5G for CAM: A Deployment Metastudy

A synthesis of three Pan-European studies on 5G deployment for connected, automated mobility in border regions

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List of Acronyms

5G	Fifth Generation of Cellular Communications
V2X	Vehicle-to-Everything
CEF2	Connecting Europe Facility 2
RAN	Radio Access Network
CAV	Connected and Autonomous Vehicle
CAM	Connected and Automated Mobility
MNO	Mobile Network Operators
CBC	Cross-Border Corridors
EU	European Union
ES-PT	Spain – Portugal
GR-TR	Greece – Turkey
DE-NL	Germany – Netherlands
FI-NO	Finland – Norway
ES-FR	Spain – France
CAPEX	Capital Expenditure
OPEX	Operational Expenditure
FDD	Frequency Division Duplex
BW	Bandwidth
MIMO	Multiple-Input and Multiple-Output
TDD	Time Division Duplex
V2N	Vehicle-to-Network
V2I	Vehicle-to-infrastructure
RSU	Roadside Units
IRU	Indefeasible rights of use (dark fiber)
IsD	Inter-site Distance

DL	Downlink
UL	Uplink
MEC	Multi-access Edge Computing
SAE	Society of Automotive Engineers
BoQ	Bill of Quantity
2G	Second Generation of Cellular Communications
3G	Third Generation of Cellular Communications
4G	Fourth Generation of Cellular Communications
BS	Base station
RF	Radio frequency
E2E	End-to-End
5GAA	5G Automotive Association
AASHTO	American Association of State Highway and Transportation Officials
5GPPP	5G Infrastructure Public Private Partnership
GSMA	Global System for Mobile Communications Association
EBU	European Broadcasting Union
IEEE	Institute of Electrical and Electronics Engineers
3GPP	3rd Generation Partnership Project
QoS	Quality of Service
NSA	Non-Standalone
SA	Standalone
HW	Hardware
SW	Software
RO	Road Operators
VUCA	volatility, uncertainty, complexity, and ambiguity
eMBB	enhanced Mobile Broadband
M2M	Machine-to-Machine

TCO	Total cost of Ownership
VCoC	Vehicle Control Center
ADAS	Advanced driver-assistance system
AD	Autonomous Driving
ToD	Tele-operated driving
KPI	Key Performance Indicator
EC	European Commision

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1 Management Summary

The following metastudy represents a systematic review of three deployment studies examining determinants of the 5G infrastructure investment delta and related research questions in various European cross-border corridors for connected, automated mobility services.

There are three projects working on 5G-enabled connected, automated mobility in cross-border scenarios: 5G-CARMEN, 5GCroCo and 5G-MOBIX. All three are ICT-18 projects[1] and aim at qualifying 5G as a core connectivity infrastructure to address vehicle-to-everything (V2X) for advanced and automated mobility services.

All three of the aforementioned projects produced deployment studies which have been conducted almost entirely independently of each other, differing significantly in the methodological approaches, input, sources, geographic and technological scopes and underlying assumptions, as well as the corresponding results (albeit not directly comparable due to entirely different scenarios).

It is therefore the overall objective of the metastudy to systematically review and compare the three underlying studies, consolidate, and align the results, identify methodological and analytical gaps, while reflecting the diversity of the three different approaches in order to arrive at a consolidated perspective on 5G deployment and related investment estimates with respect to the future CEF2 Digital deployment.

In order to meet the overall objective, the metastudy consists of the following chapters:

- Introduction
- Comparative analysis
- “Gap” Analysis
- Harmonization of the deployment studies’ results
- Synthesis of the key findings

The results show that a broad scope in terms of geographic corridors was covered, while some of the applied methodologies differ substantially. Yet, investment delta results are somewhat comparable when the methodological differences are taken into account. Key cost drivers are geographic location, the existing RAN infrastructure and planned 5G roll-outs of the mobile operators along the corridors. This study has identified a lot of gaps, which may affect the deployment delta. One of the most prominent ones is the fact, that the actual requirements from connected, automated vehicles (CAVs) remains unclear.

[1]https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/ict-18-2018

2 Introduction

The purpose of this metastudy is to produce a systematic review of three deployment studies examining determinants of the 5G infrastructure investment delta and related research questions in various European cross-border corridors for connected, automated mobility services.

2.1 The Deployment Studies: 5G-MOBIX, 5G-CARMEN, and 5GCroCo

There are three projects working on 5G-enabled connected, automated mobility in cross-border scenarios: 5G-CARMEN [1], 5GCroCo [2] and 5G-MOBIX [3]. All three are ICT-18 projects and aim at qualifying 5G as a core connectivity infrastructure to address vehicle-to-everything (V2X) for advanced and automated mobility services. The projects share the objective to build a sustainable future for connected and automated vehicles and have received funding from the European Union's Horizon 2020 research and innovation program. The projects are briefly summarized below.

Note: The deployment studies analyzed within the present study only reflect a small part of the three projects. For improved readability, we refer to each of the deployment studies as per its project name (e.g., *5GCroCo* rather than *5GCroCo Deployment Study*).

5G-MOBIX:

In order to enable innovative and advanced automated driving applications 5G-MOBIX has the objective to align the benefits of both 5G technology and CAM use cases.

By using 5G key technological innovations, 5G-MOBIX develops and tests vehicular functionalities along several cross-border corridors (Greece-Turkey and Spain-Portugal) and urban pilot sites. Besides economic, legal, and social aspects different from region to region, further conditions of automotive traffic, network coverage and service demand are considered throughout the test phase.

5GCroCo:

5GCroCo is testing and trialing 5G technologies for connected, automated mobility (CAM) use cases along the borders of France, Luxembourg, and Germany with the main focus on the technical validation of cross-border and cross-mobile network operator (MNO) handovers to ensure service continuity. Furthermore, 5GCroCo is seeking to identify new business models which can be established based on the exceptional connectivity and service provisioning capacity. Relevant standardization committees are impacted by the automotive and telecommunications industry by this project.

5G-CARMEN:

The project 5G-CARMEN focuses on the Bologna-Munich corridor which is crossing Italy, Austria and Germany (600 km). 5G-CARMEN is aiming at implementing a multi-tenant platform that can assist the automotive sector in delivering more eco-friendly, intelligent, and secure transportation with the support of 5G technology.

Deployment Studies:

Within these projects, three deployment studies were conducted with the common goal of assessing the connectivity demands of connected, automated mobility (CAM) and the corresponding 5G infrastructure investment delta in different European cross-border corridors (CBCs). The objective was to provide an indication to policymakers, 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.

The deployment studies set out to cover various related questions such as

- traffic characteristics, needs of CAM services at border areas,
- planned investments in physical & digital infrastructure,
- deployment "delta" between currently planned investments,
- necessities with regards to networking,
- market characteristics and business risks and enablers.

As the work on these deployment studies has been conducted almost entirely independently of each other, the ensuing methodological approaches, input, sources, geographic and technological scopes, and underlying assumptions, as well as the corresponding results (albeit not directly comparable due to entirely different scenarios), vary to a significant degree.

2.2 Key Objectives of the Metastudy

The overall objective of the metastudy is to compare the three underlying studies, consolidate their results, identify methodological and analytical gaps, while reflecting the diversity of the three different approaches in order to arrive at a consolidated perspective on 5G deployment and related investment estimates with respect to the CEF2 Digital deployment. This metastudy does not attempt to repeat all information and details from the underlying studies.

Accordingly, the key objectives of the metastudy are:

- **Reflecting the diversity of potential methodological approaches and covered scenarios**
- **Understanding methodological and analytical gaps and shortcomings**
- **Understanding the various sources and inputs**
- **Allowing for a comparative view of the results**
- **Providing a synthesized overview of the studies**

The results shall help parties, interested in submitting proposals for CEF2 funding, to validate their own approaches in determining the financial scope in different deployment scenarios and provide a panoply of matters and challenges worth considering. However, the goal is not to provide a universally applicable toolkit as the results derived solely represent a snapshot applicable only to the specific assumptions and scenarios in scope of each of the studies at the time of the survey. Moreover, the results may provide inputs to further research of this or similar nature, for example in the context of the ICT-53 projects that are focusing on other technological components such as railway, waterways and coastal maritime transport.

3 Comparative Analysis of the Applied Prominent Methodologies

The three deployment studies compared in within this metastudy all share a common goal: calculating the investment delta of providing seamless 5G coverage in key EU corridors. The drive for this coverage is to enable 5G for connected automated mobility (CAM) in the EU for level 3 and beyond vehicles. Calculating such an investment delta requires consideration of many parameters and making certain assumptions, such as the overall deployment methodology, radio planning parameters, or the cost assumptions. As these studies were conducted independently of each other, the assumptions and parameters considered differ leading to certain methodological similarities and many contrasts.

In order to compare theses similarities and differences, we determined a cross-study list of comparative angles. In this section, we will describe and discuss theses angles that have been grouped into six categories: corridor characteristics and scenarios, radio access network (RAN), traffic forecasts and demands, financial observations, regulatory obligations, and the sources.

3.1 Corridor Scenarios and Characteristics

The corridor selection, scenarios and characteristics vary between the studies. Therefore, we identified four main comparative angles in this category consisting of the corridor location and length, the time period of the scenario, the environmental and geospatial characteristics and the consideration of planned upgrades on said corridors.

3.1.1 Location and Corridor Length

In 5G-MOBIX, the study covered five European cross-border corridors (CBCs) each of around **40 km** length in total (20 km on each side of the corridor).

The five corridors cross from/into nine European countries designated by a two-letter country code followed by the name of the border town as follows:

- **Spain – Portugal** (ES-PT): Tui/Valenca
- **Greece – Turkey** (GR-TR): Kipoi/Ipsala
- **Germany – Netherlands** (DE-NL): Veldhuizen
- **Finland – Norway** (FI-NO): Kilpisjärvi
- **Spain – France** (ES-FR): Le Perthus

In 5GCroCo, the deployment study covered three corridors, each alongside a border area in three different countries, as follow:

- The first corridor, located in **France**, stretches **96.76 km** from Metz to the Luxemburgish border.
- The second corridor, located in **Germany**, stretches **78 km** alongside the French border between the French-German border at Forbach/Saarbrücken and the German-Luxembourgian border at Perl/Schengen

- The last corridor, located in **Luxembourg**, stretches **24.5 km** alongside the French and German border between Schengen to Dudelange which in turn, adjoins the borders of Germany and France.

5G-CARMEN considered a corridor of 600 km from Munich, **Germany**, over Austria to Bologna, **Italy**. This corridor is comprised of eight segments to trade-off between simplifying the complexity of the whole corridor and addressing the distinction of each type of a potential geographical scenario.

The individual segments vary in length and characteristics. Each of the segments is defined below:

- Segment I: **6.6 km**, Kufstein-Kiefersfelden, German-Austrian border
- Segment II: **3.3 km**, Brenner pass, Austrian-Italian border
- Segment III: **7.5 km**, A8, Munich, Germany
- Segment IV: **7.2 km**, A8, near Munich, Germany
- Segment V: **5.5 km**, A12/A13, Innsbruck, Germany
- Segment VI: **4.4 km**, Europa Bridge, Schönberg toll zone
- Segment VII: **4.9 km**, A22-E45, Laghetti, Italy
- Segment VIII: **7.1 km**, A22, Pegognaga/Bondeno, Italy

To conclude, 5G-MOBIX compares three corridors of comparable size, whereas the 5GCroCo study focuses on long corridors of vastly different sizes. 5G-CARMEN focuses on comparatively small segments of a long corridor, with a focus on addressing as many geographical scenarios as possible. All three studies thereby reflect a vast number of diverse geographical scenarios within Europe.

3.1.2 Time Period

In 5G-MOBIX, all results focus on the years 2023 and 2025 as per the defined time scope of the study with the investment delta remaining affected by deployment obligations and planned upgrades.

In 5GCroCo, no assumptions were made regarding years of deployment or availability of CAM services.

In 5G-CARMEN, a continuous rollout approach has been taken for the years 2021 to 2025 that would meet the basics demands of preliminary V2X services determined by a timeline. Additionally, an extension of the study has been added covering the years 2026 to 2030, for one of the segments.

To conclude, the studies have taken three different approaches in terms of time period of deployment, 5G-MOBIX considered a deployment in two specific years, 5GCroCo an immediate deployment and 5G-CARMEN a continuous rollout scenario over five years.

3.1.3 Environmental and Geospatial characteristics

In 5G-MOBIX, the five corridors are cross-border corridors similar in length but highly different in geographical characteristics, road traffic and population density [3]. The five corridors are situated in 9 countries and include:

- **ES-PT:** soft border, mostly rural area, river
- **GR-TR:** hard border area, mostly rural, bridge

- **DE-NL:** soft border, rural and urban areas, river, bridge
- **FI-NO:** soft border, mostly rural, forest, lakes, flat
- **ES-FR:** soft border, rural and urban areas, forest, bridge, mountainous

In 5GCroCo, the three corridors are located within three countries and include:

- **French corridor**: rural and urban areas, some forest, river, flat
- **German corridors**: rural and urban areas, some forest, flat
- **Luxembourgish corridor**: mostly rural, flat

In 5G-CARMEN, the 600 km corridor is divided in eight segments crossing three countries (Germany, Austria, and Italy) with specific geographical characteristics:

- **Segment I**: urban area, river
- **Segment II**: mountainous area, tunnel
- **Segment III**: urban area, tunnel, high traffic
- **Segment IV**: suburban area, high traffic, forest, flat road
- **Segment V**: urban area, slopes, tunnel
- **Segment VI**: bridge, toll zone, tunnel, steep roads
- **Segment VII**: rural and mountainous area, river
- **Segment VIII**: rural and suburban areas, straight road, flat landscape

To conclude, the corridors represent a wide array of geographical characteristics.

3.1.4 Planned upgrades along corridor

In 5G-MOBIX, the study investigated, through interviews with representatives of relevant MNOs and additional research (such as NRAs' websites), the deployment obligations and planned upgrades of MNOs. This data was subsequently used to calculate the investment delta.

In 5GCroCo, the study did not consider planned upgrades or regulatory obligations. However, planned deployments are reflected in the cost calculation, using a percentage of CAPEX attributed to the CAM model.

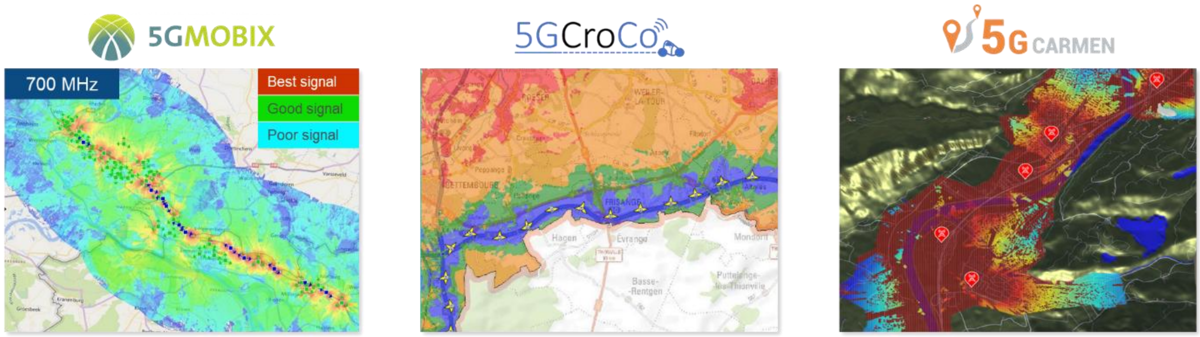
In 5G-CARMEN, a fix discount on hardware of 15% has been considered for already planned deployments. Road coverage obligations have not been explicitly considered.

To conclude, two of the three studies considered planned deployments or upgrades as a flat, constant, discount on capital expenses. However, the other study investigated, through research and interviews, corridor specific deployment obligations, planned upgrades and planned new sites.

Note: Road coverage obligations are also covered in more depth in section 3.5.2 (see also Figure 7).

3.2 Mobile Network Considerations

Other major parameters that vary the studies are the technology and radio planning approaches taken. These are regrouped within this RAN considerations section and include comparative angles such as the radio and capacity planning, the technology deployed, and network sharing considerations. The different approaches are illustrated below in Figure 1.



RAN Core: 5G NSA is considered as a current primary requirement.
5G SA is foreseen to be deployed in the future.
Simulation Environment: HTZ simulation tool considering landscape, path loss and gain.

Source of sites: cellmaper.net, antennekaart.nl

RAN Core: Deployment is independent from 5G core structure.
5G SA is foreseen to be deployed in the future.
Simulation Environment: Estimated based on existent network maps acquired from public agencies and operators.

RAN Core: 5G NSA is considered as a current primary requirement.
5G SA is foreseen to be deployed in the future.
Simulation Environment: UPV's Unity 5G pathloss simulator.

Figure 1: Radio Planning Approaches

3.2.1 Technology Deployed

In 5G-MOBIX, two spectrum deployment scenarios have been considered:

- **700 MHz** (FDD, BW: 10 MHz, MIMO: 2T/4R, 43.01 dBm)[2] spectrum
- **3.5 GHz** (TDD, BW: 100 MHz, MIMO: 8T/8R, 50 dBm) spectrum

Furthermore, the antenna has a gain of 15.10 dBi and is mounted on a 25 m base station with a tilt of -3 degrees. Additionally, the existing base stations are upgraded to 3 sector antennas and new sites are deployed with 2 sector antennas next to the corridor.

In 5GCroCo, two spectrum bands have been used, **700 MHz** and **3.5 GHz** in 5G New Radio. However, the 700 MHz band is only considered for upgrades, whereas the 3.5 GHz band is considered for both upgrades and new sites deployed. In this study, the deployment depends on **density scenarios**, and in all cases, sites are upgraded with both the 700 MHz and the 3.5 GHz technology.

In 5G-CARMEN, two spectrum bands have been considered for a **Vehicle-to-Network (V2N) deployment**, **700 MHz** and **3.7 GHz**, with two sectors along the road, and three sectors close to urban areas. Additionally, the study includes a **Vehicle-to-Infrastructure (V2I) deployment** of RSU along the eight segments. These RSUs are each with two sector antennas and work at 5.9 GHz frequency.

To conclude, the technology deployed uses, in all three cases, the same frequency bands: 700 MHz and 3.x GHz. These are the most common 5G bands in Europe and also most relevant for CAM services along motorways. Furthermore, the two studies considering antenna sectors choose to deploy antennas with three sectors, when the corridor passes close to rural area, to allow for additional income from potential new subscribers.

[2] FDD: Frequency Division Duplex; TDD: Time Division Duplex; BW: Bandwidth; MIMO: multiple-input and multiple-output; dBm: decibel-milliwatts

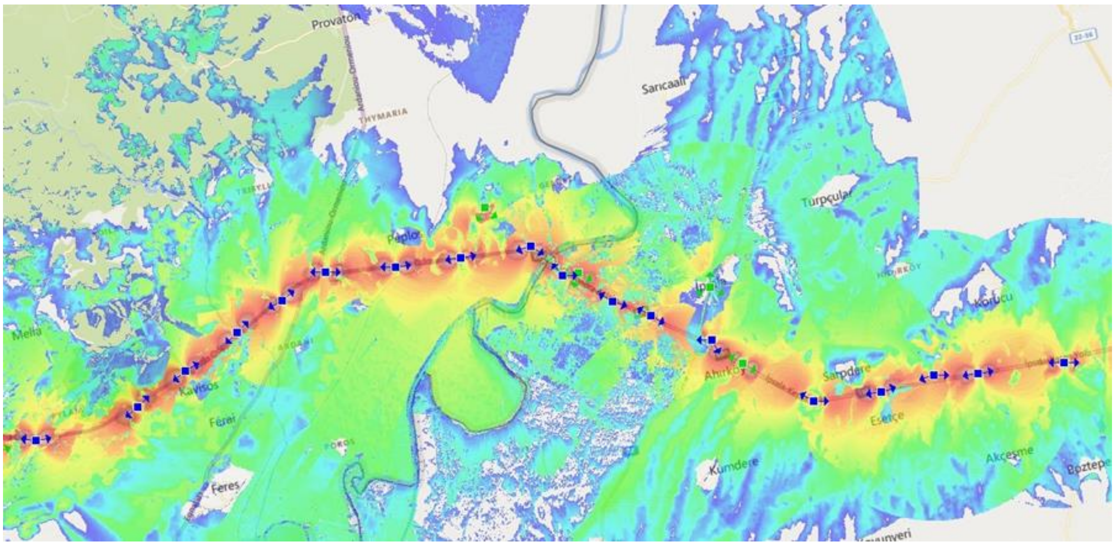
3.2.2 Radio Planning

In 5G-MOBIX, all radio planning simulation and development were executed with the **ATDI HTZ Communications tool** [4] offering advanced radio network planning and optimization capabilities. The nominal radio planning exercise has been done using existing maps from public authorities and operator interviews, upgrading existing sites and deploying new sites directly on the side of the road, see Figure 2, for the **two deployment scenarios**, the **700 MHz** and the **3.5 GHz** scenario.

In 5GCroCo, the radio planning is based on **network maps** from public authorities in Germany (Bundesnetzagentur) and France (Agence national des frequences), and the MNO POST in Luxembourg. Furthermore, the network planning was performed for **three density scenarios** with different Inter-site Distance (IsD):

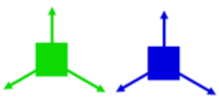
- A **basic low/medium band 5G coverage** (studied only on the French corridor with 1 site per 6 km)
- A **3.x GHz band 5G coverage** (1 site per 3 km)
- A **3.x GHz high throughput coverage** (1 site per 1 km)

With the base station being deployed directly along the road or in closed proximity hence serving an identical section of the road (mainly highways).



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 2: Existing and new sites in the area of GR-TR Kipoi/İpsala corridor for the 3.5 GHz deployment, from 5G-MOBIX [1]

In 5G-CARMEN, the vehicular traffic has been simulated using the **SUMO simulation tool** [5], and fed into a precise geographical model of each segment. The deployment is then simulated using **Universitat Politècnica de València's Unity 5G pathloss simulator**. This radio planning method, illustrated in Figure 3, has been used to simulate the deployment of both the **V2N scenario** and the **V2I scenario**. Additionally, the traffic has been estimated using two service penetration forecasts, an optimistic and a conservative forecast, resulting in a total of **four deployment scenarios** for each segment.

To conclude, we can clearly identify major differences in the radio planning methodology. Indeed, two of the studies based their deployment on precise radio planning using path loss simulation tools, whereas the third one used inter-site distances (IsD) to determine upgrade and new site locations. Moreover, the three studies use different deployment scenarios, leading to a variety of deployment scenarios.

Figure 3: Signal-to-noise heat map for the geographical locations of the RSUs required for the V2I deployment [3]

3.2.3 Capacity Planning

Capacity planning refers to dimensioning the mobile network in a way that it can support the expected network traffic demand. Generally, capacity planning is a highly complex exercise. Therefore, the deployment studies have developed simplified approaches for capacity estimations.

In 5G-MOBIX, the capacity of the gNodeB[3] was considered and defined as the data rate which can be provided for the downlink (DL) and the uplink (UL), for all the connected devices to that gNodeB. For simplification reasons, calculating the capacity was based on the Shannon–Hartley theorem [5] whereas throughput calculation was computed using a specific throughput calculation formula [6]. The number of vehicles within a site's service areas was calculated based on vehicular speed and inter-site distance (see 3.3.2),

[3] gNodeB refers to a 5G-NR base station.

multiplied with the CAV penetration rate (as forecasted) to arrive at the number of CAVs within the cell service area. In order to arrive at the overall throughput load for the base stations, an average CAV data traffic rate (in the form of 3 different scenarios) was developed based on the use case requirements and then multiplied by the number of CAVs within the service area.

In 5GCroCo, capacity planning was reflected implicitly in the three different throughput scenarios (see 3.2.1).

In 5G-CARMEN, capacity planning was conducted by meeting a set of KPIs defined by the different scenarios during the capacity simulation in Unity. The simulators implement a detailed model the geographical aspects of the segment, for the on-the-fly generation of vehicle users with the same traffic densities as reported in the segments.

To conclude, two of the studies have attempted to simulate and/or calculate overall data traffic based on technical assumptions and projections. Yet, this is a fairly vague approach to the complex exercise of radio network capacity planning. Therefore, it is included in the technical gaps (see 4.1).

3.2.4 Other Comparative Angles

Background Data Traffic

The consideration of background data traffic has only been detailed in **5G-MOBIX**, as 160 kbps per non-CAM vehicle. However, in **5GCroCo** and **5G-CARMEN**, the background traffic is reflected in the financial calculations.

Backhaul Assumptions

The backhaul[4] assumptions in the three deployment studies are all fiber-based, with the main difference being the resulting impact on the costs. In all studies, microwave connection of RAN sites has been assessed as too unreliable for CAM services.

Network Sharing

Full network sharing was assumed in **5G-MOBIX,** and similarly in **5GCroCo** with the exception of the Luxembourgish corridor, where only POST sites where considered. In **5G-CARMEN**, in the segment studied only Telekom and Magenta sites were considered.

Multi-access Edge Computing

Multi-access Edge Computing has been discussed in all three studies. However, in **5G-MOBIX** and **5GCroCo**, the studies only approximate the overall cost it would have, whereas in **5G-CARMEN** MEC is part of the deployment strategy specific for each segment and scenario.

Minimum Signal Strength

[4] “Backhaul” refers to the transport network connecting the core network with the RAN.

For the minimum required signal strength, both **5G-CARMEN** and **5GCroCo** did not consider a minimum signal strength. Whereas **5G-MOBIX**, considered **-80 dBm** as the minimum signal strength.

On-board Technology of Vehicle

The on-board technology considered in the deployment studies is only detailed in **5G-MOBIX** [2] as follow:

- Nominal power of 23 dBm
- Gain of 0 dBi, lossless
- Using a MIMO antenna (1T/2R) and an antenna height of 1.5 m

The two other studies did not detail the technology deployed, however more details can be found in the **5GCroCo** and **5G-CARMEN** deliverables.

3.3 Data and CAM Traffic Demand

Data and road traffic demand is another key category in which we identified comparative angles. The traffic demand regroups two things, the actual road traffic (i.e., vehicles) and the data traffic generated by this road traffic. In order to calculate this, the studies have to determine, on one side the CAM use cases and their requirements, and on the other side the number of cars and the frequency at which these will be used.

3.3.1 CAM Use Cases and Requirements

In 5G-MOBIX, the use cases and requirements of CAM have been clearly defined in five categories:

- **Advanced driving**, with maximum requirements of **throughput** in **Downlink (DL) 36 Mbps** and in **Uplink (UL) 36 Mbps,** and **latency of <50 ms**, it includes the use cases: Cooperative collision avoidance, Lane Merge, Overtaking, Infrastructure assissted advanced driving, Automated shuttle driving across borders
- **Vehicle platooning**, with maximum requirements of **throughput** in **DL 30 Mbps** and in **UL 30 Mbps**, and **latency <50 ms**, it includes the use cases: SeeWhatISee and eRSU-assisted platooning
- **Extended sensors**, with maximum requirements of **throughput** in **DL 30 Mbps** and in **UL 36 Mbps**, and **latency <100 ms**, it includes the use cases: Hdmaps, AssBCrossing, TruckRouting, Enabled Dynamic Map, EdgeProcessing and extended sensors with CPM messages
- **Remote driving**, with maximum requirements of **throughput** in **DL 36 Mbps** and in **UL 36 Mbps,** and **latency of <50 ms**, it includes the use cases: BCrossing, 5GPositioning and Remote driving in redundant network environment
- **Vehicle QoS Support**, with maximum requirements of **throughput** in **DL 20 Mbps** and in **UL 25 Mbps,** and **latency of <1000 ms**

In 5GCroCo, three use cases have been identified and defined, with some requirements:

- **Tele-operated Driving,** with maximum requirements of **throughput** in **DL 0.5 Mbps** and in **UL 25 Mbps**
- **HD mapping,** with maximum requirement of **throughput** in **DL 10 Mbps**

- **Anticipated Cooperative Collision Avoidance**

In 5G-CARMEN, twelve use cases have been identified, with the corresponding requirements, and an adoption timeframe has been defined as follow:

- **By 2020:**
  - **Local hazard and traffic information**, with maximum requirements of **throughput** in **UL 0.006 Mbps, latency** of **2000 ms**, and **reliability** of **50%**
- **By 2022:**
  - **Hazard information collection and sharing for automated vehicles**, with maximum requirements of **throughput** in **DL 0.048 Mbps** and in **UL 0.048 Mbps, latency** of **20 ms**, and **reliability** of **99.9%**
  - **Emergency electronic brake light**, with maximum requirements of **throughput** in **DL 0.064 Mbps** and in **UL 0.064 Mbps, latency** of **120 ms**, and **reliability** of **99.99%**
  - **Left turn assist**, with maximum requirements of **throughput** in **DL 0.08 Mbps** and in **UL 0.08 Mbps, latency** of **100 ms**, and **reliability** of **90%**
- **By 2024:**
  - **HD map collection and sharing for automated vehicles**, with maximum requirements of **throughput** in **DL 16 Mbps** and in **UL 47 Mbps, latency** of **100 ms**, and **reliability** of **99%**
  - **Vulnerable road user: collective awareness**, with maximum requirements of **throughput** in **DL 16 Mbps** and in **UL 47 Mbps, latency** of **20 ms**, and **reliability** of **99.9%**
- **By 2025:**
  - **Information sensor sharing**, with maximum requirements of **throughput** in **DL 16 Mbps** and in **UL 4 Mbps, latency** of **100 ms** and **reliability** of **99%**
  - **Tele-operated Driving**, with maximum requirements of **throughput** in **DL 0.4 Mbps** and in **UL 36 Mbps, latency** of **20 ms** and **reliability** of **99.999%**
- **By 2026:**
  - **Group start**, with maximum requirements of **throughput** in **DL 0.048 Mbps** and in **UL 0.048 Mbps, latency** of **10 ms** and **reliability** of **99.999%**
  - **Sensor sharing for automated vehicles**, with maximum requirements of **throughput** in **DL 15 Mbps** and in **UL 15 Mbps, latency** of **50 ms** and **reliability** of **99%**
  - **Cooperative maneuvers**, with maximum requirements of **throughput** in **DL 64 Mbps** and in **UL 64 Mbps, latency** of **10 ms** and **reliability** of **99.9%**
  - **HD sensor sharing for automated vehicles**, with maximum requirements of **throughput** in **DL 0.08 Mbps** and in **UL 0.08 Mbps, latency** of **100 ms** and **reliability** of **99.9%**

The translation of these CAM use case requirements into the overall cell load has been conducted in different ways (refer to 3.2.3 Capacity Planning).

To conclude, the three studies include multiple use cases, including details about the necessary requirements (latency, throughput, and reliability). Although the list of use cases for each study is different, three common use cases can be identified: Tele-operated Driving, HD mapping, and Cooperative Collision Avoidance.

3.3.2 Vehicular Traffic Considerations

In 5G-MOBIX, corridor-dependent road traffic was determined for each border crossing with information obtained by public vehicle counter data from road operators and road authorities and information shared during interviews. The data was divided to obtain an hourly average, and peak traffic was determined by multiplying by 2 based on comparable traffic data. The number of vehicles per base station has been calculated using the formula in Figure 4.

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

Figure 4: 5G-MOBIX vehicles per base station

In 5GCroCo, the assumptions have been made that **rural** and **urban areas**, two lane traffic with one lane per direction, have an average traffic of 6,000 vehicles per 24 hours. Additionally, the traffic on a **highway**, defined as having a total of 4 lanes, has been determined to be an average of 24,000 vehicles per 24 hours. Moreover, the amounts of cars in peak hour have then been determined based on the percentage of daily traffic, 10% for **rural roads** (600 vehicles per hour) and **highways** (3,000 vehicles per hour), and 25% for **urban roads** (1,500 vehicles per hour).

In 5G-CARMEN, SUMO simulation was used to generate a realistic vehicular traffic mobility trace. The assumption that was made, for the first segment, is 1,500 vehicles per hour per lane, for a road with two lanes, resulting in a total of 3,000 vehicles per hour per road.

To conclude, the road traffic is corridor-dependent in 5G-MOBIX, and road type dependent for 5GCroCo. Moreover, 5G-CARMEN's study used the same number of vehicles per hour than the peak hour highway of the second study.

3.3.3 Other Comparative Angles

Evolution of Network Demand

The evolution of network demand has been correlated to the evolution of CAM enabled vehicles on European roads. In **5G-MOBIX**, this was reflected by using a country dependent **'churn' rate** [2] at which old vehicles are replaced by new ones based on sales figures and average fleet ages in the countries. Furthermore, in **5G-CARMEN**, an **optimistic** and **conservative service penetration** forecast of connected vehicles has been determined and translated in V2X service penetration on a yearly basis between 2021 and 2025. In **5GCroCo**, the evolution of network demand has not been specified.

Vehicle Types

Different types of vehicles have only been considered in **5G-MOBIX**: passenger vehicle, transport vans, (shuttle) buses and trucks. For each type, a national-level share of type of vehicle has been calculated, and uplink and downlink bit rate requirements have been derived for three cases: high bit rate, medium bit rate and low bit rate.

CAV Definition

The definition of Connected Automated Vehicles varies between the studies, in **5G-MOBIX** and in **5G-CARMEN** it is defined as SAE level 3+[5] cars, whereas in **5GCroCo** it has not been specified.

3.4 Financial Observations

As discussed previously, the three studies are generally aligned in terms of the deployed technology, however the cost considerations for the deployment vary. In this comparative category we compare the CAPEX and OPEX of the three deployment studies.

3.4.1 5G-MOBIX

In **5G-MOBIX**, the cost catalogue has been determined using a country dependent price estimation approach. Therefore, in order to harmonize the costs between the countries we have, in Table 1, calculated the average costs for the different configurations for all nine countries. The resulting **average total CAPEX** for 700 MHz and 3.5 GHz, are respectively **96,694 EUR** and **102,950 EUR**, and the **average upgrade CAPEX** is **19,633 EUR** for 700 MHz and **25,888 EUR** for 3.5 GHz. Additionally, the average annual OPEX for a base station is **17,122 EUR**. Moreover, cost estimations for RSUs and MEC deployment have also been also included and are compared to the other studies in T and T.

5G-MOBIX	
Configuration	**Average Costs**
Active Equipment CAPEX 700 MHz	19,633 EUR
Active Equipment CAPEX 3.5 GHz	25,888 EUR
Total CAPEX 700 MHz (including Backhaul)	96,694 EUR
Total CAPEX 3.5 GHz (including Backhaul)	102,950 EUR
OPEX per year	17,122 EUR

Table 1: Cost per site CAPEX and OPEX from 5G-MOBIX

In this study, the investment delta, for each corridor has been calculated as the result of multiplying the bill of quantity (BoQ) by the cost catalog, illustrated in Figure 5. The BoQ

[5] In partnership with ISO, the Society of Automotive Engineers defines level 3 as conditional driving automation as per the latest version of the SAE J3016 recommended practice (https://www.sae.org/blog/sae-j3016-update)

includes all new upgrades and sites to be deployed, using existing RAN infrastructure and information about planned 5G deployment. The final investment delta has been calculated for both 700 MHz and 3.5 GHz deployments in 2023 and in 2025.

$$\Delta = RAN_{required} - (RAN_{planned} + RAN_{existing})$$

Figure 5: 5G-MOBIX Costing Equation

3.4.2 5GCroCo

The cost study in **5GCroCo** [6] focused on a global evaluation of the main cost driving elements with relevance to the CAM infrastructure. Indeed, as mentioned before, the study considered a percentage of the costs to be for CAM services. Therefore, as shown in Table 2, the **new site** and **upgrade to 3.x GHz CAPEX** where **discounted by 50%**, and cost respectively **75,000 EUR** and **35,000 EUR**. The **upgrade to 700 MHz CAPEX** was discounted by **90%** to **6,000 EUR**.

5GCroCo		
Configuration	**Cost**	**% for CAM**
CAPEX of new 3.5 GHz site (including Backhaul)	150,000 EUR	75,000 EUR
CAPEX of upgrade to 700 MHz	60,000 EUR	6,000 EUR
CAPEX of upgrade to 3.5 GHz	70,000 EUR	35,000 EUR
OPEX per 8 years	100% of CAPEX	100% of CAPEX

Table 2: Cost per site CAPEX and OPEX from 5GCroCo

The resulting costs have then then been calculated for the three corridors using the BoQ of each scenario. It should be noted that for upgraded sites, the total CAPEX results in the addition of the upgrade costs to 700 MHz and to 3.x GHz, i.e. **41,000 EUR**.

3.4.3 5G-CARMEN

In 5G-CARMEN, the more detailed cost model **includes a 15% discount** on hardware and installation to take into account the planned deployments by MNOs. The costs of a new base station comprise the macro site tower construction (not discounted), the hardware, installation, labor, and respective antenna costs. Resulting in a **total discounted CAPEX** of **61,975 EUR** for a **700 MHz site** and of **64,270 EUR** for **3.7 GHz site**. The upgrade costs include the 5G upgrade of a base station with installation costs, a 3-sector 5G antenna, with either 700 MHz RF front end or 3.7 GHz RF front end, and labor costs. This results in a **discounted upgrade CAPEX** of **28,475 EUR** for a **700 MHz upgrade** and **30,770 EUR** for a **3.7 GHz upgrade**. The **OPEX** costs considered include: 1,200 EUR of base station vendor services, 270 EUR of licensing maintenance costs, the yearly electricity bill, and 10% of the CAPEX for site maintenance. This results in a **total OPEX** of, **1,565 EUR plus 10% of the yearly CAPEX**.

5G-CARMEN			
Configuration		Cost	Cost with 15% discount
New base station	CAPEX macro site tower	25,000 EUR	
	2G+3G+4G+5G BS hardware	5,000 EUR	4,250 EUR
	2G+3G+4G+5G BS installation	35,000 EUR	29,750 EUR
Base station upgrade	5G upgrade of BS hardware + installation	30,000 EUR	25,500 EUR
Antenna	3-sector 5G antenna + 700 MHz RF front end	2,700 EUR	2,295 EUR
	3-sector 5G antenna + 3.7 GHz RF front end	5,400 EUR	4,590 EUR
	Installation + labor cost (2 people, 1 day)	800 EUR	680 EUR
Total CAPEX 700 MHz		68,500 EUR	61,975 EUR
Total CAPEX 3.7 GHz		71,200 EUR	64,270 EUR

Table 3: Cost per site CAPEX and OPEX from 5G-CARMEN

However, unlike the other studies the cost results calculated above do not include the backhaul, which has been calculated separately for each segment. The backhaul costs for a new site is the sum of 15-year lease of indefeasible rights of use (IRU) of fiber or dark fiber of half of the segment's length and 3% of the CAPEX of the site, as can be seen in Table 4. Considering a cost per km of **6,000 EUR** for the lease, the **total CAPEX including backhaul** is **81,775 EUR** for a **700MHz site** and **84,070 EUR** for a **3.7GHz site**. These prices vary depending on the segment: the longer the segment, the higher the costs.

Another financial consideration made in 5G-CARMEN is the inflation and the overhead:

- **Inflation** is set at 5% per year
- **Overhead** includes marketing, helpdesk, HR and finances, and is set to 22% of the sum of the final CAPEX and OPEX per year

5G-CARMEN		
Configuration		Cost
Backhaul segment I	CAPEX (IRU fiber 15y lease of half segment length/new site)	19,800 EUR
	OPEX (3% of CAPEX)	594 EUR
Total CAPEX 700MHz with backhaul for segment I (including 15% discount)		81,775 EUR
Total CAPEX 3.7GHz with backhaul for segment I (including 15% discount)		84,070 EUR

Table 4: Total backhaul costs for segment I

Furthermore, unlike **5G-MOBIX** and **5GCroCo**, the financial calculations include a **business case**. Indeed, in the deployment studies two income sources were considered:

- **5G non-V2X subscribers**: the yearly revenue of new 5G subscribers due to the deployment of 5G in urban areas around the highway. Therefore, the number of inhabitants in towns and villages along the segment are calculated. Using a yearly adoption percentage, the number of new 5G subscribers is calculated and divided by the number of MNOs covering the area. The resulting subscribers are multiplicated by a potential yearly revenue of 420 EUR per subscriber. This is repeated for each year between 2021 and 2025 for the eight segments.
- **5G V2X subscribers**: the yearly revenue that comes from charging 0.5 EUR per 100 km per vehicle. This revenue is determined by the yearly service penetration of CAM services. Therefore, it was calculated for the optimistic and conservative CAM adoption model mentioned in 3.3.3, by multiplying the revenue with the expected, CAM enabled vehicle, traffic flow in the corridor.

Finally, this study also includes, for each segment the cost of deployment of RSUs to enable V2I communications along the corridor.

3.4.4 RSU and MEC cost considerations

All three studies include estimations of cost for RSU and MEC deployment. In Table 5, the RSU costs can be seen, **5G-MOBIX** and **5G-CARMEN** both are aligned on the price per unit of 4,500 EUR and **5GCroCo** considered a higher price of 10,000 EUR.

Deployment study	Price per unit
5G-MOBIX (price for a C-V2X RSU)	4,500 EUR
5GCroCo (price including civil works)	10,000 EUR
5G-CARMEN (price incl. hardware and installation)	4,500 EUR

Table 5: Price of RSU units in the three deployment studies

The MEC costs also vary between the studies. In **5G-MOBIX**, a rough estimation of 75 kEUR to 115 kEUR per corridor has been derived. In **5GCroCo**, a 5-year total cost of ownership of 250,000 EUR attributed to CAM services is estimated for an MEC location covering roughly 20,000 km of road. And finally, in **5G-CARMEN** the costs for an MEC are detailed as: **10,000 EUR** (for the CyberServe R2224WTTYSR), **1,000 EUR** for the cabinet for edge server, **2,200 EUR** cooling system costs and **5,700 EUR** for fixed costs (power, boards, sockets, lighting, enclosure and cabling).

3.4.5 Comparing the CAPEX between the studies

To compare the total CAPEX (including backhaul) of the three DS, in **5G-CARMEN** the average of the eight segments has been calculated for both the 700 MHz and the 3.7 GHz sites. Moreover, 5GCroCo only has cost estimation for a new 3.5 GHz site and only the percentage attributed to CAM (has been considered).

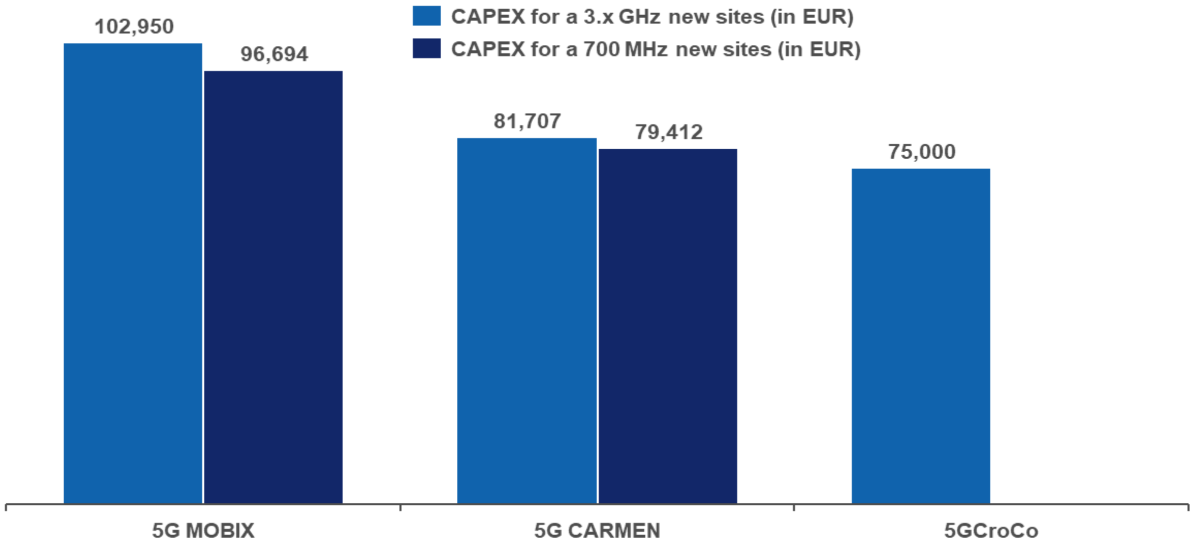


Figure 6: Total CAPEX for new sites comparison between the three deployment studies

In Figure 6, we can see that **5G-MOBIX** has the highest total CAPEX for both 700 MHz and 3.5 GHz sites. Moreover, **5GCroCo** has the lowest CAPEX and **5G-CARMEN**, with around 80,000 EUR per site, the smallest CAPEX difference between the 700MHz and 3.7 GHz sites.

3.5 Regulations and Obligations

3.5.1 Spectrum License Costs

The spectrum license costs have only been considered in **5GCroCo**, where they assume that 50% of the available spectrum could be required for CAM services. Additionally, the costs have been discussed, normalized to 100 km and deemed negligible compared to the 5G network costs.

3.5.2 Regulatory coverage obligations

Regulatory coverage obligations often include obligations to cover certain types of roads, often motorways. Especially with 5G licenses, many European regulators have imposed such obligations (see Figure 7). As the investment delta should not cover investments that MNOs are obliged to spend, it can be argued that these road coverage obligations are a valid determinant of the planned upgrades and new sites.

This has only been considered in **5G-MOBIX**. In the study, the coverage obligations in most countries of deployment were determined based on the license conditions as per NRA publications.

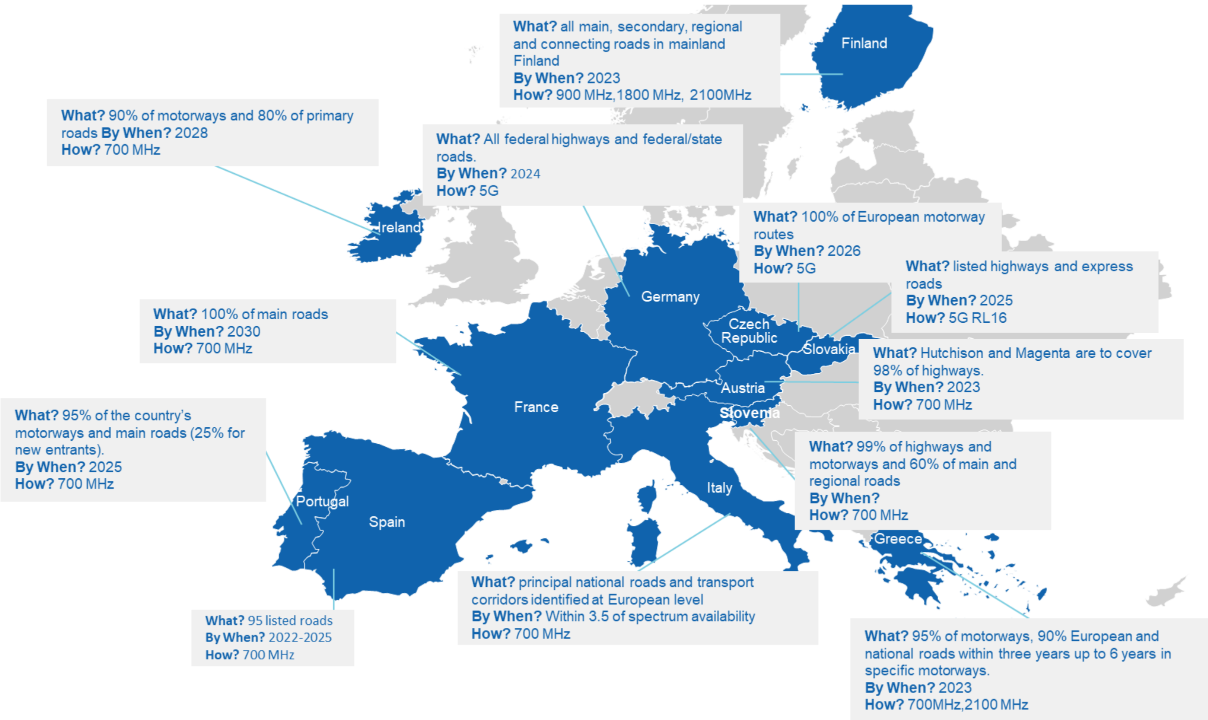


Figure 7: EU regulatory road coverage obligations

3.6 Key Sources

Comparative Angle	5G-MOBIX	5GCroCo	5G-CARMEN
RSU Deployment	13 road operator interviews	«5GCroCo D3.2 Intermediate E2E, MEC & Positioning Architecture», 5gcroco.eu;	5GAA; AASHTO
Network deployment	15 MNO interviews; national regulatory authorities; publicly available coverage maps; 5GPPP; ATDI, HTZ	BNetzA, ANFR (French National frequencies agencies); Fraunhofer	5G PPP Automotive Working Group; GSMA Intelligence; 5GAA
Cost estimation	15 MNO interviews; Detecon Analysis;	5gcroco.eu; European Commission	ITS conference; EBU; IEEE; Telecommunications

	5G Observatory; ANACOM;		Policy; www.sbaedge.com; IET Communications; Procedia Computer Science
CAM requirements and industry stakeholder information	7 interviews with industry stakeholders (e.g., 5GAA, vendors, automotive industry)	5GAA; European Commission	European Commission; NikkeiAsia; TechCrunch; TechXplore; MANTRA
Use Cases	3G PPP, 5G Observatory, 5G-MOBIX Trial Sites;	«5GCroCo D2.1 Test Case Definition and Test Site Description Part 1», 5gcroco.eu; 3GPP;	5GAA; 5G-CARMEN; 5G-NORMA

4 Gap Analysis

In this section, we briefly present topics requiring more detailed attention when considering a cross-border CAM deployment scenario along with matters that go beyond the scope of the three deployment studies but are relevant with respect to the original objectives of the studies and 5G deployment for CAM services in general. These so-called “gaps” are identified after reviewing the three deployment studies and comparing their inherent similarities and differences to outline a set of aspects that were either taken into account without giving detailed information about or completely disregarded by the studies as their involvement was out of scope of the individual deployment scenario. After outlining the set of gaps, discussion rounds with Detecon’s subject matter experts (in- and outside the project team) as well as external experts were conducted to gather and compile critical views on gaps identified along with other aspects of the gaps which might have been missed in the initial outline phase. The gaps along with their relevance to the 5G CAM ecosystem and approaches that should be taken to address them were also discussed in these workshops. In addition, we examined similar relevant research from third parties on the same or closely related subjects for further understanding of the gaps allowing for proper contextualization and presentation of these gaps.

Along with identifying and presenting the gaps and their relevance, a potential solution path is also presented that may provide more insights into these topics and a way to incorporate their aspects in future 5G CAM deployment studies and implementation.

The Gaps identified are categorized into three different types:

- Technical Gaps
- Regulatory and Institutional gaps
- Financial Gaps

The Gaps identified will be presented in the following manner:

- **Gap:** Title/Name for the gap identified.
- **Description:** A brief high-level overview of the gap.
- **Relevance:** Gap’s relevance to the key objectives as well as the rationale for taking these aspects into consideration by understanding their value and notable effects to the CAM deployment landscape.
- **Solution Path:** Developing high-level solution paths and recommendations including potential action steps for covering the gap in future research or deployment studies.
- **Reference to the corresponding step/option within the indicative deployment framework (see 0):** Within the framework there are estimations of potential efforts and potential cost impacts.
- **References for further reading:** Citations of relevant articles, information and further readings regarding the gap presented for the curious reader

4.1 Technical Gaps

We have identified 12 technical gaps ranging from aspects of network planning, infrastructure, and resource allocation to requirements of individual CAM services, service penetration of CAM by focusing on their effects towards the cost associated thereby allowing for better understanding of the gap with their possible financial implications with relation to a 5G CAM deployment scenario.

Gap	**Site acquisition process and related challenges**
Description	The site acquisition process is an important part of 5G deployment. 5G-MOBIX has described it to some extent, yet, not provided any cost implications. In all three deployment studies, it is assumed that the location of the deployed base stations will be available and approved in time. This may not always be the case. Therefore, regulation, bureaucracy and landownership need to be taken into account within the cost calculation.
Relevance	According to a study by the GSMA of 2013, the site acquisition process takes, between two and 24 months. This duration varies drastically and seems to be worsening for some countries. Additionally, the land availability is not guaranteed and the cost of the lease on the land can add around EUR 15k per year to the OPEX according to Dinc et al. **[7].** Lease and acquisition costs differ significantly from region to region.
Solution path	The duration of the process to obtain the necessary rights to build a base station for each country would have to be estimated and translated into a certain cost for the MNO to be taken into consideration in future deployment studies. In the long-term, regulations and obligations can be advanced to facilitate and expedite this process. Finally, an average cost of leasing and/or acquiring a site could be included for each country and deployment area.
Ref. to ind. framework	Step 3: Country-dependent regulatory necessities, Option A
Reference for further reading	[A] GSMA, https://www.gsma.com/publicpolicy/wp-content/uploads/2013/05/GSMA_BaseStation_Planning_EuropeWEB.pdf [B] E. Dinc, M. Vondra and C. Cavdar, "Total Cost of Ownership Optimization for Direct Air-to-Ground Communication Networks,"

Gap	The diversity in CAM requirements challenge the necessary coverage and throughput
Description	As individual requirements of CAM services (e.g., high throughput, low latency, and high reliability) grow, the requested site capacity and density, and accordingly the associated costs are expected to increase. The (commercial and/or socio-economic) necessity for certain high service specific requirements is not always justified, hence there is an inherent debate between simply achieving coverage on all the roads and setting up a high throughput network. Moreover, the average data traffic rates originating from CAVs will heavily depend on the development of services, vehicle types and more factors, creating high uncertainty around the expected network demand.
Relevance	The CAM requirements vary drastically between the deployment studies, e.g., if a service needs a throughput of 47 Mbps in UL, like Tele-operated Driving the deployed network will need to be much denser. Additionally, full continuous coverage is necessary for such a safety critical application and if requirements are too high, slight decrease in factors like coverage will be risky for the passenger. Finally, the requirements for specific services need to be clearly defined after thorough testing.
Solution path	A consensus, after consultation with key industry stakeholders could be found on minimum necessary requirements for key safety applications. Furthermore, an updated version of planned CAM services roll-out included in future level 3+ cars, in line with standards and regulation, could be made. Studies could be performed by implementing test cases of the application to derive service specific requirements to attain the desired QoS-level and safety level.

Ref. to ind. framework	Step 1: CAM requirements and services, Options: A, B & C

Reference for Further Reading	[A] Boban, Mate, et al. "Connected roads of the future: Use cases, requirements, and design considerations for vehicle-to-everything communications." IEEE vehicular technology magazine 13.3 (2018): 110-123. [B] 5GAA, "A Visionary Roadmap for Advanced Driving Use Cases, Connectivity Technologies, and Radio Spectrum Needs", https://5gaa.org/news/the-new-c-v2x-roadmap-for-automotive-connectivity/

Gap	Non-terrestrial communications
Description	Non-terrestrial (e.g., satellite) communication technologies are expected play a significant role in the future of telecommunications. The industry may use a network of small satellites usually in lower earth orbits to allow full coverage in rural areas where base stations are not deployed by MNOs. The large range attainable by these satellites could possibly allow coverage of all planned roads/highways for CAM service deployment with minimal coverage gaps.
Relevance	A big advantage of satellites is that the challenges faced by ground deployment are not an issue. Indeed, apart from the physical limitations set by ground deployment of base stations, such as availability of the land to build a site or the range of the tower, regulations, and delays to obtain the necessary licenses add a lot of uncertainty in the 5G

	network deployment. Satellites do not face those issues and could also become a viable alternative especially considering the aspect of expenditures. However, since MEC's are placed on ground, latency and other such KPI's may be affected risking the availability and reliability of the CAM service being provided. Data must be processed constantly to support high throughput services across different network technologies and how sustainable will it be for MNOs and other stakeholders needs to be analyzed.
Solution path	To assess the role of satellites in enabling full coverage for highways and roads in rural areas, a dedicated deployment study would be necessary. In such a study, costs could be determined by deducing whether satellites complement a 5G ground deployment. Additionally, a new category of stakeholders could be identified. Finally, a cost analysis could be done to understand the different financial impacts it would have compared to only ground deployment. It is necessary to differentiate deployment scenarios and satellite types (LEOs, HAPS, etc.). There may be various regulatory and technical limitations to such a complementary deployment scenario. A key technical hurdle to overcome is the support of a handover between terrestrial networks and non-terrestrial networks as well as inter-PLMN handovers between operators in different countries.
Ref. to ind. framework	Step 6: Deployment scenarios, Option A
Reference for Further Reading	[A] R. Gopal and N. BenAmmar, "Framework for Unifying 5G and Next Generation Satellite Communications" [B] I. Leyva-Mayorga et al., "LEO Small-Satellite Constellations for 5G and Beyond-5G Communications," [C] Z. Yan and R. Woo, “China's Geely launches first nine low-orbit satellites for autonomous cars”, Reuters, 2022

Gap	CAM service penetration forecasting
Description	While 5G-CARMEN and 5G-MOBIX have attempted to forecast CAM service penetration and developed multiple scenarios to account for the uncertainty, the actual numbers of CAVs on highways (and corresponding data traffic) remains unclear. The uncertainty around these forecasts stems from many factors, such as the regulatory environment, the success of the initial market entrance of level 3 cars, global supply chain concerns and more.
Relevance	This gap is a major driver of cost as the deployment of functionalities and the use of level 3+ cars will, not only be the driver for the actual deployment of the network but also make or break the business case standpoint. Additionally, initial predictions of CAM penetration from 2019 predicted up to 20% of level 3 cars by this year **[8]**, whereas the first market ready and approved vehicle has been released this year. Finally, the service penetration should be considered for categories of countries and not on a global European scale as the market for level 3+ cars will be highly dependent on the level of economy and income per capita of each individual country.
Solution path	To fill this gap, penetration forecasts must be newly analyzed considering upcoming information about future car releases, their availability and user acceptance rate for the country specified. This would be mostly research based on data obtained from auto manufacturers, public opinions and sales contribution of relevant CAM services.
Ref. to ind. framework	Step 5: CAM, road and network traffic demand necessities, Option A, B & C
Reference for Further Reading	[A] Ahmed, Mohammed & Iqbal, Rahat & Karyotis, Charalampos & Palade, Vasile & Amin, Saad. (2021). Predicting the Public Adoption of Connected and Autonomous Vehicles. IEEE [B] Frost & Sullivan analysis based on publicly available industry information and interviews with key participants in the automotive industry

Gap	Capacity planning for CAM
Description	The cross-border studies are primarily focused on coverage planning. Capacity required for the cross-border corridors has been estimated based on different vehicular traffic forecasts, service requirements, and additional utilization based on background traffic. Detailed capacity assessment however requires total throughput uplink/ downlink targets that depend on the number of CAM cars active in a cell with the reference service. Capacity expansion measures like spectrum, MIMO version, number of cells and sites define then the costs additional to coverage. Typically, coverage planning based on radio network planning is therefore complemented by capacity planning based e.g. on Monte Carlo simulations.[6]
Relevance	Ubiquitous coverage for CAM is a prerequisite for services. With increasing CAM traffic the rollout will chance from coverage to demand driven. Capacity expansion will become a cost driver and therefore needs to be modelled in detail. Multiple schemes for resource allocation can be used to sustain a service however, each scheme comes with their own uses and limitations which restrict the possibility of a single scheme enabling all CAM services. With each scheme having its own costs and technical challenges, this aspect must be accounted for optimized resource allocation in the CAM ecosystem.
Solution path	Field trials and simulations may help in estimating the required data rate in up- and downlink. This can then be modelled by tools using e.g., Monte Carlo simulations. A dynamic resource allocation scheme or a combination of schemes (for uplink and downlink) could be considered, and studies could be conducted on existing sites testing their viability and readiness. Additionally, the financial implications on the total cost of ownership should be

[6] In telecommunications, when planning a wireless network, design must be proved to work for a wide variety of scenarios that depend mainly on the number of users, their locations, and the services they want to use. Monte Carlo methods are typically used to generate these users and their states. The network performance is then evaluated and, if results are not satisfactory, the network design goes through an optimization process. [Source: Monte Carlo method, Wikipedia, https://en.wikipedia.org/wiki/Monte_Carlo_method]

	investigated to identify the impact of these techniques being used.
Ref. to ind. framework	Step 7: Radio network planning and capacity planning, Options A & B
Reference for Further Reading	[A] F. Tang, Y. Zhou and N. Kato, "Deep Reinforcement Learning for Dynamic Uplink/Downlink Resource Allocation in High Mobility 5G HetNet,“ [B] Le, T.T.T. and Moh, S., 2021. Comprehensive survey of radio resource allocation schemes for 5G V2X communications. IEEE Access.

Gap	On-Board Entertainment and effects on the CAM ecosystem.
Description	There are many possibilities of entertainment services available within the connected car environment, especially with the increase in use of streaming video/music/gaming application. There is hence an important need to consider the safety measures implemented for the passengers in such an environment.
Relevance	With the requirements of these entertainment services due to rising customer demands, priorities must be assigned so that CAM services which directly impact the safety of the passengers and/or cargo are not given up easily. With another perception of some stakeholders, entertainment can be viewed as a platform to gain revenue.
Solution path	Strict regulations in terms of bandwidth/latency/network coverage must be made to ensure that basic requirements of different CAM services are reached. Additionally, priority should be assigned to CAM traffic so that the safety requirements can be achieved. To build an efficient system supporting CAM and entertainment service should be

	prioritized so that none of the stakeholders suffer any significant loss (revenue, customer safety, etc.).
Ref. to ind. framework	Step 7: Radio network planning and capacity planning, Option A, B & C
Reference for Further Reading	[A] https://www.ericsson.com/en/blog/2021/10/powering-connected-cars-with-5g [B] https://www.fortunebusinessinsights.com/automotive-infotainment-market-102676

Gap	Multi-Access Edge Computing to sustain CAM services.
Description	All the deployment studies agreed (supported by the trials) that **Multi-Access Edge Computing (MEC)** will play a major role in sustaining CAM services along cross-border corridors. MEC refers to decentralized data processing at the edge of the network or 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 centers). The calculations are carried out close to the highways where the data originates. All three studies have made referenced MEC to some extent, however, due to its very nascent stage the studies' assumptions regarding MEC have been relatively vague.
Relevance	As edge computing is in its nascent stage, there is a high uncertainty on MEC size and quantities required to achieve even lower latencies. As the deployment studies estimates range from one MEC per base station to one MEC for 20,000 km of road, costs can vary significantly.
Solution path	To get a clear understanding of the quantity, size and corresponding costs of local MECs, future deployment studies could use data and inputs from trial sites. Data on real achieved latencies in 5G networks (NSA & SA) are necessary to estimate the need for local MECs.
Ref. to ind. framework	Step 8: Multi-access Edge Computing, Options A & B

Reference for Further Reading	**[A]**[**https://5gcroco.eu/images/templates/rsvario/images/5GCroCo_MEC_v2.pdf**](https://5gcroco.eu/images/templates/rsvario/images/5GCroCo_MEC_v2.pdf) **[B]** https://www.5G-MOBIX.com/assets/files/5G-MOBIX-D4.2-Report-on-the-methodology-and-pilot-site-protocol-_v1.0.pdf **[C]** https://5G-CARMEN.eu/wp-content/uploads/2021/10/D2.2-18May2021.pdf

Gap	Small Cells / Use of existing infrastructure
Description	Small cells offer the possibility of being mounted onto light poles and similar low-cost infrastructure rather than expensive base station masts and towers. However, they also require a much higher density, as they typically operate in the millimeter Wave spectrum.
Relevance	The cost impact of small cells is difficult to estimate at this stage as studies have not yet been performed for deployment for small cells with CAM applications. While some rule it out entirely for rural highways, others argue that due to lower costs per cell, higher density is possible at a lower overall cost. If an infrastructure can be built and operation can be sustained using small cell technology, CAPEX can be reduced significantly.
Solution path	To estimate whether small cells could be a viable alternative to macro cell deployment, a careful estimation of the cost of small cells along highways is needed. Many rural highways are not covered with light poles entirely. Also, in many countries' regulations require masts for mobile communication cells with specific technical requirements, ruling out the possibility of using other infrastructure.
Ref. to ind. framework	Step 6: Deployment scenarios, Option A
Reference for Further Reading	[A] GSMA, https://gsma.force.com/mwcoem/servlet/servlet.FileDownload?file=00P1r000025E2yhEAC [B] Indian https://tec.gov.in/pdf/Studypaper/TEC%20Committee%20Report%20on%20Rollout%20of%20small%20cells.pdf,Indian Ministry of Communications. [C] Kousaridas et al., 5G Vehicle-to-Everything Services in Cross-Border Environments: Standardization and Challenges

Gap	Impact of Network Sharing and the different options available
Description	Network sharing refers to multiple MNOs sharing the same active and/or passive network infrastructure in order to reduce CAPEX/OPEX. This can range from sharing a tower (passive) with each MNO placing its own active equipment (e.g., antennas, transceivers) up to sharing the active infrastructure itself.
Relevance	Network sharing can play a crucial role in reducing the MNOs CAPEX burden and accelerating 5G deployment particularly in rural areas. With different forms of sharing options available (such as passive sharing, co-location, site sharing, active sharing, RAN sharing, frequency pooling, backhaul sharing, etc.), which form is agreed upon by MNOs and how will they be assessed by NRAs, these questions must be taken into consideration with regards to the CAM deployment scenario. At this stage it remains unclear to what extent MNOs will (be able to) rely on network sharing, as regulations and agreement schemes are under development.
Solution path	Considering the cost impact of network sharing is difficult to impossible as it is entirely based on the agreements between two MNOs. Many factors must be considered such as competitive market forces evolution, the feasible level of competition, type of sharing, shared information between the sharing parties and its impact on their ability to compete, reversibility and contractual implementation, etc. These factors must be agreed upon by MNOs and even then, most of those agreements are confidential. Interviews with MNOs could shed more light onto this and provide some insights for an assumption-based approach to calculate the enabled savings from employing network sharing within the CAM infrastructure.
Ref. to ind. framework	Step 6: Deployment scenarios, Option A
Reference for Further Reading	[A]https://www.gsma.com/futurenetworks/wiki/infrastructure-sharing-an-overview/ [B]https://www.accenture.com/us-en/insights/communications-media/active-network-sharing

[C]https://www.accenture.com/_acnmedia/PDF-165/Accenture-EP9-Telco-Cloud-POV-Draft-V13.pdf#zoom=40
[D] The Body of European Regulators for Electronic Communications, https://berec.europa.eu/eng/document_register/subject_matter/berec/download/0/9738-summary-report-on-the-outcomes-of-mobile_0.pdf

Gap	Cross-border network handovers
Description	When passing in a cross-border corridor the network reselection procedure usually comes with delays of up to several minutes **[9]**, particularly in a multi-MNO, multi-vendor and multi-manufacturer scenario.[7] Such delays could lead to the failure of safety critical applications, enabled by CAM, that require low latency and service continuity. Additionally, the 5G slice necessary to sustain the applications requirements must be communicated and matched between operators in different countries **[10]**.
Relevance	Taking into consideration the costs of facilitating cross-border network handover and minimizing the handover times is crucial for 5G for CAM. The main technical solution, in **[9]** and **[11]**, to solve the handover is the implementation of Mobile Edge Computing close to network edge while serving as an interconnection between MNOs on both sides of the border.
Solution path	Based on the various cross-border trials within the ICT-18 projects it is possible to derive the best practice cross-border set-up of the MEC-enabled network handover. This can be used as a starting point to derive the costs of the necessary equipment. Yet, the organizational and contractual efforts for the MNOs remain a significant cost driver, that is hard to estimate and will highly depend on the individual case. Standardized technical and non-technical cross-border interfaces must be developed and implemented in order to facilitate these handovers in the future.

[7] It should be noted that the trials within the ICT-18 projects have achieved network handovers within milliseconds under optimized conditions.

Ref. to ind. framework	Step 7: Radio network planning and capacity planning, Option A Step 8: Multi-access Edge Computing, all Options
Reference for Further Reading	[A] 5GAA, Cross-Working Group Work Item: Network Reselection Improvements (NRI) [B] 5GCroCo, Deliverable D3.2: Intermediate E2E, MEC & Positioning Architecture, https://5gcroco.eu/images/templates/rsvario/images/5GCroCo_D3_2.pdf [C] Mazen, Abdel Latif, Demonstration and Evaluation of Cross-Border Service Continuity for Connected and Automated Mobility (CAM) Services

Gap	CAM coverage gap tolerance and signal strength requirements
Description	The signal strength refers to the strength of the radio signal at the cell edge that is required from the car for sufficient connectivity. CAM coverage gap tolerance refers to the time and/or distance that a CAV (level 3+) may be able to continue driving without compromising on critical services.
Relevance	In the radio planning, the signal strength at the cell edge is one the main determinants of the point at which a new cell is required to provide seamless connectivity. Hence, it is a critical parameter significantly affecting the site density (or BoQ) and thereby the overall investment required. Additionally, it is possible, in cases where V2V communication is enabled for a specific service, interference with the V2N signals may get affected and therefore reduce the reliability of the service.
Solution path	Covering this gap requires an in-depth analysis of the requirements of OBUs in the coming years. This can be done by analyzing technical specifications of the on-board equipment (possibly available from the trial sites) as well as direct discussions on the topic with representatives of the automotive industry and OEMs.

Ref. to ind. framework	Step 1: CAM Requirements and services, Option A, B & C
Reference for Further Reading	[A] Toril, Matias & Wille, Volker & Luna-Ramírez, Salvador & Fernandez-Navarro, M. & Ruiz-Vega, Fernando. (2021). Characterization of Radio Signal Strength Fluctuations in Road Scenarios for Cellular Vehicular Network Planning in LTE. IEEE Access. PP. 1-1. 10.1109/ACCESS.2021.3060995.

Gap	Network Slicing
Description	Network slicing plays a major role in continuously fulfilling the CAM requirements as it allows partitioning of the physical network into virtual networks optimized for specific applications. The challenge in network slicing is a fair resource allocation wherever the vehicle (using CAM services) is located to support the necessary latency, reliability, and capacity. Network slicing also constitutes a major new market for communication service providers of up to 200 bUSD by 2025 **[12]**.
Relevance	This gap plays a key role in the network deployment as the CAM service can require specific network slicing in order to provide the necessary reliability. Additionally, most CAM services require Ultra-Reliable Low-Latency Communication (URLLC) to operate, which would come at higher costs. Particularly for safety-related use cases, a separate slice can be envisioned to avoid service failure in peak data traffic scenarios.
Solution path	The network slicing requirements for the different CAM use cases should be identified. Furthermore, studying the cost of fulfilling those network slicing requirements for each of the different identified use cases would give a simple insight on the financial impact it would have on a

	deployment study. Finally, including market predictions for network slicing could give an insight in future revenues and major stakeholders.
Ref. to ind. framework	Step 7: Radio network planning and capacity planning, Option A
Reference for Further Reading	[A] A. Lekidis and F. Bouali, "C-V2X network slicing framework for 5G-enabled vehicle platooning applications," [B] S. Zhang, "An Overview of Network Slicing for 5G," in IEEE Wireless Communications, vol. 26, no. 3, pp. 111-117, June 2019, [C] Network slicing, John Burke, TechTarget https://www.techtarget.com/whatis/definition/network-slicing

Gap	**Availability of space on base station site for antenna upgrade**
Description	All deployment studies have assumed that new 5G antennas can be installed at any existing site. However, the use of existing base stations is not a certainty, as it does not take into consideration if the existing sites have enough capacity and even have space on the tower to install a new antenna to cover the required sectors.
Relevance	Considering the actual possibility of upgrading (i.e., placing additional antennas/active equipment) at each site is important, as additional sites may be needed while further increasing the passive CAPEX/OPEX for deployment and operation.
Solution path	In order to investigate this, it would be necessary to evaluate the capability of each site to "carry" additional 5G equipment. The MNOs/TowerCos are likely to have the most comprehensive view on this.
Ref. to ind. framework	Step 7: Radio network planning and capacity planning, Option A
References for further reading	[A] Huawei, 5G-oriented Site Evolution, https://carrier.huawei.com/en/trends-and-insights/emsite/5g-oriented-site-evolution#:~:text=A%20typical%205G%20site%20has,antennas%20is%20about%2050%20kg.

4.2 Regulatory and Institutional Gaps

We have identified 6 Regulatory-Institutional gaps focusing on aspects that have the most influence on the swift deployment of CAM infrastructure within a cross-border corridor which will be governed by regulators and lawmakers of each individual nation as well as the European Union.

Gap	Harmonized Roll out obligations across various NRAs
Description	Each European NRA may independently assign spectrum and issues roll-out obligations to license holders. This means that license holders (i.e., MNOs) may face very coverage obligations in one country, while others may deploy 5G solely driven by commercial incentives.
Relevance	Deployment studies focus on the investment gap/delta. If an MNO is obligated to cover a certain type or section of road as per its license, then it is not part of the investment delta. Thus, the impact of license obligations is highly significant and clearly calls for harmonization among EU countries and possibly also with non-EU countries.
Solution path	Including the roll-out obligations of each license holder is a relatively simple task and needs to be considered. License obligations are publicly available information published by the respective NRA. Deriving whether the corridor under investigation will be covered may require more detailed analysis depending on the obligations' level of complexity (definition of service levels, capacity, latency, reliability, signal strength).
Ref. to ind. framework	Step 3: Country-specific regulatory environment, Option A
Reference for Further Reading	[A] 5G Observatory, https://5gobservatory.eu/national-5g-plans-and-strategies/

Gap	Environment and climate impact
Description	The climate footprint of the mobile communications infrastructure has been getting more and more attention. Stricter rules and higher CO2 certificate prices may also affect 5G infrastructure and related costs in the coming years. The higher network density will likely cause a significant CO2 and environmental impact.
Relevance	A large share of the costs to mitigate 5G's climate impact will likely fall into the RAN network domain. This also has a significant impact on the rural infrastructure along highways. Although there will be environmental and climate benefits from CAM, the energy consumption of the RAN infrastructure may not be ignored.
Solution path	In a first step, future deployment studies could estimate the CO2 footprint as well as other environmental impacts of the 5G for CAM infrastructure. Secondly, potential mitigation measures could be explored along with the corresponding price tag. The share of which is attributed to CAM-specific usage could then be considered relevant to the investment delta.
Ref. to ind. framework	Step 3: Country-specific regulatory environment, Option A Step 9: Cost and delta calculation, all Options
Reference for Further Reading	[A] Detecon, Telco Journey towards net-zero: Challenges, https://www.detecon.com/en/journal/telco-journey-towards-net-zero-challenges [B] France's High Council on Climate, Controlling the Carbon Impact of 5g, https://www.hautconseilclimat.fr/wp-content/uploads/2020/12/hcc_rapports_5g-en.pdf [C] Du, Jianhe & Ahn, Kyoungho & Farag, Mohamed. (2022). Environmental and Safety Impacts of Vehicle-to-Everything Enabled Applications: A Review of State-of-the-Art Studies. 10.20944/preprints202201.0144.v1. [D] Massar, M., Reza, I., Rahman, S.M., Abdullah, S.M.H., Jamal, A. and Al-Ismail, F.S., 2021. Impacts of Autonomous Vehicles on Greenhouse Gas Emissions—Positive or Negative?. International Journal of Environmental Research and Public Health, 18(11), p.5567

Gap	Cross-border policies for data access and control
Description	Constant data broadcasting through CAVs raises potential concern about how to address privacy and data protection. The issue becomes even more complex when looking at cross-border scenarios where data will be moved to and from different countries and operators. More complexity comes from borders between EU and non-EU countries, such as the Greek-Turkish corridor.
Relevance	Additional privacy layers in the form of encryption between CAVs and surrounding road and communications infrastructure may add to the costs in terms of software development ensuring interoperability between different manufacturers of in-car software, on-board units, road-side infrastructure**,** and the like. The same applies to privacy concerns of 5G infrastructure. However, this appears to be a general issue and not directly CAM-specific. The effect on the investment delta is unclear at this stage.
Solution path	The necessary measures implemented within hardware and software of 5G infrastructure to incorporate data privacy and access issues that are specific to CAM services would have to be evaluated in terms of necessity and cost impact. In case of services being implemented within CAM which allow for access to data, additional regulations and amendments to existing laws might be needed.
Ref. to ind. framework	Step 3: Country-specific regulatory environment, Option A
Reference for Further Reading	[A] https://5gaa.org/news/privacy-by-design-aspects-of-c-v2x/ [B] **https://www.ctrl-shift.co.uk/wp-content/uploads/2021/08/Growth-of-the-Connected-Vehicle-Data-Market-May-2020.pdf**

Gap	Regulatory-legal uncertainty
Description	With respect to CAV fleet penetration (level 3 and up), there are still many legal hurdles to take. So far, only very few countries have implemented legislation regulating the use of level 3 and above CAVs.[8] Accidents caused by faulty software could easily have a severe impact on public opinion and force policy makers into restricting CAM service applications. This would obviously come with a severe reduction of possible use cases and potentially a reduced connectivity demand.
Relevance	A reduction in the demand coming from CAM due to restrictive legislation is not an entirely unrealistic scenario. It may lead to "over deployment" of 5G infrastructure along highways. However, this scenario is likely to be temporarily restricted and may be overcome eventually by advances in technology.
Solution path	As of now, it is difficult to say how policy makers across Europe will regulate the advent of connected, automated driving. This can be a very dynamic process in the coming years and different countries may take different legislative decisions. The coming years and real market entrance of level 3+ vehicles will test the legislative environment and soon show the need to amendments.
Ref. to ind. framework	Step 5: CAM, road and network traffic demand necessities
Reference for Further Reading	[A] Telenor, Regulatory uncertainty in the development of 5G services, https://www.telenor.com/media/public-policy/telenor-principle-position-on-the-open-internet-and-net-neutrality/european-open-internet-regulation-regulatory-uncertainty-in-the-development-of-5g-services/ [B] Bauer, J.M. and Bohlin, E., 2022. Regulation and innovation in 5G markets. *Telecommunications Policy*, *46*(4), p.102260.

[8] Germany's cabinet has adopted new legislation for level 3 cars (https://www.bundesregierung.de/breg-en/federal-government/faq-autonomous-driving-1916398)

Gap	Access modalities to the road operator network
Description	Many road operators maintain fiber along highways. This may provide an opportunity for cooperation with MNOs. However, in many countries this is prohibited by market and competition regulations. NRAs could consider exceptions along rural highways in order to reduce the backhaul CAPEX burden for operators with respect to CAM.
Relevance	Using third-party (i.e., road operators') fiber infrastructure could significantly reduce backhaul-related infrastructure CAPEX for MNOs in commercial less relevant areas, specifically among highways running through areas with low population density.
Solution path	To estimate the optimization potential of MNOs renting out fiber from road operators, it is necessary to first check the regulatory-legal situation. If it is generally permitted, the next challenges lie in understanding the fiber rental agreements and commercial conditions. This may pose a significant challenge, as these individual agreements between private companies are typically confidential. Industry interviews may be one option to arrive at an estimation, however at high efforts and high uncertainties regarding the results.
Ref. to ind. framework	Step 3: Country-specific regulatory environment Step 7: Radio network planning and capacity planning
Reference for Further Reading	[A] UNESCAP, https://www.unescap.org/sites/default/files/g_Mr%20Murat%20Barut.pdf [B] https://vxfiber.com/open-access-model/

4.3 Financial Gaps

We have identified 7 Financial gaps which highlight possible new stakeholders which can become part of the CAM ecosystem by developing new services and products, thereby giving rise to new forms of revenue that will further incentivize other stakeholders to expedite the deployment of CAM infrastructure.

Gap	Role of big tech
Description	There is high uncertainty around forecasting CAM service deployment and the requirement coming from the actual hardware and software that will be on the roads in the coming years. Automakers are catching up in developing connected products and software but remain behind the capabilities of the big tech companies. Therefore, these companies are likely to play a crucial role in determining the future of the connected car.
Relevance	These companies plan to play a major role in this sector and are expected to massively invest into resources and knowledge to develop on-board software and applications. Therefore, they are likely to determine a large part of the necessary requirements for the different services and will enter in the financial equation. Finally, cooperation between the big tech and car makers could completely change the service penetration forecast and allow for faster deployment of level 3+ cars.
Solution path	To analyze the impact of this gap, it would be necessary to first research the big tech companies and investigate where their major resources are being invested in this field. Additionally, the cooperation between car makers and big tech could be investigated and interviews could give an improved insight as to what role big tech may play in the final product.
Ref. to ind. framework	Step 1: CAM requirements and services, all Options
Reference for Further Reading	[A] Big Tech vs the automakers: The battle for the connected car, Automotive World, https://www.automotiveworld.com/articles/big-tech-vs-the-automakers-the-battle-for-the-connected-car/ [B] Big Tech's Next Monopoly Game: Building the Car of the Future, Politico, https://www.politico.com/news/magazine/2021/12/27/self-driving-car-big-tech-monopoly-525867

Gap	Connected Vehicle Cloud and the data generated
Description	The Connected Vehicle Cloud is part of an integrated automated system that allows connected vehicles to exchange real-time traffic data in order to increase the safety and efficiency of traffic flows. The focus on this aspect are mainly on cloud applications, their roles, their cost and challenges.
Relevance	Cloud for CAM is expected to improve cost-efficiency, scalability, and reliability along with bringing access to new and innovative technologies as a readily available service. OEMs especially will benefit greatly from using such platforms and thereby facilitate provision of services to the CAM ecosystem.
Solution path	Solutions for cloud-based transformation must be designed and adopted by stakeholders in order to unlock the full capabilities of a connected vehicle ecosystem. At this stage it is unclear which stakeholders would bear the cost of the cloud but would be a highly relevant topic for future research.
Ref. to ind. framework	Step 8: Multi-access Edge Computing
Reference for Further Reading	[A] McKinsey, https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/unlocking-the-full-life-cycle-value-from-connected-car-data [B] Ericsson, https://www.ericsson.com/en/connected-vehicles/platform [C] Accenture, https://www.accenture.com/us-en/insights/automotive/cloud-imperative

Gap	Communal benefits in absence of a transaction
Description	CAM services will allow to optimize road traffic, facilitating mobility. In the immediate future, the business case for CAM services is not clear, but the communal benefits to European citizens, particularly from C-ITS applications, in the form of increased traffic safety and efficiency can be identified and set into perspective of the goals of the European Union.
Relevance	The goal of reducing accidents and optimizing road traffic has been on the European and regional agenda for a long time. CAM services could allow it and enabling it would benefit the European community.
Solution path	The challenges in the automotive transport sector could be studied and clearly identified. Furthermore, the potential impact of CAM services improving those challenges, such as avoiding road hazards, optimizing transport routes, avoiding congestion and reducing deaths linked to car accidents could be studied. The effort would be small.
Ref. to ind. framework	Step 4: Country-specific financial aspects Step 9: Cost and delta calculation
Reference for Further Reading	[A] J. A. Guerrero-Ibanez, S. Zeadally and J. Contreras-Castillo, "Integration challenges of intelligent transportation systems with connected vehicle, cloud computing, and internet of things technologies," [B] Car 2 Car, https://www.car-2-car.org/about-c-its/

Gap	Development of new services and products by OEMs and suppliers
Description	At this stage, on-board units (both software and hardware) are going through dynamic changes with fast paced evolution of technologies. A separation of hardware (HW) and SW would fundamentally change the landscape of the automotive industry and the accompanying services provided by them.
Relevance	The rapid development of vehicular on-board hardware and software has significant implications for the expected network traffic and corresponding capacity demand. Partially, this has been addressed by the studies by investigating different scenarios. However, it remains a gap as it is extremely hard to predict the extent of OEM reliance on 5G connectivity.
Solution path	Constant observation of real-time traffic data from connected, automated vehicles is necessary as they hit the market, while exploring results from trial sites and closely observing the newest developments of on-board units from OEMs to make sure that network traffic estimates are as accurate as possible. However, there will always be a risk that OEMs may use different technologies eventually.
Ref. to ind. framework	Step 1: CAM requirements and services, all Options Step 7: Radio network planning and capacity planning, Option A & B
Reference for Further Reading	[A] Yang Wang, Wei Ning, Shengyu Zhang, Hao Yu, Hongjie Cen, Sunan Wang, Architecture and key terminal technologies of 5G-based internet of vehicles, Computers and Electrical Engineering, Volume 95, 2021, 107430, ISSN 0045-7906, https://doi.org/10.1016/j.compeleceng.2021.107430. (**https://www.sciencedirect.com/science/article/pii/S0045790621003918**) [B] McKinsey, Automotive software and electronics 2030**,** https://www.mckinsey.com/~/media/mckinsey/industries/automotive%20and%20assembly/our%20insights/mapping%20the%20automotive%20software%20and%20electronics%20landscape%20through%202030/automotive-software-and-electronics-2030-final.pdf

Gap	Role of logistic companies
Description	CAM will offer many functionalities that will bring benefits to stakeholders such as logistic companies. Indeed, logistic companies use European highways and therefore cross border regions intensively. Additionally, regulators are enforcing new regulations to minimize the carbon footprint and pollution in urban areas. New CAM technology for trucks and busses, may play a major role in meeting the new expectations set by the industry and therefore fast adoption
Relevance	Unlike the random behavior of a single car driver, trucks follow a precise route mostly on specific corridors, including many cross-border corridors, outside of urban areas. Therefore, logistics companies are a central beneficiary of 5G network deployment and should be considered as such by deployment studies. Additionally, for this non-random behavior, achieving full coverage proves much easier as the main routes stay the same and unexpected changes of directions do not need to be covered.
Solution path	To cover this gap, the CAM services, requirements and the use cases for transport vehicles should be investigated in more detail. Additionally, with more complexity the most frequently used corridors and trucks stops could be identified **[13]**, in order to understand the necessary coverage. Finally, calculating the potential financial benefits of this infrastructure for logistic companies and the business case for the MNOs and ROs, would be of interest but would be rather complex to do.
Ref. to ind. framework	Step 1: CAM requirements and services, all Options Step 4: Country-specific financial aspects, Option A & B
References for further reading	[A] 5G-MOBIX Deliverable 6.2: Plan and preliminary report on the business models for cross border 5G deployment enabling CAM, **https://5g-mobix.com/assets/files/5G-MOBIX-D6.2-Plan-and-preliminary-report-on-the-business-models-for-cross-border-5G-deployment-enabling-CAM-v2.pdf**

Gap	Revenue model for CAM services yet to be defined
Description	Revenue models from CAM services have not yet been clearly defined by any of the studies. The 5G-Carmen DS has made some assumptions with respect to the revenue side of the case, yet many factors remain vague. The charging models of CAM services are expected to vary drastically depending on the type of service. Additionally, according to **[14]**, the global connected car market will experience considerable growth leading to major revenue streams for CAM services.
Relevance	Identifying the core business cases would allow to identify key stakeholders, which will profit from the deployment of a 5G network for CAM. Furthermore, assuming **[15]** that more than 50% of the cars would be connected, these organizations could also be profiting from the massive market of car-data monetization.
Solution path	A study could be conducted using white papers, interviews and publicly available estimation of revenue per car for the CAM services and the connectivity enabled value of data. The effort would be not too considerable and potentially allow identification of the future beneficiary of this expanding market.
Ref. to ind. framework	Step 9: Cost and delta calculation, Option A & B
References for further reading	[A] 5G-MOBIX Deliverable 6.2: Plan and preliminary report on the business models for cross border 5G deployment enabling CAM, **https://5g-mobix.com/assets/files/5G-MOBIX-D6.2-Plan-and-preliminary-report-on-the-business-models-for-cross-border-5G-deployment-enabling-CAM-v2.pdf**

Gap	Price Evolution and Inflation
Description	Considering at the volatile market situation across the globe, price evolution factors as well as inflation rates deserve additional attention.
Relevance	The impact of this situation can significantly affect both the demand and the cost side. Global supply chain issues (e.g., semiconductors) may affect RAN equipment prices as well as the CAV fleet penetration due to delayed vehicles sales.
Solution path	Using external sources on equipment price evolution, such as World Bank/IMF data as well as industry-specific resources, it may be possible to account for these uncertain developments to some extent.
Ref. to ind. framework	Step 4: Country-specific financial aspects, Option A & B
Reference for Further Reading	[A] https://www.rcrwireless.com/20220103/5g/5g-supply-chain-challenges-continue-during-2022-abi-research [B] **https://www.lightreading.com/5g/supply-chain-problems-may-slow-midband-5g-in-us/d/d-id/773490** [C] https://bscw.5g-ppp.eu/pub/bscw.cgi/d293672/5G%20PPP%20Automotive%20WG_White%20Paper_Feb2019.pdf

5 Harmonization of the deployment studies' results

5.1 Overview of the cost results between the studies

In order to harmonize the costs between the studies, the key methodological differences need to be discussed. Therefore, we identified three parameters that impact the costs and need to be addressed: the timeframe, the corridor choice, and the RAN deployment choices.

5.1.1 The timeframe

The timeframe of each study impacts majorly the resulting costs. Indeed, in 5G-MOBIX, the deployment study focused for each of the corridors on two years where the network would be deployed, in 2023 and 2025. This was done taking into consideration the country specific coverage obligations, linked to spectrum allocation, and the planned deployments and upgrades, and therefore has a substantial impact on total costs of the same deployment in both years. In 5GCroCo, no specific timeframe has been considered and therefore the costs correspond to an immediate deployment of the planned network. And finally, in 5G-CARMEN, the deployment corresponds to a continuous roll-out of sites between 2021 and 2025, and later for a specific segment from 2026 to 2030. This continuous roll out is based on a timeline of availability of CAM services and two CAM service penetration estimations, and therefore impacts majorly the costs.

5.1.2 The corridor choice

The corridor choice represents another major cost driver. In 5G-MOBIX, the corridors selected are all standardized to stretch across 20 km of motorways on each side of the border. Additionally, the costs for each deployment are calculated based on prices calculated for each country, therefore each 20 km corridor segment will have different costs. In 5GCroCo, the corridors are determined within a country, close to the border and vary completely in length, with 24.5 km in Luxembourg, 78 km in Germany and 96.76 km in France. This makes it much harder to compare the deployment costs them within each other without normalizing the costs to 100 km. Finally, for 5G-CARMEN, the corridor chosen of over 600 km between Munich and Bologna has been divided in three- to seven-kilometer-long segments. Those segments have very specific geographical landscape and include, mountainous areas, river crossings, border crossing, rural and densely populated areas. This has a major impact on costs as precise radio planning in these specific segments has been conducted, taking into consideration things such as path loss and scattering.

5.1.3 RAN deployment choice

The RAN deployment choices represent the last major cost driver in the studies. In 5G-MOBIX, the deployment has been studied using a 700 MHz spectrum and separately a 3.5 GHz spectrum, leading to a considerable difference in IsD in the two cases, hence impacting the costs. Additionally, the costs have been determined independently for both frequency spectrum, for each country, and for both the CAPEX of a new site and an upgraded site. In 5GCroCo, the costs have been calculated based on a deployment with an IsD of 3 km or 1 km, and the deployment of 3.5 GHz for new sites, and upgrades of existing sites to 700 MHz and 3.5 GHz. Additionally, the costs of these upgrades and new sites have been calculated using a percentage of the CAPEX attributed to CAM, making it a major factor of the costs. Finally, in 5G-CARMEN, the deployment is based on precise radio planning on small segments of the corridor with a deployment of new sites of 700 MHz or 3.7 GHz and the upgrade of existing sites to those respective frequencies.

5.2 Assessment of the key methodological differences of the results

To furthermore analyze the costs between the studies, we compare the key methodological differences mentioned in the previous section for each of the studies cost results. Additionally, we will make assumptions to allow for a harmonized cost comparison. To harmonize the costs between the studies, we first compare the key methodological differences in cost calculation. In the following sub sections, we will list the costs for each of the studies with the key assumptions.

5.2.1 5G-MOBIX

As mentioned earlier, in 5G-MOBIX the main deployment cost drivers of the total deployment costs is the countries where the network is deployed, the timeline and the corridors chosen.

The impact of the country where the deployment is performed is major. When observing Figure 8 and Figure 9, we can see a difference in costs for a 700 MHz site of -38% between Norway and Turkey, and -43% for a 3.5 GHz site.

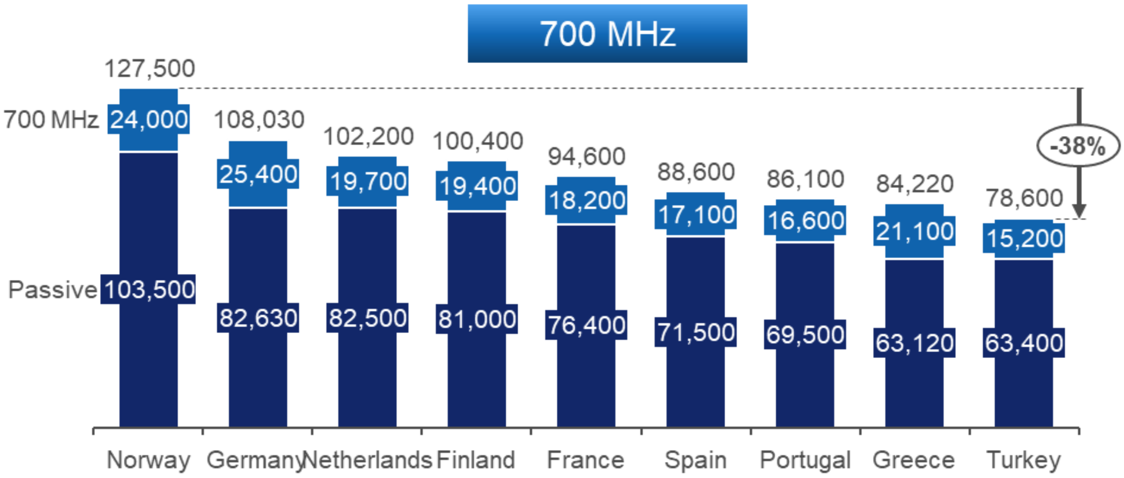


Figure 8: Total CAPEX cost comparison between countries for 700 MHz

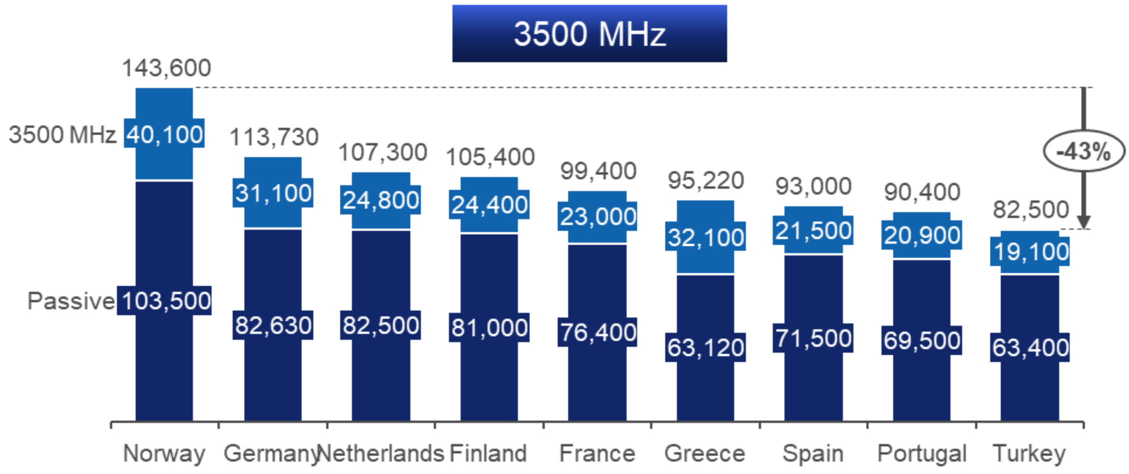


Figure 9: Total CAPEX cost comparison between countries for 3.5 GHz

Furthermore, the timeline also makes a big difference as we can observe overall lower cost of deployment in the 2025 horizon. This is mainly explained by the assumption that the operators fulfill their spectrum related obligations, which vary between countries and therefore add a variable of uncertainty. Therefore, we choose to consider the deployment in 2023 to compare the costs between corridors as seen in Figure 10 and Figure 11.

When looking into the corridor costs, we observe a major difference in costs between corridors. Indeed, when comparing the deployment costs of a 3.5 GHz deployment on the Dutch – German (DE-NL) corridor with the Finnish – Norwegian (FI-NO) corridor we can observe a price more than five times higher for the FI-NO corridor. In this case, the higher costs of the deployment are mostly due to the already existing 3.5 GHz network in Germany and the Netherlands.

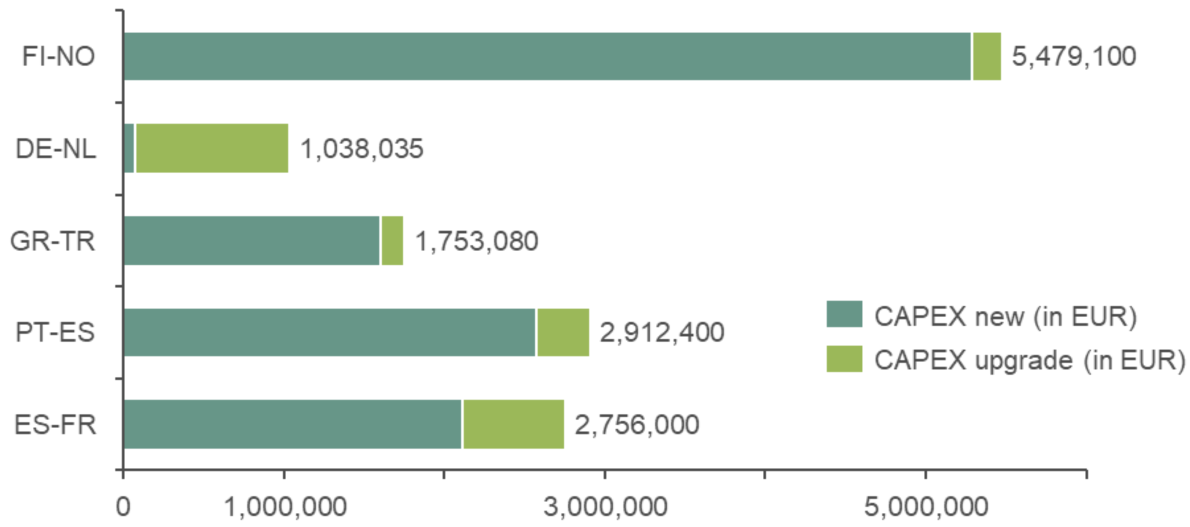


Figure 10: CAPEX for new sites and upgrades for all five corridors for 3.5 GHz

In Figure 11, the total cost of a 700 MHz deployment shows a difference of more than four times higher costs between FI-NO and the Spannish – French (ES-FR), with the FI-NO corridor staying the most expensive.

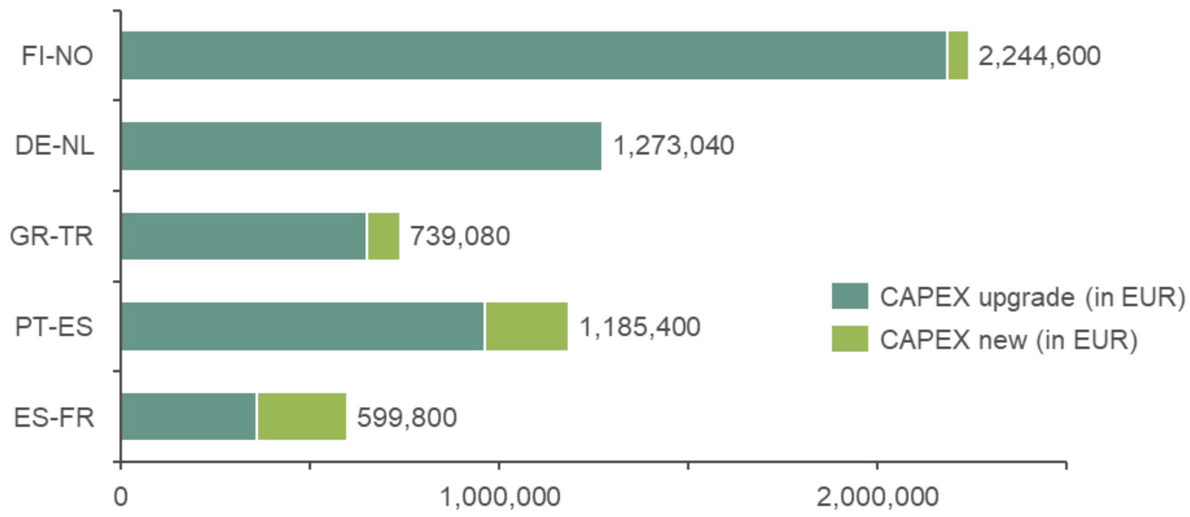


Figure 11: CAPEX for new sites and upgrades for all five corridors for 700 MHz

These graphs show the diversity of costs between corridors, especially how the locations completely influence the total cost. Therefore, with up to 500% CAPEX cost differences between corridors, the average total CAPEX and the average IsD for both deployment scenarios should be considered in order to compare with the other studies.

5.2.2 5GCroCo

As mentioned previously, the 5GCroCo costs are based on an immediate deployment and have as main cost drivers the inter-site distance and the chosen corridor. Additionally, for two of the corridors, the French and the German, the exiting sites considered are mapped based on the national network authorities, whereas the Luxembourgish corridor considers only sites of one of the local operators, POST. Furthermore, for the Luxembourgish corridor, a low/mid band coverage scenario, with an IsD of 6 km, has been considered.

When studying the costs for each scenario, we can observe many similarities between the corridors, especially for the upgrade costs. Indeed, the costs of the low/mid band and 3.x band upgrade within each corridor arrive at a similar cost range. This is because in each case the costs of the upgraded sites all include an 10% of the CAPEX of a low/mid band upgrade and 50% of the CAPEX of a 3.x band upgrade.

The total costs for the French corridor, seen in Figure 12, show the impact of the IsD on the price. Between the 3 km IsD scenario and the 1 km IsD scenario we can observe an increase of new hardware CAPEX of more than five times.

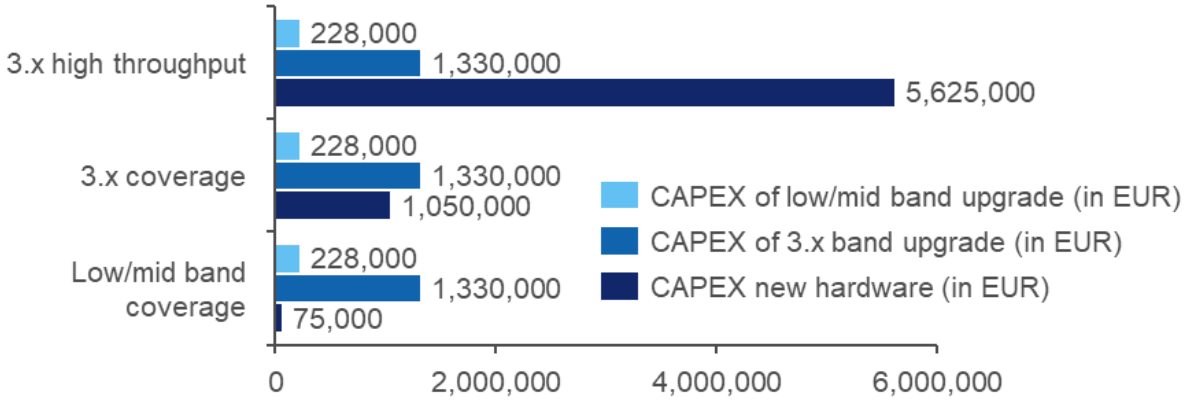


Figure 12: Deployment cost for each scenario, on the 96.76 km French corridor

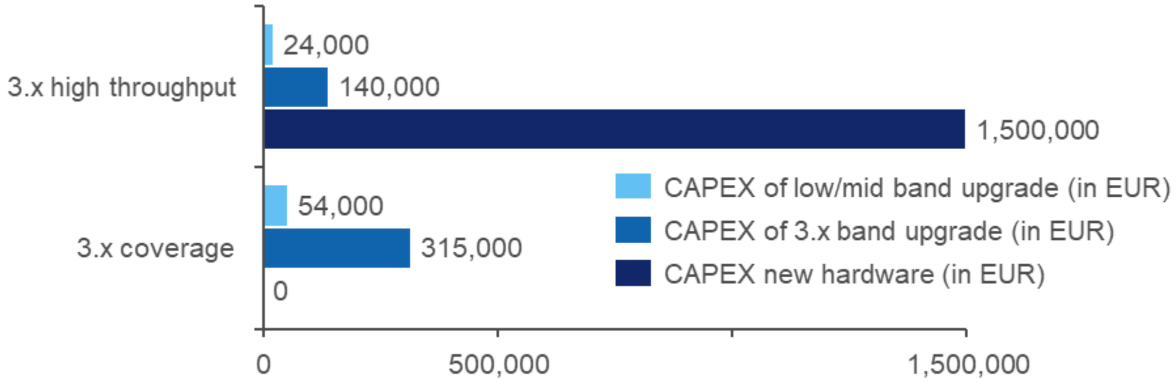


Figure 13: Deployment cost for each scenario, on the 24.5 km Luxembourgish corridor

For the German corridor, seen in Figure 14, the difference between the new hardware CAPEX is more than 7 times higher for the 1 km IsD than for the 3 km IsD. And for the Luxembourgish corridor, seen in Figure 13, the study shows no new sites necessary for the 3 km IsD and a total CAPEX for new hardware, of only 25% less than for the German corridor, of 1.5 mEUR.

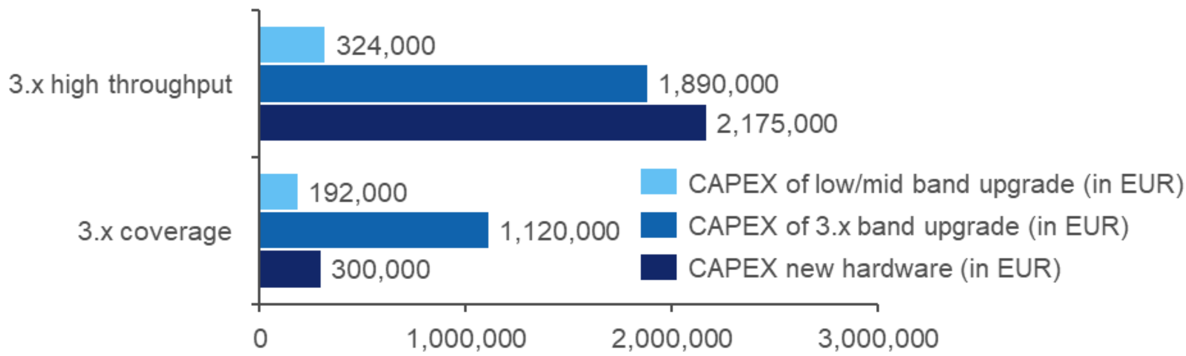


Figure 14: Deployment cost for each scenario, on the 78 km German corridor

Finally, to compare the costs of all three corridors the total CAPEX costs have been calculated and plotted in Figure 15, except for the low/mid band scenario in France, as it has been only considered in one of the corridors. This figure, show a difference in total CAPEX for the 3.x high throughput case of -77% between the French and the

Luxembourgish corridor, almost aligned with the close to -75% difference in corridor size. However, when comparing to the German corridor, the costs difference in the high throughput case is -39% lower than for the French corridor, with a difference of less than 20% in size. These type of comparison showcases the necessity to normalize the costs to a specific price per km in order to allow for a fair comparison.

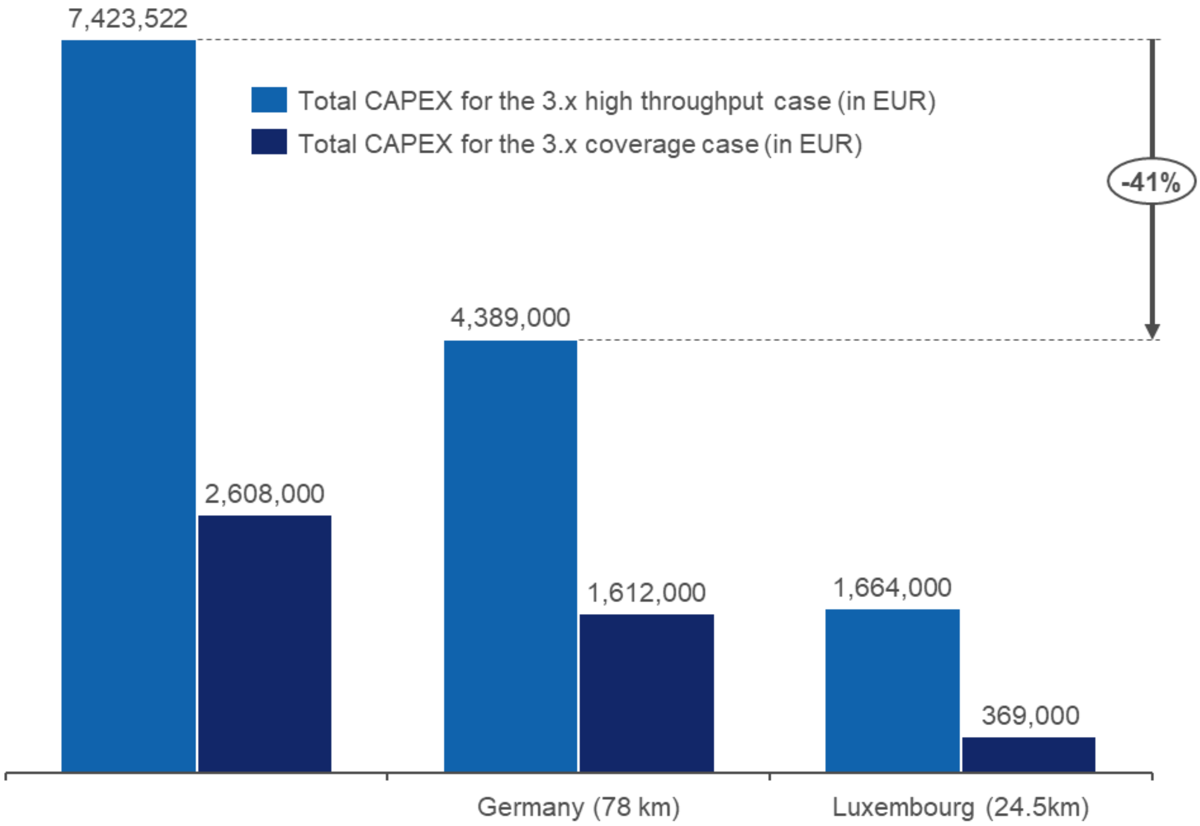


Figure 15: Total CAPEX for all the three corridors and the 3.x coverage and 3.x high throughput scenarios

5.2.3 5G-CARMEN

In the case of 5G-CARMEN, the main cost drivers are the deployment timeline, the specific requirements depending on the service penetration and the geographical location of the corridor segments. Those segments vary in size from 3.3 km to more than double that, therefore, to compare the costs in a meaningful way, we normalized the costs to euros per 100 km for each service penetration forecasts. Additionally, we plotted the sum of the costs from 2021 to 2025, as the yearly deployments did not provide a meaningful comparison.

In Figure 16 and Figure 17, we can see the total costs for respectively the conservative and the optimistic service penetration forecast. In both cases, the total CAPEX varies drastically between the different segments and leads to more than 80% lower cost from the most expensive segment to the cheapest segment. The figures also include an average CAPEX for all segments normalized to 100 km. This allows us to get a better idea of the variance between the segments.

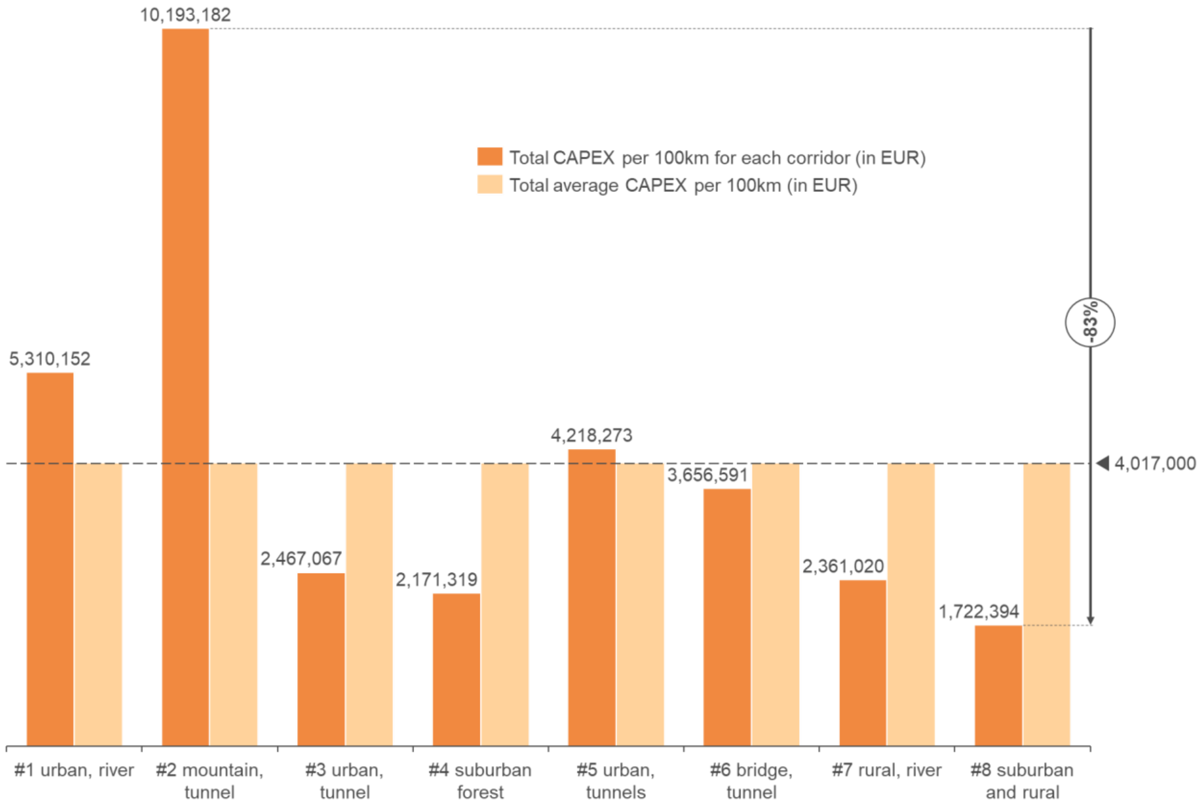


Figure 16: Total CAPEX per 100 km for all 8 segments for the optimistic service penetration case in 5G-CARMEN

The main conclusion we can draw from those results, is the impact of the geographical landscape and surrounding urban environment on the total deployment. Indeed, if we consider the costs of the corridor's third segment, which is located on the A8 in Munich, a dense urban area, the costs compared to the average CAPEX is more than 60% below the average in the conservative scenario and around 40% below the average in the optimistic case. These costs increase to more than double the average when we consider segment #2, the Brenner pass, which consist of a rural, mountainous area with tunnels.

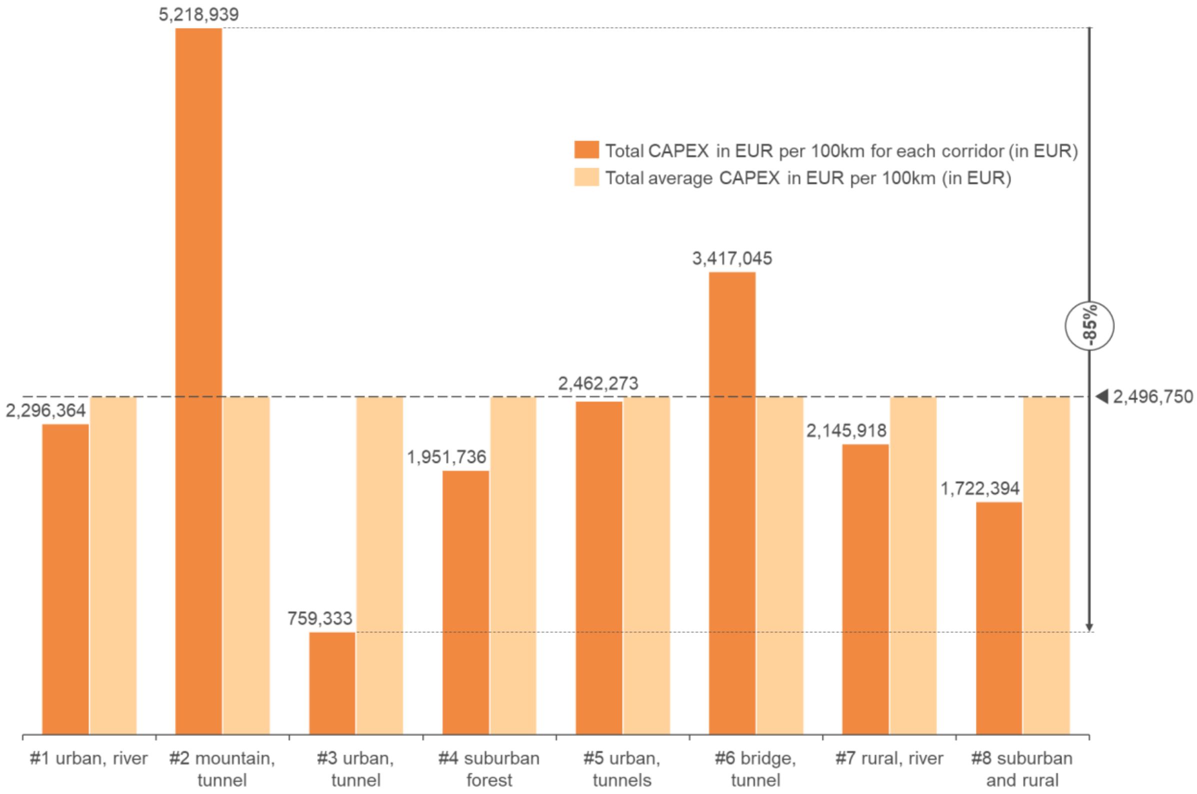


Figure 17: Total CAPEX per 100 km for all 8 segments for the conservative service penetration case in 5G-CARMEN

5.3 Harmonization of the results

As mentioned above, to be able to compare the studies we need to harmonize the total costs results, by adjusting the differing parameters.

The timeframe chosen for each study needs to be comparable. Therefore, we choose for 5G-MOBIX to consider the deployment in the year 2023, and for 5G-CARMEN the total costs of deployment from 2021 to 2025 for each segment.

The corridors also differ in size and location. In order to make them comparable we choose to normalize the costs for each corridor in 5G-MOBIX and 5GCroCo and each of the eight segments in 5G-CARMEN to 100 km.

Finally, the RAN deployment is different between the studies. Therefore, we categorized the costs into two scenarios, a low and a high site-density scenario. The total costs are then to be calculated in a comparable manner to reflect the differences. Table 6 below, describes the two density scenarios with respect to the three studies.

Scenario	5G-MOBIX	5GCroCo	5G-CARMEN
Low Density Scenario	700 MHz deployment. **IsD: 1670 m**	Coverage Scenario. **IsD: 2170 m**	Conservative Model. **IsD:2130 m**
High Density Scenario	3.5 GHz deployment. **IsD: 880 m**	High Throughput Scenario. **IsD: 930 m**	Optimistic Model. **IsD: 1520 m**

Table 6: Concluded Scenarios adopted by Detecon for Result Harmonization

5.3.1 Comparing the Bill of Quantity

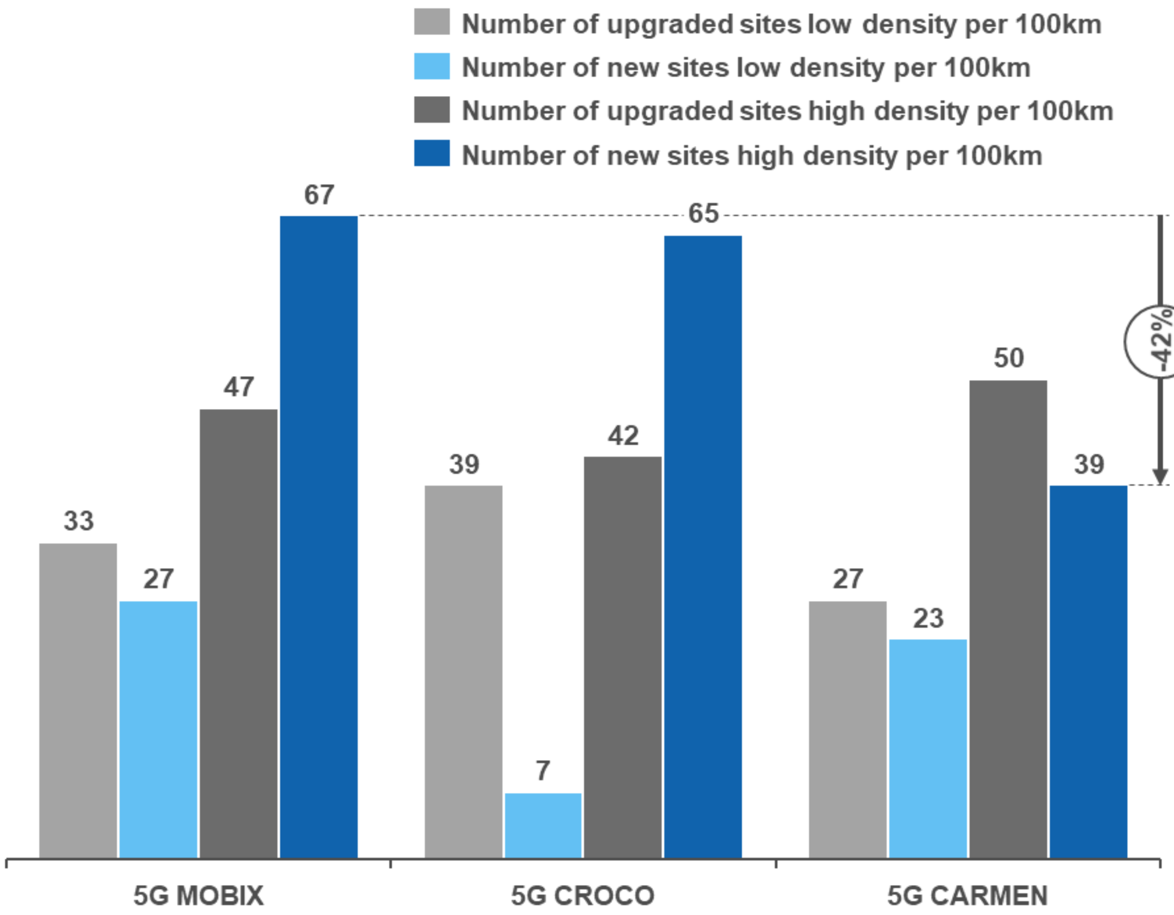


Figure 18: Total Bill of Quantity of the new and upgraded sites for the low- and high- density scenarios of the three deployment studies

The Bill of Quantity between the studies, shown in Figure 18 above, shows similar results in terms of number of sites upgraded for the three deployment studies, suggesting the overall average number of sites per 100 km for all the corridors are similar. Additionally, the number of new sites deployed in the low-density scenario are similar for 5G-MOBIX and 5G-CARMEN and in the high-density scenario similar for 5G-MOBIX and 5GCroCo.

Furthermore, there is a major difference in number of sites, -42%, between 5G-MOBIX and 5G-CARMEN. Overall, the deployment study with the highest BoQ is 5G-MOBIX,, which correlates with the higher costs we can observe in the following sub-section.

5.3.2 Comparing the costs between the studies

In order to compare the final costs, we calculated the average deployment costs per 100 km for all three deployment studies. Additionally, we included the average costs per 100 km (site including backhaul) of the EU CEF2 2017 [16] (as it represents the simplest form of cost deployment).

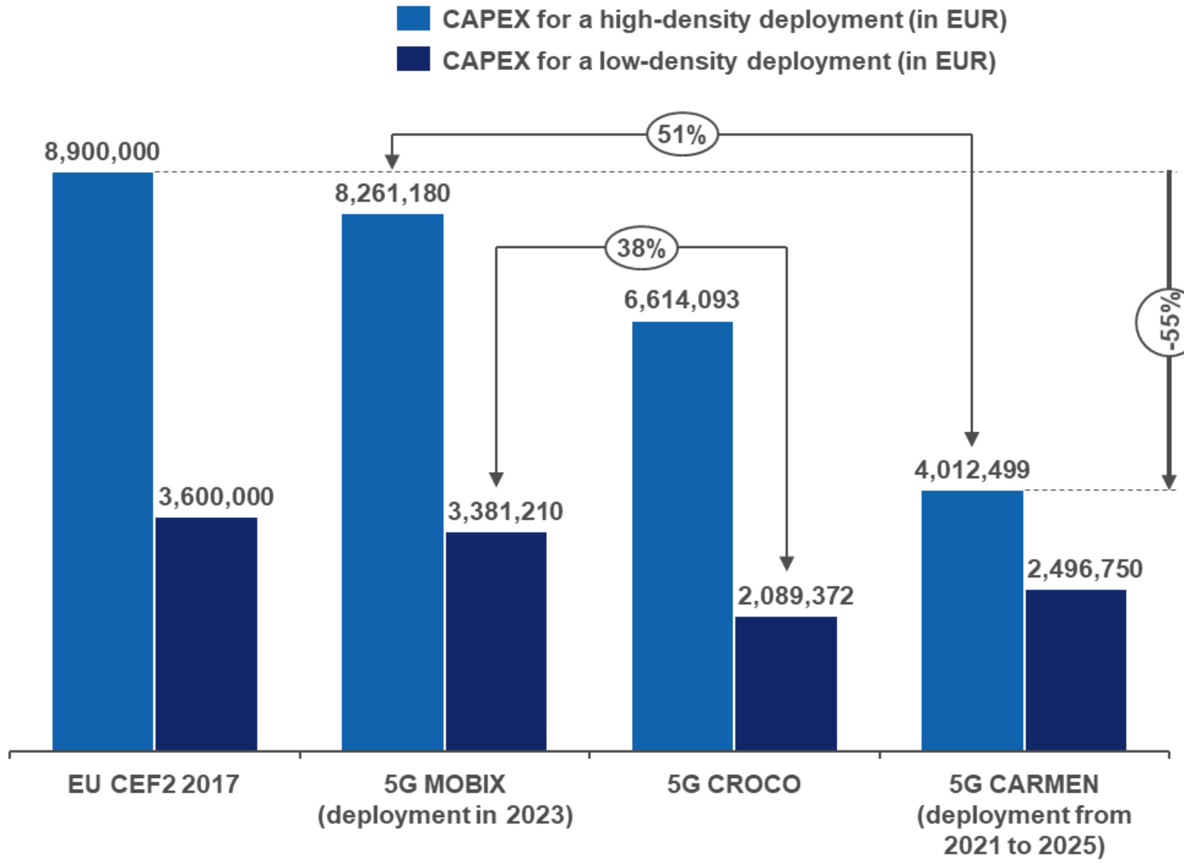


Figure 19: Average total costs for all corridors, in the low- and high-density scenarios, for all deployment studies and the EU CEF2 report

In Figure 19, we can see the average cost of all corridors or segments. The three studies, show major cost differences when normalized to 100 km. For the high-density deployment, the average total 5G-CARMEN costs are 51% lower than the 5G-MOBIX costs. Furthermore, the total average 5GCroCo costs, are between the two other studies in the high-density scenario but the lowest in the low-density scenario around 38% cheaper than 5G-MOBIX. These differences are primarily caused by the differences in the Bill of Quantity between the studies. Finally, when comparing the three deployment studies to the rough estimation of the EU CEF2 report from 2017, we can observe lower costs from the deployment studies of up to -55% in 5G-CARMEN, likely caused by the consideration of existing infrastructure and more precise planning.

In Figure 20, we can see the average cost of all corridors or segments, but on comparable corridors. Therefore, we picked two corridors and a segment showcasing similar geographical characteristics. For 5G-MOBIX, the corridor selected is the cross-border corridor between Portugal and Spain, with a highway, a river crossing and suburban areas. For 5GCroCo, the corridor selected is the corridor at the German-Luxembourgish border (on the German side), with a highway, a river, a forest, and suburban areas. Finally, for 5G-CARMEN the segment selected is at the German-Austrian border, with a river, suburban areas, and small parts of forest. The graph shows more aligned results in terms of deployment costs, especially between 5G-MOBIX and 5GCroCo. Additionally, we can observe lower cost differences between those and 5G-CARMEN, less than -28% cost instead of -51% in Figure 19.

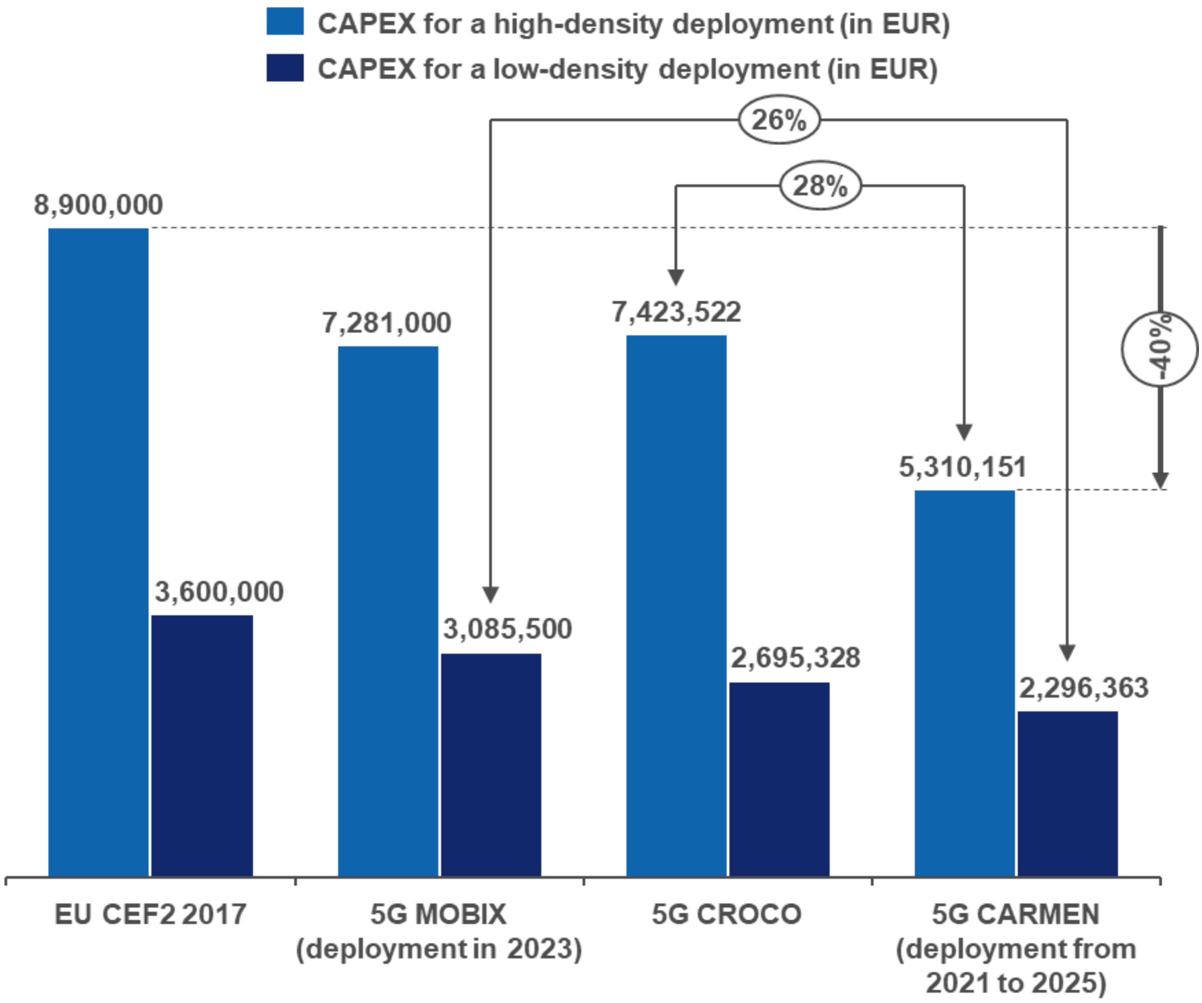


Figure 20: Average total costs for similar geographical corridors, in the low- and high-density scenarios, for all deployment studies and the EU CEF2 report

6 Synthesis of the key findings

6.1 Summary of the key findings of each deployment study

Below we summarize some of the key findings of each of the deployment studies. For a full view of the studies' findings including details, we recommend reviewing the original works.

6.1.1 5G-MOBIX

According to the authors of 5G-MOBIX and based on the assumptions made with respect to CAM Requirements, a 5G roll-out in the 700 MHz is expected to be sufficient up to 2023 in most cases. Only past 2023 and/or in high density border crossings, 5G deployment in the 3.x GHz becomes necessary.

Further, the authors identified road coverage obligations tied to 5G operator licenses as one the major drivers of 5G deployment in rural areas (which often applies to the cross-border corridors).

During several interviews with representatives from different large car manufacturers, the 5G-MOBIX deployment study authors collected, that lack of connectivity was not the main issue. The interviewees stated that their main concern currently focuses on

- the lack of unified standards for CAM,
- expensive on-board equipment,
- lack of clear business models and
- lack of regulation.

While the authors could only estimate different scenarios for CAV based on 3GPP information and various use cases from the 5G-MOBIX trial sites, the average rates of data transmission in uplink and downlink of an average connected, automated vehicle, remain unclear.

Finally, one of the main obstacles towards seamless cross-border connectivity is the issue of cross-border signal interference. This has also been stressed by several interview partners from the telco industry and is in line with the findings of this present metastudy.

6.1.2 5GCroCo

The 5GCroCo DS identified 2 key demand drivers for 5G deployment:

- standard eMBB traffic generated by end-users in proximity of the corridors
- plus M2M/eMBB traffic generated by connected vehicles (<level 3 automation)

Moreover, the authors identified the following key requirements for the deployment of cross-border corridors:

- a change of radio planning approaches at the borders,
- a constant exchange of up-to-date RAN planning parameters,

- an extension of roaming interfaces and a harmonization of service delivery
- Cooperation between MNOs, supplier, TowerCos and road operators is key to mitigating 3.x GHz cost.

Considering the share attributable to CAM Network and MEC the 5G coverage costs are approximately 13.5 mEUR per 100 km based on an 8-year TCO. MEC costs including local breakout per MEC location are estimated at approximately 250 kEUR based on a 5year TCO; since one MEC location is serving 10,000 km2 and 20,000 km of roads, the effective cost is 1.25 kEUR per 100 km.

Regarding the vehicles, the authors estimate average incremental system platform costs for CAM at around 75 kEUR. Assuming a lifetime milage of a vehicle to be 200,000 km, the CAM cost per 100 km would come down to 3.75 EUR.

With respect to services, the cost of CAM software (vehicle clients and corresponding server applications), plus dedicated service infrastructure like VCoC for ToD, cannot be calculated on a “per 100 km” basis. However, they scale with the number of instances deployed, like number of vehicles, number of MEC/edge cloud or cloud instances. VCoC/ToD comes at a rather high cost compared to the other CAM services and service categories. These costs need to be set in relation with the costs of recovering a “stuck” ADAS level 4 or higher vehicle and putting it back on course as it would be done in the classic case of a broken-down vehicle, requiring on-site mobile repair or towing services. In addition, it is expected that parallel to a growing number of AD vehicles, which could require a capacity and hence cost increase of VCoCs for ToD without further improvements to the AD capabilities, the need for human intervention with ToD will gradually be reduced (KPI e.g. number of ToD interventions per 10,000 km of AD driving) through continuous system/software improvements.

6.1.3 5G-CARMEN

According to the authors of 5G-CARMEN, the CAV services may reach profitability before 2025. To support this scenario, background traffic from classical customer segments (premium 5G subscribers) may help suffice for profitability in densly populated areas. Keeping conservative estimations in mind, the risk-averse approach of focusing on 5G deployment with low band/low density is considered first with further capacity extension and densification by 2030. The topography of the area under consideration has a tremendous cost impact and for exhaustive 5G coverage along highways, EC funding is crucial.

Impact of full-scale 5G V2X adoption

The adoption of 5G V2X communications in the 2021-2025 timeframe imply that full-scale deployments is profitable with 5,000-15,000 EUR/km for uncomplicated segments (without any complex features) yearly in an optimistic prediction.

However, conservative predictions imply that there might be no clear, short-term return on investment in that timeframe. Alternative approaches which are more risk-averse could help satisfy the simpler anticipated V2X services and postponing the support for the more sophisticated V2X services for 2026-2030.

Co-funding by the EC

The potential co-funding by the EC is one of the key elements making such 5G V2X deployments possible. The split required (Whether 55%, 60%, etc.) for the co-funding is a matter for further study and co-financing alone will not be sufficient for assuring the economic success of V2I deployments without the advent of novel, sustainable, and innovative business models in anticipation of conservative adoption scenarios.

Profitability

Profitability from 5G V2N services is possible in conservative 5G V2X adoption prospects because of their potential to reach the general population as (non-V2X) 5G premium subscribers. However, this does not assure that some special types of segments will be profitable because of their complex topography features (bridges, tunnels, river, curvy roads) which does not allow deployments with a reasonably low number of RSUs or cell sites. It is highly unlikely that V2I conservative deployment will become profitable when there is a literal lack of V2X subscribers. In such cases, road infrastructure operators are left with expensive deployments, with only long-term possibilities for the return of their investment.

It is important to note that even with 60% of co-financing from the EU, V2N deployments enjoy beneficial traits with a real positive impact on profitability with most new V2N deployments getting built on top of an already established 3G/4G infrastructure. A fraction (e.g.,15%) of the 5G upgrade costs may be naturally funded by MNO's internal sources justified on obsolescence and maintenance considerations, which reduces the CAPEX.

This makes the cost of deploying future-proof services far less taxing for MNOs in the V2N cases serving non-V2X 5G customers. For areas with less than 10,000 inhabitants, the background source of profit comes from the V2X customers (if they are available). Between 10,000 and 50,000 inhabitants, there is a healthy 50-50% mix of 5G V2X and 5G non-V2X revenue. In densely populated areas with more than 50,000 inhabitants, non-V2X 5G subscribers are increasingly important for the cumulative profit, until becoming the primary source of income for the stakeholders.

6.2 An indicative framework for assessing 5G for CAM deployment costs

As part of this metastudy, we have identified some key common steps (see Figure 21) that appear to be necessary to calculate the 5G investment delta in any given corridor.

The ***estimated effort*** listed below for each option reflects a high-level estimation of the hypothetical effort in staff days (SDs) needed to conduct the deployment study steps listed below for a generic highway corridor of **100 km** in Europe.

The ***estimated potential impact on overall deployment costs*** reflects a rough experience-based estimation of the prospective effect of each step on the end result. It should be taken into consideration that this impact may certainly vary highly from case to case.

1 **Defining CAM requirements** for the services to be supported.

2 **Specifying the deployment corridor** geographically.

3 Considering **country-specific regulations** to estimate time and dependencies for deployment.

4 Considering **country-specific financial aspects** to estimate equipment and operational cost items.

5 Studying CAV penetration in market to **calculate corresponding network traffic demand**.

6 **Determine network deployment type** and dimensioning parameters.

7 **Radio network planning and capacity planning** for the corridor.

8 Calculating the **cost of multi-access edge computing** to support CAM.

9 **Cost delta calculation** for the entire planning and deployment process.

? **Additional steps?**

Figure 21: An indicative framework to estimate the costs of 5G for CAM deployment

6.2.1 Step one: CAM requirements and services

Estimated potential impact on overall deployment costs: up to +/- 50%

Option A: Precisely defined CAM requirements (data traffic volumes, necessary reliability, and latency) based on extensive trials and tests with existing vehicles **+** consider network slicing requirements as well as developing average data traffic patterns of CAVs (in uplink and downlink)

Estimated Effort: 15 – 20 SDs (depending on data availability)

Option B: Precisely defined CAM requirements based on extensive research and estimations of future level 3+ **+** consideration of network slicing requirements

Estimated Effort: 5 – 10 SDs

Option C: Use of standardized CAM requirements as baseline for service requirements **+** consideration of network slicing requirements

Estimated Effort: 2 – 3 SDs

6.2.2 Step two: Geographical landscape

Estimated potential impact on overall deployment costs: +/- 70%

Option A: Precise selection of a corridor including definition its characteristics (rivers, mountains, tunnels, urban, suburban, rural, nature of border crossing, if applicable)

Estimated Effort: 1 – 2 SD (per corridor)

Option B: Definition of corridor length regardless of landscape characteristics at border crossing

Estimated Effort: 1 SD

Option C: Selection of a highway segment regardless of characteristics

Estimated Effort: max. 1 SD

6.2.3 Step three: Country-specific regulatory environment

Estimated potential impact on overall deployment costs: +/- 5 to 15%

Option A: Considering (for each country of deployment) the regulatory conditions to deploy sites, duration to obtain official site deployment approvals, environmental regulations affecting deployment, spectrum license obligations for motorway coverage, spectrum allocations and network sharing regulations.

Estimated Effort: 10 – 20 SDs (possibly more)

Option B: Considering a spectrum license obligation for motorway coverage, spectrum allocations and network sharing regulations

Estimated Effort: 5 SDs

Option C: Considering spectrum availability

Estimated Effort: 2 SDs

6.2.4 Step four: Country-specific financial aspects

Estimated potential impact on overall deployment costs: +/- 30 – 40%

Option A: Considering prices for each domestic market based on existing studies, interviews **+** identifying all stakeholders for each country **+** considering inflation and price evolution

Estimated Effort: 5 – 15 SDs (highly dependent on data availability)

Option B: Considering average prices based on the usual European market **+** identifying all stakeholders for each country **+** considering inflation and price evolution

Estimated Effort: 3 – 5 SDs

6.2.5 Step five: CAM, road, and network traffic demand necessities

Estimated potential impact on overall deployment costs: +/- 40%

Option A: Study of detailed service penetration of vehicles using CAM services for each target corridor **+** consider road and network traffic demand for each corridor considered

Estimated Effort: 10 – 15 SDs

Option B: Study of detailed service penetration of vehicles using CAM services on European scale **+** consider road and network traffic demand in border areas

Estimated Effort: 5 – 10 SDs

Option C: Study of global service penetration for CAM services and direct application to target corridor

Estimated Effort: 3 – 5 SDs

6.2.6 Step six: Deployment scenarios

Estimated potential impact on overall deployment costs: +/- 40 – 60%

Option A: Deployment or upgrade of sites to a specific frequency band in different years. Additional assessment of the use of alternative technologies supporting the mobile network.

Estimated Effort: 5 - 10 SDs

Option B: Deployment or upgrade of sites to a specific frequency band continuously over a specific time period

Estimated Effort: 5 – 8 SDs

Option C: Deployment or upgrade of sites to a specific frequency band regardless of year or time of deployment

Estimated Effort: 3 – 5 SDs

6.2.7 Step seven: Radio network planning and capacity planning

Estimated potential impact on overall deployment costs: +/- 30 – 40%

Option A: Precise radio planning using high precision path loss modeling software for each corridor (e.g., HTZ simulation tool, UPV's simulation tool, …) to perfectly place each site **+** considering existing sites and availability of space for new antennas **+** capacity planning to determine achievable throughput

Estimated Effort: 15 – 25 SDs

Option B: Radio planning based on assumption-based inter-site distances **+** considering existing sites **+** capacity planning to determine achievable throughput

Estimated Effort: 10 – 15 SDs

Option C: Radio planning based on assumption-based inter-site distances regardless of existing infrastructure

Estimated Effort: 5 SDs

6.2.8 Step eight: Multi-access Edge Computing

Estimated potential impact on overall deployment costs: +/- 5 – 10%

Option A: Cost calculation of MEC deployment for the specific deployment **+** study of the impact on backhaul costs

Estimated Effort: 5 – 10 SDs

Option B: Considering overall cost of MEC not specific to the deployment

Estimated Effort: 1 – 2 SDs

6.2.9 Step nine: Cost and delta calculation

Estimated potential impact on overall deployment costs: +/- 10 – 20%

Option A: Cost calculation combining the outputs from all the previous steps assuming the most sophisticated option

Estimated Effort: 10 – 15 SDs

Option B: Cost calculation combining the outputs from all the previous steps assuming the least sophisticated option

Estimated Effort: 5 SDs

6.3 Key Findings of the Metastudy

The results of this metastudy underline that all three deployment studies provided major contributions to the assessment of the costs of 5G for CAM along European cross-border corridors.

This metastudy set out to review and compare the three deployment studies. The studies covered a broad scope in terms of geographic corridors providing insights into how topographical characteristics, urbanization and existing infrastructure affect 5G deployment costs. The differing, yet comprehensive, assumptions and methodologies applied with respect to the mobile network infrastructure provide meaningful insights into how complex this technological ecosystem is and which pitfalls to look out for when planning actual deployment. The various estimations around actual CAM road traffic and related data traffic on the network stress the importance of considering real data from actual motorways as soon as possible. Uncertainty around the data traffic requirements of CAM services remains, although the studies have provided a reasonable range for these figures, also based on the related trials. Additional financial and legal-regulatory considerations provide insights into non-technical challenges that operators may face during roll-outs in the coming years.

Moreover, this metastudy also aims to look beyond the deployment studies. Therefore, we have compiled a list of so-called “gaps”, topics which will require more detailed attention in future studies considering cross-border 5G for CAM deployment costs. The identified gaps cover technical issues, regulatory and institutional topics as well as financial considerations. One of the most prominent ones is the fact that the actual requirements from connected automated vehicles (CAVs) remain unclear.

Despite the variety of the applied approaches, the investment delta results are somewhat comparable when the geographical differences are taken into account. One key cost drivers are geographic location and the existing RAN infrastructure and planned 5G roll-outs of the mobile operators along the corridors. When comparing more similar corridors, the prices are more aligned. This shows that the estimations of the investment deltas generally align among the three studies.

Further, the demand for low or mid-/high band 5G highly depends on assumed CAV penetration and data transmission rates.

Accordingly, the two key cost drivers among all studies are

1. the forecasted CAV-incurred network demand and
2. the geographical location/topography

There are additional costs for the CAM service requirements and deployment cost, such as: mitigation of cross-border interference between MNOs, cloud/data storage costs. Deployment costs between countries may vary significantly.

Generally, cost drivers of the investment deltas align among the three studies. Thus, there are several key steps in estimating the investment delta that all three studies have in common. These have been used to derive an indicative framework for assessing 5G for CAM deployment costs (see section 6.2).

An additional important finding among all of the studies was that it is crucial to identify new major stakeholders and the way they will benefit from the deployment. The ensuing business models may help in finding ways to recover the deployment costs. Moreover, all three studies stress the importance of cooperation within this complex stakeholder ecosystem in order to arrive at efficient deployment strategies.

The gaps identified in this study (see chapter 4) clearly underline the need for further study with respect to 5G for CAM along cross-border corridors. Yet, the three deployment studies have paved the way for more concrete deployment planning endeavors, which can be expected given the CEF2Digital funding in the coming years.

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