Business Case Evaluation of Cooperative, Connected and Automated Mobility Service Provision in cross-border settings[INVITED PAPER – Project 5G-CARMEN]

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***Abstract*— In this paper, we present a techno-economic analysis of providing a Cooperative, Connected and Automated Mobility (CCAM) use case, namely Cooperative Lane Merging (CLM), in a specific cross-border environment. Multiple network deployment scenarios are proposed to provide Vehicle to Infrastructure (V2I) connectivity with respect to PC5 Mode 4 – enabled RSUs. Total cost of Ownership (TCO) model together with four revenue models are developed to assess the viability of providing CCAM services in the studied settings. Results show that the higher the number of simultaneous connected cars, the higher the TCO of the required deployment needs to be to meet the defined KPIs and especially for the green field deployment where no existing fibre cable or electricity facilities. Another important insight from this analysis is that only with a high fleet penetration rate of connected vehicles we can have a viable business case.**

Keywords—TCO model, techno-economic analysis, 5G networks, C-V2X, CCAM services, revenue models, cross-border.

I. Introduction

Cooperative connected and automated mobility (CCAM) is one of the next big trends and necessities in the transportation industry. This became clear with the different European incentives and agendas with regards to connected mobility corridors in Europe [1] and [2]. However, providing CCAM services at the continental scale raises many challenges, amongst which the seamless cross-border continuity of CCAM services is the obvious one. This latter is not only challenging from a technical perspective but also from a business model one, due to the multi-stakeholders' nature of the CCAM ecosystem in the cross-border settings (including cars and equipment manufacturers, road operators, mobile network operators, service providers, institutional entities...). To this end, the European Commission has funded several projects to research these challenges and the 5G-CARMEN project in which this study was carried out is one of them [3].
On the other hand, to realize the societal benefits CCAM promise, penetration of connectivity in passenger cars is essential. However, as for now, the automotive industry remains divided on the technology aspect, hampering adoption of CCAM in passenger cars according to authors of [16]: "the stakeholders of the automotive industry (e.g., car manufacturers and road operators) are still skeptical about the capability of the telecom industry to take the lead in a market that has been dominated by dedicated intelligent transport systems (ITS) deployments.". Therefore, current adoption in new vehicles is significantly lower than initially predicted, and it remains highly uncertain for upcoming years. Currently, it is increasingly considered as a societal issue to provide assistive systems immediately for all and not only for car owners of new cars who can afford increasing cost due to assistive services and advanced levels of automated driving. Yet, several telecom network operators have openly communicated, that investment into deploying 5G infrastructure in Europe will be targeted towards industrial uses of IoT and toward agglomerations with high population density. European rural areas and highways without big agglomerations or significant industrial IoT usage are openly rated as third level priorities in deploying 5G – even significantly later than 2030 or 2035. This low prioritization of connectivity deployment in highways especially next to country borders is justified by the high investment cost required especially for low latency-sensitive services such as CCAM services and for the unclarity around sustainable CCAM business models.
On the other hand, deployment of broadband connectivity in Europe has seen some entirely new dimension from unresolved issues regarding actual payment streams for streaming services without sufficiently contributing to investment into infrastructure deployment. Somehow the narrative after Covid-19 is like: we have had the investment cost for upgrading the communication infrastructure and consumers use the network at flat rates to use streaming services. The providers of those streaming services earn from advertising and paid subscription without due contribution to actually upgrading European digital networks. There is rather high risk perceived that this scenario might be repeated with OEMs providing connectivity-based services. Therefore, the need for clear CCAM revenue models, that capture the revenue streams and show how key CCAM stakeholders can pay off their initial investment, is becoming more prominent.

Therefore, there is a need to shed more light on identifying revenue models for CCAM service provision since in the literature there are few papers, only discussing the investment costs and not the revenue part as such [4], [5] and [6].

Therefore, in this paper we perform a techno-economic analysis to evaluate the provision of a CCAM use case namely Cooperative Lane Merging (CLM) in the Brenner pass cross-border considering the use of Vehicle-to-Infrastructure (V2I) connectivity with respect to Road Side Units (RSUs) based on the Cellular-V2X (C-V2X) sidelink (i.e., PC5-Mode4). For this purpose, we first identified three deployment scenarios with regards to different fleet penetration rates and developed a Total Cost of Ownership (TCO) model to study the investment cost for these three deployment scenarios (discussed in section II). In section III , we proposed 4 different revenue models to evaluate the viability of the business case for the different penetration rates.

II. CCAM deployment scenarios and Total cost of ownership

We study the CLM use case detailed in [7], where one vehicle intends to move onto a side lane containing already some vehicles. Hence, these side vehicles should create a gap as such the initiator vehicle can insert between them. This manoeuvre is centralized since a centralized manoeuvring application running in the Multi-Access Edge Computing (MEC) or a local server (i.e., on local RSU). The execution of the centralized CLM is based on the collection of the positional information requested by the different vehicles. In our specific operating context, the CLM procedure can be initiated and completed before, while or after crossing the border. The studied highway segment is the Brenner pass between Austria and Italy of approximately 4.5 km of length [5].

A. Penetration rate assumptions

On the one hand, it seems unrealistic to assume a 100% of penetration rate of connected cars from the starting year of the deployment. On the other hand, there is no common agreement within the research and concerned communities about convergent forecasts of the connected car penetration rate in the upcoming years. There are outdated studies with findings ranging from pessimistic [8] to optimistic [9] penetration rates which cannot be used as such since the automotive industry was hardly hit by the Covid crisis [10]. One way out is to follow two different approaches in overcoming this issue:

1. Generic and abstract approach based on a variation of penetration rates:

In this approach, we work with a variation of penetration rates which are not linked to specific starting year, i.e., working with abstracted years (year 1 to 10) and hence give generic results that road operators or CCAM providers can use and extrapolate when a clearer idea about the penetration rates and their evolution over time can be conducted. The results of the techno-economic analysis using this approach have been published in [5].

2. Assuming three penetration rate scenarios:

In this approach we define three different scenarios: Low, Medium and High scenarios in line with the Strategic Deployment Agenda (SDA) study [15]. The two first forecasts namely the low and medium scenarios are taken from the CEDR's MANTRA project [8] and [15]. For these two scenarios they defined "Low scenario" as the "business as usual" scenario, where the automated driving use cases are taken into use as in usual market economy, utilizing solutions based on the utility or economic value to the customer or user. In this low scenario, the fleet penetration rate varies from 1.19% (2021) to 1.30% (2030). The Medium scenario in our case is the "High scenario" in the MANTRA study where it is assumed an acceleration of automated driving use cases via financial incentives such as reduced taxation or via regulatory actions, for instance by mandating automated driving in specific conditions. In the MANTRA study, they started the forecasts from year 2030, and in this study, we consider 2021 as the starting year of the deployment hence we consider a 1% yearly increase in sales for vehicles equipped with V2X technologies to predict the missing figures. The penetration rate hence varies from 6.03% (2021) to 6.60% (2030). The High scenario is the most optimistic scenario and is taken from IHS Mark-It study [11], where fleet penetration rate is rising from 6.82% (2021) to 39.12% (2030).

B. Network deployment scenarios and resulting TCO

For the V2I links with respect to PC5 Mode4 – enabled RSUs, three deployment scenarios have been defined. These three deployment scenarios are as follows:

- The baseline V2I scenario corresponds to the physical deployment currently available in the studied corridor: 2 RSUs in total in the test portion of highway of length ~ 4.5 km (i.e., ~ 0.5 RSU/km).
- The dense V2I deployment scenario: this scenario corresponds to a doubled baseline density: 4 RSUs in total in the same environment (i.e., ~ 1 RSU/km).
- The ultra-dense V2I deployment scenario: this scenario corresponds to a quadrupled baseline density: 8 RSUs in total in the same environment (i.e., ~ 2 RSUs/km).

Note that the names attributed to these different scenarios are defined based on the densification of RSUs comparing to the baseline V2I scenario.

The TCO model as well as input data used to run the cost model are described in detail in [5].

Based on the number of simultaneous connected users/cars the required deployment for each fleet penetration rate scenarios are derived to fulfil the service availability KPI depicted in Table 1. For the low scenario a low deployment scenario is defined where 2 RUSs are installed in the first two years (for the green field deployment/ and maintain the existing 2 RSUs for the Brenner pass corridor i.e., case of pre-equipped field) and by the third year an additional 2 RSUs are installed to ensure a low rejected CLC request rate. Yet, for the medium scenario a medium deployment scenario is considered where from year one we deploy 4 RSUs (4 new RSUs in the green field scenarios, but in the pre-equipped where we have already 2 existing RSUs we add 2 additional ones). To mitigate the high traffic generated by the high number of connected cars in the high fleet penetration rate scenario 4 RSUs are needed in the first year but by the second year 4 new RSUs are required to have 8 RSUs in total (considering the existing infrastructure, 2 RSUs in the pre-equipped field scenario).

Table 1 The rate of rejected CLM requests based on the variation of the connected cars for the three infrastructure density scenarios derived by means of system-level simulations [5]

Fleet penetration rate	RSU deployment		
	2 RSUs	4 RSUs	8 RSUs
5%	14.9%	0%	0%
10%	17.1%	3.4%	0.1%
50%	21.3%	5.2%	0.5%
100%	28%	6.4%	0.7%

The cumulative TCO per Km (CUM_TCO_perKM) for the three deployment scenarios low, medium and high for two different type of fields i.e. green field and pre-equipped field are depicted in Figure 1 and Figure 2 respectively.

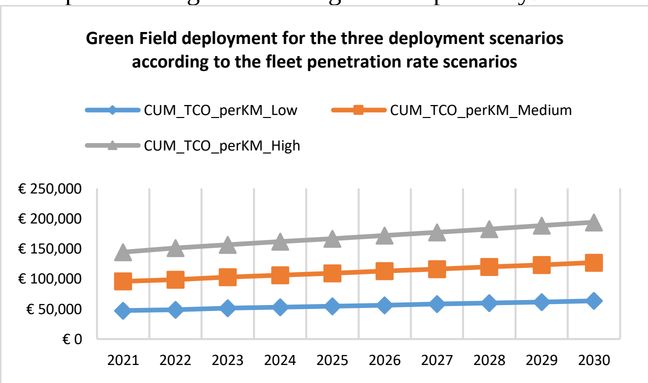

Figure 1: Cumulative TCO per KM for the low, medium, and high deployment scenarios for a green field corridor segment

As expected, the higher the number of simultaneous connected cars, the higher the TCO of the required deployment needs to be to meet the defined KPIs. Results show how expensive it is to deploy in a green field of the highway where no existing fibre cable or electricity facilities. The green field deployment is three times more costly than the pre-equipped field deployment.

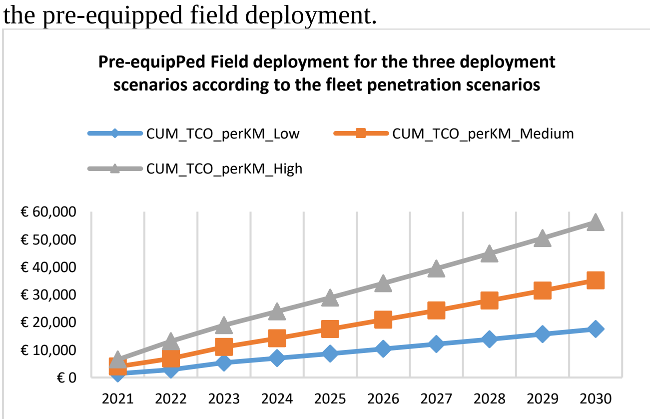

Figure 2: Cumulative TCO per KM for the low, medium, and high deployment scenarios for a pre-equipped field corridor segment

III. Proposed Revenue models

To evaluate the economic viability of the proposed CCAM services in the cross-border environment, revenue assumptions have to be taken. We hereafter work with four revenue models reflecting four different assumptions, aiming at giving as much as possible of useful insights into the viability of the use case using different revenue models for CCAM connectivity providers in the cross-border area.

1. **Revenue model 1:** this model uses the assumption taken from the 5GPPP white paper [12], where they assume a revenue of 0.5 euro per user for each use of the highway segment (which has a length of 100 Km). This connectivity fee can be collected via the toll fees on the highway or via another approach depending on the operator providing the connectivity. For our case we divide this 0.5 euro by 100 to derive the revenue per user per use per Km.
2. **Revenue model 2:** this model assumes that drivers of cars supporting V2X connectivity would pay a yearly subscription of 250 euro. This payment is done when buying new car such there is a lumpsum payment (for the car) and a yearly fee to benefit from the V2X services. To have a unified metric to compare between the different revenue models, we derive here as well a revenue per Km using the average driven distance in Europe per year, being 12,000 km [13].
3. **Revenue model 3:** since we are studying the cross-border segment (the Brenner pass) where an extra-investment is needed to ensure the CCAM service continuity, it is reasonable to assume that in order to pay-off this extra-investment we need to charge more for this specific segment in the toll fees. Therefore, in this model we assume that the revenue of 0.5 euro per user for each use of the corridor segment (of revenue model 1) is for the 4.5 Km portion of the cross-border segment.
4. **Revenue model 4:** in this model a cost-based pricing is considered. Starting from the cost of the deployment needed and an Average Cost Per User (ACPU) per Km is calculated, thus adding a profit margin on top results in an Average Revenue Per User (ARPU) per Km. Usually the margin profit of Telco's ranges from 10% to 30% [14]. Using this revenue model, we guarantee to break-even before the end of the project period (10 years in this study).

We run the simulation for these 4 revenue models considering all the different parameters and taking into account the three fleet penetration rate scenarios presented in section II, in order to derive the cumulative TCO per deployment scenario (low fleet penetration scenario results in a low deployment scenario and so on..) and also to calculate the number of users using the service to derive the cumulative revenue per model and per fleet penetration scenario.

For the deployment scenarios we have, as usual, the two alternatives: deploying on a green field segment of the corridor or on a pre-equipped one.

For all the scenarios we assume that:

- There is a way to collect the revenues from only the connected users (those using the V2X connectivity in the studied segment) not all the users on the road.
- For revenue model 4 we assume a profit margin of 10%.

- Since in the revenue model 4 the ACPU is used to derive the cumulative revenue, we can only compare the cumulative revenue for the green field deployment to the cumulative TCO of the green field deployment and the same applies for the pre-equipped field. Yet, for the other revenue models they can be compared to both deployment TCO.

Starting with the low fleet penetration scenario where we assume that the cumulative TCO per Km used is the one of the low deployment scenarios for the green and pre-equipped field as presented in section II.B.

Figure 3 presents the cumulative revenue per Km of all the revenue models as well as the cumulative TCO per Km of the two low deployment scenarios (green/pr-equipped field). Results show that using revenue models 1, 2 and 3 would not allow to break-even neither during the project lifetime nor even in the near future if the fleet penetration rate remains low. However, using revenue model 4, we break-even around the fourth year for the pre-equipped field deployment and around year 8 for the green-field deployment.

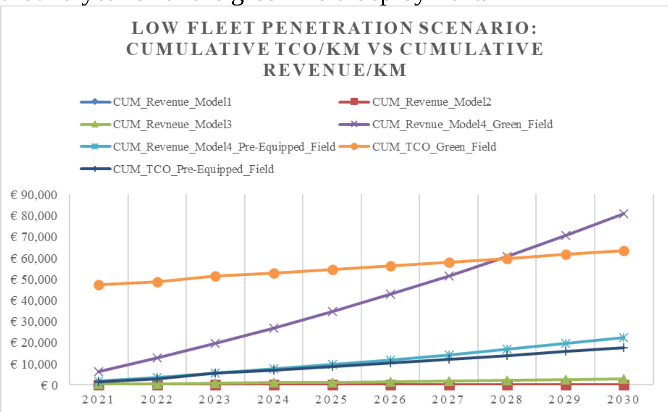

Figure 3: Low fleet penetration scenario: Cumulative TCO/Km VS Cumulative Revenue/Km for the four revenue models

For the medium fleet penetration scenario, we assume that the cumulative TCO per Km used is the one of the medium deployment scenarios for the green and pre-equipped field as presented in section II.B.

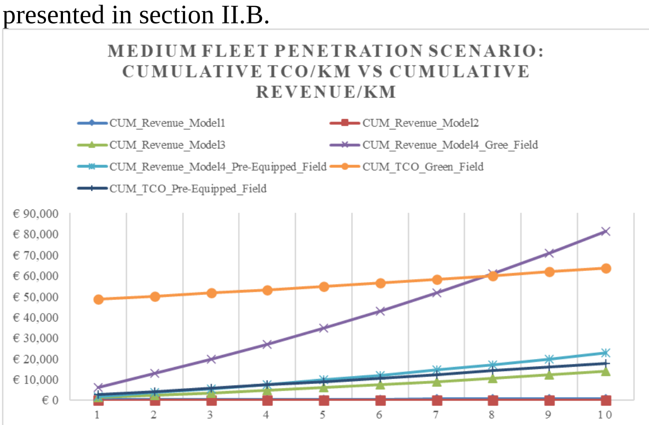

Figure 4: Medium fleet penetration scenario: Cumulative TCO/Km VS Cumulative Revenue/Km for the four revenue models

Similar to the low scenario, results presented in Figure 4, which presents the cumulative revenue per km of all the revenue models as well as the cumulative TCO per km of the two medium deployment scenarios (green/pr-equipped field), show that using revenue model 1, 2 and 3 would not allow to break-even during the project lifetime and even in the near future if the fleet penetration rate remains medium, except for revenue model 3 which could break even around year 13 to 14 (2033 to 2034). However, using revenue model 4, we break-even around the fifth year for the pre-equipped field deployment and around year 8 for the green-filed deployment.

For the high fleet penetration scenario, we assume that the cumulative TCO per Km used is the one of the high deployment scenarios for the green and pre-equipped field as presented in section II.B.

Figure 5 shows that even with high penetration rate (which means high number of users) revenue models 1 and 2 cannot pay-off the investment cost. But, for the revenue model 3 and unlike the low and medium scenarios, the break-even point can be reached around the fourth year (2024) for the pre-equipped field deployment and around year 2031/2032 for the green-field deployment.

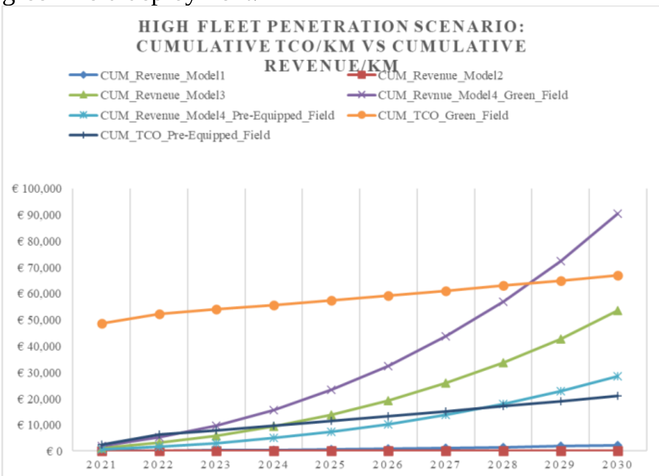

Figure 5: High fleet penetration scenario: Cumulative TCO/Km VS Cumulative Revenue/Km for the four revenue models

However, for the revenue model 4, we see that the break-even point is reached later compared to the low and medium scenario, around year 8 for the pre-equipped field deployment (comparing to year 4 in the previous two scenarios) and between year 8 and 9 for the green field deployment (comparing to only at year 8 in the previous scenarios). This can be explained by the fact that the revenue model 4 is based on the average cost per user which is very high in the high deployment scenario comparing to the low and medium ones with a low profit margin of only 10%. With higher profit margin, higher revenues can be reached as shown in Figure 6.

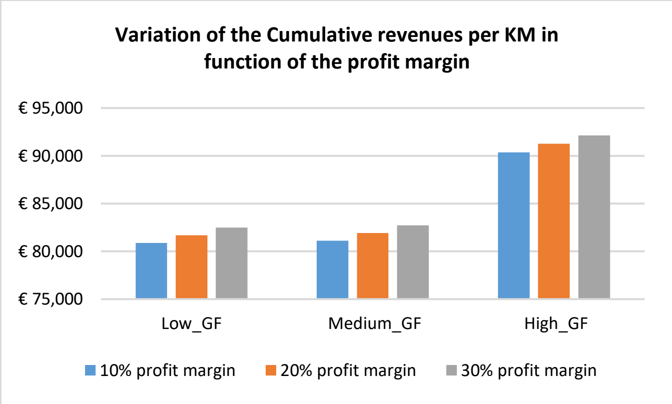

Figure 6: Variation of the Cumulative revenues per KM in function of the profit margin for the three fleet penetration scenarios with a green-field deployment

If we assume that the revenue per user is charged as part of the toll fees, it is difficult to differentiate between road users who are using the V2X connectivity from those who are not. Therefore, we used our model to derive the ARPU for the three penetration scenarios, low, medium, and High scenarios (which implies low, medium, and high infrastructure deployment) while counting only the connected users and then while counting all the road users (users of the corridor segment under study). The results of this comparison are presented in Figure 7 and Figure 8.

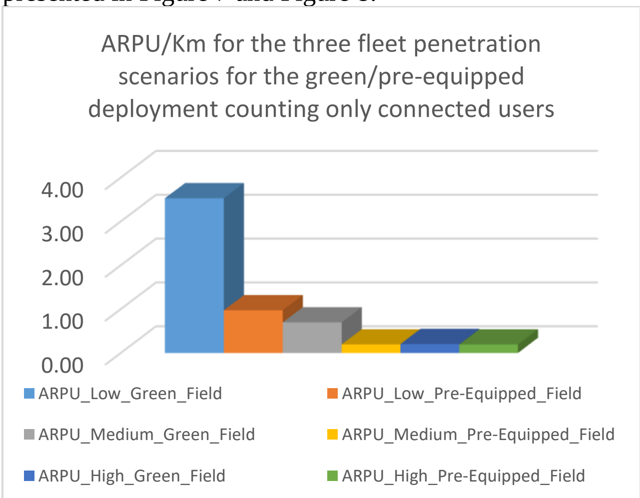

Figure 7 : ARPU for the three fleet penetration scenarios for the green/pre-equipped deployment counting only connected users

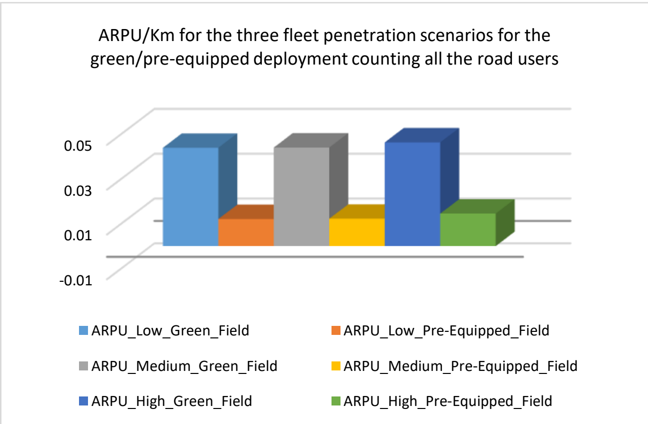

Figure 8 : ARPU for the three fleet penetration scenarios for the green/pre-equipped deployment counting all the road users

It is important to mention that the two figures Figure 7 and Figure 8 have different Y axis since the ARPU in the case where all the corridor segment users are taken into account are way too small (in the order of 4 Euro-cents for the green filed deployment) comparing to the case where only the connected users are counted (3.5 Euro for low penetration rate in a green field deployment scenario).

Results also show a comparison between the ARPU/km for a green field versus pre-equipped field deployment, which demonstrate how low is the ARPU (which is based on the ACPU) that needs to be collected to pay-off the deployment cost in a pre-equipped (brown) field comparing to a green field one.

In order to have a clear idea how counting all corridor segment users can reduce the connectivity fees to be charged to the road users, we take the example of the low penetration scenario: for the green field with counting only connected users the fee requested per user for the 4.5 km of the Brenner pass is 4.5*3.5=15.75 Euro versus only 4.5*0.0438= 0.197 Euro (19 Euro-cents) if we consider all the corridor segment users. For the high fleet penetration scenario for pre-equipped field deployment, we need to request 4.5*0.19=0.855 Euro (85 Euro-cents) when only connected user are considered versus only 4.5*0.0145=0.0652 Euro (6.5 Euro-cents) when all users are counted.

Hence it seems reasonable to incorporate the connectivity fee in the toll fees while distributing it among all users rather than charge it directly to the connected users.

The main takeaways from this exercise are:

- For the low and medium fleet penetration scenarios, only revenue model 4 (the one based on the ACPU) guarantee to break-even before the end of the project lifetime.
- For the high fleet penetration scenario and using the revenue model 3 the break-even point can be reached around the fourth year (2024) for the pre-equipped field deployment and around year 2031/2032 for the green-field deployment (after the project lifetime), but models 1 and 2 are always non-viable even with high penetration rate. Yet using model 4 guarantee to break-even before the end of the project for the two types of deployment.
- Using a high profit margin in revenue model 4 help collecting more revenues but on the expenses of the end user since a higher ARPU will be charged.
- It seems realistic/feasible to incorporate the connectivity fee in the toll fees while distributing it among all users rather than charge it directly to the connected users.

IV. Conclusion

In this paper we performed a techno-economic analysis of providing CLM use case in a cross-border environment. The network deployment cost of three deployment scenarios have been discussed with respect to the service availability KPI. Results showed that the higher the number of simultaneous connected cars present, the higher the TCO of the required deployment is, and discussed how expensive it is to deploy in a green field of the highway where no existing fibre cable or electricity facilities. The green field deployment is three times more costly than the pre-equipped field deployment. We proposed four revenue models reflecting four different assumptions, aiming at giving as much as possible of useful insights into the viability of the use case using different revenue models for CCAM connectivity providers in the cross-border area. Findings suggested the use of a cost-based revenue model to ensure reaching a fast break-even point. We also think that it is realistic/feasible to incorporate the connectivity fee in the toll fees while distributing it among all users rather than charge it directly to the connected users. Future work will address the scenario where Vehicle to Network (V2N) are available .

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