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Socio-economic evaluation of the deployment of the Smart Parking technology in Ettelbruck, Luxembourg

CITIZING for UPCITI and RMS

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Non-technical summary

This report constitutes the socioeconomic evaluation of the smart parking project undertaken in the city of Ettelbruck in Luxembourg. The project uses a smart parking technology developed by *UPCITI*, a French firm which produces and provides real-time data to the public in a bid to make cities smarter. The project is implemented in partnership with *RMS.lu*, a firm based in Ettelbruck which specializes in the development, installation, and support of solutions of automatic identification and mobility.

The smart parking project, implemented in October 2019, enables real-time monitoring of the city's conventional parking spaces, as well as those reserved for persons with reduced mobility (PMRs), electric vehicles, delivery personnel, and taxis. Since drivers in cities spend a great deal of time looking for parking spaces, such technologies not only help drivers save time, but also reduce carbon dioxide emissions and air pollution by reducing the amount of fuel burnt while looking for parking spaces. They also aid in reducing noise pollution due to reduction in traffic congestion. It was with this perspective that Ettelbruck, which aims to be a smart city and is in the early stages of experimenting with solutions towards that end, undertook the smart parking project.

The socioeconomic assessment of public investment constitutes a tool that aids decision-making: it allows, through a cost-benefits analysis, to question the collective value generated by a project, over a given period of time and for all the actors affected, compared to its costs. Socioeconomic assessment presents three main particularities:

- **Firstly, and contrarily to a financial evaluation, it does not only take into account financial value, but also the major economic, social and environmental gains that society can expect to reap from a given project. The costs and the benefits of the project being of different natures (social, environmental, economic and financial), a common unit is used in order to compare the different types of costs and benefits. By convention, this unit is the monetary unit.**
- **Secondly, a socioeconomic assessment is carried out as a differential assessment between the project option and a counterfactual option (the scenario if the project was not carried out).**
- **Lastly, indicators such as the socio-economic Net Present Value (SE-NPV) are calculated. A positive SE-NPV indicates that the discounted social, economic, and environmental gains of the project, net of its discounted costs, are greater than they would be if the project was not undertaken. The project is then considered to be collectively desirable, since it creates more value than it destroys.**

This report presents the results of socioeconomic benefits of the smart parking project over a period of five years, net of its costs. The socioeconomic benefits studied in this report include reduced 'cruising times' (time spent looking for parking) of drivers, as well as net reductions in CO_2 emissions, reductions in vehicle operating costs, and reductions in air and noise pollution due to reduction in cruising times. The socioeconomic **NPV (net present value) of this project is 7 million €**$_{2020}$ and **the socioeconomic ROI (return on investment) is 20,91**. This means that for every euro of public money invested in the project, the project yields 21 euros in benefits over a period of five years. The positive NPV and an ROI of greater than 1 indicate that the project creates more value for the society than it costs the society, making it desirable for society as a whole.

The time-horizon studied for the purpose of this evaluation starts from November 2019, until the end of the year 2024. The evaluation assumes that until the end of the time the status quo is maintained. In other words, any micro-level changes (changes in the scale of the project, number of people who benefit from the project, composition of users) or macro-level changes (economic shocks, demographic changes, drastic shifts towards utilization of electric vehicles than conventional automobiles) that could affect the results of the evaluation, are assumed away.

A major limit of this evaluation is that qualitative effects of the deployment of the technology (for example, an increase in the attractivity of the city), which do not have well-established reference values[1], are not estimated, monetarized and taken into account in the estimation of the NPV. Such favorable impacts are likely to further increase the socio-economic value created by this project, above and beyond the socio-economic net present value presented in this evaluation.

[1] As are available for time, CO_2 emissions, as well as air and noise pollution

Chapter 1: The Context and Ambitions of the Project

1.1 Why is the world talking about Smart Cities?

The last few decades witnessed substantial gains in the living standard of urban cities, owing to a wide array of services and infrastructure which make life easier. Nonetheless, the burgeoning population of urban centers, with the pressure it creates on existing infrastructures and delivery of high-quality services, poses a challenge for administrators, architects, and urban planners alike. In comes the concept of 'smart cities'. At the heart of the concept lies a technology-centered approach enabling the optimization of a cities' resources, towards the end of making cities more livable, resilient, inclusive, and sustainable. But what is the need for such an approach ?

As of 2011, the world's cities occupied 2% of the planet's surface but were home to almost half of its population, consumed 75% of the total energy generated, and accounted for 80% of the greenhouse effect[2]. By 2040, 65% of the world's population will live in cities[3]. If cities are to be made sustainable, their resources need to be monitored and services need to be delivered more efficiently than ever. Innovative technologies that permit a rethinking and rewiring of cities' critical infrastructures – roads, bridges, tunnels, rails, subways, airports, seaports, communications, water, power, and major buildings – become an urgent need.

Smart solutions are being applied in cities across the world to address a multitude of issues and improve performance in various sectors: energy and water management, lighting solutions, road safety, city planning, citizen cooperation, waste disposal, governance, health delivery, and traffic congestion, to name a few. Between 2015 and 2020, the global spending on smart cities has more than doubled from US$ 14.85 billion in 2015 to US$ 34.35 billion in 2020[4]. *Persistance Market Research* estimates that the size of this market is set to reach US$ 3.5 trillion by 2026[5]. In Europe, a study[6] published by the *Directorate-General for Internal Policies* of the European Union in 2014, identified the United Kingdom, Spain, and Italy to be the European countries with the highest number of smart cities (31 or more). France, Germany, the Netherlands, and Sweden followed with 11-30 smart cities each.

1.2 Why is Ettelbruck talking about Smart Parking?

As is evident, smart city solutions are meant to make people's lives easier, while ensuring that cities are run in a sustainable manner. An important pillar of a smart city is the concept of *smart mobility*. The concept entails approaching the mobility of people innovatively, with the principal purpose of improving the sustainability, reliability, and ease of travel. Given this, a significant aspect of smart mobility is intelligent parking management.

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[2] United Nations Environment Programme. (2011). Visions for change: recommendations for effective policies on sustainable lifestyles. http://hdl.handle.net/20.500.11822/8009

[3] Smart City Infographic | The Dramatic Stats Behind the Rise of Global Networked Cities. https://www.postscapes.com/anatomy-of-a-smart-city/

[4] Global smart city spending 2015-2020 | Statista. (2018). https://www.statista.com/statistics/757638/spending-on-smart-cities-worldwide/

[5] Raconteur. Smart Cities. (2017). https://www.raconteur.net/smart-cities-2017

[6] European Parliament. (2014). Mapping Smart Cities in the EU. http://www.europarl.europa.eu/RegData/etudes/etudes/join/2014/507480/IPOL-ITRE_ET(2014)507480_EN.pdf

In 2012, a report by the *International Parking Institute* mentions that an estimated 30% of the traffic in cities is people in cars searching for traffic. The report also emphasizes that contrary to a growing view, professionals in the parking industry don't desire more parking but a more efficient parking system that benefits overall transportation flow[7]. The report presents results of a survey conducted in 2012 : of the 11 solutions that can improve sustainability in parking, the second most important solution[8] seemed to be the development of guidance systems that make it easier to find parking, with 51% professionals in the parking industry voting it as the solution possessing the greatest potential to improve sustainability in parking. Indeed, when parking lots are made more accessible, fluid, and operational, people save time 'cruising' for parking spaces, traffic congestion is ameliorated, wasteful fuel and carbon emissions are reduced, traffic noise is decreased, the utilization of available parking spaces is optimized, and people feel more stress-free while driving.

Ettelbruck, a city of around 9 000 inhabitants, is a principal economic center of the northern Luxembourg. The city witnesses a strong daily flux of visitors. Around 3 000 students, enrolled in the cities' 5 post-primary schools, visit the city daily. Many people also travel to the city daily for work, including the medical personnel of the cities' two hospitals, *Centre Hospitalier du Nord* and *Hospital Center Neuropsychiatrique*. The former has around 700 employed personnel and 400-500 visitors each day. The city also welcomes many visitors to its sport clubs, local shops, opera, concerts, and other leisure activities. On an average day, around 20 000 cars pass through the city each day. However, among these visitors, as with the city's residents, the problem of finding a parking space has been a real concern. The traffic manager of Ettelbruck attests that difficulties in finding parking spaces along with the resulting traffic congestion and noise pollution, have been a recurrent concern when it comes to the management of traffic in the city.

1.3 How is Ettelbruck parking smart?

Faced with these challenges, and in line with its vision of being a future smart city, Ettelbruck undertook to revamp the manner in which it manages its traffic.

In October 2019[9], the city deployed a technology which enables real-time monitoring of 954 of its 1700 parking spaces (or 8 of its 20 parking lots). This includes the city's conventional parking spaces, as well as those reserved for persons with reduced mobility (PMRs), electric vehicles, delivery personnel, and taxis. The city partnered with *UPCITI*, a French firm whose sensor technology based on image analysis using Artificial Intelligence, permits the collection of real-time data. The 32 installed UPC5 sensors of UPCITI detect free parking bays in real time. Then, the observed data is transmitted to *RMS.lu*, an enterprise based in Ettelbruck, which processes this data. The information is then transmitted to the users, via 34 panels installed across various point in the city, which display the number of parking places available in each of the 8 parking lots. This information is also made available in real-time on the site of the *Ville d'Ettelbruck*[10].

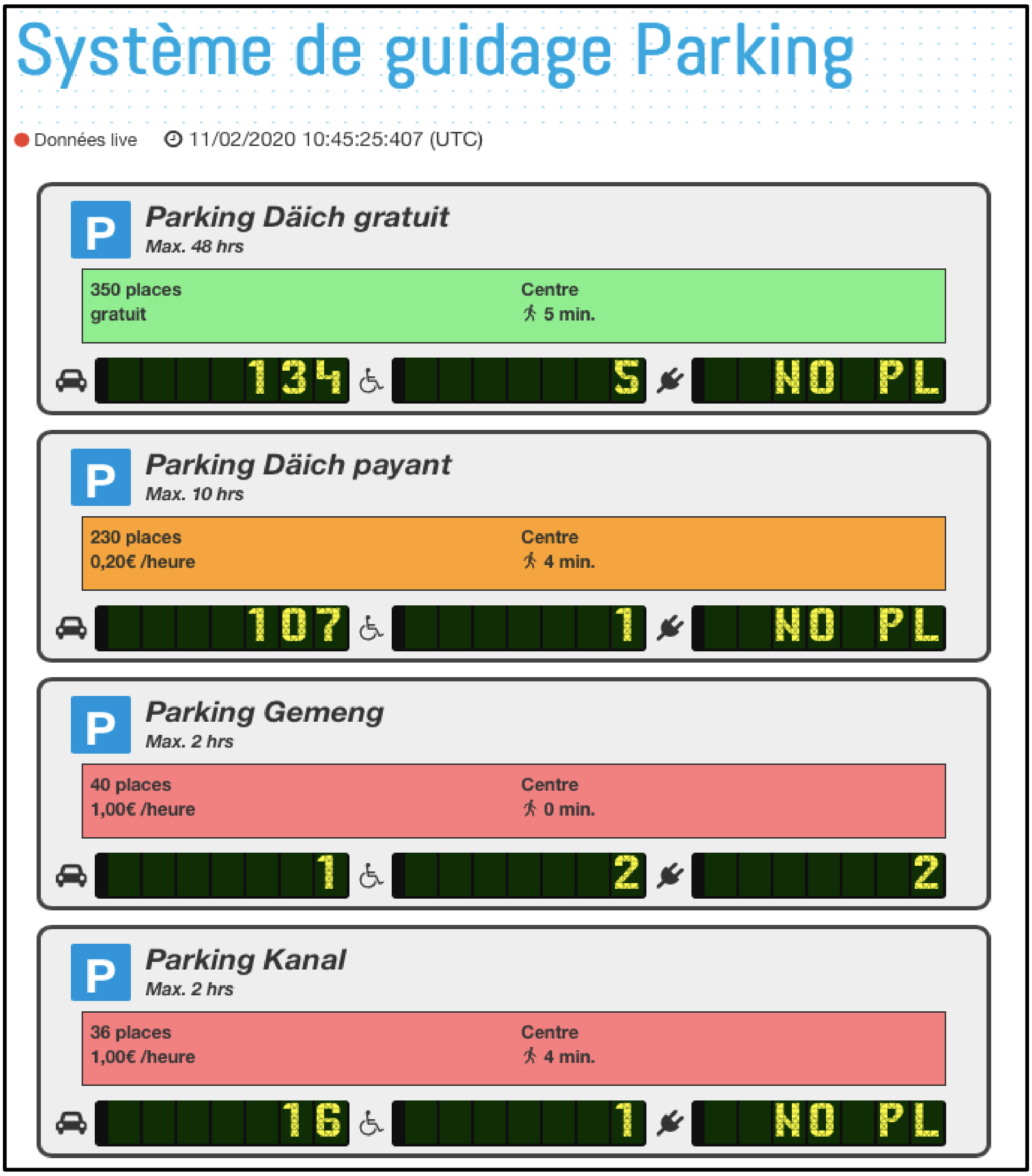
[7]International Parking Institute. (2012). *2012 Emerging Trends in Parking*. https://www.parking.org/wp-content/uploads/2015/12/Emerging-Trends-2012.pdf

[8] The most important solution seemed to be increasing the use of energy-efficient lighting in parking lots.

[9] The pilot phase of this project lasted for 2.5-3 years and was carried out near the *Administration Communale de la Ville d'Ettelbruck*, to enable a better management and monitoring of the solution.

[10] http://ettelbruck.lu/systeme-de-guidage-parking/

Figure 1: Information on availability of parking spaces as transmitted on the city's website



Note: Example shows information for 4 out of the 8 parking lots monitored.
Source: City of Ettelbruck website, http://ettelbruck.lu/systeme-de-guidage-parking/

An important issue that can hamper the effectiveness of such a technology is the risk that the displayed parking space(s) would be occupied by other driver(s) by the time a driver reaches the indicated park. To minimize this problem, RMS offers parking managers the possibility of defining, according to certain thresholds, how busy the areas are where the parking lots are located. In busy zones, if there are two parking spaces left, the parking lot is displayed as full. On the other hand, in less busy zones, the actual number of parking spaces available gets displayed. Real-time detailed information on the status of each parking space (available or occupied) is also available to the personnel of RMS.lu as well as the traffic manager of the city, along with daily, weekly, and monthly statistics on the rate and time of occupation throughout the day.

So far, the technology has proved its utility. The feedback from the visitors as well as the residents is largely positive, and the city hopes that the project will go a long way in improving the attractivity of this dynamic city by improving the comfort of its travelers. The traffic manager of the city asserts that the technology is functioning well and has proved to be effective : average cruising times have reduced, and the problems of traffic congestion and high levels of noise pollution, especially in busy centers like areas near the city town hall, have ameliorated. **Currently, the technology benefits around 2 200 cars each day[11], 200 of which are of students, 620 of people travelling for work, and the remaining 1 380 of people travelling for shopping, leisure, sports, etc.** Plans are also in place to construct another multi-level parking structure in the city with 500 places and extend the technology to those parking spaces.

[11] These are cars which are ultimately parked in the parking lots which are monitored by the smart parking technology (8 out of 20 parking lots or 954 out of the 1700 parking spaces in the city).

Chapter 2: Socio-economic evaluation: the method

According to the recommendations of the *Guide to the socioeconomic evaluation of public investments* (2017)[12], the socio-economic evaluation of a project must first set out the objectives that explain why the investment under question was undertaken, and the structural problems that the investment seeks to solve. In this sense, the description of the current situation forms the basis of the evaluation.

The socioeconomic assessment then compares investment option with a reference option - also known as a *counterfactual* situation - which represents the situation which would prevail in the event that the investment was not made.

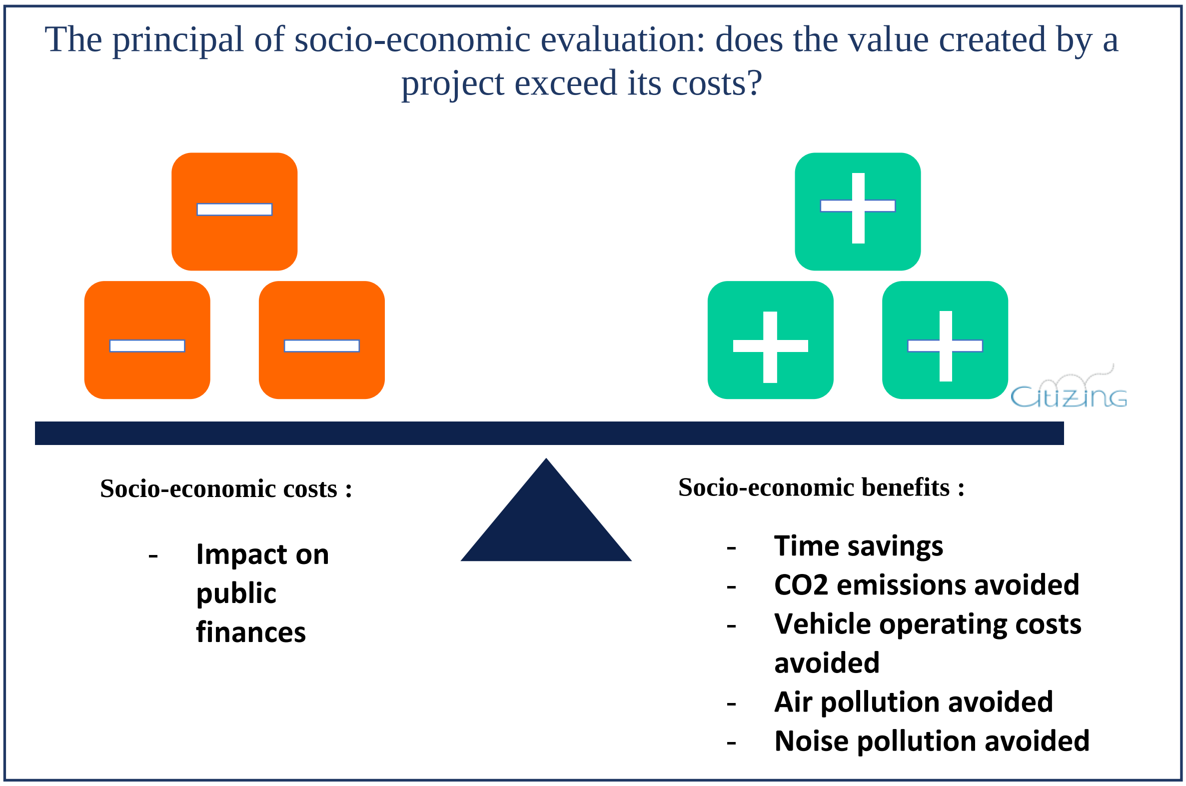
Finally, the effects of the investment under question are identified, estimated, and monetarized, allowing socio-economic indicators to be calculated. It is these indicators that ultimately give rise to conclusions on the socio-economic viability of the project. The subsections below explain step by step the principle and methodology of socio-economic assessment.

2.1 The Principle of Socio-economic Evaluation

Socio-economic evaluation constitutes a tool for aiding public decision-making since it makes it possible to measure the usefulness of an investment. Through the means of a cost-benefit analysis, it helps in determining whether, given its cost, a project creates sufficient value for the society. Such an evaluation compares the costs and benefits of various natures, for the totality of stakeholders affected by the project, and often, in the long term. Public investments affect many actors without providing for commercial exchanges: those negatively affected by a project are not always compensated and those affected positively do not necessarily pay for the benefits they enjoy. For example, the reduction in noise induced by a reduction in car traffic greatly benefits residents of a city; residents are however not asked to pay for this benefit. It is then evident that the costs and benefits of these projects are not only financial; they can be economic, social, and environmental in nature.

[12] France Stratégie et Direction Générale du Trésor. (2017). Guide to the socioeconomic evaluation of public investments in France. https://www.strategie.gouv.fr/sites/strategie.gouv.fr/files/atoms/files/fs-guide-to-socioecomic-evaluation-of-public-investments-in-france_final-web.pdf

Figure 2: The principle of socio-economic evaluation



2.2 The Specificities of a socio-economic evaluation

Several features characterize socio-economic evaluations:

Evaluation in differential

These evaluations are always carried out in differential: they compare a situation **without the project** (called the *reference or counterfactual option*) and a situation **with the implementation of the project** (called the *project option*). Thus, the results of these studies indicate the *delta* in the creation (or destruction) of value with the project, compared to the situation where the project is not undertaken.

Monetarization

In order to compare costs and benefits of different natures, they must be expressed in a common unit. By convention, this unit is the monetary unit, and this is where the exercise of monetarization comes into the picture.

The monetarization of impacts can be done in several ways:

a. When the impact constitutes a direct economic impact, it is expressed directly in monetary units (for example, costs incurred linked to higher maintenance expenditures).

b. For other impacts, reference values can be used. The *Quinet* reports (2013[13], 2017[14], and 2019[15]) define certain types of reference values, such as the value of time, the value of a ton of CO2, the value of air and noise pollution, or the value of human life.

It is important to mention here that in the absence of such reference values for Luxembourg, as well as any harmonized database that provides such values for Europe, the best option for this evaluation was to mobilize the reference values for France for determining the reference values for Luxembourg. The earliest date for which the reference values for France are available is 2010. To ensure their validity for the case of Luxembourg, the reference values for France in 2010 were multiplied by the ratio of the per capita GDP of Luxembourg[16] and the per capita GDP of France[17] in 2010. Moreover, the evolution of these values depends on the growth of per capita gross domestic product (GDP) of a country and all reference values[18] for Luxembourg, were estimated using the growth of per capita GDP of Luxembourg to make these values as valid as possible to the Luxembourgish context.

c. When such benchmark values do not exist, the impacts, which nonetheless have an effect on the well-being of individuals, are monetarized by extrapolating the results of academic articles. These articles often aim to "reveal the preferences" of individuals, and ultimately give them a value using revealed preference techniques or hedonic prices. For example, these methods could reveal the willingness to pay (WTP) of citizens to have 10% more parking spaces.

The mechanism of discounting

A discount rate is applied to all identified socio-economic costs and benefits of the investment. This rate helps to express in today's terms the costs or benefits that will arise tomorrow. Such discounting is necessary for the simple reason that € 1 tomorrow is worth less than € 1 today. The choice of this rate therefore represents the arbitrage between the present and the future: a high rate gives little weight to the future. A low discount rate, on the contrary, means that the current generation gives a strong weight to the future: the society is ready to sacrifice more in terms of its present resources to prepare for the future. This rate also takes into account a risk premium. This evaluation uses the discount rate recommended by the *Guide to Cost-benefit Analysis of Investment*

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[13] Quinet, E. (2013). L'évaluation socio-économique des investissements publics. Commissariat Général à la Stratégie et à la Prospective.
https://www.strategie.gouv.fr/sites/strategie.gouv.fr/files/archives/CGSP_Evaluation_socioeconomique_17092013.pdf

[14] France Stratégie et Direction Générale du Trésor. (2017). Guide to the socioeconomic evaluation of public investments in France. https://www.strategie.gouv.fr/sites/strategie.gouv.fr/files/atoms/files/fs-guide-to-socioecomic-evaluation-of-public-investments-in-france_final-web.pdf

[15] France Stratégie. The value for climate action. (2019).
https://www.strategie.gouv.fr/sites/strategie.gouv.fr/files/atoms/files/fs-the-value-for-climate-action-final-web.pdf

[16] *Source*: International Monetary Fund. IMF DataMapper.
https://www.imf.org/external/datamapper/NGDPDPC@WEO/OEMDC/ADVEC/WEOWORLD/LUX?

[17] *Source*: International Monetary Fund. IMF DataMapper.
https://www.imf.org/external/datamapper/NGDPDPC@WEO/OEMDC/ADVEC/WEOWORLD/FRA?

[18] Reference values for time, air pollution, and noise pollution have been calculated using this method. However, for CO2 emissions, values recommended by the Directorate-General for Climate Action (European Commission, 2016) have been used. For vehicle operating costs (including maintenance cost of a car, fuel costs, insurance costs, etc.) per kilometer driven, values recommended by Maibach et al (European Commission, 2006) have been used.

Projects (European Commission, 2015)[19]. The guide recommends using a social discount rate of 5% for all evaluations undertaking an economic analysis of investment projects in the European Union.

The time horizon of the calculation

In general, the technical or economic life of investments is used as the time horizon of the calculation. In other words, the costs and benefits are estimated and updated over this entire period. In the case of this evaluation, however, the principal interest is to measure the short-term benefits to the society after the implementation of the technology. Hence, the time horizon used for this evaluation is that of 5 years. Precisely, the temporal horizon considered starts from November 2019 (after the implementation of the project in October 2018) and ends by the end of 2024. This is also consistent with Thiébaud et al (2018) which argue that technology becomes obsolete after 5 years, on average.

The opportunity cost of public funds (OCPF) and the fictitious price of scarcity of public funds (FPSPF)

Public goods are mostly financed by public tax levies. However, one euro taken from a taxpayer costs more than one euro to the society. This is because taxes generate a market distortion[20] and this *inefficiency* is called the "opportunity cost of public funds (OCPF)". For this reason, the Quinet report recommends that, all costs representing public money spending should be multiplied by a coefficient of 1.20[21].
The OCPF is different from the "fictitious scarcity of public funds price (FPSPF)", which represents the *insufficiency* of public funds, thus requiring the community to choose between different public projects. While the OCPF is linked to the structure of taxes, the FPSPF is linked to their level. The FPSPF requires adding a coefficient of 0.05[22]. In sum, a coefficient of 1.25 is applied to the amount of all expenditure made using public funds.

All methodological elements having been laid down, it can be seen that the socio-economic cost of a project represents a far wider notion than only the amount invested in the project. There are several reasons for this:

a. The cost of not doing the project (the cost of the counterfactual) is deducted from the amount of investment in the project.
b. The costs related to the maintenance and upkeep of a project, over the temporal horizon under consideration, are also taken into account.

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[19] Directorate-General for Regional and Urban policy (European Commission). (2015). Guide to Cost-Benefit Analysis of Investment Projects (2015). https://ec.europa.eu/regional_policy/sources/docgener/studies/pdf/cba_guide.pdf
[20] This is because when taxes are levied, consumers pay more than producers receive, leading consumers to consume less and producers to produce less.
[21] For projects undertaken in the European Union, the 'Guide to Cost-Benefit Analysis of Investment Projects' (European Commission, 2015) also recommends adjusting public expenditure towards (or revenue from) a project to reflect the OCPF. However, in the scenario where national guidelines do not exist, the default rule suggested in the guide is OCPF = 1 (which is equivalent to not taking the opportunity cost into consideration). Nonetheless, with the conviction that this cost should not be assumed away and in order to get as conservative results as possible, this evaluation proceeds with assuming an OCPF of 1,2, as recommended by Quinet (2013).
[22] While Quinet (2013) recommends adding 0,05, Quinet (2019) recommends adding 0,07. However, the latter recommendation is made in a document that provides guidelines only for socioeconomic evaluation of construction and restructuration of buildings dedicated to higher education. Given the lack of clarity over which coefficient should be used in general, and the fact that the value 0,05 has been used in France for a long period of time for the socioeconomic evaluation of numerous projects, this evaluation proceeds with adding 0,05.

c. Because public funds are scarce and costly to raise, all expenditures that represent public funds, are applied an opportunity cost of public funds (OCPF) and the fictitious price of scarcity of public funds (FPSPF). In other words, these expenses are multiplied by a coefficient 1.27.

d. The socio-economic cost includes the negative externalities generated by the project.

2.3 The indicators calculated

Once all the costs and benefits have been translated into the monetary unit, socio-economic indicators are calculated, particularly:

The Socio-economic Net Present Value (SE-NPV)

This indicator represents the collective value created by the project (socio-economic gains), net of the costs of the project, over the temporal horizon studied, reduced to a value of today. In other words, it's the socio-economic benefits, minus the socio-economic costs.
A SE-NPV > 0 indicates a project that creates more socio-economic value than it costs to the society. In other words, it is socio-economically desirable.

It is recalled that the creation (or destruction) of value is calculated as a differential compared to the situation where the project is not undertaken (counterfactual). To ensure comparability between these two situations, the socio-economic NPV is calculated over the same time horizon.

Return on Socio-economic Investment (SE-ROI)

It is the collective value created *per* euro public invested. In other words, these are the total socio-economic and environmental benefits of the project, over the temporal horizon, minus the socio-economic cost of the project, per euro public.

2.4 Considerations and Caveats

While interpreting the magnitude of the results of this evaluation, it is important to keep in mind a few considerations. Firstly, this evaluation measures the socio-economic costs and benefits of the project assuming that the status quo is maintained for the five-year period under consideration. That is, we assume that until the end of 2024, there are no micro-level changes (changes in the scale of the project, number of people who benefit from the project, the composition of users) or macro-level changes (economic shocks, demographic changes, drastic shifts towards utilization of electric vehicles than conventional automobiles) that may have a bearing on the impacts of the project. At the same time, this evaluation did not have for objective a monetarization of qualitative effects of the deployment of the technology, for example, an increase in the attractivity of the city. Such favorable impacts are further likely to increase the socio-economic value created by this project, above and beyond the socio-economic net present value presented in this evaluation.

Secondly, all impacts measured in this evaluation are for cars that *ultimately park* in the parking lots monitored by the technology (8 out of the 20 parking lots or 954 of the 1700 parking spaces in the city). After discussions with the traffic manager of Ettelbruck, it was determined that cars that park in the non-monitored parking lots are not expected to witness reduced cruising times following the deployment of the technology. The reason for this is that many of these spaces are occupied by the residents of the city, who park their cars there for 2-3 days[23], or more. Some even purchase yearly tickets to use these spaces as permanent parking spaces. In all, this takes up around 500 (out of around 800) of the non-monitored parking spaces. The remaining 300 parking spaces make it very difficult to find parking in the non-monitored lots. Thus, the cars parking in the non-monitored lots are not expected to witness reduced cruising times. Therefore, time savings of only cars that are ultimately parked in monitored lots are used for this evaluation.

Finally, to carry out this evaluation, a certain number of hypotheses have been made. Extreme caution has been exercised in the process and an attempt has been made to get as conservative results as possible. Some hypotheses are: determining the base value (in the year 2010) of the reference values for Luxembourg (as compared to values for France) and their evolution over time; the average level of time savings following the deployment of the technology, and the average carbon emissions of a car in the European Union. At all relevant junctures, attention is drawn to the hypotheses made.

[23] In the monitored parking lots, however, each ticket allows no more than two hours of parking.

Chapter 3: Socio-economic evaluation applied to the UPCITI project at Ettelbruck: defining the Reference Option and the Project option

As already mentioned, a socio-economic evaluation is carried out in differential: the costs and benefits of an investment (called **project option**) are compared to those in the situation where the investment is not undertaken (called **reference option** or **counterfactual**).

The Reference Option

The reference option of this socio-economic evaluation constitutes the scenario where the UPCITI and RMS technologies to monitor available parking spaces and communicating such information to drivers would *not* have been put in place. In simple words, it refers to *maintaining the status quo* as it was before October 2019, the month when these technologies were made available for public use.

The Project Option

This option corresponds to the situation where real time monitoring of 954 of 1 700 parking spaces in Ettelbruck is put into place. As described above, the project option thus consists of the costs and benefits of the installation of 32 UPC5 UPCITI sensors and 34 panels and the transmission of the data to the end users (via the panels and the Ettelbruck website).

Chapter 4: Impacts of the Project: Identification, Quantification, and Monetarization

In what follows, six costs and benefits related to the project have been monetarized:

- **the difference in direct costs between the project option and the reference option**
- **the time savings of drivers, due to reduction of cruising times, under the project option**
- **the *net* reduction in CO_2 emissions (the difference between CO_2 emissions avoided and additional CO_2 emissions) under the project option**
- **the reduction in vehicle operating costs under the project option**
- **the reduction in air pollution under the project option**
- **the reduction in noise pollution under the project option**

4.1 Investment and maintenance costs

a. Description of the effect

Investment and maintenance costs are costs that have a direct market value (i.e., they are already expressed in monetary terms).

The reference option of this socioeconomic evaluation refers to the scenario where the smart parking technology is not deployed. As a result, the costs associated to the reference option are zero.

On the other hand, the project option of this evaluation represents the scenario where the technology is deployed.
The deployment of the technology the entails a **total investment cost of 302 306 €**, of which 55 051 € are attributable to the installation of the sensors, battery kits and parking material, 136 191 € to the installation of panels, and 20 603 € to the installation of masts. The remaining costs represent supplementary and assistance costs: road foundations, configuration of the parking spaces, etc. A detailed review of the costs is provided in the Annex (Table A.1).

Once the technology is deployed, the city will also incur annual maintenance costs. These are estimated at 35 787 €, and include sensor operating licences, RMS parking licences, sensor cleaning, sensor replacement, and the energy consumption of the sensors and the panels. A detailed review of these costs is provided in the Annex (Table A.1). **Over the time horizon of the study end of 2024), the maintenance cost of the project is therefore estimated to amount to 182 820 €.**

The total (investment + maintenance) cost of the project is thus estimated at 485 126 €. This result does not take into account (i) the discount rate and (ii) the opportunity cost of public funds (OCPF) and the fictitious price of scarcity of public funds (FPSPF)

b. Results

As mentioned in the methodological section, once the cost differential between the project option and the reference option is calculated for each year, the values are discounted and added up. Finally, the OCPF and FPSPF are applied to the discounted value (i.e., the value is multiplied by 1,25 – see the methodological section for more details).

The discounted investment cost of the project, after applying the OCPF and PFRPF, is **359 888 $€_{2020}$ HT.**

The maintenance costs are first calculated for each year over the relevant time horizon (until the end of 2024). Then the sum of their discounted values is determined, to which the OCPF and the FPSPF are applied, giving **189 076 $€_{2020}$ HT** of discounted maintenance costs**.**

Thus, the total discounted costs (including OCPF and FPSPF) of the project sum up to 548 964 $€_{2020}$ HT.

A detailed table with the breakdown of the discounted costs is presented in the Annex (Table A.2).

4.2 Time Savings

a. Description of the effect

One of the principal reasons for deploying this technology was to reduce 'cruising times', the time drivers spend looking for a space to park their vehicles. UPCITI's sensors identify available parking spaces in real time and this information is communicated it to the drivers through panels installed in the city and through the website of the city[24]. This reduces the time they *would've spent* looking for a parking space, had the technology not been deployed.

b. Magnitude of the effect

Lu et al (2009) developed a model to evaluate a proposed parking scheme, SPARK, which relies on VANET (Vehicle Ad Hoc Networks), a technology that allows cars to communicate with units employed in parking lots that surveil and manage the parking. Their simulations for a parking mall facility showed that smart parking technologies do reduce cruising times. Fries et. al. (2010) conducted a study to evaluate the impact of information on the parking activities on a rural university campus, which is transmitted in real-time via variable-message signs places along the perimeter road. They found that the system reduced average searching times by 15%. In France, the smart parking solution *Parkassist* was found to reduce cruising times by up to 44%. Thus, so far, smart parking technologies seem to be effective in proving their utility.

As a measure of the impact of the smart parking technology in question, this evaluation uses the estimation for average reduction in cruising times, provided by the traffic manager of Ettelbruck. Firstly, this allows for one to be assured that the results presented in this evaluation are *directly attributable* to the specific technology in question. Secondly, this also permits to draw upon the rich parking data available to the manager as well as his experience and insights on the functioning of the technology.

[24] http://ettelbruck.lu/systeme-de-guidage-parking/

The traffic manager estimates that following the implementation of the technology, the average cruising time per driver is expected to have been reduced from 10 minutes to 6 minutes, giving, *on average, a reduction of 4 minutes of cruising time per driver.*

c. Method of monetarization

In order to monetize the time savings linked to reduced cruising times, the reference value of time recommended by the Quinet (2013) report, are utilized. As already mentioned, in the absence of the reference value for Luxembourg, *first the Luxembourgish equivalents of the French 2010 reference values were calculated (by multiplying them with the ratio of GDP per capita of Luxembourg and France in 2010). Then, their evolution in the successive years was in accordance with the growth of per capita gross domestic product (GDP) of Luxembourg, to make these values as valid as possible to the Luxembourgish context.* As an example, the value of time for one person for one hour of travel between home and work in an urban[25] area like Ettelbruck would be 28,7 $€_{2020}$ in the current year and would rise to 31,4 $€_{2020}$ in 2024.

As mentioned, the technology benefits around 2 200 cars each day. The share of these cars belonging to students, working people, and people travelling for other purposes was estimated as accurately as possible by the traffic manager of the city, and we use these shares for the purpose of this evaluation. It was estimated that of the 2 200 cars that benefit each day, 200 belong to students, 620 to people travelling for work, and the rest 1 380 to people travelling to Ettelbruck for shopping, leisure, sports, etc. Since the above-mentioned reference values are for a single person, in consultation with the traffic manager of the city, it was determined that each car can be estimated to be carrying 1,5 passengers. Thus, except for the case where people are travelling for work, we assume that each car carries 1,5 passengers. This gives us 2 990 people who benefit from the technology *each* day: 620 working people, 300 students, and 2 070 people travelling for other purposes.

Having calculated the number of people benefitting each day, the average time savings translate into 200 hours of time savings each day. Further, the calculation of time savings per year requires the calculation of the number of days in a year that people under question benefit. For students, number of days of travel is estimated considering that they would not travel to school on weekends, during vacation periods[26], and on public holidays[27] (11 in Luxembourg), giving 133 days of travel annually. Similarly, working professionals would not travel to work on weekends, public holidays[28], and their formal leave days (25 days), giving 227,5 days of travel in a year. Finally, for people travelling for other purposes (sport, leisure, shopping, etc.), all days of the year but public holidays and days where city shops are closed are considered[29]. This gives a total of 315 days of travel in a year. Taking into account these figures gives 55 533 hours of time savings each year.

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[25] For the purpose of socioeconomic calculations, Quinet (2013) defines urban area as an area where the population density is between 450 and 1 500 habitants per km^2. Ettelbruck, with a population density of 580 habitants per km^2 is therefore considered an urban area.

[26] *Source*: https://ettelbruck.lu/enseignement-formation/

[27] *Source*: https://fonction-publique.public.lu/fr/carriere/organisation-temps-travail/conges-absences/jours-feries.html

[28] As per interviews with the traffic manager of Ettelbruck, professionals in Luxembourg end up with 7,5 public holidays in a year.

[29] City shops are closed on 50 days per year: for 40 Sundays out of 52 Sundays in a year and for 10 days during Christmas.

d. Results

The estimated discounted value of total time savings until the end of 2024 are **5 344 145,41 $€_{2020}$**.

The table below summarizes these results.

Table 1: Summary of results for time savings after deployment of technology

Average time savings per user after the deployment of the technology for those who park in monitored spaces (in minutes)	4
Number of people who benefit each day	
Workers	620
Students	300
People travelling with other motives (leisure, sport)	2 070
Total	**2 990**
Total time savings per day (in hours)	199
Total time savings per year (in hours)	55 533
Reference value of time spent during travel (in €2020) (2020-2024)	
Home to work / Home to place of study	28,7 - 31,4
Other (shopping, health, visits, leisure, tourism)	19,6 - 21,4
Discounted value of time savings over a 5-year period (in €2020)	**€5 344 145**

4.3 CO_2 Emissions

4.3.1 CO2 emissions avoided

a. Description of the effect

The more time people spend looking for parking spaces, the more is the fuel burnt, and more is the carbon dioxide emitted. Thus, any technology that reduces cruising times indirectly reduces CO_2 emissions.

b. Magnitude of the effect

The extent to which CO_2 emissions decrease following the implementation of the technology depends on the following factors:

- **Average time savings for drivers after the implementation of the technology**
- **Number of cars that benefit from the implementation of the technology**

- **Average speed at which the drivers drive when searching for a parking place**
- **Emissions of CO_2 by an average per kilometer driven**

To estimate the CO_2 emissions of an average car, data on the average emissions of new cars registered in the European Union between 2014-2018[30] were utilized. This amounts to 119,98 g CO2/km[31]. During the interview with the traffic manager of Ettelbruck, it was estimated that drivers in search of a parking space drive at an average speed of 20 km/hour. With an average time savings of 4 minutes after the implementation of the technology, this equates to each driver traveling 1,33 km less every time he or she searches for a parking space. This would translate into avoiding 160 g of CO_2 emissions per car per day and 0,35 tons of CO_2 emissions overall, on any given day.

To calculate emissions avoided per year, differences in the days of travel of students, working people, and those travelling for other purposes are taken into account. As calculated during the monetarization of the previous effect, days of travel for students, working people and those travelling for other purposes are 133, 227,5, and 315, respectively. Taking into account these figures, distance of travel avoided each year is 803 133 km per year, which translates into avoiding 96 tons of CO_2 emissions per year.

c. Method of monetarization

This impact is monetized using the reference value of CO_2 emissions (or equivalent gases) in the European Union as laid out by the Directorate-General for Climate Action (European Commission, 2016)[32]. At the beginning of the time horizon considered in this study, i.e., the year 2020, the reference value of carbon is 41,28 $€_{2020}$[33]. In 2024, the end of the time horizon of this study, the value will be 47,63 $€_{2020}$.

d. Results

The estimated discounted value of CO2 emissions avoided from the beginning of the project until the end of 2024 is **18 582 $€_{2020}$.**

4.3.2 Additional CO_2 emissions

a. Description of the effect

While the smart parking technology helps reduce CO_2 emissions by decreasing cruising times, the sensors and panels used in the process consume electricity, and the generation of electricity leads to emissions of CO_2.

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[30] The latest five-year period for which the data are available.

[31] European Environment Agency. (2019). Average CO2 emissions from newly registered motor vehicles. https://www.eea.europa.eu/data-and-maps/indicators/average-co2-emissions-from-motor-vehicles/assessment-1

[32] Directorate-General for Climate Action (European Commission). (2016). *Climate change and major projects - Outline of the climate change related requirements and guidance for major projects in the 2014-2020 programming period : ensuring resilience to the adverse impacts of climate change and reducing the emission of greenhouse gases*. https://ec.europa.eu/clima/sites/clima/files/docs/major_projects_en.pdf

[33] The report presents reference values in €2015. In order to ensure consistency, the values have been put in €2020 using the following source: Euro Inflation Calculator. https://www.in2013dollars.com/europe/inflation/2015?amount=39

b. Magnitude of the effect

Each sensor consumes 88 Wh of energy. Each master panel consumes a maximum of 83 Wh of energy and each slave panel a maximum of 58 Wh. With 32 sensors, 14 master panels, and 20 slave panels in utilization, the annual energy consumption by sensors, master panels, and slave panels amounts to 24 668 kWh, 10 179 kWh, and 10 162 kWh, respectively.

In Luxembourg, as of 2014, generation of one kWh of electricity leads to the emission of 307,7 grams of CO_2[34]. This amounts to annual CO_2 emissions of 7,59 tons for electricity consumed by sensors, and 3,13 tons each for electricity consumed by master and slave panels.

c. Method of monetarization

This effect is monetarized using reference values for CO_2 emissions, as mentioned above.

d. Results

The discounted value of the additional CO_2 emissions is 1 463 €$_{2020}$ for sensors, 604 €$_{2020}$ for master panels, and 602 €$_{2020}$ for slave panels, giving a total of **2 670 €$_{2020}$.**

4.3.3 Net CO_2 emissions avoided

The discounted value of net CO_2 emissions avoided is given by the difference between the discounted value of CO_2 emissions avoided and the discounted value of additional CO_2 emissions. This figure amounts to 15 912 €$_{2020}$.

The table below summarizes all results on CO_2 emissions.

Table 2: Summary of results on net CO2 emissions

CO2 emissions avoided due to the technology	
CO2 emissions of an average car in the EU (g CO2/km)	119,98
Drivers' speed while looking for parking (in km/h)	20
Number of cars which benefit per day	2 200
Distance driven avoided per car per day (in km)	1,3
Distance driven avoided per day (in km)	2933
Distance driven avoided per year (in km)	803 133
CO2 emissions avoided per car per day (in g)	160
CO2 emissions avoided per day (in ton)	0,35

[34] European Environment Agency. (2018). CO2 emission intensity. https://www.eea.europa.eu/data-and-maps/daviz/co2-emission-intensity-5#tab-chart_2_filters=%7B%22rowFilters%22%3A%7B%22ugeo%22%3A%5B%22Luxembourg%22%5D%7D%3B%22columnFilters%22%3A%7B%7D%7D

CO2 emissions avoided per year (in ton)	96
Reference value for per ton of carbon (€2020) (2020-2024)	41,28 - 47,63
Discounted value of avoiding carbon emissions over a 5-year period (€2020) (A)	**€18 582**
Additional CO2 emissions due to the technology	
Energy consumption (kwh/year)	
Sensors	24 668
Master Panel	10 179
Slave Panel	10 161
CO2 emissions (in grams) per kWh in Luxembourg (2014)	307
Additional CO2 emissions (in tons) per year	
Sensors	7,6
Master Panel	3,1
Slave Panel	3,1
Discounted cost of additional carbon emissions over a 5-year period	
Sensors	€1 463
Master Panel	€604
Slave Panel	€603
Total Discounted cost of adding carbon emissions over a 5-year period (€2020) (B)	**€2 670**
Value of net CO2 emissions (emissions avoided – additional emissions) (A-B)	**€15 912**

4.4 Vehicle operating costs

a. Description of the effect

When cars travel lesser distances, their wear and tear is prevented and the maintenance expenditure that should be incurred to keep them running is also reduced. In addition, lesser distances directly imply that lesser fuel costs are borne by the drivers of the cars.

b. Magnitude and monetarization of the effect

Maibach et al (European Commission, 2006) present country-wise vehicle operating costs per kilometer driven. These costs are based on seven cost components: costs for wear and tear, capital costs (considering average purchase prices and age of vehicles), personnel costs in the road transport sector, fuel costs, insurance costs, taxes and charges, and any other additional costs. For Luxembourg, the cost is 0,46 $€_{2005}$ per kilometer driven, which translates into 0,57 $€_{2020}$ per kilometer driven[35][36]. As mentioned before, the technology results in 1,33 km of less driving by each car per day and benefits 2 200 cars per day. While determining the magnitude of the previous effect, it was estimated that the reduction in cruising times translates into avoiding 803 133 km of distance travelled each year.

c. Results

The estimated discounted value of vehicle operating costs saved, from the beginning of the project until the end of 2024 is 1 960 258 $€_{2020}$.

The table below summarizes these results.

Table 3: Summary of results on vehicle operating costs avoided

Number of cars who benefit per day	2 200
Distance driven avoided per year (in km)	803 133
Vehicle operating cost (per km) (in $€_{2020}$)	0,57
Discounted value of pollution avoided over a 5-year period (in €2020)	**€1 960 258**

4.5 Air Pollution

a. Description of the effect

Drivers' search for parking spaces burns fuel, which releases into the atmosphere not only CO_2, but also other greenhouse gases (GHGs) which are harmful for the environment. This includes gases like nitrous oxides (NO_x), methane (CH4), and sulphur dioxide (SO_2). Thus, lesser the fuel being burnt, lesser is the amount of such gases that gets released into the atmosphere.

b. Magnitude and monetarization of the effect

Quinet (2013) provides reference values for air pollution[37] per 100 kilometers driven. This value takes into account the health effects of air. As an example, in the current year, the cost of air pollution per 100 kilometers driven by a private vehicle in an urban area is 5 $€_{2020}$. This cost will rise to 5,73 $€_{2020}$ in 2024.

To estimate the magnitude of this effect, the distance avoided (in kilometer) due to reduced cruising times is used. As mentioned before, the technology results in 1,33 km of less driving by each car per day and benefits 2 200 cars per day. While determining the magnitude of the previous effect, it was

[35] The cost has been translated into €2020 using the following source: https://www.in2013dollars.com/europe/inflation/2015?amount=39

[36] For the purpose of this evaluation it is assumed that between 2005 and 2019, the costs in question vary only because of inflation and not due to other factors like the growth in GDP per capita of the country.

[37] These values correspond to the emissions of nitrous oxides (NO_x), particulate matter (PM2.5), Non-Methane Volatile Organic Compounds (NMVOC), and sulphur dioxide (SO_2).

estimated that the reduction in cruising times translates into avoiding 803 133 km of distance travelled each year.

c. Results

The estimated discounted value of avoided air pollution from the beginning of the project until the end of 2024 is 183 856 €$_{2020}$.

The table below summarizes these results.

Table 4: Summary of results on air pollution avoided

Number of cars who benefit per day	2 200
Distance driven avoided per year (in km)	803 133
Reference values for pollution by a private vehicle in urban areas (€2020/100km) (2020-2024)	5,04 - 5,73
Discounted value of pollution avoided over a 5-year period (in €2020)	**€183 856**

4.6 Noise Pollution

a. Description of the effect

When people spend lesser time looking for parking spaces, traffic congestion and the noise pollution that results from it reduces.

b. Magnitude and monetarization of the effect

To estimate the magnitude of this effect, yet again, the distance avoided (in kilometer) due to reduced cruising times is used. Quinet (2013) provides reference values for noise resulting due to variations in traffic, per 1000 kilometers driven. This value takes into account the discomfort caused due to noise exposure, its health effects, the costs of hospitalization, as well as the value of the human life. For example, in the current year, the cost of road traffic noise in urban areas is 5,64€$_{2020}$ per 1000 kilometers driven within a commune. This value will rise to 6,42€$_{2020}$ in 2024.

As mentioned, the distance travelled avoided each year was calculated to be 803 133 km.

c. Results

The estimated discounted value of noise pollution avoided since the deployment of the project until the end of 2024 is 20 580 €$_{2020}$.

The table below summarizes these results.

Table 5: Summary of results on noise pollution avoided

Number of cars who benefit per day	2 200
Distance avoided per year (in km)	803 133
Reference values for noise in urban areas due to variations in road traffic (€2020/1000km) (2020 - 2024)	5,64 - 6,42
Discounted value of noise avoided over a 5-year period (€2020)	**€20 580**

Chapter 5: Socio-economic indicators and Conclusion

The table and figure below summarize the socio-economic benefits estimated in this evaluation. In addition to the direct costs (costs of investment and maintenance) involved in the program, this evaluation monetized gains in terms of time savings, net reduction in CO_2 emissions, reduction in vehicle operating costs, and reduction in air and noise pollution following the implementation of the smart parking project at Ettelbruck. It shows that over a period of five years, the project is expected to create a socio-economic value of 7 million euros, compared to the scenario where the project would not have been undertaken. The positive net socio-economic value created by the project indicates that it benefits the society more than it costs it.

Another socio-economic indicator calculated is the socio-economic return on investment (SE-ROI) generated by the project. This project's SE-ROI, *given* the indicators monetized in this study, is 20,91. In other words, for each public euro invested in the project, the project will generate 21 euros in collective value[38], over a period of five years since its implementation[39].

It is interesting to note three points here. One, all the benefits monetarized in this report depend on the reduction in time savings following the deployment of the technology. Thus, if the time savings of the project were zero, the socioeconomic benefits of the project would be zero, resulting in a negative SE-NPV[40]. Two, in order to ensure that the reduction in cruising times used in this report (4 minutes) is not driving the positive SE-NPV presented in this evaluation, a sensitivity analysis was carried out to analyze what would the SE-NPV and SE-ROI be if the reduction in cruising times was 3,6 minutes, 3 minutes, 2 minutes, or 1 minute instead. It was found that even if the reduction in cruising times was a minute, the SE-NPV of the project would be positive and the SE-ROI would be greater than 1, meaning that the project would still be socially desirable. The results of the sensitivity analysis are presented in the annex (Table A.3). Finally, it was also determined that the SE-NPV of the project would be zero if the reduction in cruising times was 18 seconds. In other words, as long as the technology allows reduction in time spent cruising superior to 18 seconds, its deployment is socially desirable.

At this point, it should be recalled that this evaluation assumes that until the end of the time horizon studied, i.e., until the end of 2024, the status quo is maintained. That is to say that any micro-level changes (changes in the scale of the project, the number of people who benefit from the project, or the composition of users) or macro-level changes (economic shocks, demographic changes, drastic shifts towards utilization of electric vehicles than conventional automobiles) that could affect the results are assumed away. At the same time, this evaluation did not have for objective the monetarization of qualitative effects of the deployment of the technology, for example, an increase

[38] The indicator SE-ROI was calculated as the ratio between the sum of socio-economic benefits (6 975 788 $€_{2020}$) and the discounted investment cost of the project option (359 888 $€_{2020}$), including OCPF and PFSPF.

[39] As mentioned previously, while Quinet (2013) recommends adding 0,05 to the OCPF to take into account the PFSPF, Quinet (2019) recommends adding 0,07. However, the latter recommendation is made in a document that provides guidelines only for socioeconomic evaluation of construction and restructuration of buildings dedicated to higher education. Given the lack of clarity over which coefficient should be used in general, and the fact that the value 0,05 has been used in France for a long period of time for the socioeconomic evaluation of numerous projects, this evaluation proceeded with adding 0,05 to the OCPF. If instead 0,07 is added, the results do not change significantly. The SE-NPV decreases by 8 783 € and the SE-ROI decreases by 0,33.

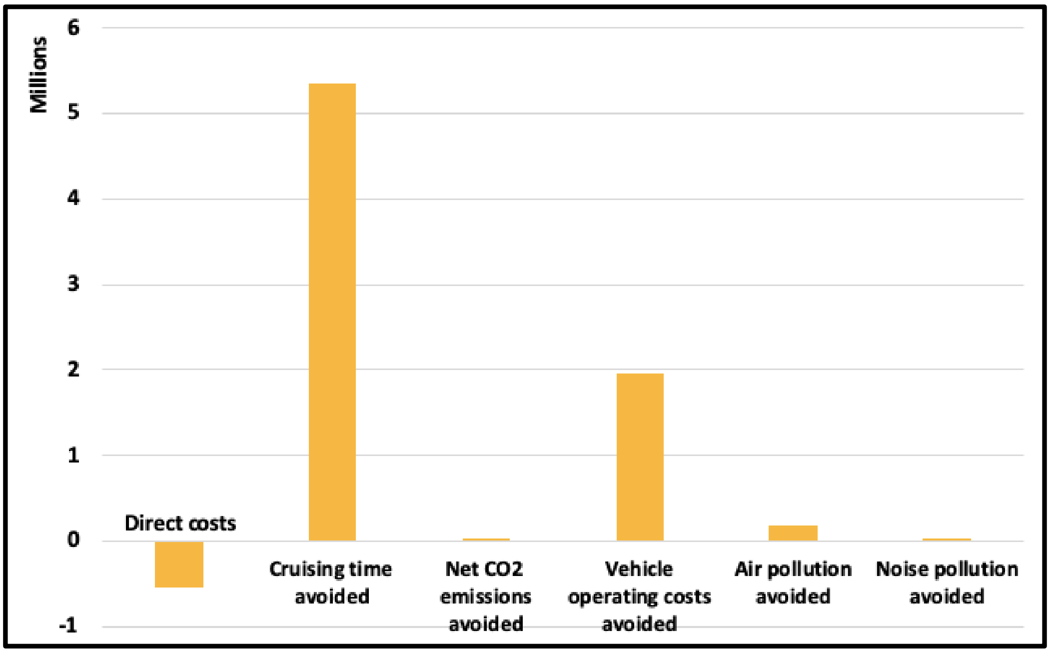
[40] The VAN is negative to the tune of 551 635 $€_{2020}$ HT.

in the attractivity of the city. Such favorable impacts are likely to further increase the socio-economic value created by this project, above and beyond the socio-economic net present value presented in this evaluation.

Table 6: Summary of the discounted Socio-economic Costs and Benefits of the Project (in €$_{2020}$ HT)

Impact	Discounted costs / benefits (in €$_{2020}$ HT)
Direct Costs	
Investment costs	359 888
Maintenance costs	189 076
Total costs (1)	**548 964**
Benefits	
Crusing time avoided	5 344 145
Net CO_2 emissions avoided (emissions avoided – additional emissions)	15 912
Vehicle operating costs avoided	1 960 259
Air pollution avoided	183 856
Noise pollution avoided	20 580
Total benefits (2)	**7 524 752**
Socio-economic Net Present Value ((3) = (2) - (1))	**6 975 788**
Socio-economic Return on Investment	**20,91**

Figure 3: Discounted Socio-economic Costs and Benefits of the project (in Million €$_{2020}$ HT)



Annex – Detailed costs of the project

Investment costs under the project option

The total (undiscounted) cost of investment for the project is 302 306 €$_{2020}$ HT. This cost is divided as follows:

a. **The cost of UPCITI sensors and associated material**
Each sensor costs 900 €$_{2019}$ HT and comes with a battery kit, each priced at 735 €$_{2019}$ HT, as well as a kit of supplementary parking material, each priced at 60 €$_{2019}$ HT. With 32 sensors deployed as a part of the project, this gives a total cost of 55 051 €$_{2020}$ HT[41].

b. **The cost of panels where real-time information is displayed**
The technology uses two types of panels: 'master panels' and 'slave panels'. Each master panel uses at least one slave panel. While each master panel costs 4 206 €$_{2019}$ HT, each slave panel costs 3 765 €$_{2019}$ HT. Currently, 14 master and 20 slave panels are in use. This gives a total cost of 136 191 €$_{2020}$ HT for the panels installed.

c. **The cost of masts**
The sensors are installed on the top of 14 masts currently. Each mast costs 1 450 €$_{2019}$ HT, giving a total cost of 20 603 €$_{2020}$ HT for masts.

d. **Supplementary costs**
- To install the sensors on the masts, aerial work platforms need to be rented, the rent of which is 1 200 €$_{2019}$ HT per day. With the platforms being rented for 16 days[42] to install the 32 sensors in question, the total rent for the platforms is 19 487 €$_{2020}$ HT.
- It costs 9,5 €$_{2019}$ HT for configuring each parking space so that it can be monitored using the technology. With 954 parking spaces being monitored, the total cost of configuration amounts to 9 198 €$_{2020}$ HT.
- The supplementary costs also include a payment made to the individual in-charge of supervising the project during the installation and configuration phase. This amounts to 16 239 €$_{2020}$ HT[43].
- The payment made to a technician for installing the sensors on the top of the masts is 50,5 €$_{2019}$ HT per hour. Assuming that technicians worked for a total of 128 hours[44] for the installation of 32 sensors, the amount paid is 6 560 €$_{2020}$ HT.
- For the installation of each panel and mast, a foundation must be laid on the road. This costs around 800 €$_{2019}$ HT per installation. The total cost of laying foundations for 48 installations (14 master panels, 20 slave panels, and 14 masts) thus amounts to 38 974 €$_{2020}$ HT.

This gives a total of supplementary investment costs of 90 460 €$_{2020}$ HT.

[41] The costs have been translated into €2020 using the following source: Euro Inflation Calculator. https://www.in2013dollars.com/europe/inflation/2015?amount=39. Roughly, the inflation rate used is 1,5%.
[42] Normally, the RMS rents platforms for 2 days to install 4 sensors. So, it is assumed that the platforms would be rented for 16 days to install 32 sensors.
[43] Using the fact that the amount paid for supervising the installation of 4 sensors is 2 000 €$_{2019}$ HT.
[44] Using the fact that installation of 4 sensors takes 16 hours.

Maintenance costs under the project option

The annual maintenance cost (undiscounted) of the project is 35 787 €$_{2020}$ HT.

It includes:

- Annual fees of licenses for operating the sensors: 2 189 €$_{2020}$ HT.
- Annual fees of licenses for RMS parking: 15 492 €$_{2020}$ HT.
- Annual expenditure for cleaning the sensors: 4 883 €$_{2020}$ HT[45].
- Annual expenditure for replacing the sensors that have stopped working: 7 603 €$_{2020}$ HT[46].
- Annual expenditure on electricity consumed by the 32 sensors installed: 3 079 €$_{2020}$ HT[47].
- Annual expenditure on electricity consumed by the panels (14 master panels and 20 slave panels): 2 539 €$_{2020}$ HT[48].

Over the time horizon studied (November 2019 - end of 2024), the total undiscounted maintenance costs amount to **182 820 €$_{2020}$ HT.**

Total undiscounted cost of the project

The total cost of the project, over the time-horizon studied, investment and maintenance costs included, is thus 485 126 €$_{2020}$ HT.

The table below summarizes the investment and maintenance costs linked to the project.

Table A.1 *Undiscounted* Investment and Maintenance Costs of the Project (in €$_{2020}$ HT; *excluding* OCPF[1] and FPSPF[2])

Investment costs	
32 UPCITI sensors, battery kits, and supplementary parking material	55 051
Panels (master and slave)	136 191
Masts	20 603
Supplementary costs	
Rent for aerial work platforms	19 487
Configuration of parking spaces	9 198
Payment to the person supervising installation of the technology	16 239
Payment to the technician for installing the sensors	6 560

[45] After consultations with RMS, it was assumed that the sensors are cleaned twice a year and the process takes 1,5 days each time.

[46] After consultation with RMS, it was assumed that 3 sensors are replaced each year and that it takes half a day to replace each sensor.

[47] Each sensor consumes 88 watts per hour; the cost of electricity for business purposes in Luxembourg is 0,123 €$_{2020}$ per kWh (Source: https://www.globalpetrolprices.com/Luxembourg/electricity_prices/).

[48] Using the information provided by the RMS that master panels consume a maximum of 83 Wh and slave panels consume a maximum of 58 Wh.

Laying foundation on the road	38 974
Total Investment Costs	**302 306**
Annual Maintenance Costs	
Fees of licenses for operating the sensors	2 189
Fees of licenses for RMS parking	15 492
Cleaning of sensors	4 883
Replacement of 3 sensors	7 603
Expenditure on electricity consumed by the sensors	3 079
Expenditure on electricity consumed by the panels	2 539
Total Annual Maintenance Costs	**35 787**
Total Maintenance Costs over the time-horizon studied (until the end of 2024)	**182 820**

1 Opportunity cost of public funds

2 Fictitious price of the scarcity of public funds

Discounted costs of the project

As mentioned in section 4.1, the discounted investment cost of the project, (including the OCPF and the FPSPF) is **359 888 €$_{2020}$** and the discounted maintenance costs over the time horizon studied (including the OCPF and the FPSPF) are **189 076 €$_{2020}$**. The table below presents the breakdown of these costs.

Table A.2 *Discounted* Investment and Maintenance Costs of the Project

(in €$_{2020}$ HT; *including* OCPF[1] and FPSPF[2])

Investment costs	
32 UPCITI sensors, battery kits, and supplementary parking material	65 537
Panels (master and slave)	162 132
Masts	24 528
Supplementary costs	
Rent for aerial work platforms	23 199
Configuration of parking spaces	10 951
Payment to the person supervising installation of the technology	19 333
Payment to the technician for installing the sensors	7 810
Laying foundation on the road	46 398
Total Investment Costs	**359 888**
Annual Maintenance Costs	
Fees of licenses for operating the sensors	2 606
Fees of licenses for RMS parking	18 443
Cleaning of sensors	5 814
Replacement of 3 sensors	9 051

Expenditure on electricity consumed by the sensors	3 666
Expenditure on electricity consumed by the panels	3 023
Total Annual Maintenance Costs	**42 604**
Total Maintenance Costs over the time-horizon studied (until the end of 2024)	**189 076**

1 Opportunity cost of public funds

2 Fictitious price of the scarcity of public funds

Table A.3 Results of the sensitivity analysis

Time savings	SE-NPV	SE-ROI
Time savings per car used in the evaluation (4 minutes)	€ 6 975 788	21
Reduction of 10% in time savings (equivalent to time savings of 3,6 minutes)	€ 6 223 046	19
Reduction of 25% in time savings (equivalent to time savings of 3 minutes)	€ 5 093 932	16
Reduction of 50% in time savings (equivalent to time savings of 2 minutes)	€ 3 212 077	10
Reduction of 75% in time savings (equivalent to time savings of 1 minute)	€ 1 330 221	5

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