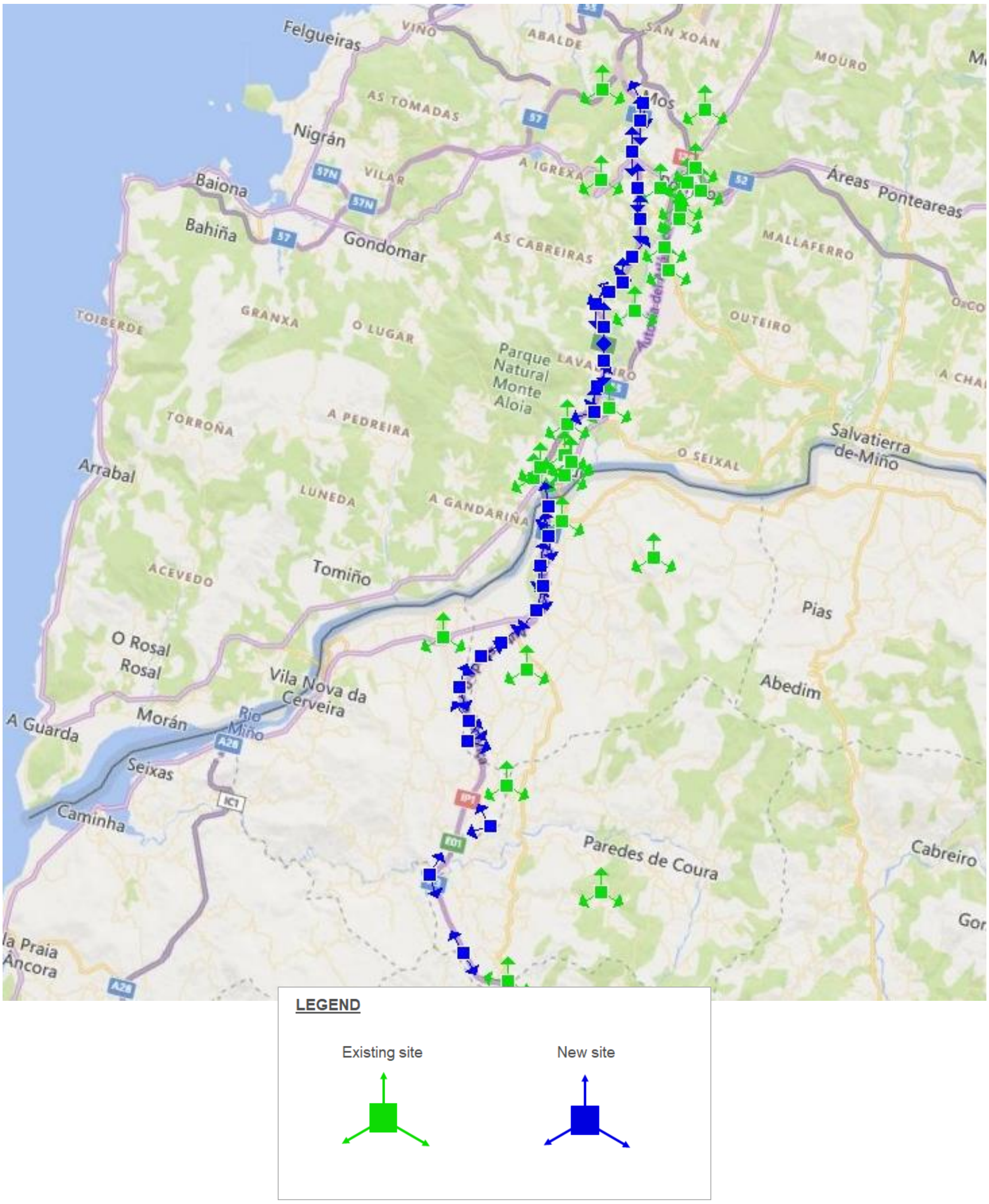

Figure 24: Existing and new sites in the area of ES-PT Minho/Mino CBC, 5G NR 3500 MHz TDD

Figure 25 shows the results of the coverage simulation for the radio network based on the existing and the new sites, required to get the seamless 5G coverage with almost continuous RSRP levels around -60 dBm to -70 dBm along the CBC at 3500 MHz.

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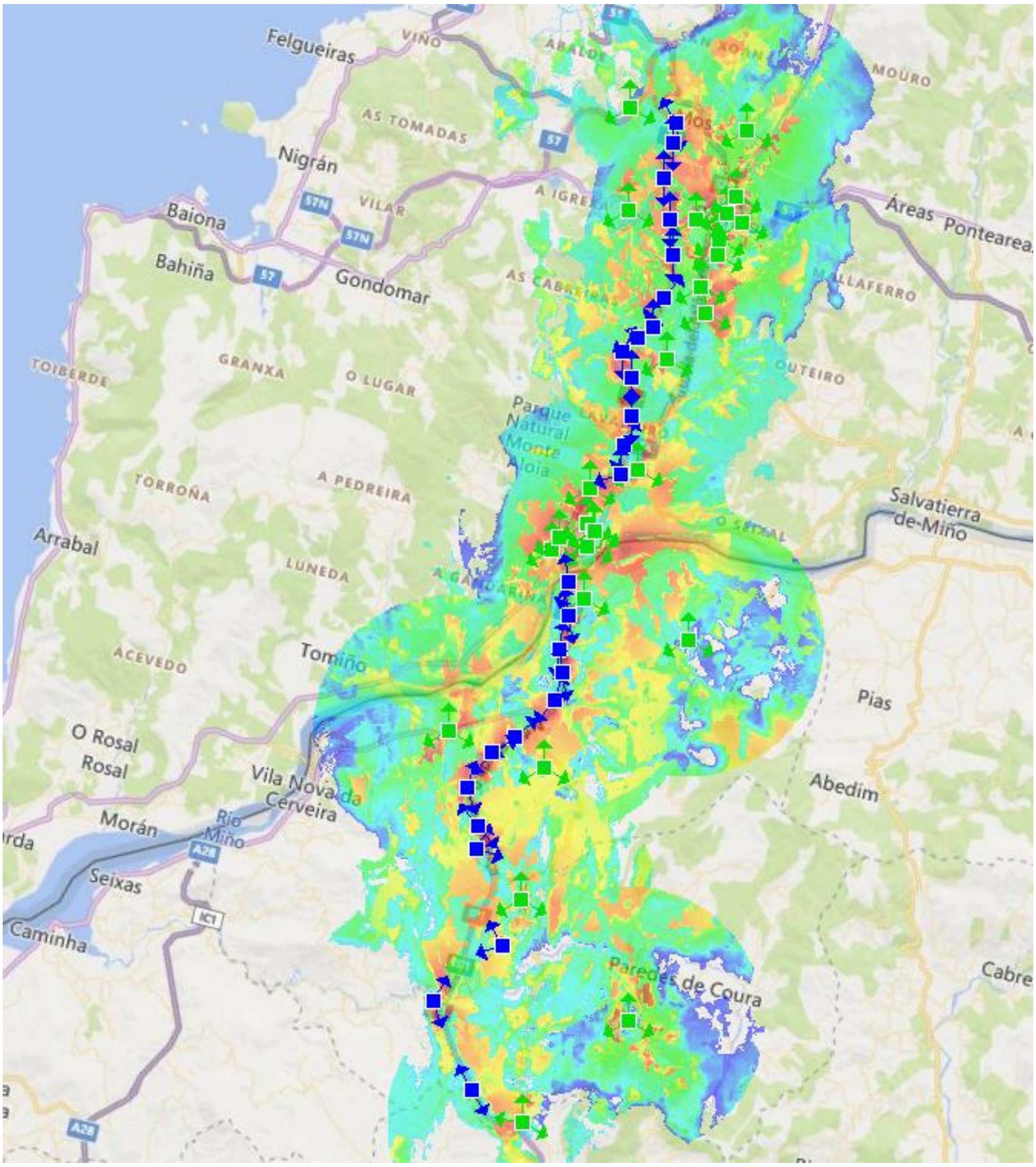
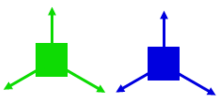


LEGEND

Existing site   New site



RSRP	Interpretation	Color code
- 60 dBm	Excellent	Brown orange
- 72 dBm	Very good	Orange
- 90 dBm	Good	Green
-111 dBm	Low	Light-blue
122 dBm	Poor	Dark blue

Figure 25: Existing and new sites in the area of ES-PT Minho/Mino CBC, 5G NR 3500 MHz TDD radio coverage simulation

Simulation of coverage of the existing and newly added sites show no gaps and RSRP levels at about -60 dBm to - 70 dBm along the examined stretch of the corridor.

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Thus, in order to provide the basic coverage of the CBC with the 5G NR @ 3500MHz in accordance with the basic use-case requirement (seamless 5G network along the selected CBC stretch) the following actions are required in the RAN domain.

- Existing sites could be upgraded to 5G:
    - 13 on the Spanish side
    - 3 on the Portuguese side

- 28 new sites were added and distributed along the road in order to provide seamless coverage:
    - 15 along the Spanish stretch of the corridor
    - 13 along the Portuguese stretch of the corridor

4.6.2 CBC GR-TR

Corridor overview

Cross-border corridor **GR-TR Kipoi/İpsala,** part of the European route E90/E84, is a motorway traffic route that stretches from Lisbon (Portugal) to the Turkish-Iraqi border in the east.

For this study a ~40 km strip (20 kms in each country) in the part which crosses the Greek-Turkish border at Kipoi/İpsala was assessed, as shown in Figure 26.

Figure 26: Cross-border corridor GR-TR Kipoi/İpsala

Existing sites and 5G NR coverage simulation

Based on the Information about the existing sites taken from the available public sources (http://cellmaper.net/, https://keraies.eett.gr/, article "TDD Synchronization Testing Over Neighbouring 5G Networks in a Cross-Border Corridor" and information from the local stakeholders the map of existing site is depicted on the Figure 27 below:

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.

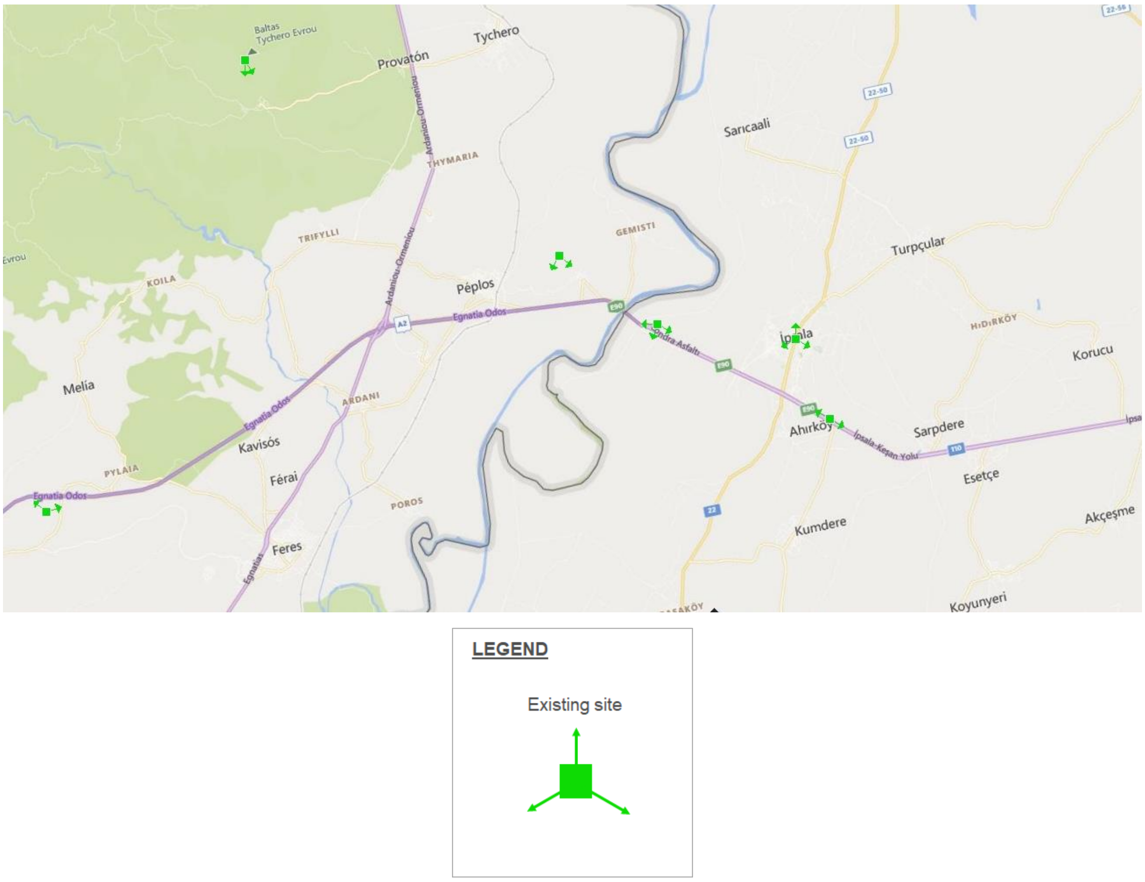
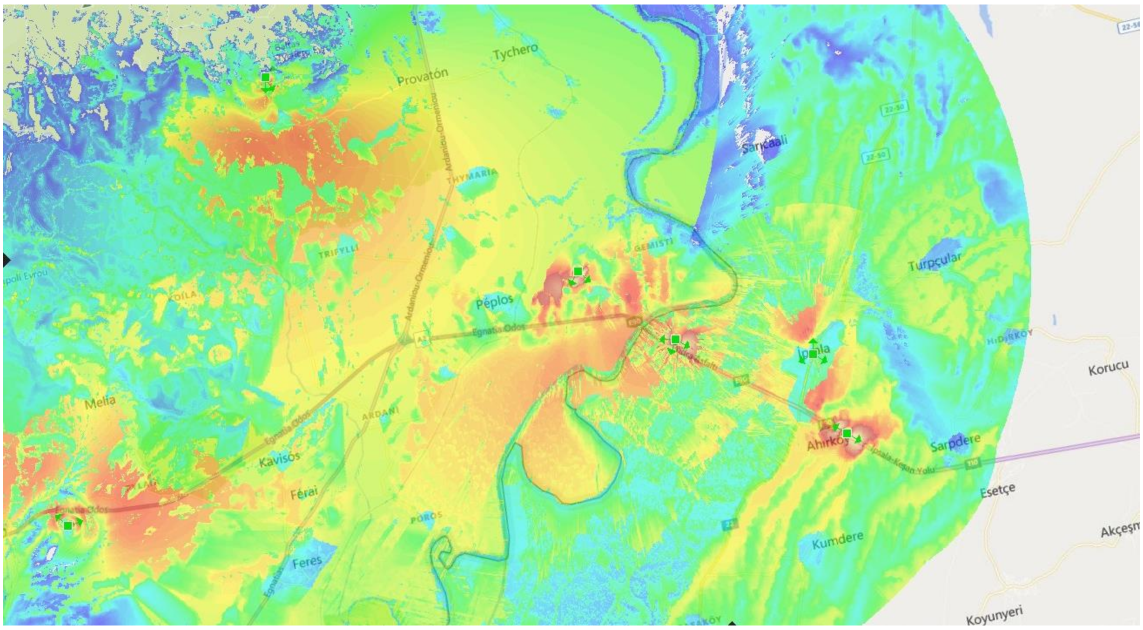


Figure 27: Existing sites in the area of GR-TR Kipoi/İpsala CBC

Network coverage of the existing sites only was simulated and depicted:

- see Figure 28 for the 700 MHz FDD
- see Figure 29 for the 3500 MHz TDD

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.



LEGEND

Existing site

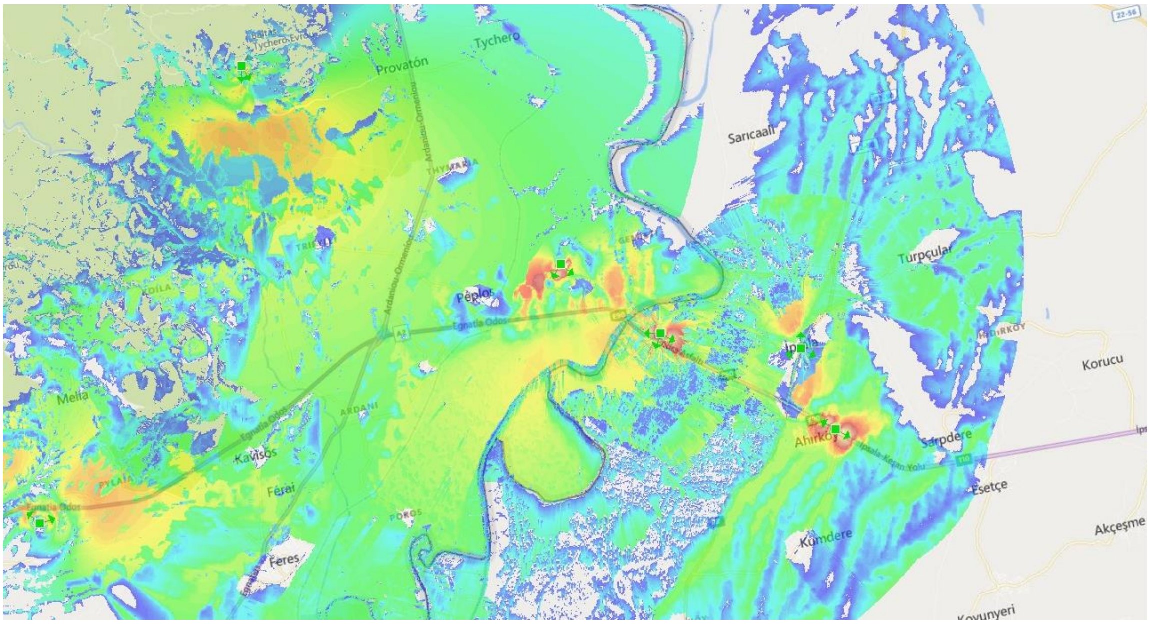
RSRP	Interpretation	Color code
- 60 dBm	Excellent	Brown orange
- 72 dBm	Very good	Orange
- 90 dBm	Good	Green
-111 dBm	Low	Light-blue
122 dBm	Poor	Dark blue

Figure 28: Existing sites in the area of GR-TR Kipoi/İpsala CBC, 5G NR 700 MHz TDD radio coverage simulation

Simulation of 700 MHz network coverage (based on existing sites only) shows that:

- the CBC is assumed to be covered with the very good and good signal (RSRP is between –72 dBm and –90 dBm)
- the border area is supposed to be covered with the very good signal (RSRP is about -70 dBm).
- coverage gap may exist on the Turkish side after the zone of simulation (due to lack of data about sites available)

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.



LEGEND

Existing site

RSRP	Interpretation	Color code
- 60 dBm	Excellent	Brown orange
- 72 dBm	Very good	Orange
- 90 dBm	Good	Green
-111 dBm	Low	Light-blue
122 dBm	Poor	Dark blue

Figure 29: Existing sites in the area of GR-TR Kipoi/İpsala CBC, 5G NR 3500 MHz TDD radio coverage simulation

The simulation of 3500 MHz deployment based on the existing only sites shows that:

- the CBC is assumed to be covered with the good signal (RSRP tends to –90 dBm)
- the border area is supposed to be covered with the very good signal (RSRP is about -70 dBm)
- there are several coverage gaps exists both on the Greek and Turkish sides of the given stretch of CBC. Coverage gaps may exist on the Turkish side after the zone of simulation (due to no data about sites available)

Target network nominal planning and coverage simulation

700 MHz FDD target network nominal planning and coverage simulation

Figure 30 shows locations of existing sites and indicative locations for the new sites, required to get the seamless 5G coverage with almost continuous RSRP levels around -60 dBm to -70 dBm along the CBC at 700 MHz.

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.

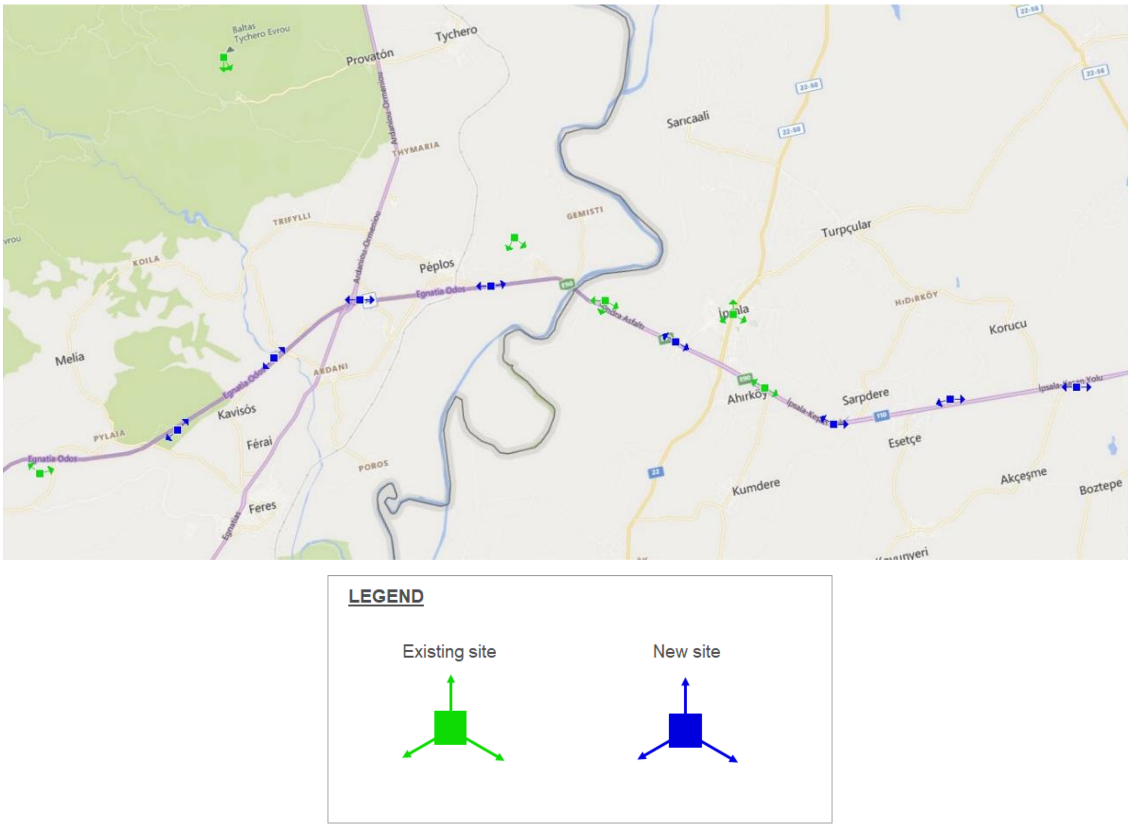
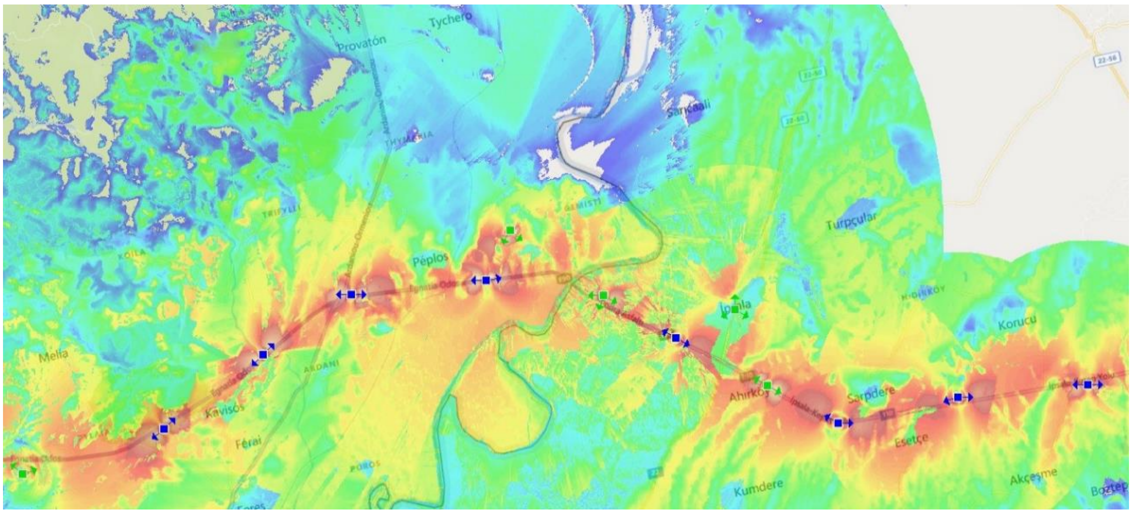


Figure 30: Existing and new sites in the area of GR-TR Kipoi/İpsala CBC, 5G NR 700 MHz FDD

Figure 31 shows the results of the coverage simulation for the radio network based on the existing and the new sites, required to get the seamless 5G coverage with almost continuous RSRP levels around -60 dBm to -70 dBm along the CBC at 700 MHz.

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.



LEGEND

Existing site New site

RSRP	Interpretation	Color code
- 60 dBm	Excellent	Brown orange
- 72 dBm	Very good	Orange
- 90 dBm	Good	Green
-111 dBm	Low	Light-blue
122 dBm	Poor	Dark blue

Figure 31: Existing and new sites in the area of GR-TR Kipoi/İpsala CBC, 5G NR 700 MHz FDD radio coverage simulation

Simulation of coverage of the existing and newly added sites shows no gaps and RSRP from -60 dBm to - 70 dBm along the entire stretch of the corridor.

Thus, in order to provide coverage at the CBC with the 5G NR @ 700MHz in accordance with the use case requirements (seamless 5G network along the selected CBC stretch) and sufficient signal strength, the following actions are required in the RAN domain.

Existing sites which could be upgraded to 5G:

- 2 on the Greek side
- 3 on the Turkish side

8 new sites should be added and distributed along the road in order to provide seamless coverage:

- 4 along the Greek stretch of the corridor
- 4 along the Turkish stretch of the corridor

3500 MHz TDD target network nominal planning and coverage simulation

Figure 32 shows locations of existing sites and indicative locations for the new sites, required to get the seamless 5G coverage with almost continuous RSRP level around -60 dBm to - 70 dBm along the CBC at 3500 MHz.

This study has received funding from the **European Union’s Horizon 2020 research and innovation programme** under grant agreement No. 825496.

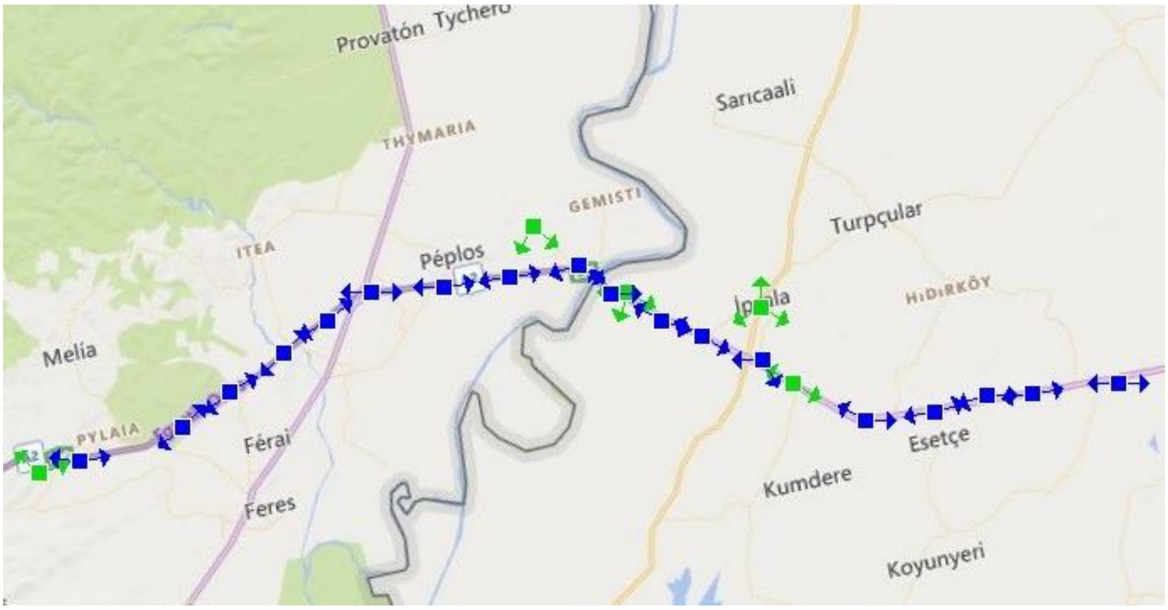
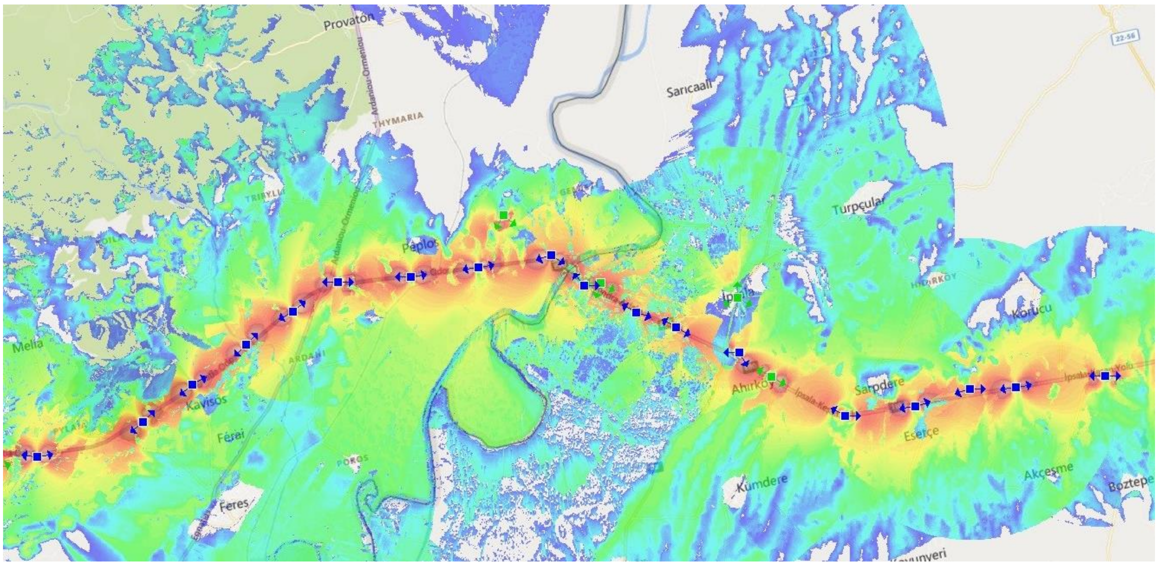


Figure 32: Existing and new sites in the area of GR-TR Kipoi/İpsala CBC, 5G NR 3500 MHz TDD

Figure 33 shows the results of the coverage simulation for the radio network based on the existing and the new sites, required to get the seamless 5G coverage with almost continuous RSRP levels around -60 dBm to - 70 dBm along the CBC at 3500 MHz.

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.



LEGEND

Existing site   New site

RSRP	Interpretation	Color code
- 60 dBm	Excellent	Brown orange
- 72 dBm	Very good	Orange
- 90 dBm	Good	Green
-111 dBm	Low	Light-blue
122 dBm	Poor	Dark blue

Figure 33: Existing and new sites in the area of GR-TR Kipoi/İpsala CBC, 5G NR 3500 MHz TDD radio coverage simulation

Simulation of coverage of the existing and newly added sites show no gaps and RSRP at about -60 dBm to -70 dBm along the whole stretch of the corridor.

Thus, in order to provide coverage at the CBC with the 5G NR @ 3500MHz in accordance with the use case requirements (seamless 5G network along the selected CBC stretch), the following actions are required in the RAN domain.

Existing sites could be upgraded to 5G:

- 3 on the Greek side
- 3 on the Turkish side

18 new sites should be added and distributed along the road in order to provide seamless coverage:

- 9 along the Greek stretch of the corridor
- 9 along the Turkish stretch of the corridor

4.6.3 CBC DE-NL

Corridor overview

Cross-border corridor **NL-DE Veldhuizen** is the European route 35 (abbreviation: E 35/A3) which goes from Amsterdam via Frankfurt am Main and Basel to Rome. It is 1647 km long.

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.

Within this study a ~40 km strip in the part which crosses the Dutch-German border near Veldhuizen was assessed, as shown in Figure 34.

Figure 34: Cross-border corridor NL-DE Veldhuizen

Existing sites and 5G NR coverage simulation

Based on the Information about the existing sites taken from the available public sources (http://cellmaper.net/, https://antennekaart.nl/) and information from the local stakeholders, the map of existing sites is depicted on the Figure 35 below:

:

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.

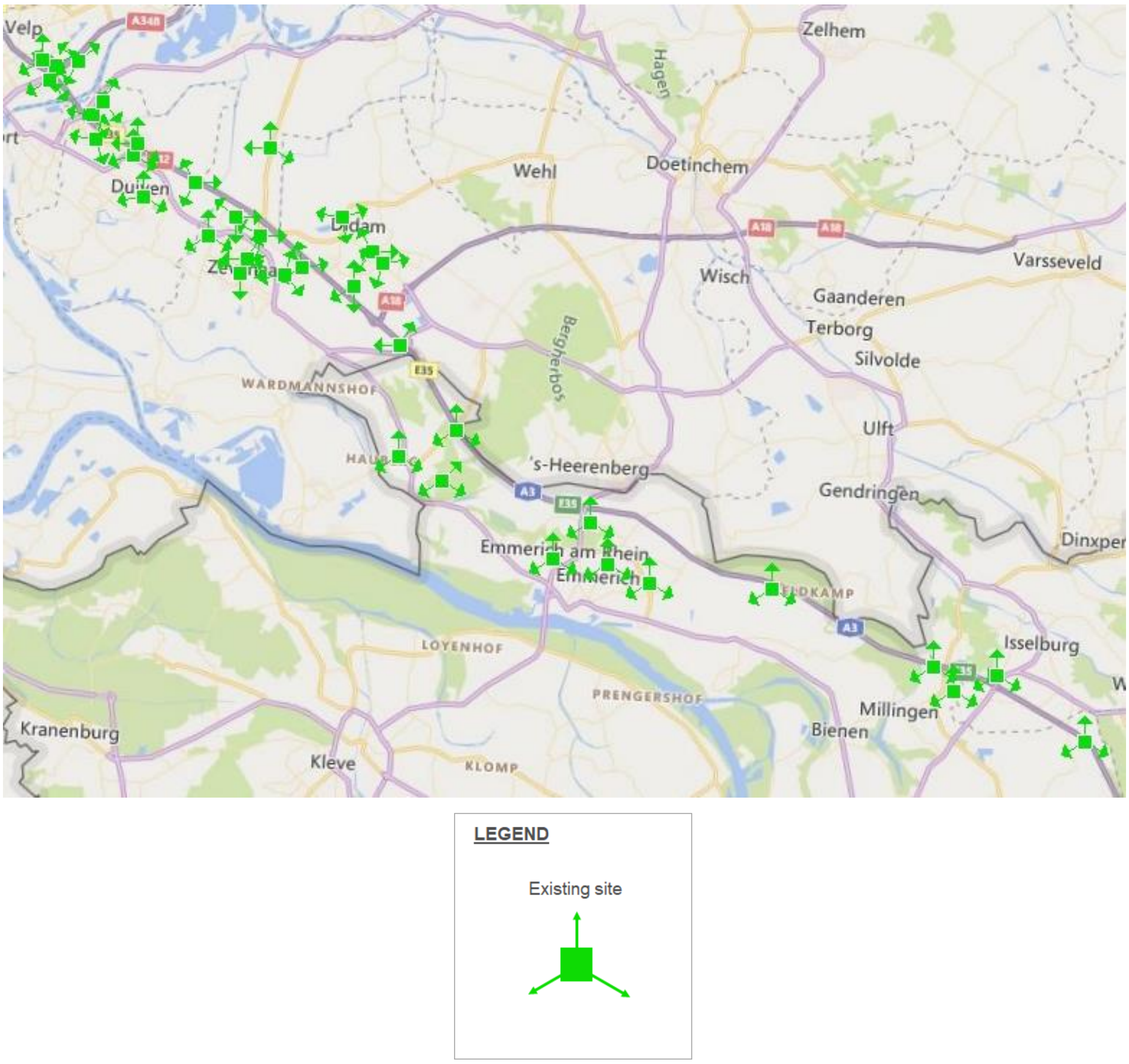


Figure 35: Existing sites in the area of NL-DE Veldhuizen CBC

Network coverage of the existing sites only was simulated and depicted below:

- see Figure 36 for the 700 MHz FDD
- see Figure 37 for the 3500 MHz TDD

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.

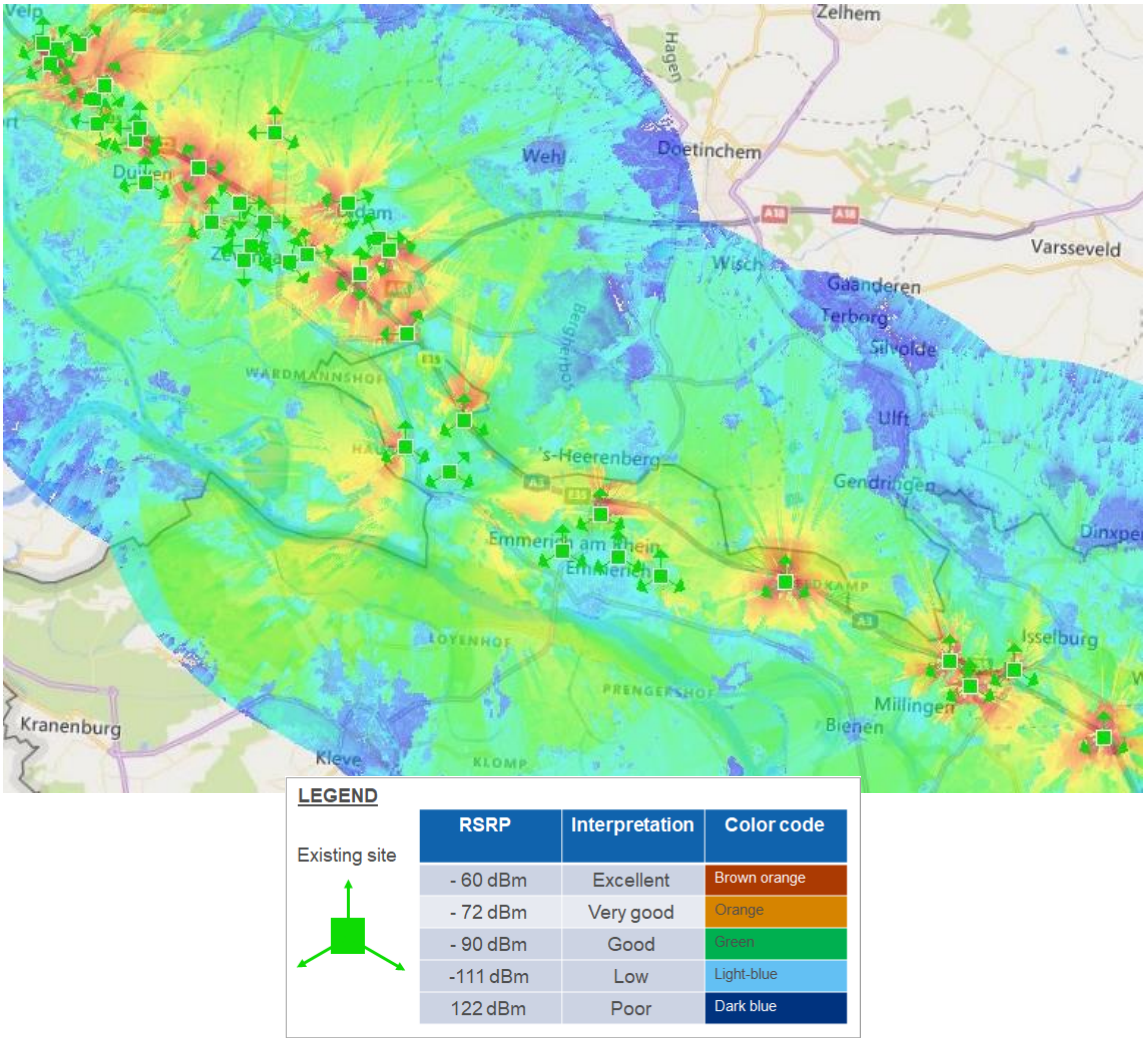
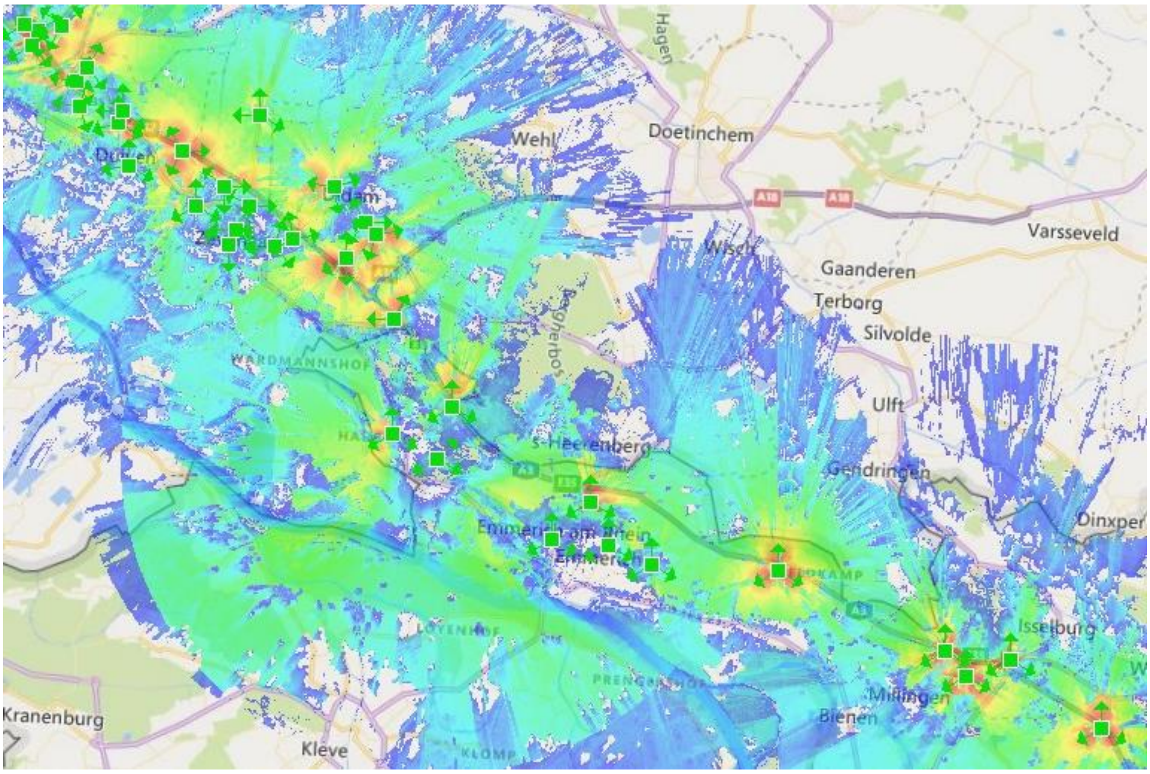


Figure 36: Existing sites in the area of NL-DE Veldhuizen CBC, 5G NR 700 MHz FDD radio coverage simulation

Simulation of 700 MHz network coverage (based on the existing sites only) shows that:

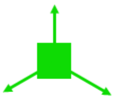
- the CBC is assumed to be mostly covered with the very good and good signal (RSRP is between –72 dBm and –90 dBm), excellent signal zone (RSRP about –60 dBm) are mostly located in settlements along the highway
- border area, a soft border between Netherlands and Germany, is assumed to be covered with the excellent signal (RSRP is about -60 dBm).
- there are no coverage gaps along the given stretch of CBC

This study has received funding from the **European Union’s Horizon 2020 research and innovation programme** under grant agreement No. 825496.



LEGEND

Existing site



RSRP	Interpretation	Color code
- 60 dBm	Excellent	Brown orange
- 72 dBm	Very good	Orange
- 90 dBm	Good	Green
-111 dBm	Low	Light-blue
122 dBm	Poor	Dark blue

Figure 37: Existing sites in the area of NL-DE Veldhuizen CBC, 5G NR 3500 MHz TDD radio coverage simulation

Simulation of 3500 MHz coverage based on the existing only sites shows that:

- the CBC is covered, but the signal is good or low (RSRP tends to -90 dBm to -70 dBm). There are several small excellent signal zones (RSRP about -60 dBm), these zones are mostly located in settlements along the highway
- although the border area is supposed to be covered with the good and very good signal (RSRP is about -90 dBm -72 dBm)
- several coverage gaps are presented

Target network nominal planning and coverage simulation

700 MHz FDD target network nominal planning and coverage simulation

Figure 38 shows locations of existing sites and indicative locations for the new sites, required to get the seamless 5G coverage with almost continuous RSRP levels around -60 dBm to - 70 dBm along the CBC at 700 MHz.

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.

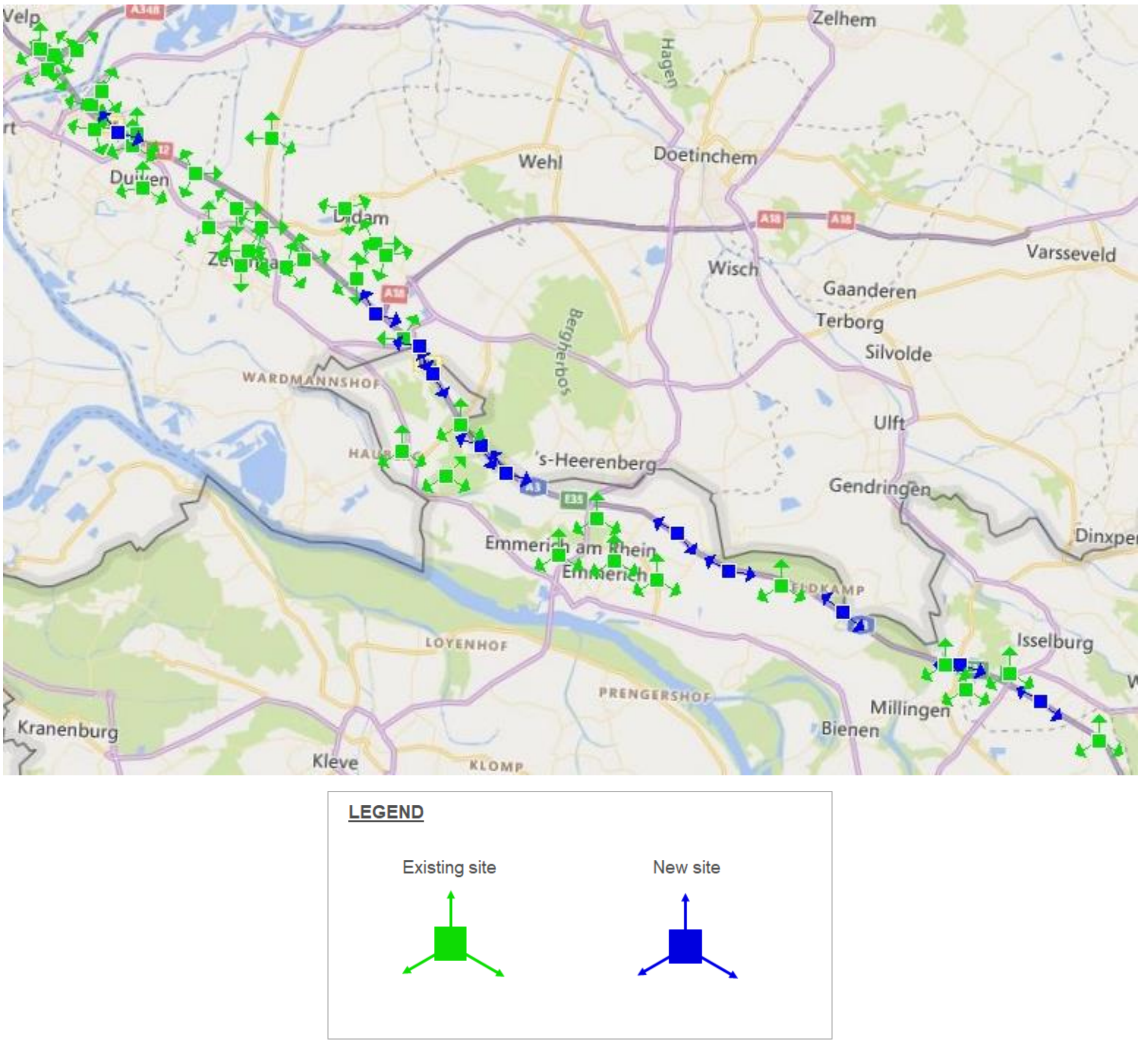
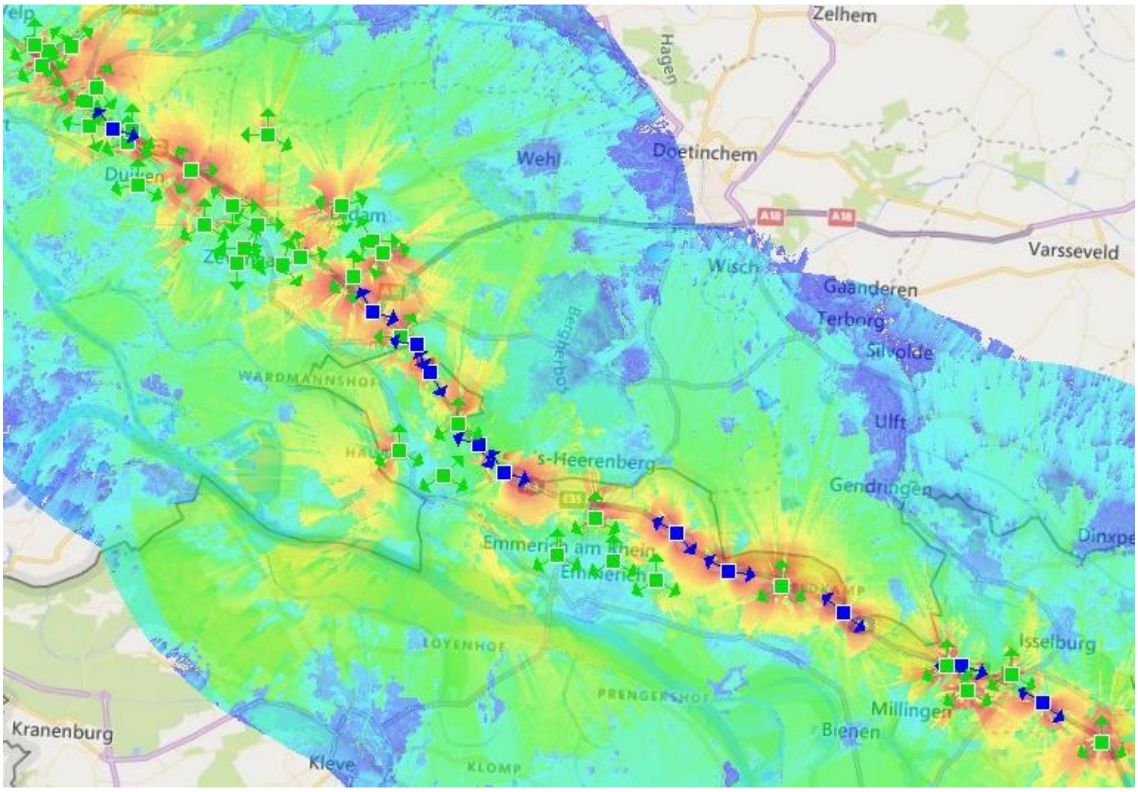


Figure 38: Existing (green) and new (dark blue) sites in the area of NL-DE Veldhuizen CBC, 5G NR 700 MHz FDD

Figure 39 shows the results of the coverage simulation for the radio network based on the existing and the new sites, required to get the seamless 5G coverage with almost continuous RSRP level around -60 dBm – - 70 dBm along the CBC at 700 MHz.

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.



LEGEND

Existing site New site

RSRP	Interpretation	Color code
- 60 dBm	Excellent	Brown orange
- 72 dBm	Very good	Orange
- 90 dBm	Good	Green
-111 dBm	Low	Light-blue
122 dBm	Poor	Dark blue

Figure 39: Existing and new sites in the area of NL-DE Veldhuizen CBC, 5G NR 700 MHz FDD radio coverage simulation

Simulation of coverage of the existing and newly added sites shows no gaps and RSRP levels at about -60 dBm to -70 dBm along all the stretch of the corridor.

Thus, in order to provide seamless coverage along the CBC with the 5G NR @ 700MHz in accordance with the use case requirement of a seamless 5G network along the selected CBC stretch, the following actions are required in the RAN domain.

- Existing sites could be upgraded to 5G:
  - 12 on the German side
  - 2 on the Netherlands side

- 12 new sites were added and distributed along the road in order to provide seamless coverage:
  - 8 along the German stretch of the corridor
  - 4 along the Netherlands stretch of the corridor

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.

Figure 40 shows locations of existing sites and indicative locations for the new sites, required to get the seamless 5G coverage with almost continuous RSRP levels around -60 dBm to - 70 dBm along the CBC at 3500 MHz.

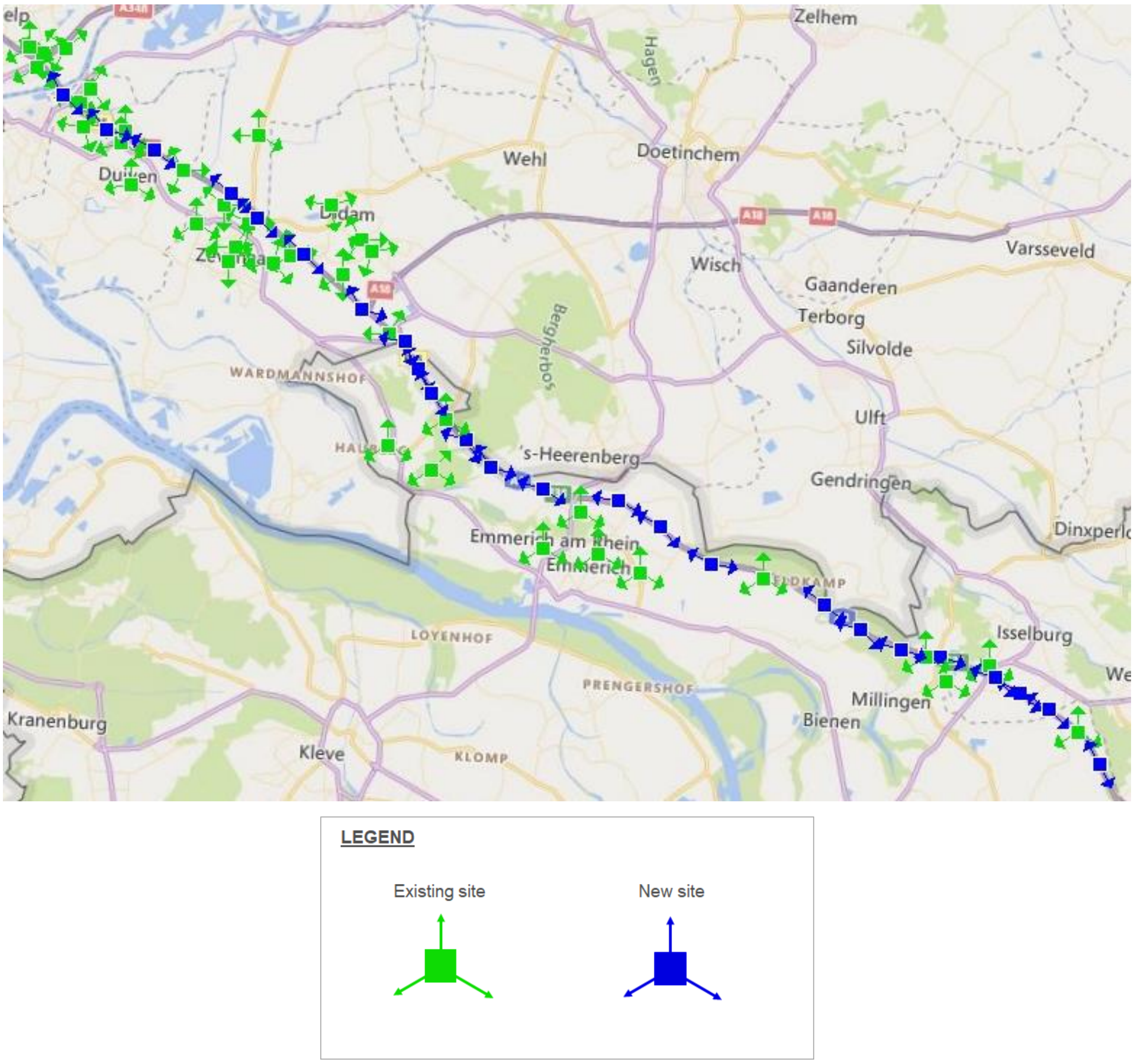
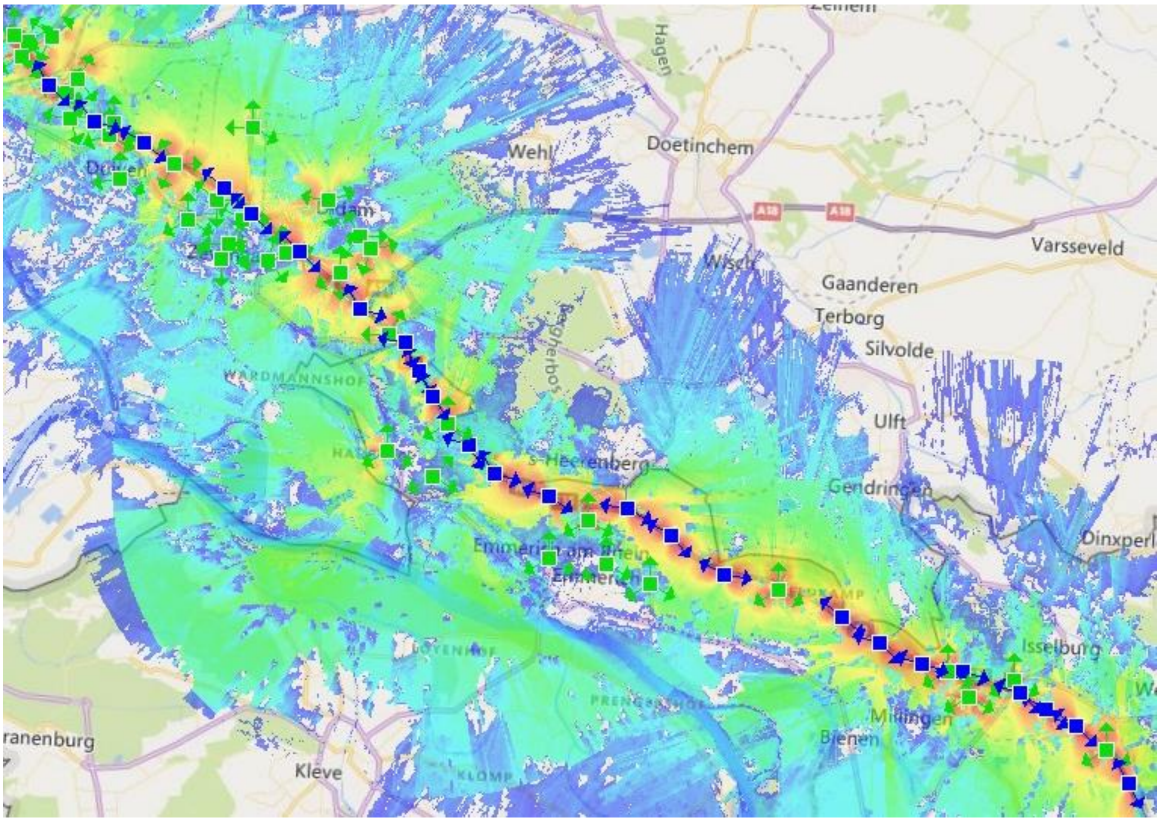


Figure 40: Existing and new sites in the area of NL-DE Veldhuizen CBC, 5G NR 3500 MHz TDD

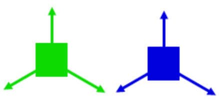
Figure 41 shows the results of the coverage simulation for the radio network based on the existing and the new sites, required to get the seamless 5G coverage with almost continuous RSRP levels around -60 dBm to - 70 dBm along the CBC at 3500 MHz.

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.



LEGEND

Existing site New site



RSRP	Interpretation	Color code
- 60 dBm	Excellent	Brown orange
- 72 dBm	Very good	Orange
- 90 dBm	Good	Green
-111 dBm	Low	Light-blue
122 dBm	Poor	Dark blue

Figure 41: Existing and new sites in the area of NL-DE Veldhuizen CBC, 5G NR 3500 MHz TDD radio coverage simulation

Simulation of coverage of the existing and newly added sites show no gaps and RSRP at about -60 dBm – - 70 dBm along all the stretch of the corridor.

Thus, in order to provide coverage along the CBC with the 5G NR @ 3500MHz in accordance with the Use-cases requirements (seamless 5G network along the selected CBC stretch) following actions are required in RAN domain.

- Existing sites could be upgraded to 5G:
  - 12 on the German side
  - 24 on the Netherlands side

- 24 new sites should be added and distributed along the road in order to provide seamless coverage:
  - 16 along the German stretch of the corridor
  - 9 along the Netherlands stretch of the corridor

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.

4.6.4 CBC FI-NO

Corridor overview

Cross-border corridor **FI-NO Kilpisjärvi** is the European route 8 (E8) or European route 08 (E 08) is a European route that extends north-south through Scandinavia. It starts in Tromsø in Norway and ends in Turku in Finland.

Within this study a ~40 km strip in the part which crosses the Finnish-Norwegian border near Kilpisjärvi was assessed (see Figure 42).

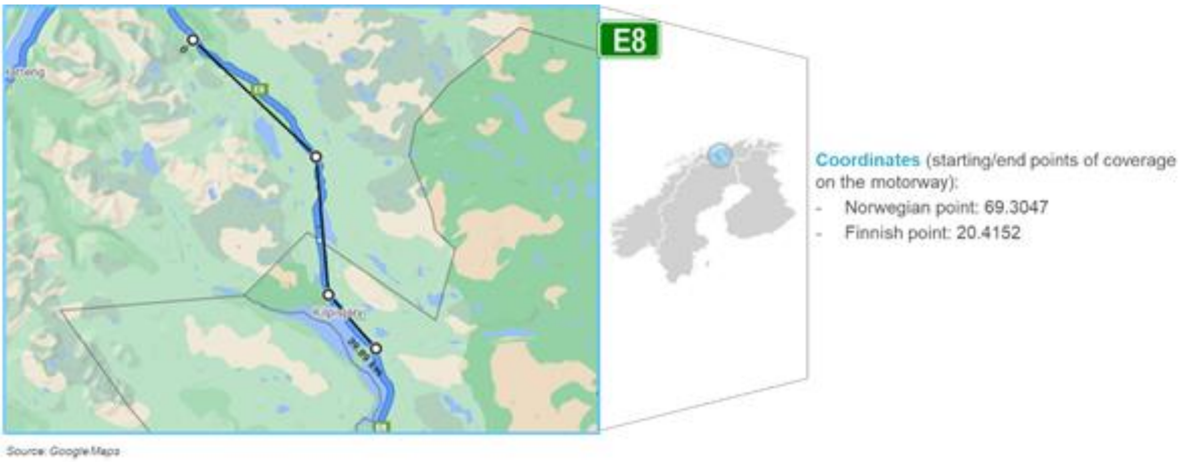


Figure 42: Cross-border corridor NO-FI Kilpisjärvi

Existing sites and 5G NR coverage simulation

Based on the Information about the existing sites taken from the available public sources (http://cellmaper.net/) and information from the local stakeholders the map of existing site is depicted on the Figure 43 below:

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.

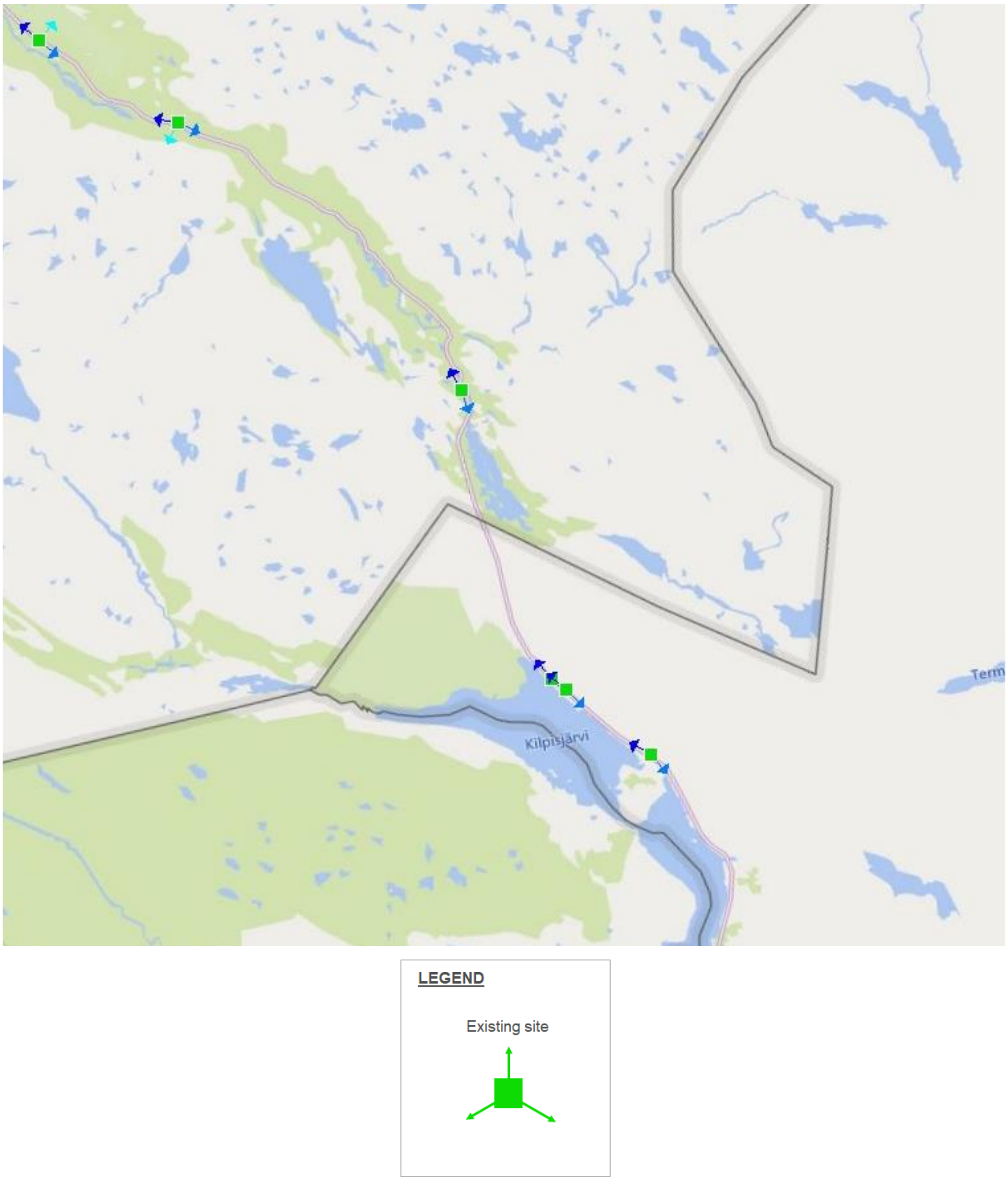
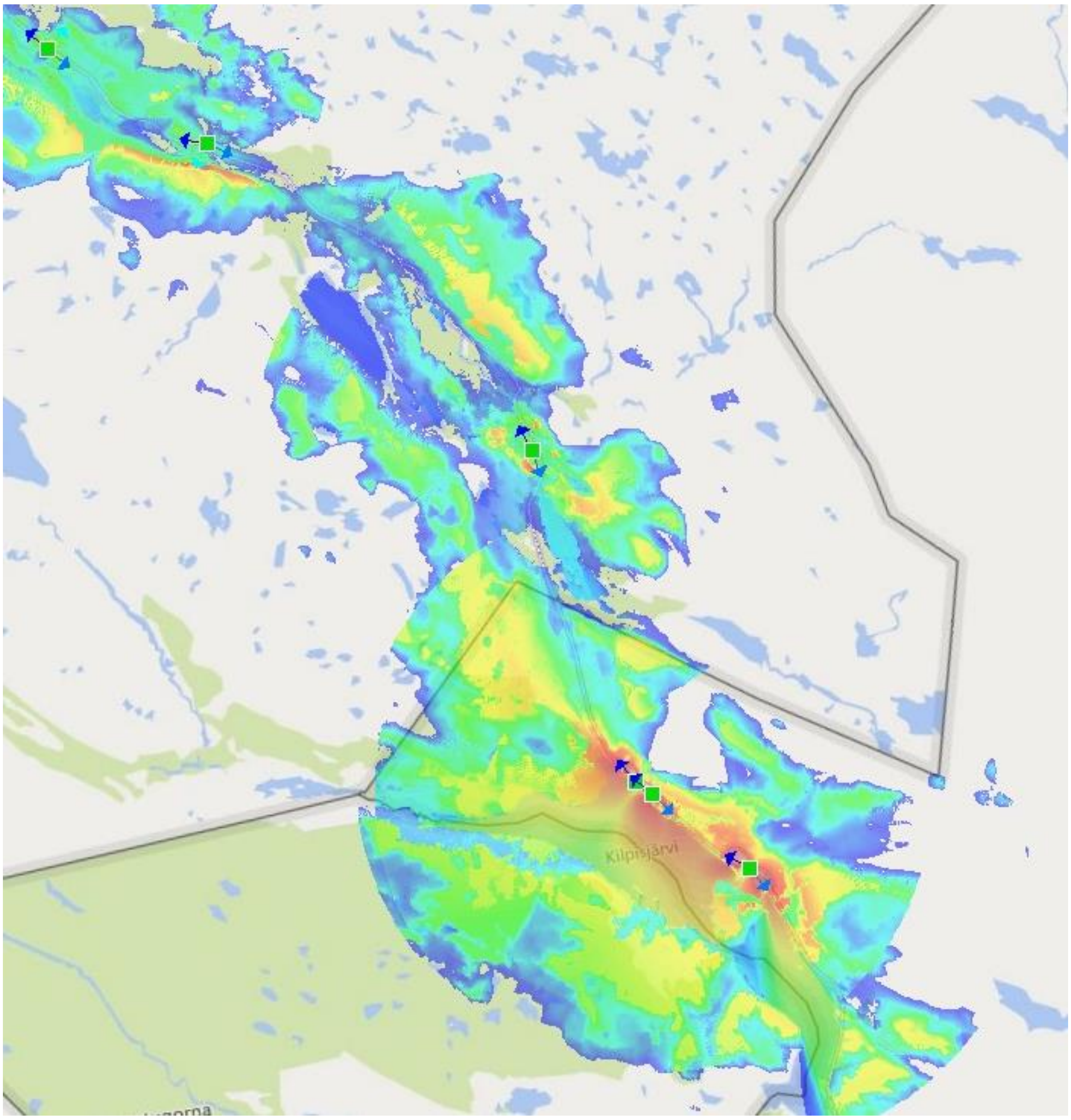


Figure 43: Existing sites in the area of NO-FI Kilpisjärvi CBC

Network coverage of the existing sites only was simulated and depicted below:

- see Figure 44 for the 700 MHz FDD
- see Figure 45 for the 3500 MHz TDD

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.



LEGEND

Existing site

RSRP	Interpretation	Color code
- 60 dBm	Excellent	Brown orange
- 72 dBm	Very good	Orange
- 90 dBm	Good	Green
-111 dBm	Low	Light-blue
122 dBm	Poor	Dark blue

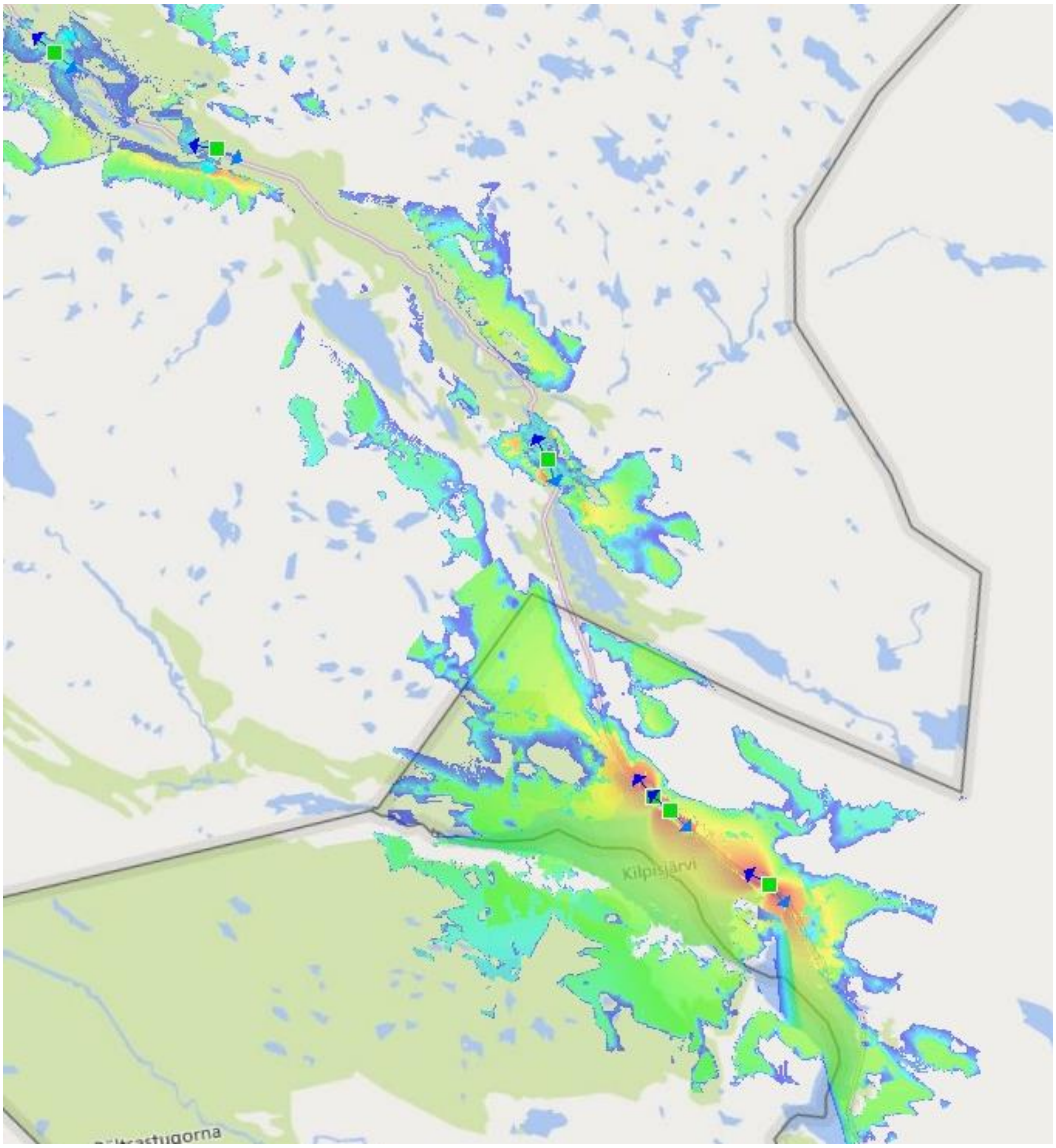
Figure 44: Existing sites in the area of NO-FI Kilpisjärvi CBC, 5G NR 700 MHz FDD radio coverage simulation

Simulation of 700 MHz network coverage (based on the existing sites only) shows that:

- the CBC is assumed to be good covered at the Finnish side due to a mostly flat landscape (RSRP is about –111 dBm to –60 dBm) and poorly covered at the Norwegian side due to the mountainous landscape (the road is located in a gorge) and many curves (RSRP is between –111 dBm and tends to – 122 dBm)

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.

- border area is assumed to be covered with the low signal (RSRP is about -111 dBm)
- there are almost no coverage gaps at the Finnish side and many coverage gaps along the Norwegian part of given stretch of CBC



LEGEND

Existing site

RSRP	Interpretation	Color code
- 60 dBm	Excellent	Brown orange
- 72 dBm	Very good	Orange
- 90 dBm	Good	Green
-111 dBm	Low	Light-blue
122 dBm	Poor	Dark blue

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.

Figure 45: Existing sites in the area of NO-FI Kilpisjärvi CBC, 5G NR 3500 MHz TDD radio coverage simulation

Simulation of 3500 MHz coverage based on the existing only sites shows that:

- the CBC is assumed to be almost not covered at the Norwegian side and badly covered on the Finnish side (RSRP levels range from -90 dBm to -122 dBm)
- border area is assumed to be not covered
- the Norwegian part looks like a non-coverage area and there are several coverage gaps along the Finnish part of given stretch of CBC

<u>Target network nominal planning and coverage simulation</u>

700 MHz FDD target network nominal planning and coverage simulation

Figure 46 shows locations of existing sites and indicative locations for the new sites, required to get the seamless 5G coverage with almost continuous RSRP level around -60 dBm to -70 dBm along the CBC at 700 MHz.

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.

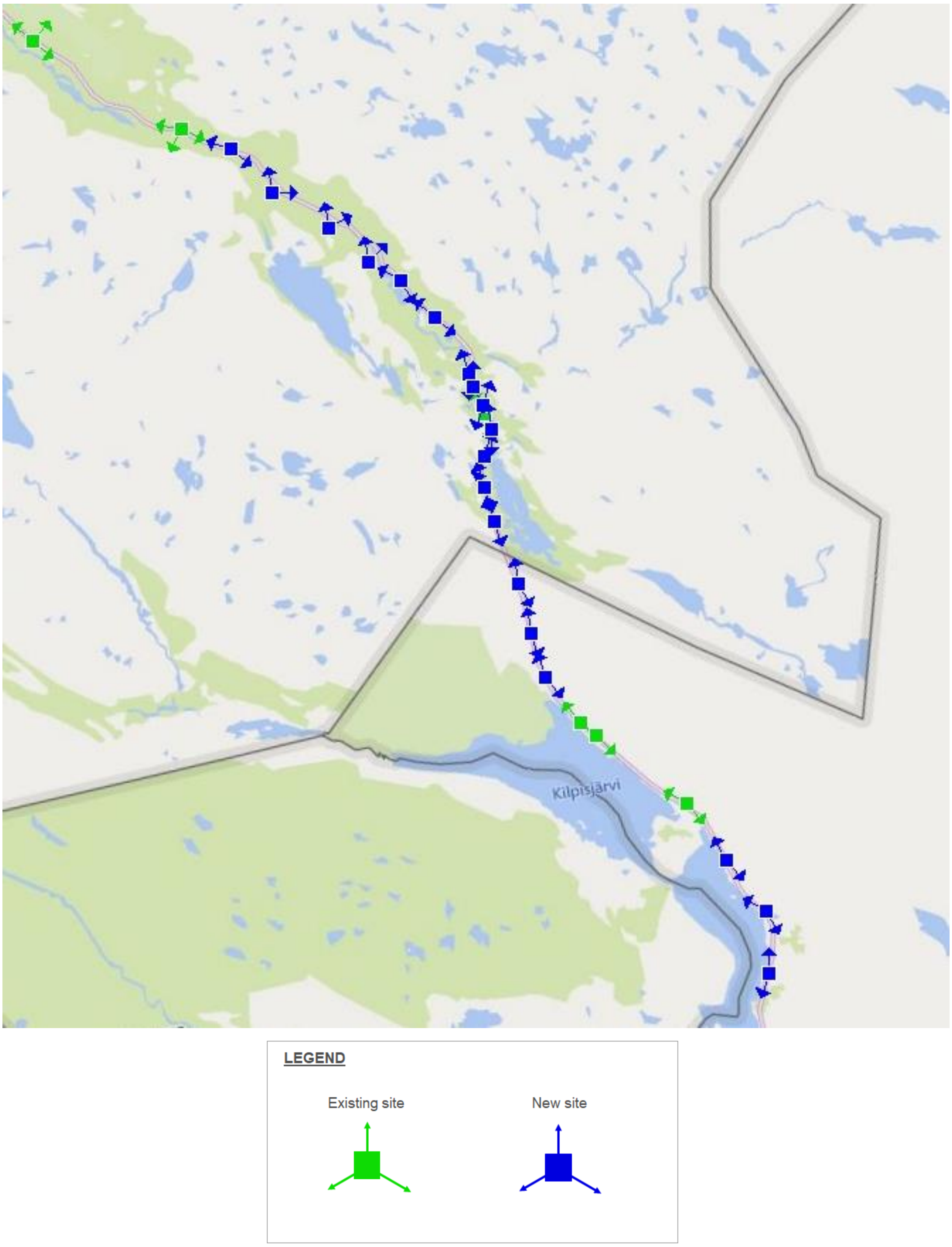
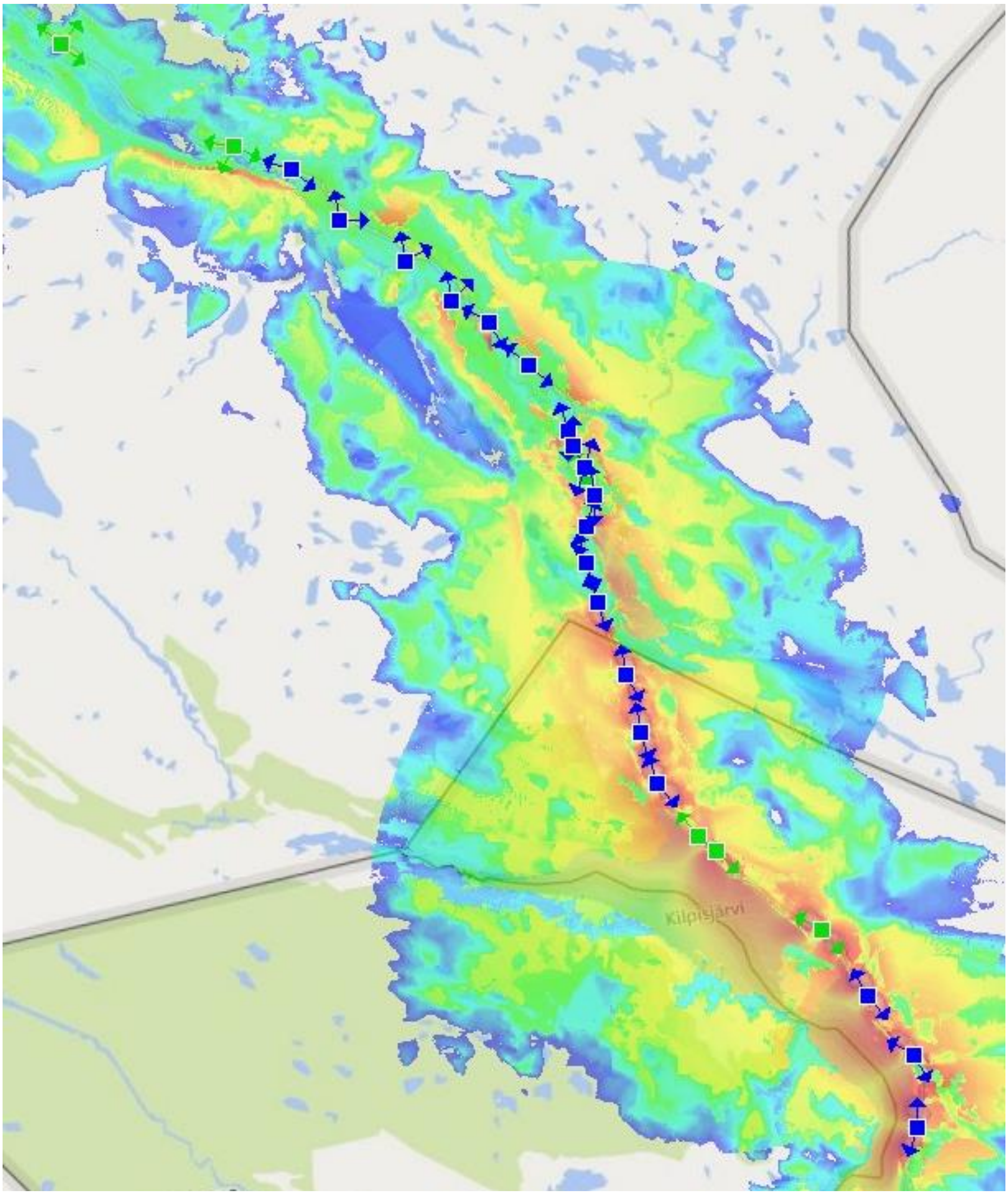


Figure 46: Existing (green) and new (dark blue) sites in the area of NO-FI Kilpisjärvi CBC, 5G NR 700 MHz FDD

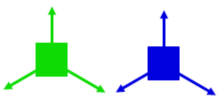
Figure 47 shows the results of the coverage simulation for the radio network based on the existing and the new sites, required to get the seamless 5G coverage with almost continuous RSRP levels around -60 dBm to -70 dBm along the CBC at 700 MHz.

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.



LEGEND

Existing site New site



RSRP	Interpretation	Color code
- 60 dBm	Excellent	Brown orange
- 72 dBm	Very good	Orange
- 90 dBm	Good	Green
-111 dBm	Low	Light-blue
122 dBm	Poor	Dark blue

Figure 47: Existing and new sites in the area of NO-FI Kilpisjärvi CBC, 5G NR 700 MHz FDD radio coverage simulation

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.

Simulation of coverage of the existing and newly added sites shows no gaps and RSRP levels at about -60 dBm to -70 dBm along all the stretch of the corridor.

Thus, in order to provide the basic coverage of the CBC with the 5G NR @ 700MHz in accordance with the Use-cases requirements (seamless 5G network along the selected CBC stretch) following actions are required in RAN domain.

- Existing sites could be upgraded to 5G:
  - 3 on the Finish side
  - 3 on the Norwegian side

- 19 new sites should be added and distributed along the road in order to provide seamless coverage:
  - 6 along the Finish stretch of the corridor
  - 13 along the Norwegian stretch of the corridor

3500 MHz TDD target network nominal planning and coverage simulation

Figure 48 shows locations of existing sites and indicative locations for the new sites, required to get the seamless 5G coverage with almost continuous RSRP levels around -60 dBm to -70 dBm along the CBC at 3500 MHz.

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.

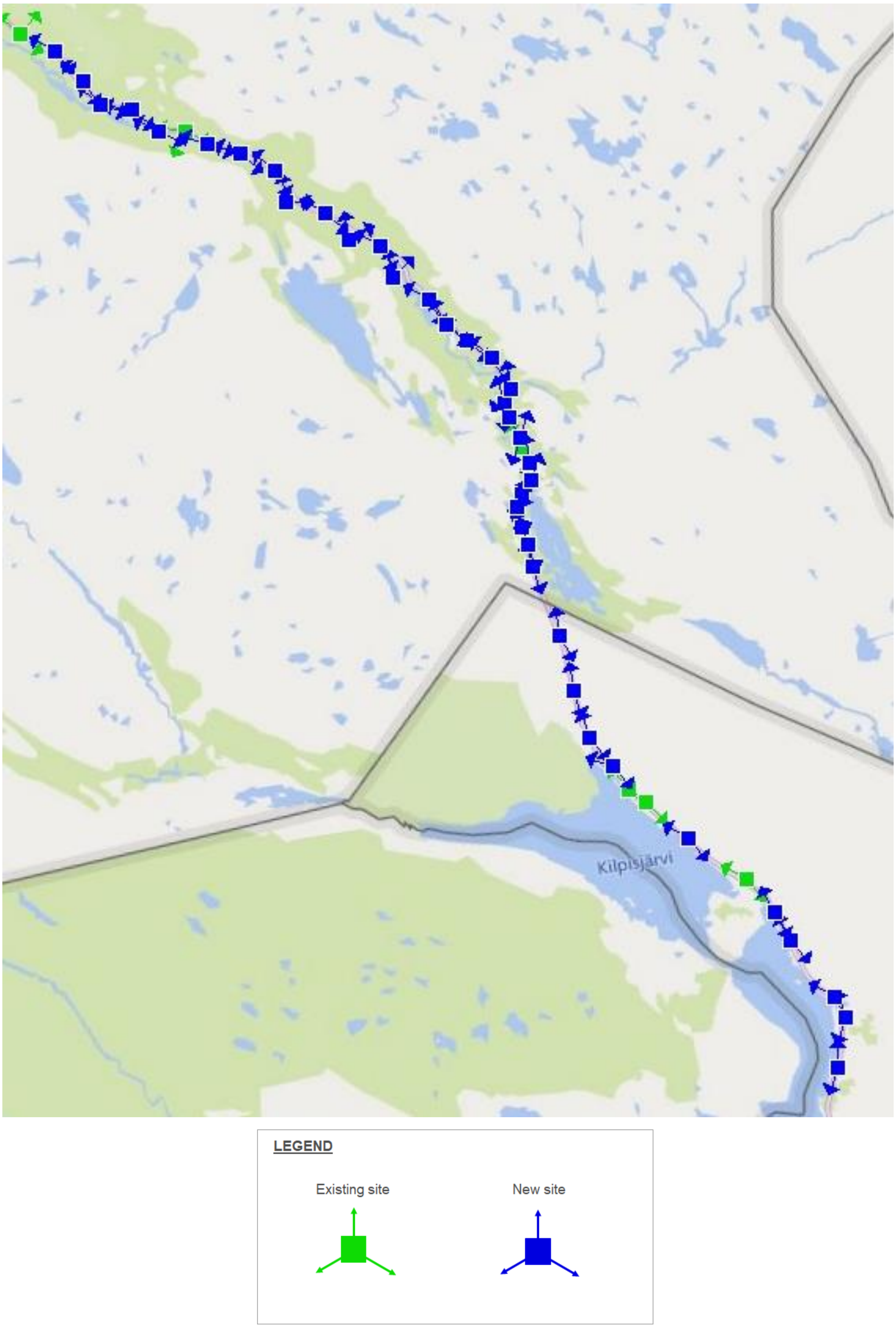
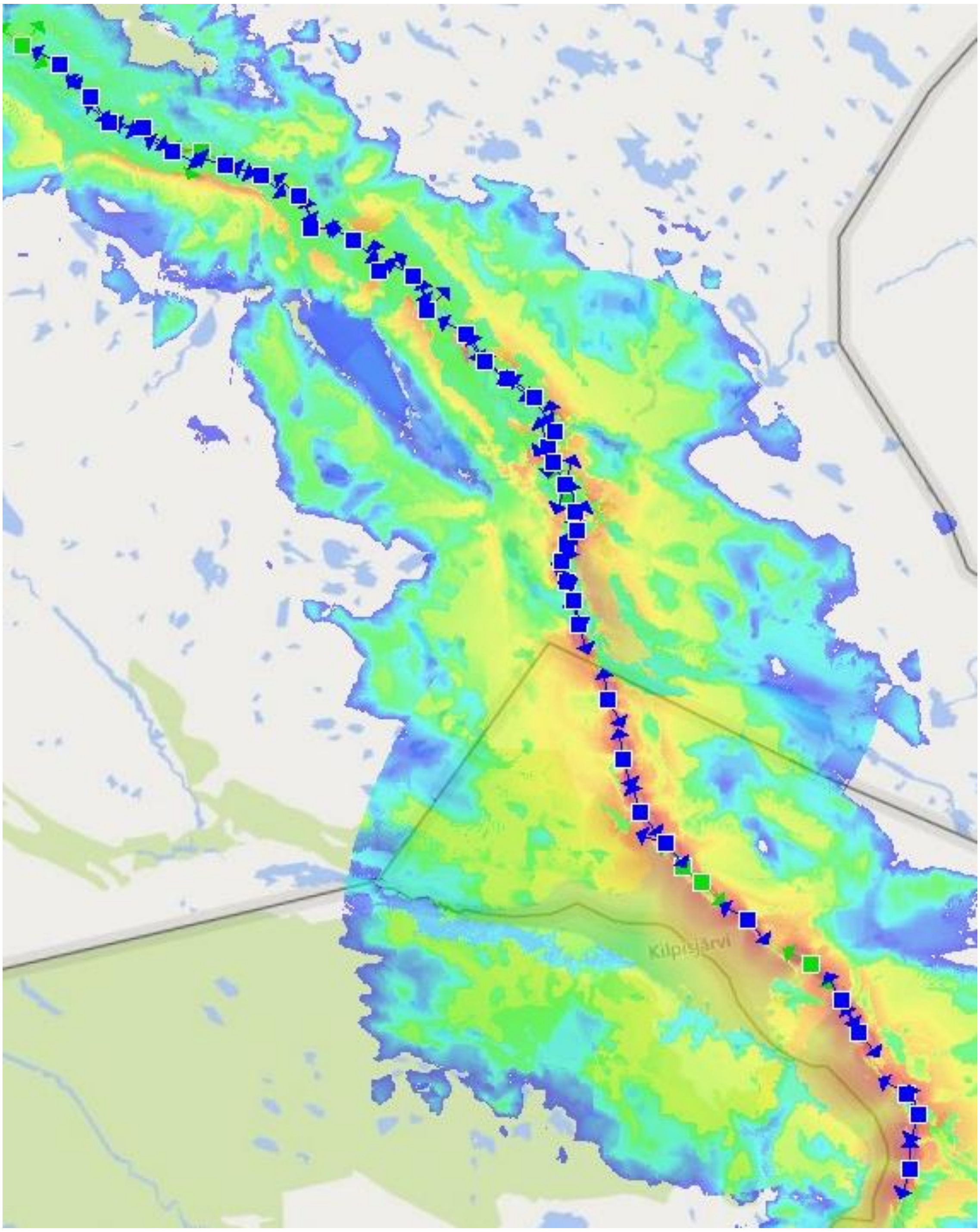


Figure 48: Existing (green) and new (dark blue) sites in the area of NO-FI Kilpisjärvi CBC, 5G NR 3500 MHz TDD

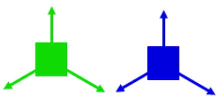
This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.

Figure 49 shows the results of the coverage simulation for the radio network based on the existing and the new sites, required to get the seamless 5G coverage with almost continuous RSRP level around -60 dBm to -70 dBm along the CBC at 3500 MHz.



LEGEND

Existing site New site



RSRP	Interpretation	Color code
- 60 dBm	Excellent	Brown orange
- 72 dBm	Very good	Orange
- 90 dBm	Good	Green
-111 dBm	Low	Light-blue
122 dBm	Poor	Dark blue

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.

Figure 49: Existing and new sites in the area of NO-FI Kilpisjärvi CBC, 5G NR 3500 MHz TDD radio coverage simulation

Simulation of coverage of the existing and newly added sites show no gaps and RSRP at about -60 dBm to -70 dBm along all the stretch of the corridor.

Thus, in order to provide the basic coverage of the CBC with the 5G NR @ 3500MHz in accordance with the Use-cases requirements (seamless 5G network along the selected CBC stretch) following actions are required in RAN domain.

- Existing sites should be upgraded to 5G:
  - 3 on the Finish side
  - 3 on the Norwegian side

- 40 new sites should be added and distributed along the road in order to provide seamless coverage:
  - 12 along the Finish stretch of the corridor
  - 28 along the Norwegian stretch of the corridor

4.6.5 CBC ES-FR

Corridor overview

Cross-border corridor **ES-FR Le Perthus** is the European route 15 (E 15) is a European long-distance connection from Inverness in Scotland via England and France to Algeciras in Spain.

Within the study a ~40 km strip in the part which crosses the French-Spanish border at Le Perthus between Perpignan and Figueres was assessed, as depicted in Figure50.

Figure50: Cross-border corridor ES-FR Le Perthus

Based on the Information about the existing sites taken from the available public sources (http://cellmaper.net/, https://antenasgsm.com/, https://data.anfr.fr/) and information from the local stakeholders the map of existing site is depicted on the Figure 51 below:

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.

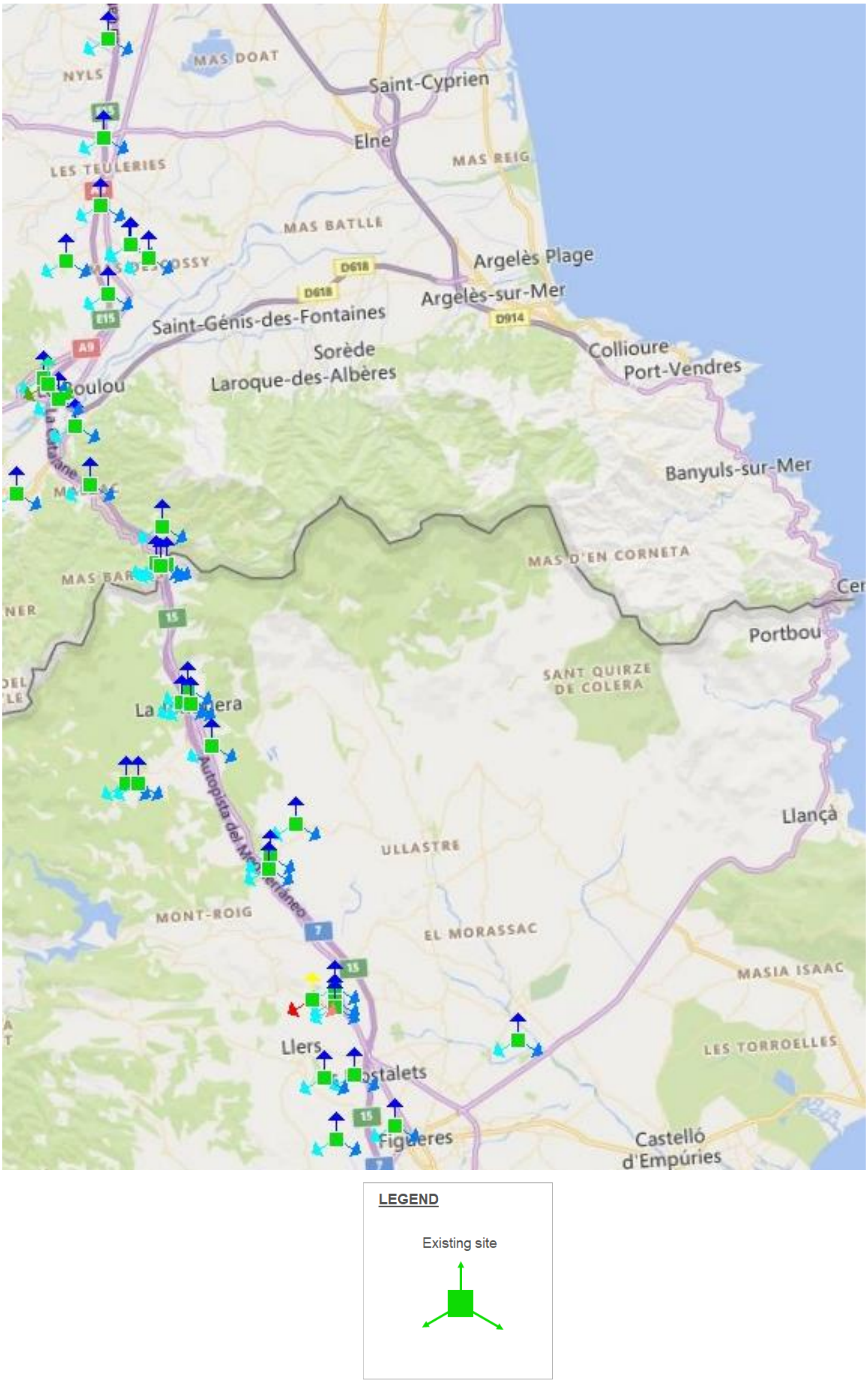


Figure 51: Existing sites in the area of ES-FR Le Perthus CBC

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.

Network coverage of the existing sites only was simulated and depicted below:

- see Figure 52 for the 700 MHz FDD
- see Figure 53 for the 3500 MHz TDD

Simulation of 700 MHz network coverage (based on the existing sites only) shows that:

- the CBC is assumed to be mostly covered with the very good and good signal (RSRP is between –90 dBm and –72 dBm) in the in the mountainous part and with the excellent signal (RSRP tend to –60 dBm) in the foothill parts (mostly in settlements close to the highway)
- border area (soft border in the mountains) is assumed to be covered with the very good and good signal (RSRP is between –90 dBm and –72 dBm)
- there are no coverage gaps along the given stretch of CBC

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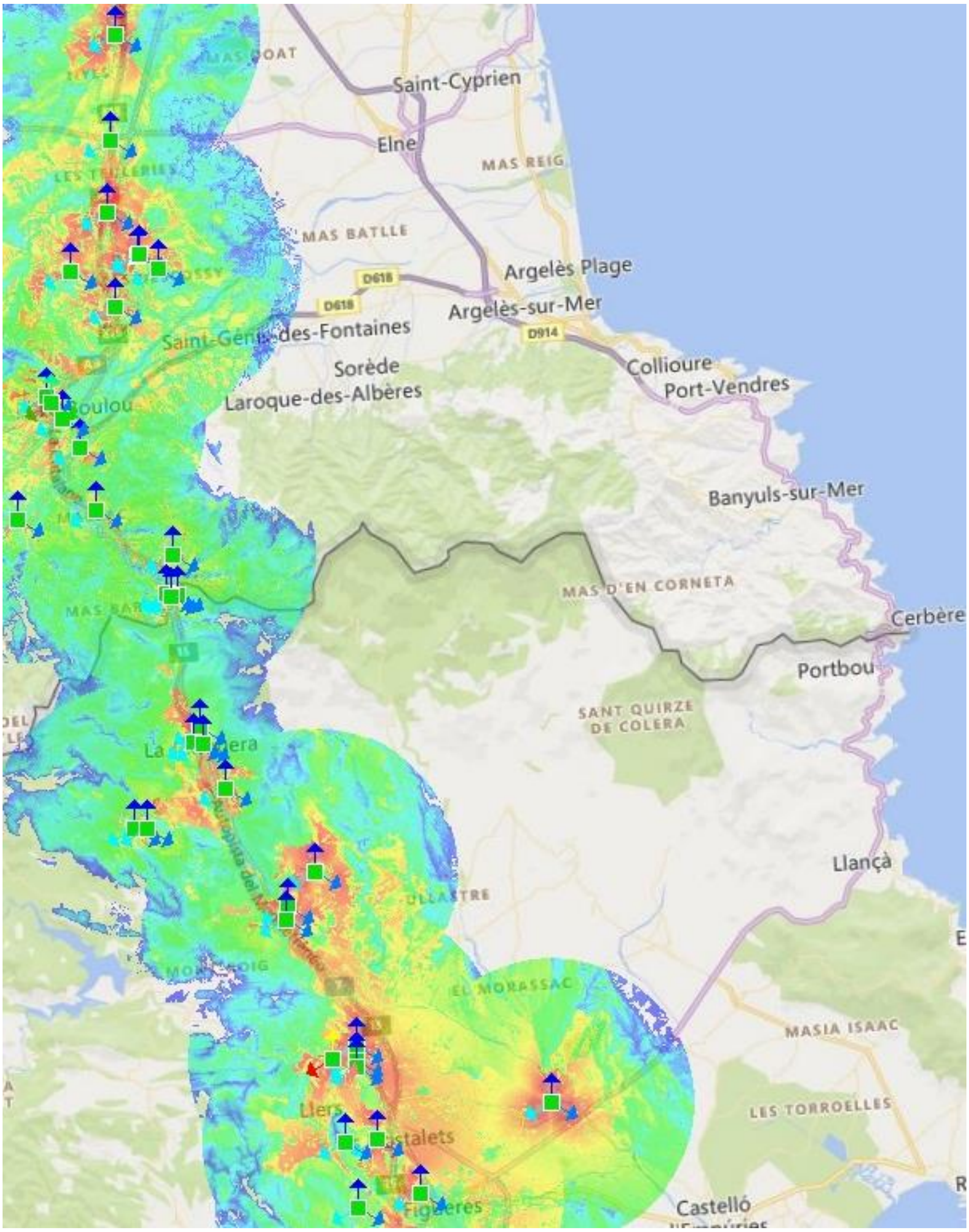
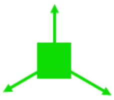


LEGEND

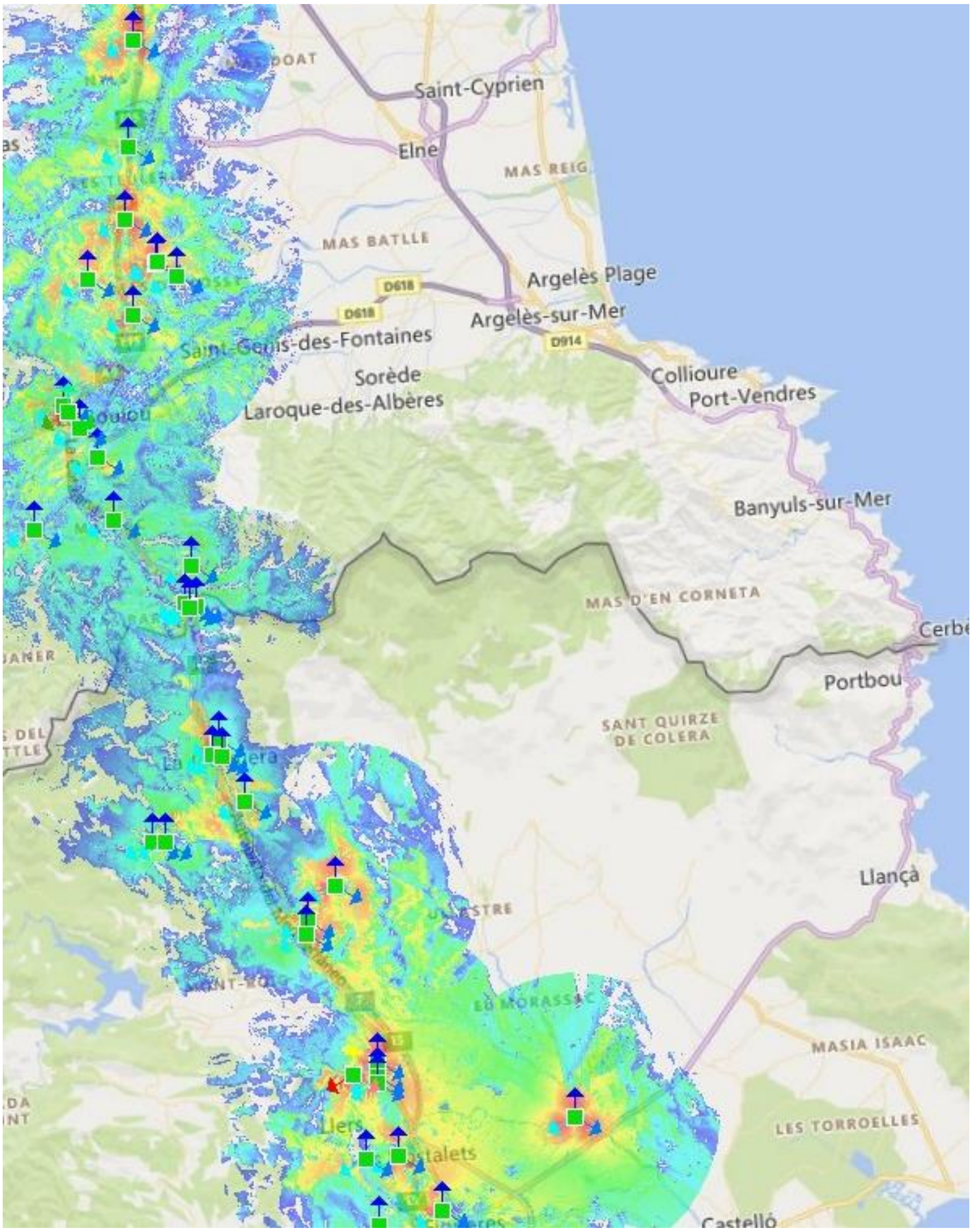
Existing site



RSRP	Interpretation	Color code
- 60 dBm	Excellent	Brown orange
- 72 dBm	Very good	Orange
- 90 dBm	Good	Green
-111 dBm	Low	Light-blue
122 dBm	Poor	Dark blue

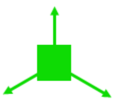
Figure 52: Existing sites in the area of ES-FR Le Perthus, 5G NR 700 MHz FDD radio coverage simulation

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.



LEGEND

Existing site



RSRP	Interpretation	Color code
- 60 dBm	Excellent	Brown orange
- 72 dBm	Very good	Orange
- 90 dBm	Good	Green
-111 dBm	Low	Light-blue
122 dBm	Poor	Dark blue

Figure 53: Existing sites in the area of ES-FR Le Perthus, 5G NR 3500 MHz TDD radio coverage simulation

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.

Simulation of 3500 MHz network coverage (based on the existing sites only) shows that:

- the CBC is assumed to be mostly covered with the low signal (RSRP tends to –111 dBm) in the in the mountainous part and with the good signal (RSRP is about –90 dBm) in the foothill parts (mostly in settlements close to the highway) as well as with small zones with the excellent and very signal (RSRP at about – -60 dBm – - 70 dBm) in the settlements in the foothill along the highway
- border area (soft border in the mountains) is assumed to be covered with the low signal (RSRP is about -111 dBm)
- several small coverage gaps are in place in the mountainous area

<u>Target network nominal planning and coverage simulation</u>

700 MHz FDD target network nominal planning and coverage simulation

Figure 54 shows locations of existing sites and indicative locations for the new sites, required to get the seamless 5G coverage with almost continuous RSRP level around -60 dBm to -70 dBm along the CBC at 700 MHz.

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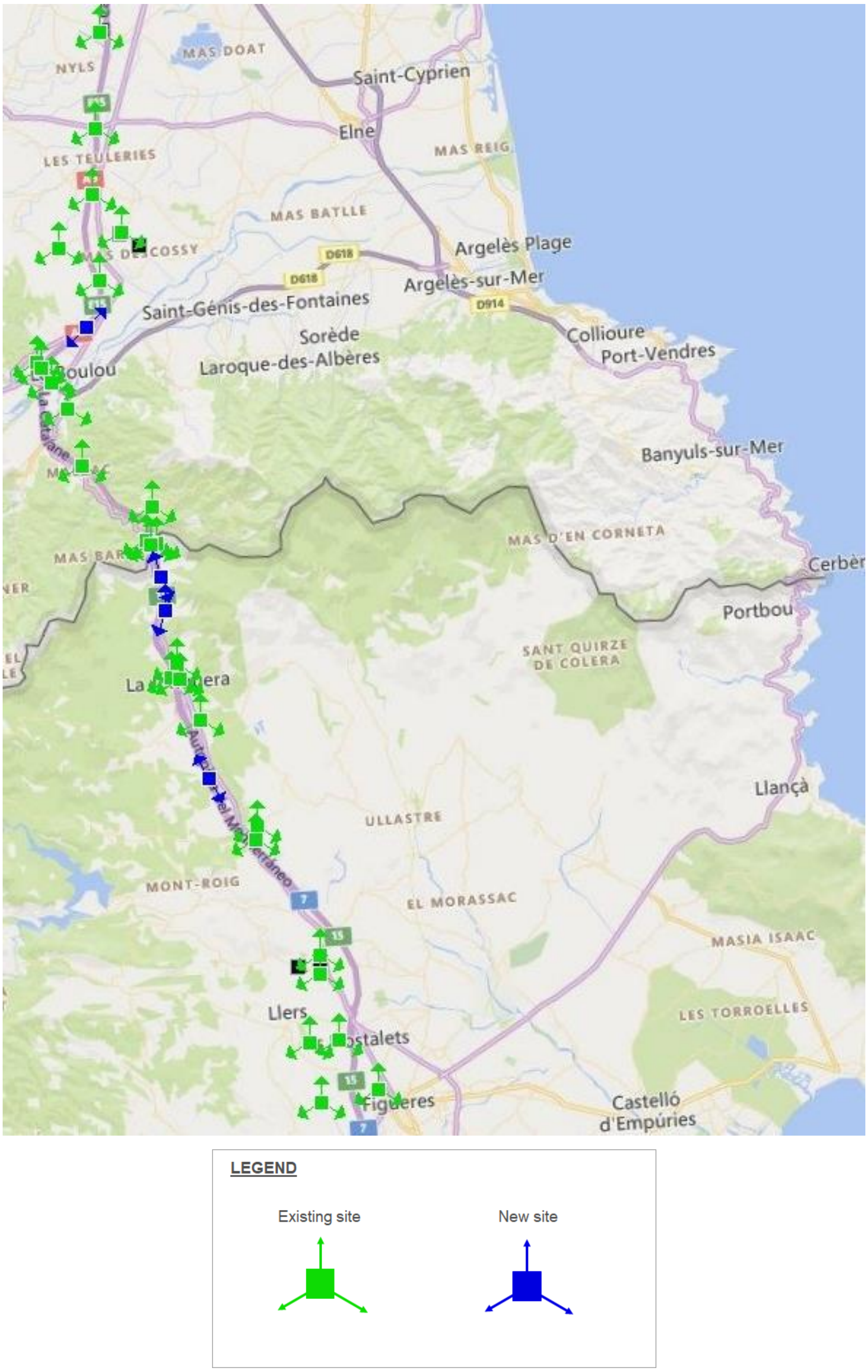
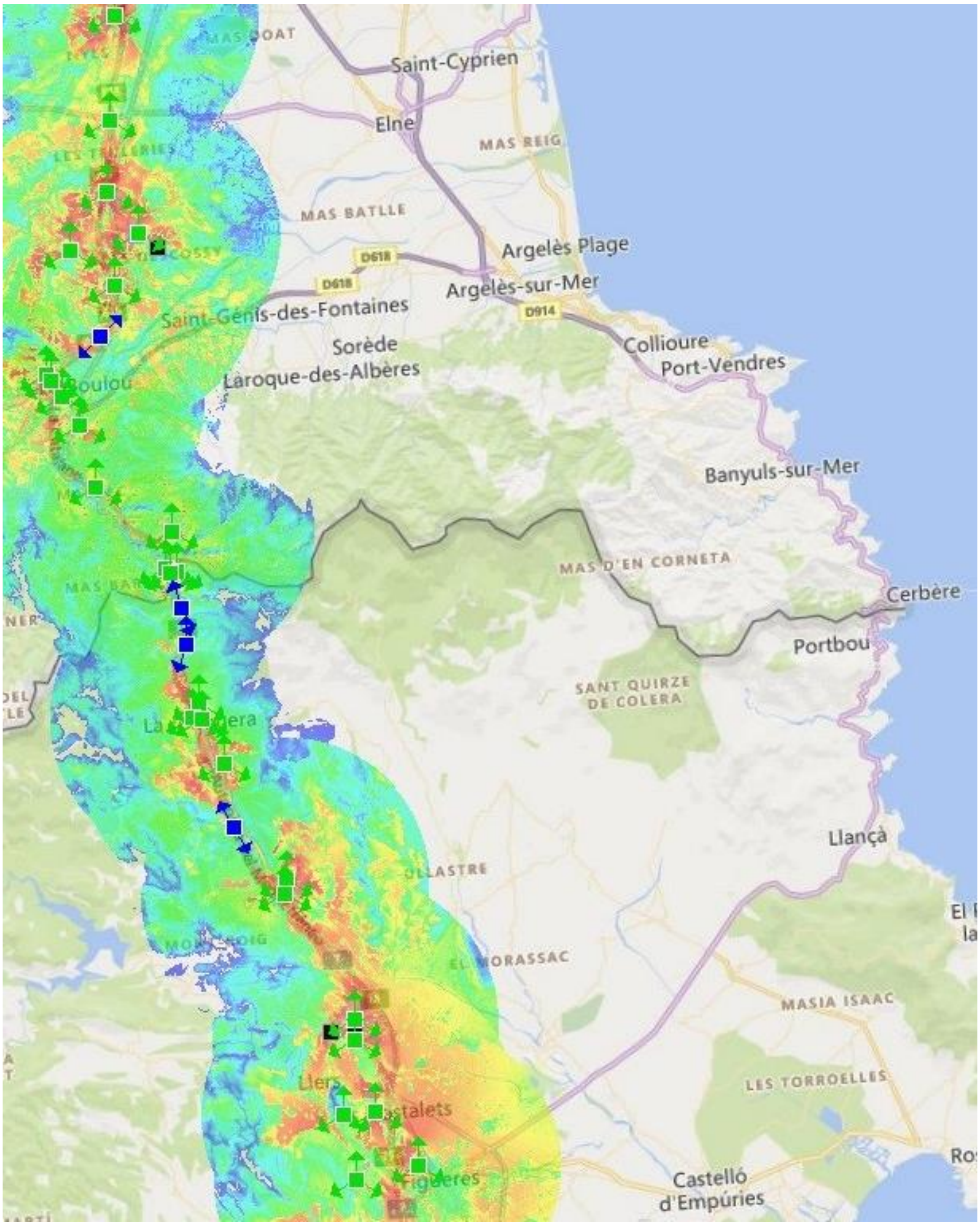


Figure 54: Existing and new sites in the area of ES-FR Le Perthus CBC, 5G NR 700 MHz FDD

Figure 55 shows the results of the coverage simulation for the radio network based on the existing and the new sites, required to get the seamless 5G coverage with almost continuous RSRP levels around -60 dBm to -70 dBm along the CBC at 700 MHz.

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.



LEGEND

Existing site New site

RSRP	Interpretation	Color code
- 60 dBm	Excellent	Brown orange
- 72 dBm	Very good	Orange
- 90 dBm	Good	Green
-111 dBm	Low	Light-blue
122 dBm	Poor	Dark blue

Figure 55: Existing and new sites in the area of ES-FR Le Perthus CBC, 5G NR 700 MHz FDD radio coverage simulation

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.

Simulation of coverage of the existing and newly added sites shows no gaps and RSRP at about -60 dBm to - 70 dBm along all the stretch of the corridor.

Thus, in order to provide the basic coverage of the CBC with the 5G NR @ 700MHz in accordance with the Use-cases requirements (seamless 5G network along the selected CBC stretch) following actions are required in RAN domain.

- Existing sites could be upgraded to 5G:
  - 14 om the Spanish side
  - 10 on the French side

- 4 new sites were added and distributed along the road in order to provide seamless coverage:
  - 3 along the Spanish stretch of the corridor
  - 1 along the French stretch of the corridor

3500 MHz TDD target network nominal planning and coverage simulation

Figure 56 shows locations of existing sites and indicative locations for the new sites, required to get the seamless 5G coverage with almost continuous RSRP levels around -60 dBm to -70 dBm along the CBC at 3500 MHz.

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.

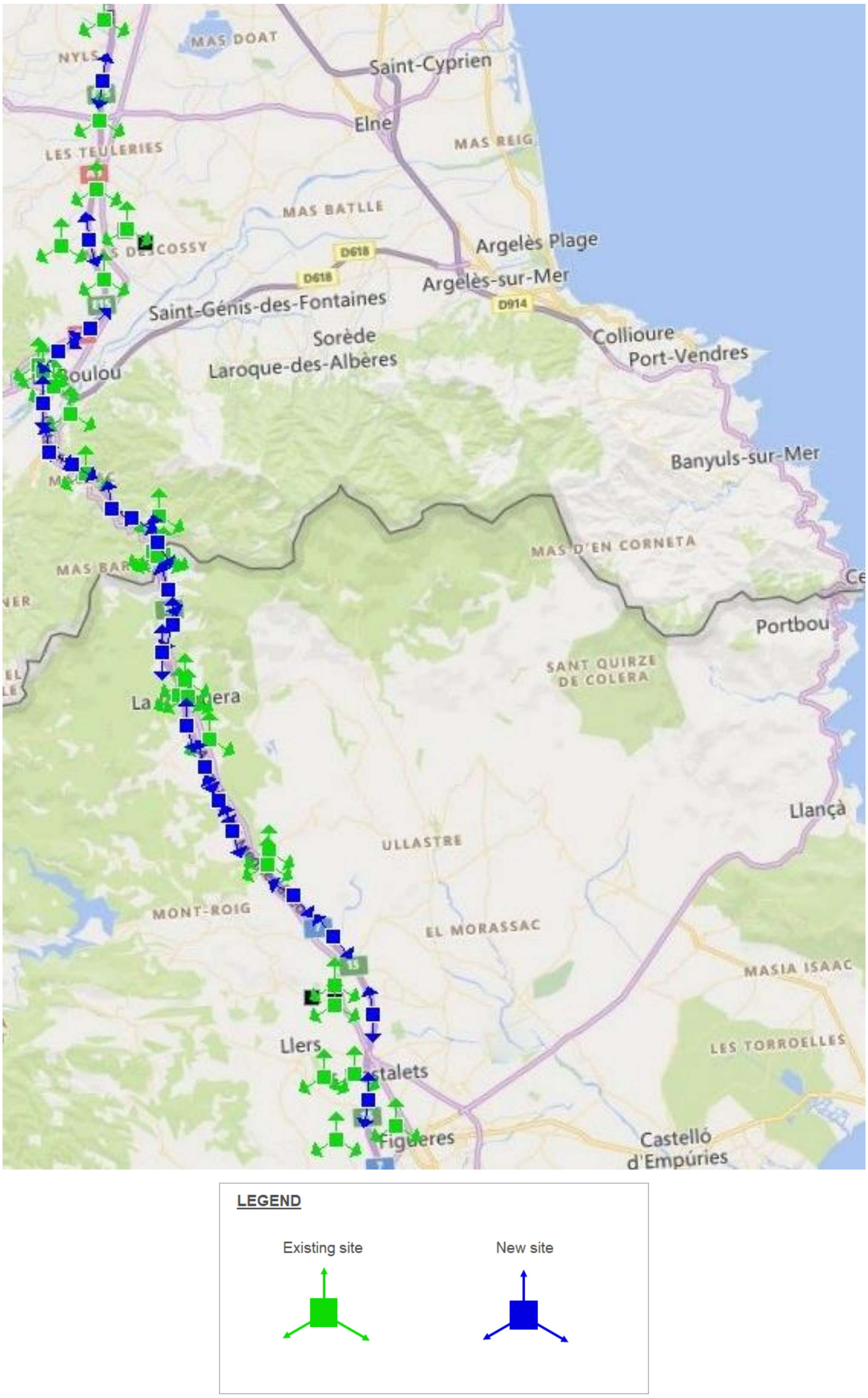
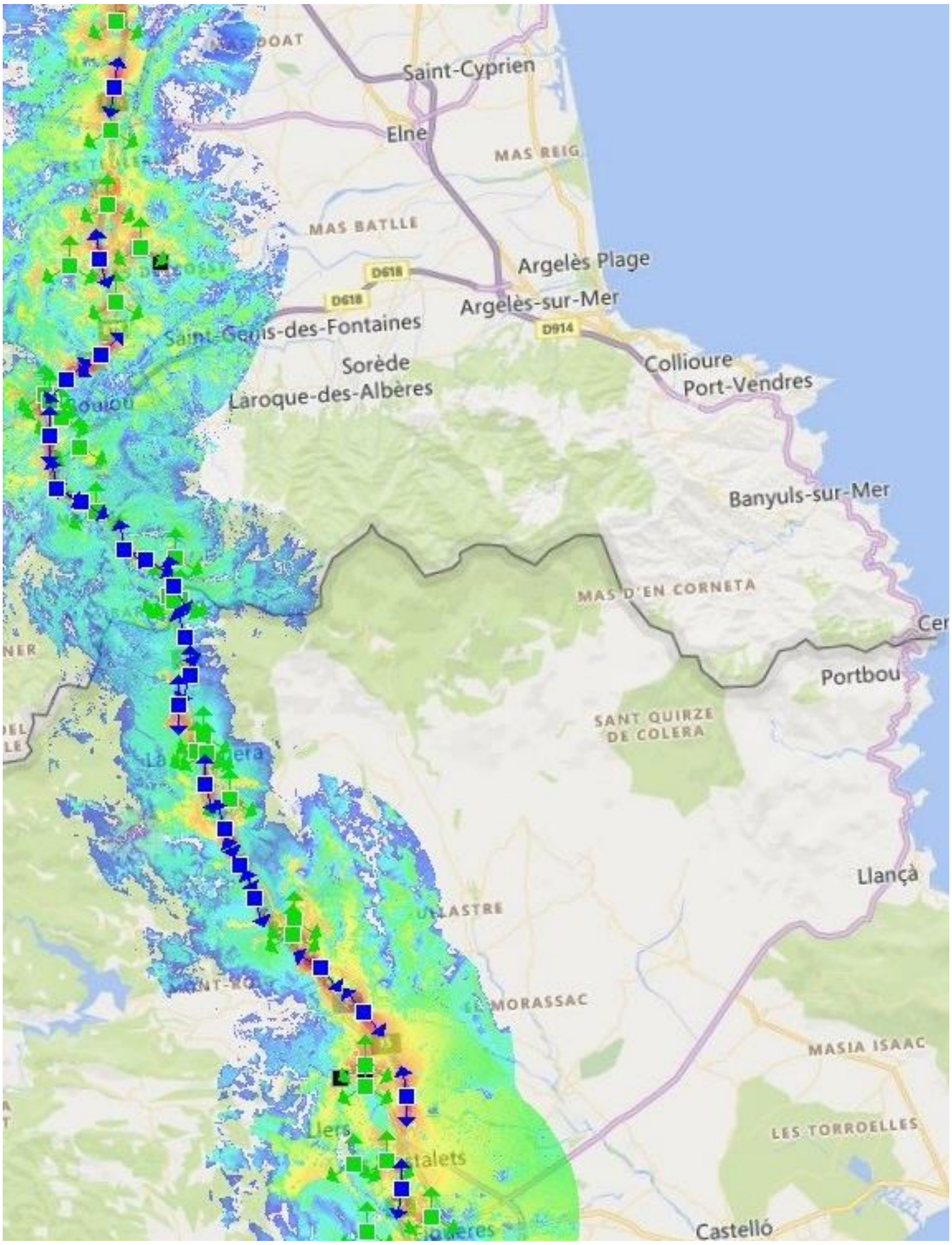


Figure 56: Existing and new sites in the area of ES-FR Le Perthus CBC, 5G NR 3500 MHz TDD

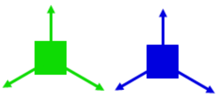
Figure 57 shows the results of the coverage simulation for the radio network based on the existing and the new sites, required to get the seamless 5G coverage with almost continuous RSRP level around -60 dBm – - 70 dBm along the CBC at 3500 MHz.

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.



LEGEND

Existing site New site



RSRP	Interpretation	Color code
- 60 dBm	Excellent	Brown orange
- 72 dBm	Very good	Orange
- 90 dBm	Good	Green
-111 dBm	Low	Light-blue
122 dBm	Poor	Dark blue

Figure 57: Existing and new sites in the area of ES-FR Le Perthus CBC, 5G NR 3500 MHz TDD radio coverage simulation

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.

Simulation of coverage of the existing and newly added sites show no gaps and RSRP at about -60 dBm to -70 dBm along all the stretch of the corridor.

Thus, in order to provide the basic coverage of the CBC with the 5G NR @ 3500MHz in accordance with the Use-cases requirements (seamless 5G network along the selected CBC stretch) following actions are required in RAN domain.

- Existing sites could be upgraded to 5G:
  - 14 on the Spanish side
  - 15 on the French side

- 22 new sites should be added and distributed along the road in order to provide seamless coverage:
  - 12 along the Spanish stretch of the corridor
  - 10 along the French stretch of the corridor

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.

4.7 Deployment Cost Delta for Connectivity Investments

The cost catalogue shows the average estimated costs for active (700 MHz & 3500 MHz) as well as passive base station infrastructure and operational expenses. Extensive industry research and interviews (for the sources, please refer to chapter 3.5.3, Costing delta calculation) provide the inputs for the cost catalogue (CAPEX & OPEX).

Important disclaimer: The cost results are estimates. These costs may vary by about **+/-20%** within one country from operator to operator.

The highest cost estimates can be observed in Norway, with a passive infrastructure per base station of about 103 kEUR. In addition, 24 kEUR can be expected for active equipment (700 MHz). Up to almost 40% lower costs can be observed in Greece and Turkey. The ranking is similar for 3500 MHz active equipment, although prices in Portugal appear to be relatively lower. In general, mid-band appears to be 5 – 10 kEUR more expensive per base station than the lower 5G band. The CAPEX for every country in the 5 corridors is visualized in Figure 58. And both CAPEX and OPEX is shown in Table 6.

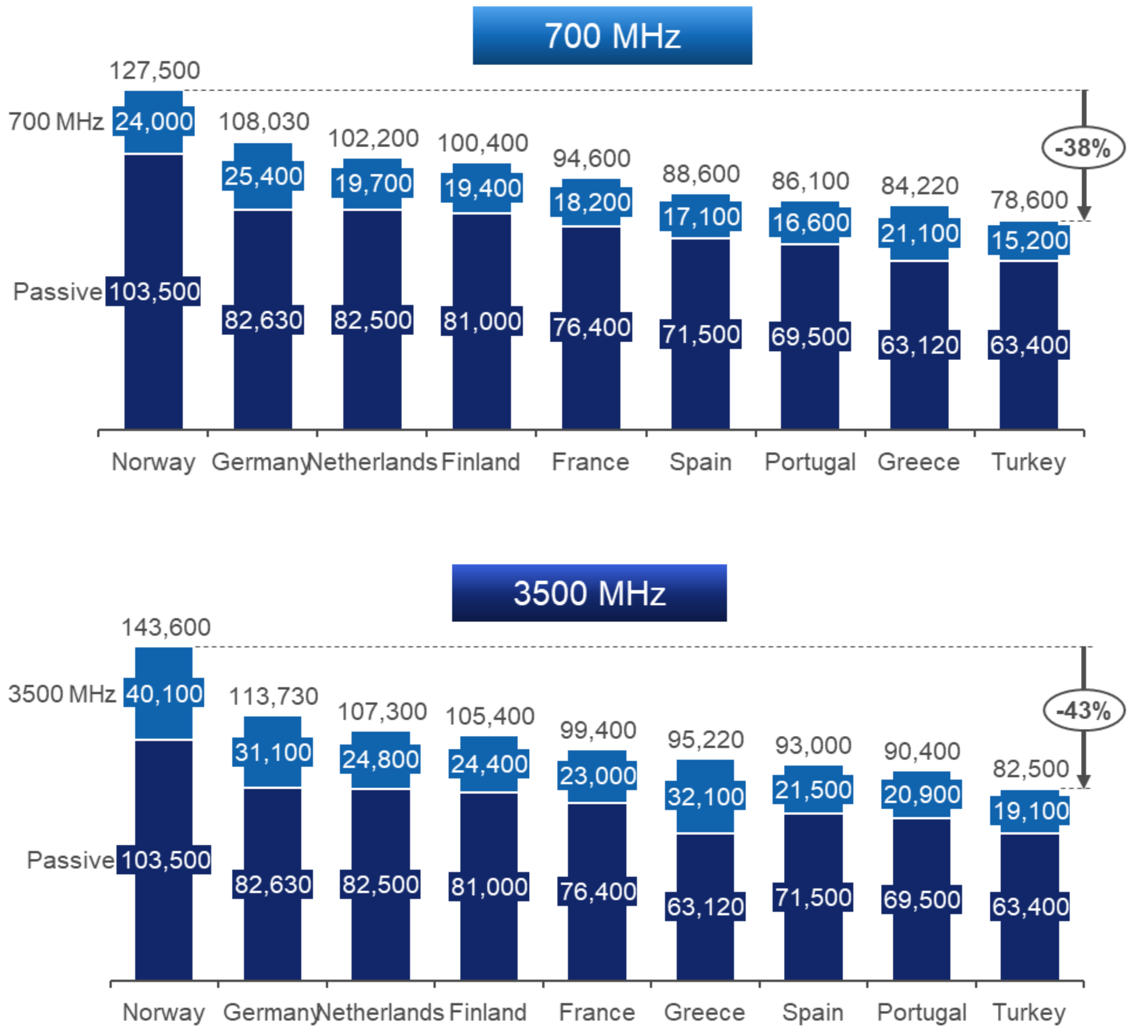


Figure 58: CAPEX per base station

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Configuratio n	Description	DE	NL	PT	ES	FR	GR	TR	FI	NO
700_1 (CAPEX)	FDD, 10 MHz bandwidth, single carrier, SU MIMO 2 layers	25.400 €	19.700 €	16.600 €	17.100 €	18.200 €	21.100 €	15.200 €	19.400 €	24.000 €
3500_1 (CAPEX)	TDD, 100 MHz bandwidth, single carrier, SU MIMO 8 layers	31.100 €	20.800 €	20.900 €	21.500 €	23.000 €.	32.100 €	19.100 €	24.400 €	40.100 €
Passive (CAPEX)	30 m tower, racks, backhaul fiber connection	82.630 €	82.500 €	69.500 €	71.500 €	76.400 €	63.120 €	63.400 €	81.000 €	103.500 €
Total new site 700 (CAPEX)	700_1 CAPEX + Passive CAPEX	108.030 €	102.200 €	86.100 €	88.600 €	94.600 €	84.220 €	78.600 €	100.400 €	127.500 €
Total new site 3500 (CAPEX)	3500_1 CAPEX + Passive CAPEX	113.730 €	107.300 €	90.400 €	93.000 €	99.400 €	95.220 €	82.500 €	105.400 €	143.600 €
OPEX	Annual operational expenses	19.100 €	20.500 €	13.800 €	14.800 €	17.500 €	12.400 €	11.300 €	21.400 €	23.300 €

Table 6: CAPEX and OPEX by country

The summary of the results for the investment delta are shown below in Figure 59, representing the most demanding scenario, HVHB (high vehicular traffic and high vehicular bit rate). The top half of the figure shows CAPEX for new 5G base stations and for 5G upgrades of existing base stations (medium blue) and annual OPEX for new base stations (dark blue), while the bottom half shows the same for the year 2025.

The differences between the investment delta in 2023 and the investment delta in 2025 are solely based on planned infrastructure deployments in between the two years. For example, if an operator plans to (or is obliged to) deploy a new 5G base station along the CBC in 2024, this will reduce the 2025 investment delta by the estimated cost of that 5G base station compared to the 2023 investment delta. The same applies to upgrades of existing sites.

In the Dutch-German corridor, an early deployment of the 5G mid-band appears to be necessary according to the connectivity demand forecasts. In the Spanish French corridor,

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the same applies in 2025 and beyond. The other CBCs (PT-ES, GR-TR, FI-NO) would be sufficiently supported with 700 MHz deployment.

Overall investment deltas range from 360 kEUR to 5.500 kEUR in CAPEX and from 94 kEUR to 909 kEUR in annual OPEX for additional operations, depending on the corridor.

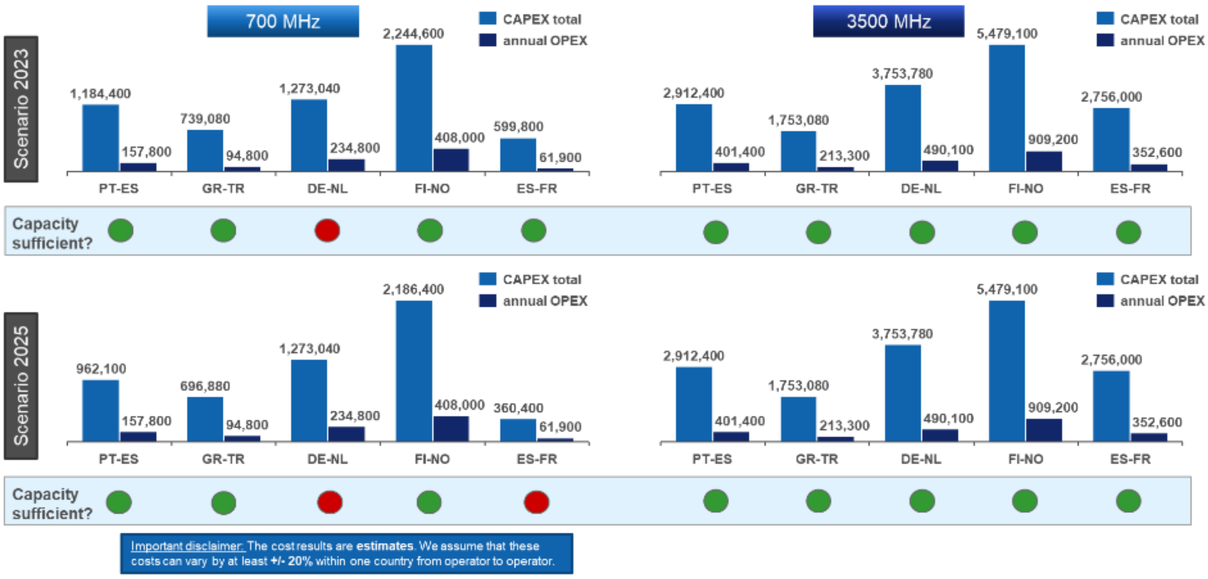

Figure 59: 5G RAN Deployment Delta (HVHB)

The following sub-chapters present the costs for each corridor in more detail.

4.7.1 CBC PT-ES

700 MHz:

Low expected road traffic along the Portuguese-Spanish CBC leads to lower requirements.

Due to its relatively low traffic numbers, 700 MHz coverage will be sufficient to enable CAM across the Portuguese-Spanish CBC in the scenarios analysed in this study. MNOs plan to upgrade their existing sites prior to 2025, however, there are no official plans for the deployment of new stations along the corridor. The differences in the cost delta for the scenarios 2023 and 2025 are visualized in Figure 60. The top half of the figure shows CAPEX for new base stations (light blue), CAPEX for upgrades of existing base stations (medium blue) and annual OPEX for new base stations (dark blue).

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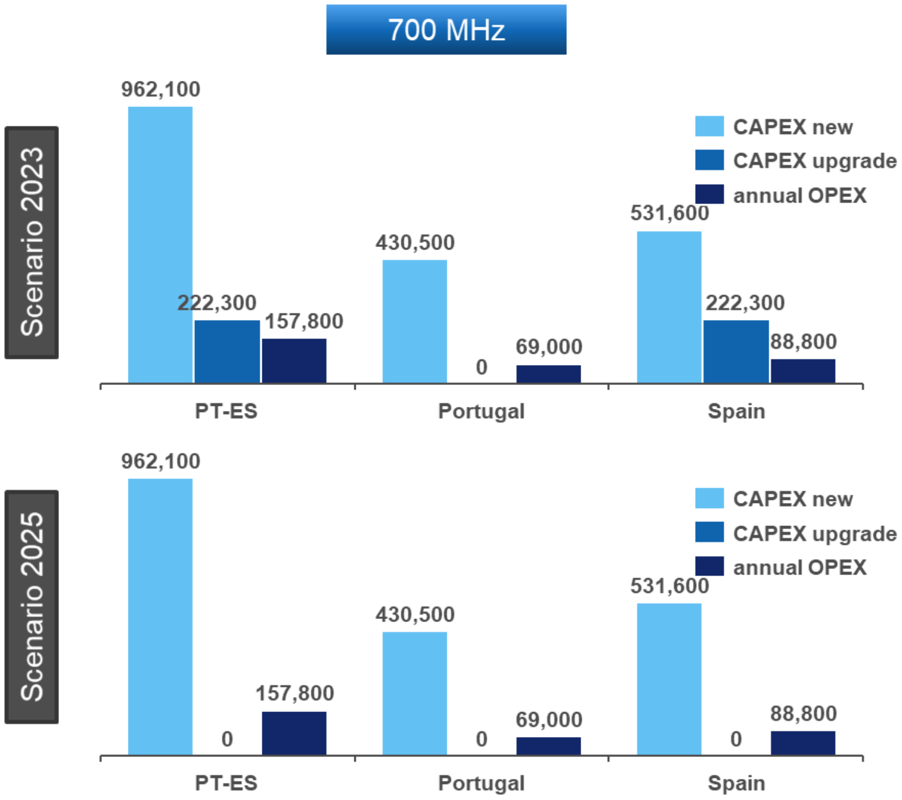

Figure 60: 700 MHz cost delta for PT-ES

3500 MHz:

Deploying the mid-band along the Portuguese-Spanish corridor does not appear to be necessary, at least until 2025, based on the analysis within this study. In all assessed scenarios, full 5G mid-band coverage would ensure sufficient capacity along the Portuguese-Spanish CBC.

The estimated costs to deploy full 5G mid-band coverage along the corridor amount to about 2.9 mEUR with additional annual OPEX at about 400 kEUR. The difference in the cost delta for the scenarios 2023 and 2025 are visualized in Figure 61. As there is no 3500 MHz deployment planned prior to 2023 or 2025, the difference in the cost delta is zero.

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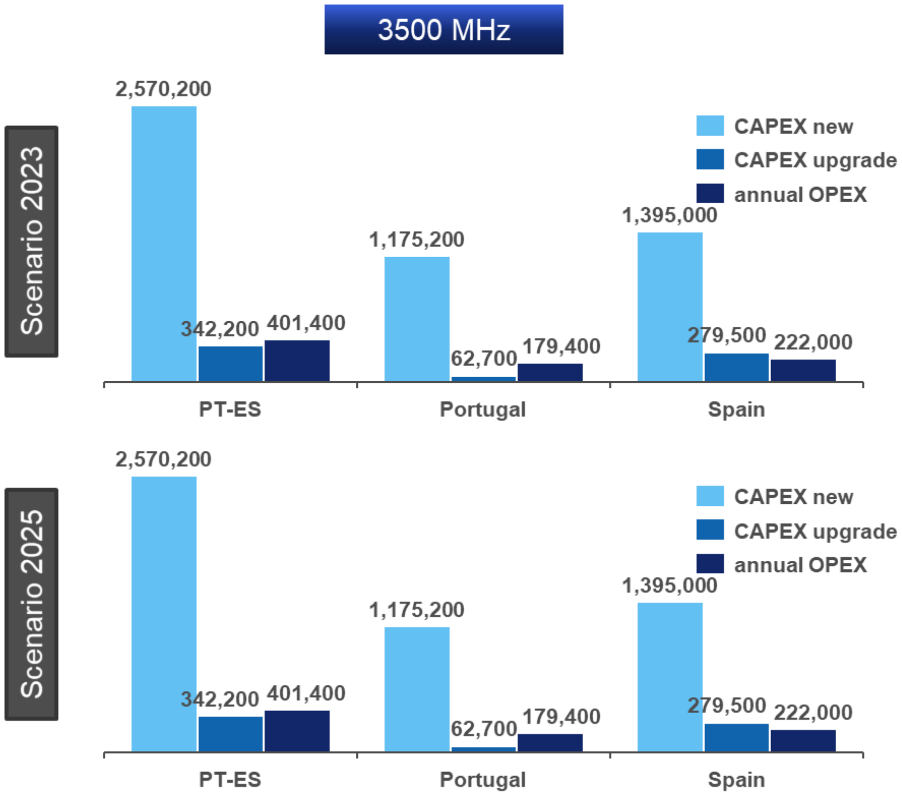

Figure 61: 3500 MHz cost delta for PT-ES

4.7.2 CBC GR-TR

700 MHz:

Along the Kipoi-Ipsala crossing, none of the forecasted traffic scenarios go beyond the capacity supported by the 700 MHz deployment scenario. According to our research, there will be upgrades to 5G on the Greek side prior to 2025. This leads to a reduced investment gap in 2025. The overall CAPEX delta amounts to around 740 kEUR in 2023 and about 700 kEUR in 2025, due to planned site upgrades to 5G in between. With current traffic forecasts, all scenarios will be supported by the 700 MHz deployment scenario. The cost deltas for 2023 and 2025 are visualized in Figure 62.

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.

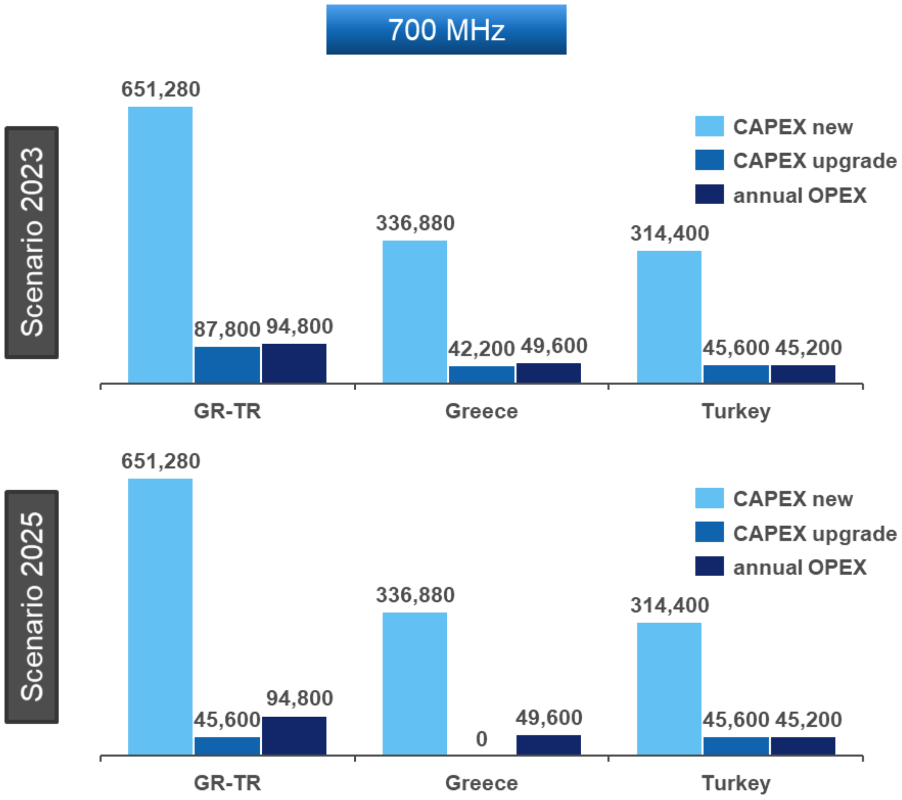

Figure 62: 700 MHz cost delta for GR-TR

3500 MHz:

Due to low price levels and more favourable topographic conditions, the costs for mid-band deployment along the Greek-Turkish corridor are among the lowest. In all assessed scenarios, full 5G mid-band deployment would ensure sufficient capacity along the assessed Greek-Turkish CBC.

The estimated costs to deploy full 5G mid-band coverage along the corridor amount to about 1.8 mEUR plus yearly operational costs of about 210 kEUR. The cost deltas for the years 2023 and 2025 are visualized in Figure 63.

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.

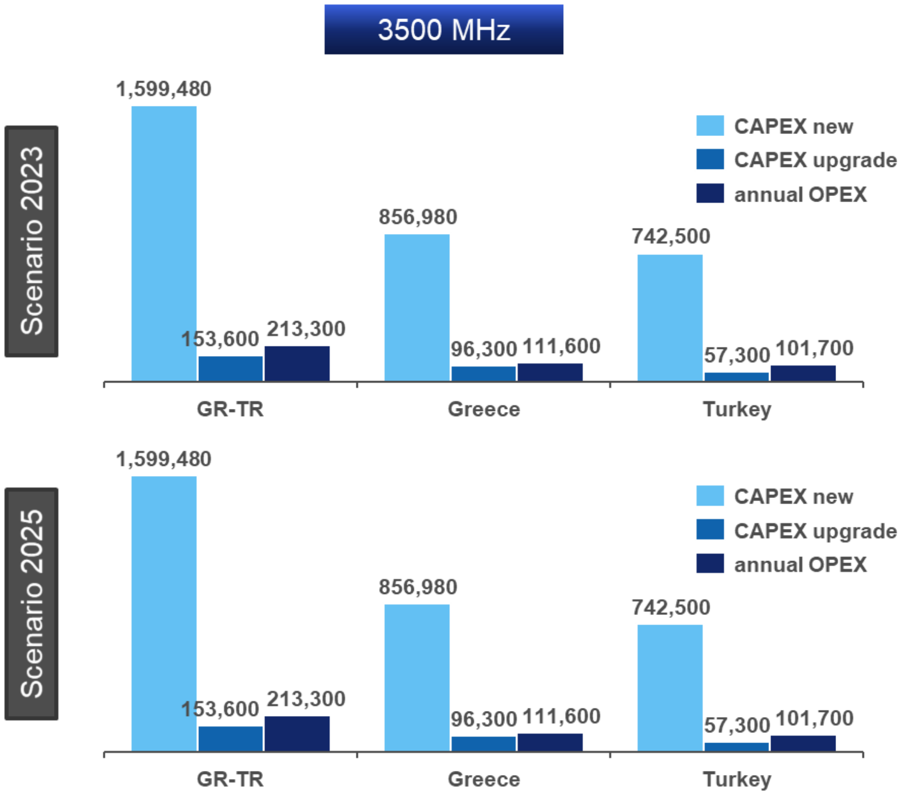

Figure 63: 3500 MHz cost delta for GR-TR

4.7.3 CBC DE-NL

700 MHz:

In the most likely scenario, 700 MHz coverage would provide sufficient capacity for CAM along the German-Dutch corridor. MNOs will upgrade all existing stations to 700 MHz prior to 2023. MNOs did not disclose any plans to deploy new stations along the corridor.

The capital expenses for new stations to ensure uninterrupted coverage along the corridor will amount to about 1.3 mEUR. Uninterrupted 700 MHz coverage would be sufficient in 2023 in all assessed scenarios except for the combination of high vehicular traffic and high bitrates per vehicles. In 2025, in 3 out of the 9 examined scenarios connectivity demand would exceed the capacities provided by 700 MHz coverage. The cost deltas for 2023 and 2025 are visualized in Figure 64.

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.

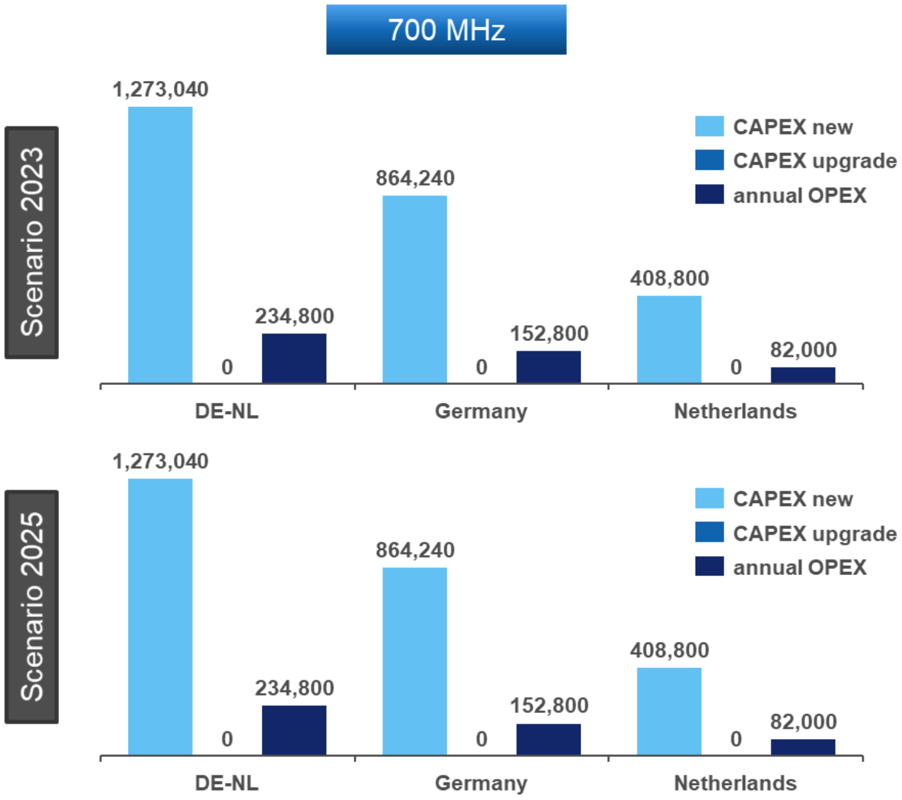

Figure 64: 700 MHz cost delta for DE-NL

3500 MHz:

There are currently no plans to deploy mid-band 5G along the corridor by 2023 or 2025 – neither on the Dutch nor on the German side. In all assessed scenarios, full 5G mid-band coverage would ensure sufficient capacity along the German-Dutch CBC assessed within this study.

The estimated costs to deploy full 5G mid-band coverage along the corridor amount to about 3.7 mEUR. The cost deltas for 2023 and 2025 are visualized in Figure 65.

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.

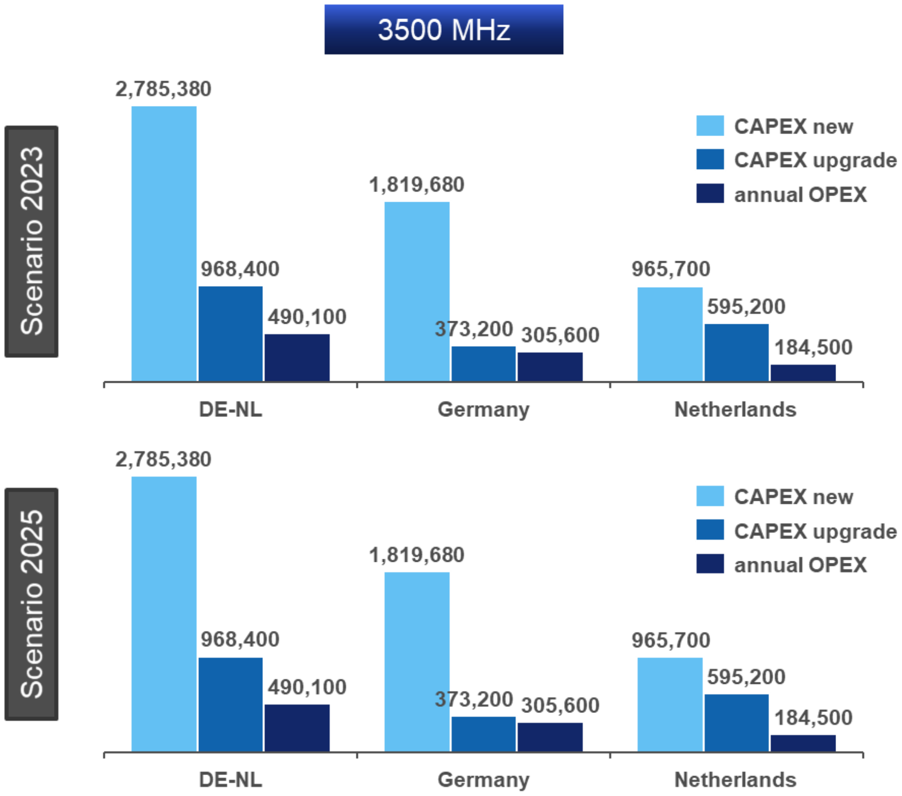

Figure 65: 3500 MHz cost delta for DE-NL

4.7.4 CBC FI-NO

700 MHz:

Due to topographical challenges, the deployment costs along the FI-NO CBC are the highest. The steep mountainside on the Norwegian side of the CBC has a severe impact on the signal strength and thereby causes the need for a denser site deployment.

Furthermore, the Finnish-Norwegian CBC has by far the lowest population and traffic density and therefore also the least developed RAN infrastructure.

The topography and the low number of existing sites create the need for a lot of new base stations in order to provide uninterrupted cellular coverage. Along with relatively high price levels, this turns the investment delta of the FI-NO CBC to the largest one within this study.

The estimated costs to deploy full 5G low-band coverage along the corridor amount to about 2.3 mEUR plus about 408 kEUR in additional annual OPEX. The investment deltas for 2023 and 2025 are visualized in Figure 66.

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.

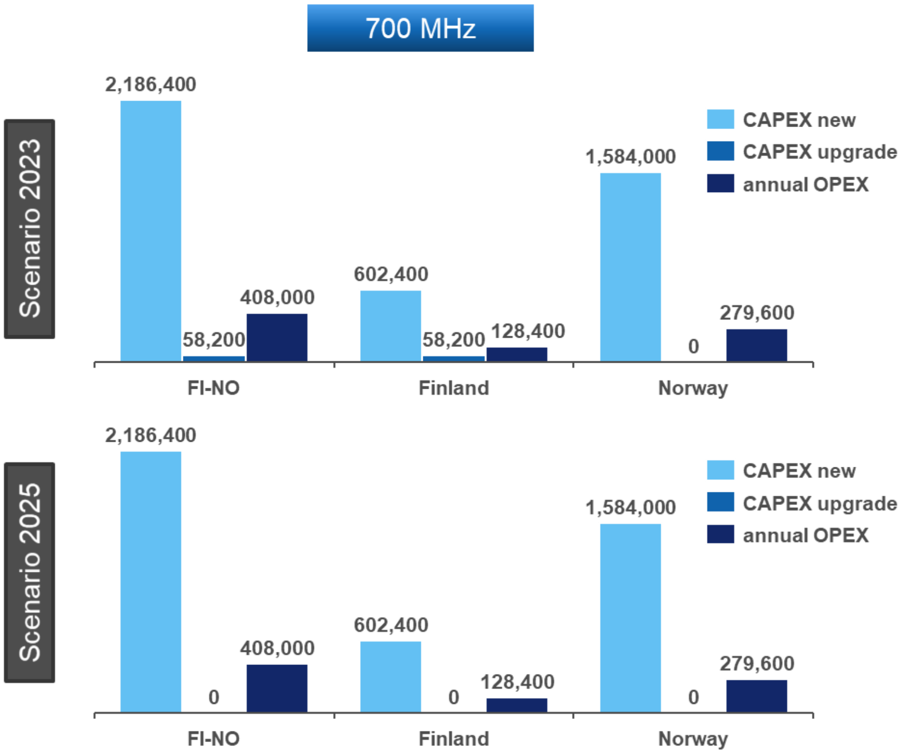

Figure 66: 700 MHz cost delta for FI-NO

3500 MHz:

Mid-band 5G deployment along the Finnish-Norwegian CBC does not appear necessary within the foreseeable future. Due to the low population and traffic density, as well as the topographical challenges along the FI-NO CBC, none of the operators intend to deploy mid-band 5G along the corridor within the foreseeable future.

Further, even within the highest forecast scenarios of CAM connectivity demands, mid-band deployment in the FI-NO CBC would create an economically unviable overabundance of cellular capacity. The differences in the cost delta for the scenarios 2023 and 2025 are visualized in Figure 67 (3500 MHz).

The estimated costs to deploy full 5G mid-band coverage along the corridor amount to about 5.5 mEUR plus about 900 kEUR in additional annual OPEX.

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.

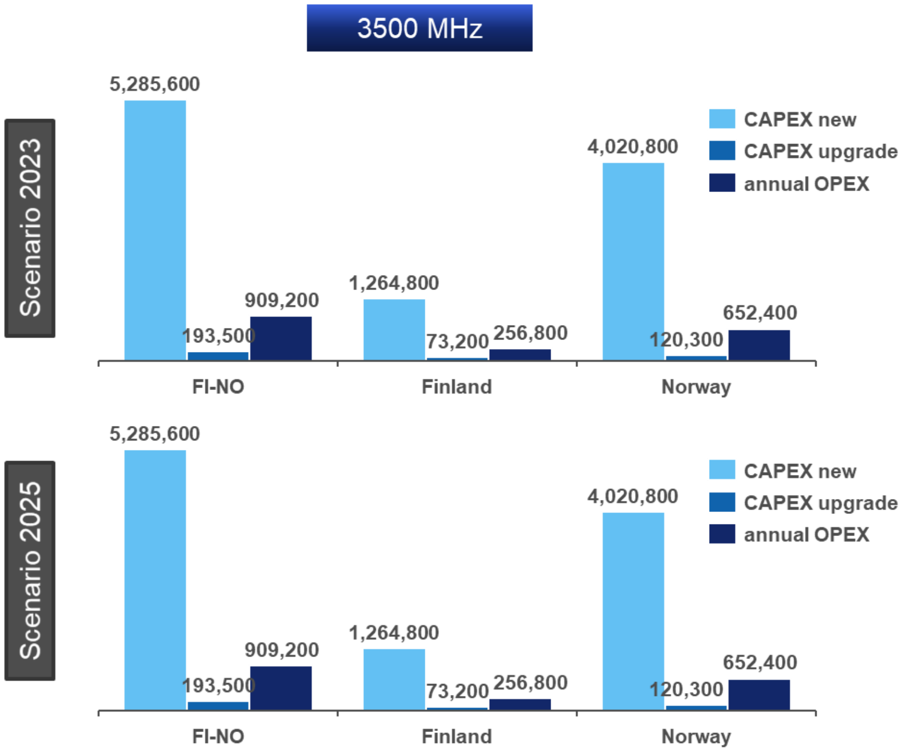

Figure 67: 3500 MHz cost delta for FI-NO

4.7.5 CBC ES-FR

700 MHz:

Low-band coverage alone may not create a CAM future-proof RAN infrastructure along the Spanish-French CBC. In the Spanish-French CBC we observe relatively high data traffic demands due to high road traffic as well as a densely populated area.

At the same time, the existing RAN infrastructure along this corridor is also comparatively well developed. Along with relatively strict regulatory obligations to provide 5G connectivity along motorways (by 2025), this creates the lowest observed investment delta.

Yet, due to high expected capacity demands, it may be advisable to roll out 5G mid-band (3500 MHz) within the next years in order to enable CAM.

The overall costs to deploy 700 MHz along the CBC would amount to about 600 kEUR with additional annual OPEX of about 62 kEUR. The cost deltas for 2023 and 2025 are visualized in Figure 68.

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.

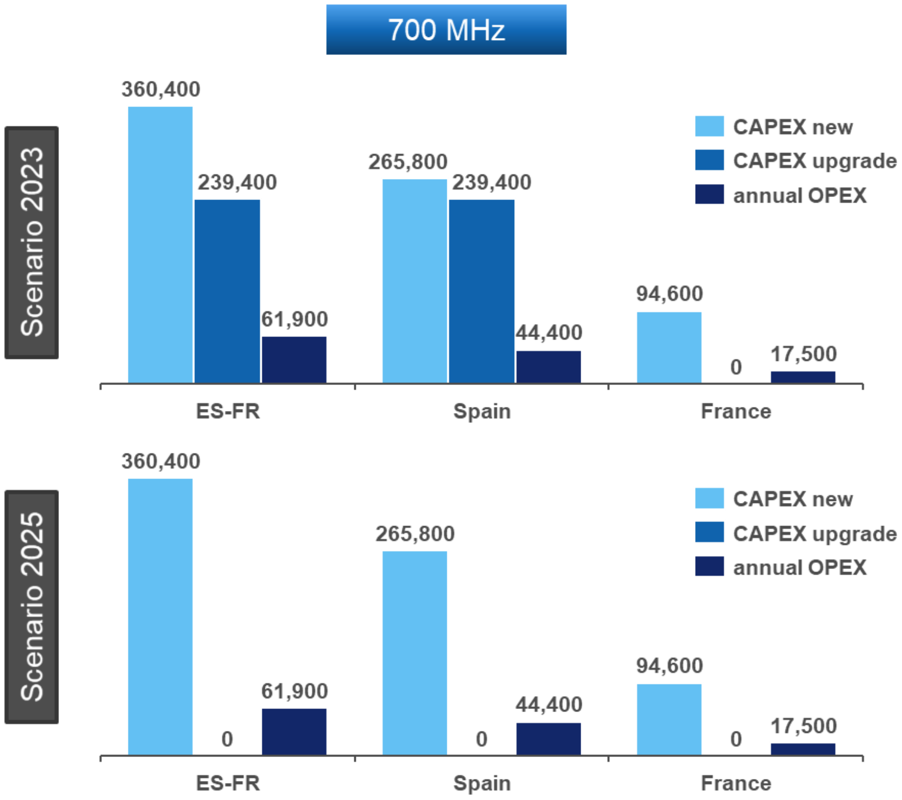

Figure 68: 700 MHz cost delta for ES-FR

3500 MHz:

In order to provide sufficient capacity for CAM demands according to the forecasted scenarios, mid-band coverage would be advisable in this CBC. High expected traffic demands may make it economically viable in the future to deploy 3500 MHz coverage along the Spanish-French corridor.

Due to higher available bandwidths in the mid-band, this would create a future-proof infrastructural environment for CAM.

The estimated costs to deploy full 5G mid-band coverage along the corridor amount to about 2.8 mEUR with 350 kEUR in additional annual OPEX. The cost deltas for 2023 and 2025 are visualized in Figure 69.

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.

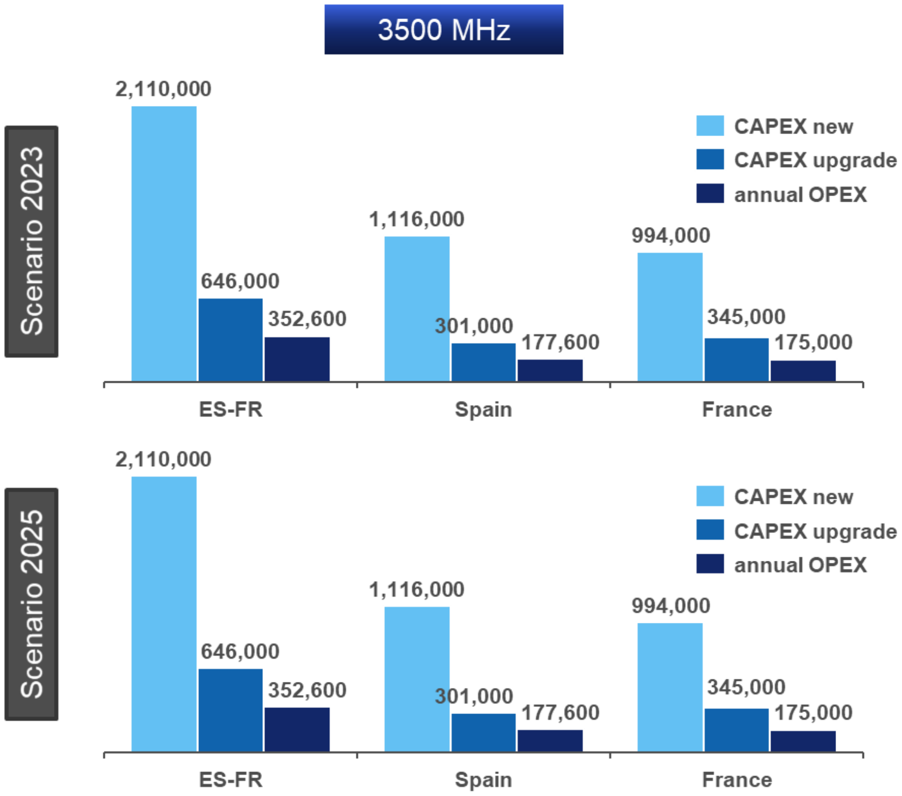

Figure 69: 3500 MHz cost delta for ES-FR

4.7.6 Multi-access Edge Computing (MEC)

As described in the assumptions listed in section 3.5.3, we excluded the costs for MEC data centres from the investment gaps shown in the previous sub-chapters.

In contrast to cloud computing, (multi-access) edge computing refers to decentralized data processing at the edge of the network or network periphery (in our case the access network or RAN). With edge computing, applications, data and services are relocated away from central nodes (i.e., core data centres). The calculations are carried out close to the location where the data is actually generated or collected, referring to the highways in our case.

By physically moving the location of the calculation closer to the origin of the data, response times (or latency) can be significantly reduced.[32] At the same time, data that is relevant for higher-level, global information can be pre-filtered and only transmitted to the data centre in the form actually required, whereby the available bandwidth is used more efficiently.[33]

[32] Gartner, What Edge Computing Means for Infrastructure and Operations Leaders, 2018, https://www.gartner.com/smarterwithgartner/what-edge-computing-means-for-infrastructure-and-operations-leaders

[33] Industry of things, Edge Computing macht IIoT-Datenberge beherrschbar, 2020, https://www.industry-of-things.de/edge-computing-macht-iiotdatenberge-beherrschbar-a-921660/

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.

There are many different deployment scenarios for MEC in 5G networks (theoretically ranging from MEC at the base station to collocation with the core data centre) and all these scenarios come with a very different structure.[34] As this is a new element in cellular networks, there is a high uncertainty associated with the optimal deployment scenario, particularly for uRLLC applications. Further information on the role of MEC DCs in a CAM environment can be found within the 5G-MOBIX deliverables, such as D2.2.[35]

With respect to this study, the minimization of latencies would be the most crucial advantage of deploying MEC data centres along the examined CBCs. However, the majority of the interviewed MNOs indicated that there are no plans to deploy local MEC DCs along the CBCs or rural highways in general. The trade-off between minimizing latency by having numerous local DCs and reducing costs by having few centralized DCs is currently addressed by optimizing the transport network towards dedicated regional data centre locations.

In case lower E2E latencies (possibly down to single-digit ms) and a local MEC DC serving a CBC/highway stretch similar to the ones examined within this study (within an existing DC, containing a local 4G/5G Evolved Packet Core (EPC), 1xAP Server, 1x10G Switch, assuming no redundancy) would be required along the CBC, the following cost ranges could be expected:

- CAPEX: 75 – 115 kEUR
- OPEX:
    - HW/SW support: 7.5 – 15 kEUR
    - 10G internet connectivity: 25 – 50 kEUR

These costs can be considered as a premium in addition to the investment deltas calculated in the previous sub-chapters (4.7) in order to minimize experienced E2E latencies for CAM applications.

4.7.7 Roadside Infrastructure Deployment Delta

As none of the interviewed road operators had deployed or planned to deploy any C-V2X roadside units (RSUs) along the corridors within the scope of this study, an insightful cost estimation for the corridors was not possible.

The road operators responsible for the corridors were all deploying ITS-G5 RSUs, however, not along the corridors examined.

Based on cost estimations from industry research, we can derive a very high-level indication of the costs for a 40 km stretch of a highway, which represents the base length applied in this study.

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[34] ETSI, MEC in 5G networks (ETSI White Paper No. 28), 2018, https://www.etsi.org/images/files/ETSIWhitePapers/etsi_wp28_mec_in_5G_FINAL.pdf)

[35] 5G-MOBIX, D2.2. 5G architecture and technologies for CCAM specifications, 2019, https://www.5g-mobix.com/assets/files/5G-MOBIX-D2.2-5G-architecture-and-technologies-for-CCAM-specifications-V1.0.pdf

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.

At a 300m average inter-RSU distance and a price of 4500€ per RSU[36], the costs to cover a corridor of 40 km length would amount to roughly 600,000 EUR. This includes installation services and the connection to the network. However, many road operators maintain optical fibre along the corridors.

4.8 Steps and timelines for 5G RAN deployment

The high-level deployment timeline (shown in Figure 70, time unit is weeks; abbreviations are explained in Table 7) is developed based on the best-practice hands-on international experience of Detecon experts and verified by the additional consultations / interviews with the key project stakeholders.

In general, the deployment timeline describes all the key steps required to deploy a cellular base station from day zero to launch, although the exact time frame may vary depending on the particularities of local telecommunication / construction regulations in each country, as well as the current ownership of the targeted site.

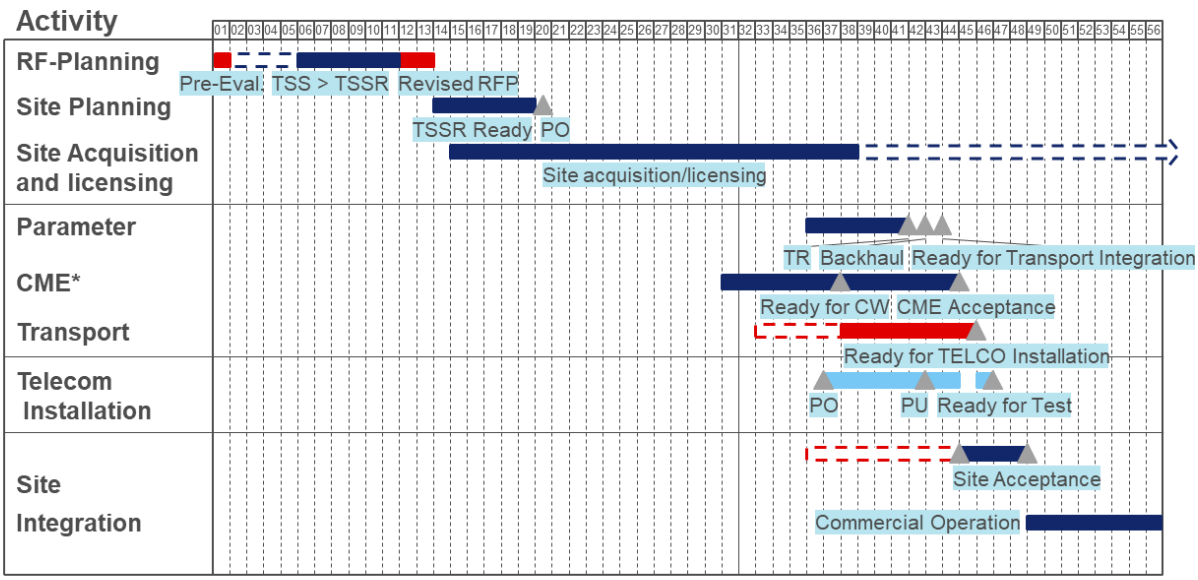

Figure 70: 5G node deployment plan (time in weeks)

Abbreviation	Explanation
RF-Planning	Radio Frequency Planning
Pre-Eval.	Pre-Evaluation
TSS	Technical Site Survey
TSSR	Technical Site Survey Report
RFP	Radio Frequency Planning
TSSR Re	Revised TSSR
TR	Transmission/Transport
CW	Civil Works
CME	Civil, Mechanical, Electrical Works

[36]Analysys Mason, "Socio-Economic Benefits of Cellular V2X", 2017: https://5gaa.org/wp-content/uploads/2017/12/Final-report-for-5GAA-on-cellular-V2X-socio-economic-benefits-051217_FINAL.pdf

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SACME	Site acquisition and civil, mechanical, electrical works
PO	Purchase Order

Table 7: 5G deployment plan abbreviations

The radio frequency planning process starts with a pre-evaluation and the decision of whether deployment is commercially viable. The next step is a technical site survey that analyses topographical and technical characteristics of the site. The results of this survey are then consolidated in the technical site survey report (TSSR).

After about 2-3 months and the decision to further pursue the deployment plan, the site acquisition and building permit application process is initiated. This represents one of the most critical stages, as the duration of this process varies strongly depending on site-specific characteristics (see below).

After the site and building permit have been acquired, the civil, mechanical, and engineering works begin in parallel to the transport and transmission installation. Shortly after the CME acceptance, the installation of the active radio equipment, i.e., antenna etc., begins. After a short testing phase and site acceptance, commercial operations are initiated which completes to deployment phase.

The overall duration of the deployment of a new 5G base station may vary and depends strongly on the site acquisition process. The minimum duration (assuming the site belongs to the deploying party and the building permit is available) would be around nine months. However, site acquisition processes may delay the overall deployment by up to a year according to MNOs and industry experts.

4.9 Qualitative Insights from Interviews

This section presents some of the key insights that were not directly related to the research questions yet represent highly interesting findings. The figure below (Figure 71) summarizes some key insights by four categories, general observations, the MNO perspective, the automotive perspective, and the road operator perspective.

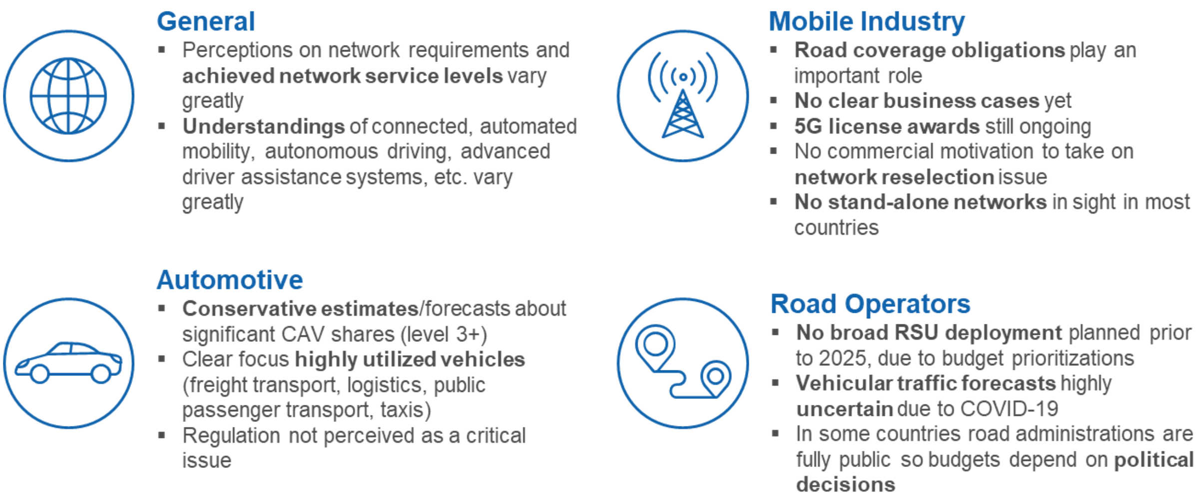

Figure 71: Key qualitative findings from interviews

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4.9.1 Regulatory Issues

With the awards of the 5G licenses many regulatory telecommunications authorities across Europe impose obligation catalogues including the coverage requirements, for example highways or municipalities. Currently, there is no harmonized approach to these coverage obligations leading to a pan-European regulatory patchwork. Therefore, every country imposes heterogenous network service qualities along roads, especially with regard to CAM. To solve this problem a European body would need to assign binding guidelines which each European country would need to retain for a harmonization of 5G connectivity provision along the EU's transport corridors.

Another issue which needs to be solved is about roadside Units. Currently, there is no determination which kind of RSU should be used (ITS-G5 or C-V2X). The absence thereof leads to uncertainty for different industries, from automotive & OEMs to telecommunications equipment vendors to road infrastructure operators. Therefore, an EU-Body should take a moderating role in this technological dispute. Other countries, such as China and the USA have already clarified the technological standards and thereby created investment safety for the involved industries.[37][38][39]

4.9.2 Automotive Industry and Suppliers

From the discussions with representatives from large car manufacturers and suppliers, we understood that there is currently a clear focus on vehicles with high utilization, i.e., commercially used vehicles, such as transport vans, trucks and public passenger transport and taxis. This is largely due to high costs of CAV on-board equipment. This leads to the fact, that expectations for large scale CAV (level 3+) fleet penetration are rather low.

Automotive, OEM, network equipment vendors point of view

According to **a large German car manufacturer,** it is Important to stress the differentiation into the 4 segments/domains of use cases:

- Highway (Corridors),
- Confined Areas,
- Urban Mobility,
- Rural road network

Big logistics companies will mostly focus hub-to-hub operations which leads to a lot of traffic on one specific route, which will create a high demand for connectivity on this specific route.

[37]Connected-automated-driving.eu," Regulations and Policies China",2014:

https://www.connectedautomateddriving.eu/regulation-and-policies/national-level/non-eu/china/

[38]U.S. Department of Transportation, "Automated Vehicles - Comprehensive Plan", 2020:

https://www.transportation.gov/sites/dot.gov/files/2021-01/USDOT_AVCP.pdf

[39]Connected-automated-driving.eu, "Regulations and Policies USA, 2028 – 2020:

https://www.connectedautomateddriving.eu/regulation-and-policies/national-level/non-eu/us/

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In confined areas one of the most important use cases are urban shuttles running on specific routes in cities where traffic lights are connected, these confined areas will represent the first step to jump into level 4 of automation. Besides that, complex mixed traffic (CAM/Non-CAM) is not expected to materialize any time soon in large volume.

To achieve even level 3 traffic a way more advanced Infrastructure is needed. Before that it's not realistic to speak of level 4/level 5.

One of the biggest problems is the cost of the technology for CAM. At the moment especially high-tech equipment (e.g., LIDARs) is way too expensive to be used widely. Today's prototypes for shuttle buses cost 100-200k€ on top of the actual vehicle cost.

Regulation of CAM also looks not mature enough yet. Thus, there are two main concepts for approval across the globe, the UN-principle and the US-American principle of regulations.

UN principle:

- Tests have to be done prior to go-to-market. Applies all over Europe, Russia, Australia, Korea, Japan has now regulated level 3; level 4 is now under "construction".
- Regulations are not an easy part but it's also helpful in preventing small start-ups from market entry who may start cheap unripe quality and thereby endanger the whole industry.

Second concept is from USA: self-certification

- Needs to ensure that every car in your fleet will fulfil requirements even when its old
- China in between the two; leaning more towards the UN concept.
- Regulation overall is not the issue; won't be the biggest burden

There is no common and unified approach at the moment.

According to a large truck manufacturer, it can be expected, that after 2024 all newly produced cars will be connected, connectivity and will provide additional information, e.g., regarding local position. Vehicles mainly work with their own sensors. OBUs are very expensive at this stage and it's not easy to find OBU-to-OBU (V2V) equipment for a reasonable price. 300 USD per unit per R&D for OEM. For the customer it will be 1000 – including OBU, R&D, services etc.

Connectivity / 5G infrastructure requirements along the road are particularly relevant for use cases such as platooning, sensor information sharing and remote driving. A common CAM service cloud provider together with all OEMs would be advisable to let all vehicles communicate through one common platform. Otherwise, end users that have one brand cannot communicate with other end users that have different brands and this cause lack of usage of CAM services by customers.

According to a French automotive supplier, the overall role of MNOs is perceived as significant in the future, but not currently in the development phase.

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Currently, the supplier is setting up use cases to be tested in cross-border corridors, but at the moment the biggest issue is the hand-over time in which use case requirements fail.

That is a big problem because trucks are the most realistic use cases because they have the strongest business case and trucks cross borders very often. Besides that, Logistics companies lack the expertise but see the potential.

A large German manufacturer of semiconductors stated that one of the key problems of connected driving could be that the stability of the connection could decrease corresponding to the velocity of the vehicle.

Also, the amount of data traffic will increase when higher CAM levels are reached. It's hard to set exact values due to the fact that many factors play a role in calculating the data traffic. One approach to deal with this could be to use "Edge Computing", this means that the sensors process some of the data by them self and the computer / control unit don't need to work with raw data.

Traditional network equipment vendors see their role within CAM in promotion of the 3GPP C-V2X for transport and automotive sector. Therefore, the first step to establish 5G in the automotive industry is to enable C-V2X.

At the same time one of the critical issues is the question how vehicles should connect with each other and to MECs. For example, when the vehicles use classical peering point you lose all the latency benefits of 5G.

Another important thing is that the licenses come together with obligations, e.g., Germany is forcing MNOs to provide coverage with very tough criteria which will lead to the fact that some of the road section in non-attractive areas will struggle to get 5G. Besides that, it's very hard to get rid of "white spots", i.e., cellular coverage gaps.

Safety standards are also reported as an issue, as nobody is ready to pay a lot for safety.

Other large equipment vendors rely on the ITS-G5 standard due to its maturity and recognition among the roadside players. From the **supplier's** perspective the digitalization of roads is an essential component of future mobility. According to the supplier, there are two main issues which need to be solved. The first one is the network service continuity. Roaming, Handover and imperfect coverage, lead to network delays which are critical for CAM traffic. The second issue is the standardization. In order to ensure interoperability between different infrastructure equipment's and applications a guideline for the systems, but who should set up these guidelines isn't clear.

4.9.3 Mobile Network Operators

The interviews with MNOs have provided some important insights. One of the key insights, is that regulatory road coverage obligations are one of the key drivers for (5G) network deployment in rural areas with low population densities. Further, the MNOs that were interviewed only perceive a very limited business value in CAM at the moment and still focus on traditional demand drivers, such as end-user subscribers, i.e., humans. Further, in many countries 5G license awards are still ongoing. The outcome of these awards (i.e., the spectrum license fee to be paid by the MNO) has important implications for the MNOs' ability to make large scale investments in 5G infrastructure. Further, we have gathered from the interviews, that there are currently no commercial incentives for MNOs to tackle

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network handover process improvements across borders. However, they acknowledge that there are already ongoing plans for public funding (by the EU) for this particular issue. With respect to the network architecture, all MNOs stated that, as of now, their plans are limited to non-standalone 5G architectures and a few more years will pass until standalone architecture gain ground.

4.9.4 Road Operators

From the road operators we gathered that none of them have plans to deploy C-V2X RSUs along the highways under their responsibility. Most of the road operators only have ITS-G5 RSUs in their trials. Further, due to the impact of COVID-19, traffic forecasts are highly inaccurate and there is a high uncertainty regarding future passenger travels along motorways. Furthermore, road operators in many of the examined countries are under full public control and thereby depend on political decision-making processes rather than commercial motivations.

4.9.5 Other

Big logistics companies stated they would mostly focus hub-to-hub operations leading to a lot of traffic on one specific route, which will create a high demand for connectivity limited to specific routes.

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5 Key Findings

This study set out to provide estimates of the expected connectivity requirements of CAM along five European CBCs and the corresponding 5G access infrastructure investment deltas to existing or planned infrastructure. Within the study, we conducted a survey with more than 36 organisations across nine European countries about their views on CAM while collecting important data to our study. These survey results were complemented with extensive industry research and thorough knowledge from numerous subject matter experts. These valuable inputs were then processed in order to derive estimations about the expected connectivity demands from CAM, the technological capabilities of different 5G configurations, as well as the associated costs.

Based on these estimations, the study provides insights as to the additional 5G RAN investments required for 9 different traffic scenarios.

The study's goal was to provide answers to the following research questions (RQs):

- **RQ1:** What are the **traffic characteristics** that would be expected for 2023 and 2025?
- **RQ2:** What are the **exact needs of CAM services at border areas** and the CAM use-cases' detailed requirements?
- **RQ3:** What are the **already planned investments in physical & digital infrastructure** to be deployed in the Cross Border areas?
- **RQ4:** What is the **deployment "delta" between currently planned investments** and the necessary investments to deliver full coverage for the CAM use-cases?
- **RQ5:** What is necessary with regards to networking, preparation for market and business risks, enablers, market analysis, and **competitive intelligence**?
- **RQ6:** What are any **assumptions and projections** that can be made **towards 2030**?

This rest of this section is structured in line with the research questions, section 5.1 corresponds to RQ1, section 5.2 to RQ2 and so forth until section 5.6 which concludes covering RQ6.

5.1 Traffic Characteristics (RQ1)

Based on the study's results, we expect rather low overall CAM fleet shares (shares of vehicles with SAE level 3+ automation of the overall vehicular fleet) along the corridors, roughly 1-2% by 2023 and up to a maximum of 4,5% by 2025 in Germany.

In terms of market shares (share of vehicle sales by number), our analysis suggests that we may see up to 14% of newly sold cars with automation levels of SAE level 3 and up by 2025 in countries with higher GDP per capita. This could translate into up to 400k new level 3+ vehicles being sold in Germany in 2025.

Generally speaking, in the CBCs that were examined the 5G background traffic is expected to be insignificantly low compared to CAM demands <5%. The high CAV bit rates as derived from the 5G-MOBIX use cases outshine traditional end-user smartphone applications in terms of cellular capacity demand.

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5.2 CAM Requirements (RQ2)

For mobile network providers average connectivity requirements per vehicle are still highly unclear due to very different technologies (e.g., cameras vs. LIDAR & radar) applied by car manufacturers. This means that the expected average continuous bit rate per CAV may vary significantly. Based on the 5G-MOBIX use cases and extensive discussions with numerous experts we derived CAV bit rate (DL) scenarios ranging from 7.5 Mbps to a remarkable 51 Mbps per vehicle.

Yet, in 3 out 5 corridors and most scenarios, 700 MHz coverage is expected to be sufficient until 2025 due to low expected CAM traffic along the CBCs. Further, we see that 3500 MHz 5G deployment provides sufficient capacity in all CBCs until at least 2025 and most likely further.

Still, a continuing lack (of insufficiency) of 5G infrastructure may create incentives for automotive technologies to be designed less reliant on connectivity. In the discussions, car manufacturers and suppliers appeared sceptical towards the idea of sufficient wide-spread 5G road coverage along motorways in the near future. This scepticism could pave the way for more investments into autonomous driving technologies, rather than connected self-driving, unless proven wrong.

5.3 Investment Plans (RQ3)

Mobile Networks:

Most MNOs do not plan to invest significantly along the examined corridors unless they are obliged to by spectrum license obligations.

Regulatory road coverage obligations are a major driver of the deployment in rural areas, yet very different from country to country and not always suitable for CAM. Road coverage obligations focus on coverage and lead to initial deployment of low-band coverage (700 MHz) along highway networks. Yet oftentimes the minimum signal strengths proposed by regulators (if any) are too low for the expected CAM requirements, which effectively leads to coverage gaps from the CAV's point of view.

Further, the MNO's 5G deployment priority is upgrading of the existing sites as opposed to deploying new sites. This approach may fall short of eliminating white spots along rural motorways based on our analysis.

Roadside Infrastructure

Most road operators are only starting to deploy first RSUs (ITS-G5) and none of them are planning static RSUs along the examined highways with the exception of a trial site in Norway. Other road operators do not even participate in any trials involving RSUs and funnel budgets towards more basic aspects of road management, such

Road operators currently focus on the ITS-G5 standard for CAM because the standard is considered mature and well developed, a lot of equipment is available on the market (in comparison with NR-V2X). Road operators are not planning to become infrastructure companies to enable seamless CAM services, but rather deploy ITS infrastructure to increase overall road safety.

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5.4 5G Infrastructure Deployment Delta (RQ4)

With respect to the costs or the investment delta, our results indicate that required 5G RAN investments for CAM (i.e., CAPEX) range from around 700k EUR in well-developed CBCs or those with low expected CAM traffic up to 3.7 mEUR for those CBCs that are expected to require dense mid-band (3500 MHz) deployment due to high expected capacity demand from connected, automated cars (CAVs). In terms of OPEX, additional expected annual costs range from 62 kEUR in the Spanish-French CBC up to 909 kEUR in the Finnish-Norwegian CBC. As of the time of the study, none of the CBCs was sufficiently covered by 5G networks to support seamless CAM services even when neglecting the country border interruption.

The key drivers for the differences in investment deltas appear to be the following:

- Development level of existing RAN infrastructure
- Overall vehicular road traffic
- Expected CAV fleet shares or adoption rates
- Population density, which correlates with overall vehicular road traffic and well-developed existing cellular infrastructure
- Topography

Further, we see that regulatory road coverage obligations tied to 5G spectrum licenses appear to be a leading driver in 5G deployment along rural motorways in Europe. Moreover, topographical characteristics have a tremendous impact on the costs as the example of the Norwegian side of the FI-NO CBC demonstrates.

Based on our estimations, in most corridors and scenarios 700 MHz deployment should be sufficient until 2025 due to low expected CAM traffic. Beyond 2025 CAM connectivity demand may exceed low-band capacities and may need to be expanded with additional infrastructure or frequency layers.

3500 MHz coverage represents a future-proof scenario for cross-border highways as the ones that were examined within this study. However, none of the operators shared plans to deploy 3500 MHz along the examined motorways.

The key findings indicate that the density of sites needs to be increased along all corridors due to high reliability requirements of 5G connectivity-based CAM applications. Only in very rural cross-border corridors, such as the Finnish-Norwegian motorway, 5G coverage in the low-band at 700 MHz will be sufficient for all connectivity demand scenarios. Corridors with higher traffic density, such as the highway between Perpignan (FR) and Figueres (ES) and the highway between Emmerich (DE) and Arnhem (NL), will need additional capacity from 2025 the mid-band (~3500 MHz).

5.5 Market Implications (RQ5)

None of the MNOs interviewed within this study indicated that they're considering CAM traffic for RAN deployment plans and do not yet see a clear business value from CAM.

Further, MNOs stated that interference from sites on the different parts of the border resulted in requirements to reduce coverage, hence now seamless connectivity during the border crossing is challenging. Also, the issue of network reselection improvement is key with respect to uninterrupted connectivity.

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According to Automotive industry experts, connectivity is not the main issue. Critical issues are the lack of unified technological standards for CAM, expensive on-board equipment, lack of clear business models and lack of regulation.

Furthermore, semiconductor shortages could have a significant effect on the expected CAV fleet penetration rates, as some car manufacturers have already begun to close down factories[40].

Besides that, interview partners from various industries have underlined that uncertainty with respect to technological standards, infrastructure deployment, cellular requirements of CAVs and business models are hindering investments. A unified pan-European approach to covering key transport corridors with clear specifications of capacity, latency, reliability and signal strength as well as cross-industry agreement on technological standardization could solve these issues and thus lead to market growth in the CAM sector and eliminate inefficient investments.

5.6 Long-term Implications towards 2030 (RQ6)

By 2030 we may see up to 20% fleet shares that can be defined as SAE level 3+. This would naturally translate into higher connectivity demands which cannot be stemmed by low-band 5G coverage. To support the expected connectivity demand from CAM, wide-spread coverage of highways in the mid-band (3500 MHz) would be necessary. With the current expected bit rates, mid-band coverage could still be sufficient by 2030, although, by then, we would expect new technologies, such as 6G, to create even higher network performances and more spectral efficiency with more capacity, better latency and higher reliability.

In order to develop a global, long-term competitive edge, promote innovation in the CAM sector and drive economic growth, the European market needs clear guidance in terms of the technological standards to enable CAM as well as well-harmonized road coverage obligations that create a reliable investment environment for all involved stakeholder groups.

[40] DW, „Germany: Opel plant to shut over global chip shortage", 2021, https://www.dw.com/en/germany-opel-plant-to-shut-over-global-chip-shortage/a-59362189

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https://ec.europa.eu/programmes/horizon2020/en/home.

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List of Figures

Figure 1: Geographical scope overview 7

Figure 2: Overall approach 9

Figure 3: Key assumptions........ 10

Figure 4: Investment delta 10

Figure 5: Target radio network structure 20

Figure 6: Shannon-Hartley Capacity Theorem 23

Figure 7: Throughput calculation........ 24

Figure 8: Costing methodology flowchart 28

Figure 9: Traffic forecast and vehicle type shares by CBC........ 37

Figure 10: Fleet share forecasts of level 3+ by country 38

Figure 11: Overview of capacity sufficiency in both scenarios (MVMB scenario)........ 39

Figure 12: CBC PT-ES capacity-fit........ 39

Figure 13: CBC PT-ES capacity-fit........ 40

Figure 14: CBC DE-NL capacity fit........ 41

Figure 15: CBC FI-NO capacity fit........ 42

Figure 16: CBC ES-FR capacity fit........ 42

Figure 17: Key steps of the nominal radio planning........ 51

Figure 18: Cross-border corridor ES-PT Minho/Mino 54

Figure 19: Existing sites in the area of ES-PT Minho/Mino CBC 55

Figure 20: Existing sites in the area of ES-PT Minho/Mino CBC, 5G NR 700 MHz FDD radio coverage simulation 56

Figure 21: Existing sites in the area of ES-PT Minho/Mino CBC, 5G NR 3500 MHz TDD radio coverage simulation 57

Figure 22: Existing and new sites in the area of ES-PT Minho/Mino CBC, 5G NR 700 MHz FDD 59

Figure 23: Existing and new sites in the area of ES-PT Minho/Mino CBC, 5G NR 700 MHz FDD radio coverage simulation........ 60

Figure 24: Existing and new sites in the area of ES-PT Minho/Mino CBC, 5G NR 3500 MHz TDD........ 62

Figure 25: Existing and new sites in the area of ES-PT Minho/Mino CBC, 5G NR 3500 MHz TDD radio coverage simulation........ 63

Figure 26: Cross-border corridor GR-TR Kipoi/İpsala........ 64

Figure 27: Existing sites in the area of GR-TR Kipoi/İpsala CBC........ 65

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.

Figure 28: Existing sites in the area of GR-TR Kipoi/İpsala CBC, 5G NR 700 MHz TDD radio coverage simulation 66

Figure 29: Existing sites in the area of GR-TR Kipoi/İpsala CBC, 5G NR 3500 MHz TDD radio coverage simulation 67

Figure 30: Existing and new sites in the area of GR-TR Kipoi/İpsala CBC, 5G NR 700 MHz FDD 68

Figure 31: Existing and new sites in the area of GR-TR Kipoi/İpsala CBC, 5G NR 700 MHz FDD radio coverage simulation 69

Figure 32: Existing and new sites in the area of GR-TR Kipoi/İpsala CBC, 5G NR 3500 MHz TDD 70

Figure 33: Existing and new sites in the area of GR-TR Kipoi/İpsala CBC, 5G NR 3500 MHz TDD radio coverage simulation 71

Figure 34: Cross-border corridor NL-DE Veldhuizen 72

Figure 35: Existing sites in the area of NL-DE Veldhuizen CBC 73

Figure 36: Existing sites in the area of NL-DE Veldhuizen CBC, 5G NR 700 MHz FDD radio coverage simulation 74

Figure 37: Existing sites in the area of NL-DE Veldhuizen CBC, 5G NR 3500 MHz TDD radio coverage simulation 75

Figure 38: Existing (green) and new (dark blue) sites in the area of NL-DE Veldhuizen CBC, 5G NR 700 MHz FDD 76

Figure 39: Existing and new sites in the area of NL-DE Veldhuizen CBC, 5G NR 700 MHz FDD radio coverage simulation 77

Figure 40: Existing and new sites in the area of NL-DE Veldhuizen CBC, 5G NR 3500 MHz TDD 78

Figure 41: Existing and new sites in the area of NL-DE Veldhuizen CBC, 5G NR 3500 MHz TDD radio coverage simulation 79

Figure 42: Cross-border corridor NO-FI Kilpisjärvi 80

Figure 43: Existing sites in the area of NO-FI Kilpisjärvi CBC 81

Figure 44: Existing sites in the area of NO-FI Kilpisjärvi CBC, 5G NR 700 MHz FDD radio coverage simulation 82

Figure 45: Existing sites in the area of NO-FI Kilpisjärvi CBC, 5G NR 3500 MHz TDD radio coverage simulation 84

Figure 46: Existing (green) and new (dark blue) sites in the area of NO-FI Kilpisjärvi CBC, 5G NR 700 MHz FDD 85

Figure 47: Existing and new sites in the area of NO-FI Kilpisjärvi CBC, 5G NR 700 MHz FDD radio coverage simulation 86

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.

Figure 48: Existing (green) and new (dark blue) sites in the area of NO-FI Kilpisjärvi CBC, 5G NR 3500 MHz TDD 88

Figure 49: Existing and new sites in the area of NO-FI Kilpisjärvi CBC, 5G NR 3500 MHz TDD radio coverage simulation 90

Figure50: Cross-border corridor ES-FR Le Perthus 90

Figure 51: Existing sites in the area of ES-FR Le Perthus CBC 91

Figure 52: Existing sites in the area of ES-FR Le Perthus, 5G NR 700 MHz FDD radio coverage simulation 93

Figure 53: Existing sites in the area of ES-FR Le Perthus, 5G NR 3500 MHz TDD radio coverage simulation 94

Figure 54: Existing and new sites in the area of ES-FR Le Perthus CBC, 5G NR 700 MHz FDD 96

Figure 55: Existing and new sites in the area of ES-FR Le Perthus CBC, 5G NR 700 MHz FDD radio coverage simulation 97

Figure 56: Existing and new sites in the area of ES-FR Le Perthus CBC, 5G NR 3500 MHz TDD 99

Figure 57: Existing and new sites in the area of ES-FR Le Perthus CBC, 5G NR 3500 MHz TDD radio coverage simulation 100

Figure 58: CAPEX per base station 102

Figure 59: 5G RAN Deployment Delta (HVHB) 104

Figure 60: 700 MHz cost delta for PT-ES 105

Figure 61: 3500 MHz cost delta for PT-ES 106

Figure 62: 700 MHz cost delta for GR-TR 107

Figure 63: 3500 MHz cost delta for GR-TR 108

Figure 64: 700 MHz cost delta for DE-NL 109

Figure 65: 3500 MHz cost delta for DE-NL 110

Figure 66: 700 MHz cost delta for FI-NO 111

Figure 67: 3500 MHz cost delta for FI-NO 112

Figure 68: 700 MHz cost delta for ES-FR 113

Figure 69: 3500 MHz cost delta for ES-FR 114

Figure 70: 5G node deployment plan (time in weeks) 116

Figure 71: Key qualitative findings from interviews 117

Lists of Tables

Table 1: 5G-MOBIX Key Use Case Requirements 14

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.

Table 2: Spectrum scenarios 21
Table 3: Vehicular bit rate assumptions 36
Table 4: Key parameters for radio coverage simulation 52
Table 5: RSRP values and its interpretation... 53
Table 6: CAPEX and OPEX by country... 103
Table 7: 5G deployment plan abbreviations 117

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.

6 Appendices

This study has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 825496.

Appendix A

A.1 Cost Calculation Model

To be submitted separately.

A.2 Traffic Forecast Model

To be submitted separately.

A.3 Questionnaires

To be submitted separately.

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Appendix B

B.1 Company Profile

B.1.1 General Information

Management consulting with pronounced technology expertise

Detecon is the leading, globally operating technology management consulting company with headquarters in Germany, which has been combining classic management consulting with high technological competence for over 40 years. The focus of its activities is on digital transformation: Detecon supports companies from all areas of business to adapt their business models and operational processes to the competitive conditions and customer requirements of the digitalized, globalized economy with state-of-the-art communication and information technology. Detecon's expertise bundles the knowledge from the successful conclusion of management and ICT consulting projects in over 160 countries.

Detecon is a subsidiary of T-Systems International, one of the world's leading independent providers of digital services and subsidiary of Deutsche Telekom.

From concept to implementation

Detecon is driving forward its consulting approach Beyond Consulting, a significant evolutionary step forward in traditional consulting methods adapted to meet the demands of digitalization today and in the future. The concept features top consulting that covers the entire spectrum from innovation to implementation. Groundbreaking digital consulting demands ever greater technology expertise and a high degree of agility that incorporates flexible, but precisely fitting networking of experts for complex, digital ecosystems in particular. At the same time, it is more and more important in digital consulting to accompany clients from innovation to prototyping to implementation.

This factor prompted Detecon to found the Digital Engineering Centers for Cyber Security, Analytical Intelligence, Co-Innovation, and Industrial IoT in Berlin in 2017 as facilities that extend the added-value chain of consulting and accelerate the realization of digital strategies and solutions by means of prototypes and proofs of concept.

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B.1.2 Facts & Figures

Established:

1954 Diebold

1977 DETECON

Reorganization:

2002 Detecon International GmbH

Registered headquarters:

Cologne

Shareholder:

T-Systems International GmbH

Managing Board:

Ralf Pichler (Chairman)

Sven Erdmann

Simone Wamsteker

Consultants:

1.124 worldwide

Turnover 2020:

€ 193.5 million

Locations:

National locations:

Berlin, Cologne, Dresden, Frankfurt, Munich

International locations:

Abu Dhabi (United Arab Emirates), Bangkok (Thailand), Beijing (China), Budapest (Hungary), Dubai (UAE), Istanbul (Turkey), Johannesburg (South Africa), Moscow (Russia), San Francisco (USA), Vienna (Austria), Zurich (Switzerland)

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B.1.3 Registrations and Memberships

Detecon's services are acknowledged worldwide. Amongst others, this is the result of more than 3,000 successfully completed projects in the past three years, alone. Detecon has long-standing registrations with all key international financial and development aid institutions:

- World Bank
- Asian, African, Inter-American, Islamic and Caribbean Development Banks
- European Commission
- United Nations
- Arab Fund for Economic and Social Development
- World Health Organization
- Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ – the German government's development cooperation organization)

Timely knowledge concerning product and technological developments is indispensable and enables us to develop innovative and progressive solutions for our clients. Our membership in the following and other organizations helps us ensure that our expertise always reflects the most recent technological developments:

- Africa Association e.V.
- German Association for Information Technology, Telecommunications and New Media e.V. (BITKOM)
- Federal Association of German Management Consultants e.V. (BDU)
- German ORACLE Users Group e.V. (DOAG)
- German SAP Users Group e.V.
- IT Service Management Forum (itSMF)
- Munchner Kreis - Supranational Communications Research Association e.V.
- Multi Protocol Label Switching (MPLS) Forum
- Near and Middle East Association e.V.
- TETRA MoU Association
- The Asynchronous Transfer Mode (ATM) Forum
- Universal Mobile Telecommunications System (UMTS) Forum
- FttH Council Europe

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B.2 Indices / Glossary / Abbreviations

3GPP	Third Generation Partnership Project	**ETSI**	European Telecommunications Standards Institute
AD	Automated Driving	**GSM**	Global System for Mobile Communications
ADV	Automated Driving Vehicle	**HD**	High Definition
ADAS	Advanced Driving Assist System	**ID**	Identifier
ISD	Inter-site distance		
		IT	Information Technology
CBC	Cross-border corridor	**KPI**	Key Performance Indicator
CAM	Connected and Automated Mobility	**LDM**	Local Dynamic Map
CSMS	Cyber Security Management	**LTE**	Long Term Evolution
		MEC	Multi-access Edge Computing
		MIMO	Multiple Input Multiple Output
		MNO	Mobile Network Operator
		OBU	On-board unit
		RO	Road operator

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