Deliverable Proof – Reports resulting from the finalisation of a project task, work package, project stage, project as a whole - EIT-BP2020

Name of KIC project the report results from that contributed to/ resulted in the deliverable	Sustainable Shared Mobility (SuSMo)
Name of report	Evaluation of shared mobility to support decarbonisation
Summary/brief description of report	Report on the current work that TU Delft is doing on mapping the impacts of shared mobility as well as a tool to provide cities with an estimation of the order of magnitude expected for pollution reduction after implementing shared mobility systems (D04).
Date of report	18.01.2021

Climate-KIC is supported by the EIT, a body of the European Union

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Contents

1. Executive Summary

This report outlines the on-going work of TU Delft on mapping the impacts of shared mobility as well as developing a tool to provide cities with an estimation of the order of magnitude expected for pollution reduction after implementing shared mobility systems. The report begins with the presentation of the results of the desk research/literature review on the existing evaluation methods for the impacts of shared mobility and provides a categorization of them. It then describes the motivation and objectives behind the development of an evaluation tool to calculate the impact of shared mobility on decarbonization of cities. Finally, the report presents in detail the methodological approach followed for the development of this tool and concludes with discussing its limitations and perspectives/ideas for further future development of it.

The workplan for year 3 of SuSMo (2021) focuses on dissemination of these outputs. SuSMo is therefore at a critical stage. It is important that this work is completed in order to maximise value for money for Climate-KIC and EIT by ensuring the SuSMo messages and outputs reach a wide audience. Without this dissemination taking place, the overall project objectives will not be fully achieved. Successful dissemination will lead to more cities adopting sustainable shared mobility, greater impacts in terms of carbon emissions reduced, and a growing ecosystem of engaged cities (municipalities, citizens and the private sector).

2. Introduction

Nowadays shared mobility is all around, but often the wide range of impacts that it can have on a city are not fully understood by the citizens and the city authorities. Evaluating these impacts is of critical importance for modern cities, in their endeavour to create a sustainable, people-oriented urban transport system. In order to better understand the different types of impacts and how they can be evaluated, TU Delft conducted a thorough literature review of the different types of methods that can be used for this evaluation and suggested a classification of them.

Aiming at providing a comprehensive and structured critical review of the state of the art and state of the practice of evaluation methods that can be used by cities to assess the impacts of shared mobility, we have reviewed academic literature as well as so-called grey literature—reports, white papers, news articles, blogs, and websites—due to the fact that there is no large volume of research yet focusing on the youngest members of the shared mobility family, such as dockless systems, transportation network companies (TNCs) and e-scooters.

In 2020, after a sharp decrease in ridership that has been reported by most shared mobility service providers during the initial period of local lockdowns and social-distancing measures implemented due to the COVID-19 pandemic, shared modes are now being considered by many cities as a strong ally in supporting urban mobility in the post-pandemic era that lies ahead. More and more cities worldwide are trying to give additional space to active modes of transport, in an attempt to relieve pressure and avoid crowded situations in public transit, encouraging this way for people to walk and cycle more while being able to maintain a physical distance from one another.

We approached the issue from the perspective of city authorities, reflecting on their role, needs, and expectations. Our objective was to provide a valid description of the key dimensions of heterogeneity within research and practice on the topic of the evaluation of the impacts of shared mobility and to provide the basis for the future development and application of methods to support cities in their decisions. Moreover, by identifying the existing gaps in the literature, we highlight the specific needs for research and practice in this field, that can help society figure out the role of urban shared mobility.

3. Classification of the existing evaluation methods for the impacts of shared mobility.

3.1 Categorizing the impacts of shared mobility

A number of studies have dealt with the ways by which shared mobility can affect a city, and the volume of literature is being continuously enriched with the launch of new shared modes like shared e-bikes and e-scooters. The impacts of the more recent ones have been investigated, as expected, to a more limited degree so far, in comparison with more established shared modes that have been operating for decades already, such as car sharing, ridesharing, and traditional docked bike sharing. Even regarding the same modes/services, there are differences in the number of existing studies, depending on the type of business model. For instance, station-based round-trip car sharing has been studied for a longer time than free-floating car sharing, which is a more recent variation. The same holds for station-based and free-floating bike sharing, respectively. The boosted popularity of on-demand ride services has led several researchers to start looking at their impact on different aspects of the urban realm.

In Figure 1 below we summarize the key areas of impact by placing them in what we consider to be the six main categories, namely, environment, travel behaviour, built environment, society, traffic conditions, and economy.

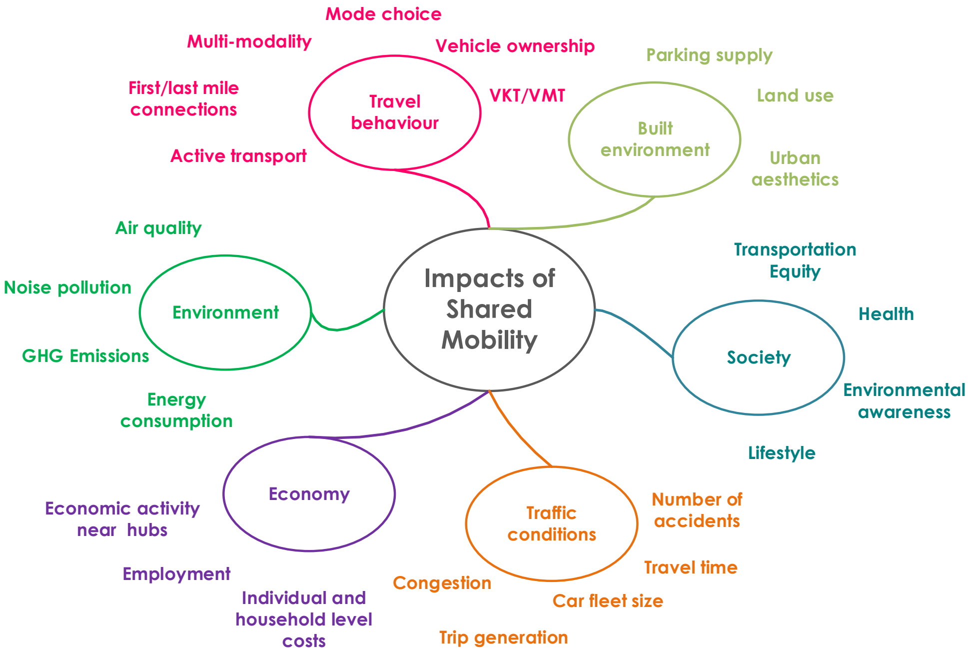

Figure 1. Main categories and key areas of impacts of shared mobility.

3.2 The role of city authorities

Cities all over the world are facing dilemmas related to how to best deal with shared mobility, and how it can be part of their strategies for tackling the changing, complex urban challenges with mobility and land use. This is currently more urgent than ever, for reasons related to the achievement of the UN Sustainable Development Goals and the aftermath of the COVID-19 pandemic. There is thus an undeniably increased interest in implementing shared modes in cities, initiated by new companies appearing on the market to offer such mobility services, but often also by the wishes of the travellers themselves who experience similar services elsewhere. Cities have to make sure that the introduction of new shared modes would indeed fit the needs of the city and citizens and not the other way around.

Many cities are thus facing challenges in understanding if shared mobility would be able to effectively bring any substantial benefit to their territories, and how the existing urban transport system will react when demand for the new mode(s) starts to grow. The difficulty in forecasting and evaluating the impacts of shared mobility can create stress to the decision-makers and can lead to the introduction of blurred policies to avoid "staying behind". Therefore, there is a clear need to provide the right methods and tools to support them in their decisions.

3.3 Available methods for the evaluation

A general observation that can be derived from our literature review is that there is a large, heterogeneous pool of different approaches that researchers have used to try to evaluate the impacts of shared mobility, but a considerable percentage of the existing studies are case-specific and exploratory, and they have thus to be carefully interpreted when trying to scale up or transfer their results. Moreover, the scope of this work is to look at the evaluation process through a city perspective, in the direction of assisting the decision-makers in the challenging process of deciding on the most suitable method or combination of methods to apply to assess the impacts of shared mobility.

In that sense, we are not interested in offering a classification of all the variations of the methods that have ever been used, by academics, researchers and practitioners, to evaluate share mobility's perks and pitfalls. We classify the main categories of options that can be used to evaluate the impact of shared mobility, in a clear format that is meaningful not only to academics and researchers but also to the city authorities and decision-makers; the ones who often face the difficult decisions regarding the implementation of shared mobility programs.

We divided the evaluation methods which according to our views are the most relevant ones that can be of interest to the cities, in several main categories, and then these categories into two groups, based on the time frame in which they can be employed; the ones that can be used before the introduction of a new shared mobility mode/service to a city (ex-ante evaluation) and to the ones that can be used after the new mode/service has been implemented (ex-post evaluation). That being said, several Cities choose to run pilots, which entail short, try-out periods for the implementation of a shared mode, to witness whether the new service provided will have a positive impact on the city, in a relatively more "safe" environment with lower risks involved, due to the temporary nature of the pilot.

The diagram of Figure 2 illustrates the main categories of evaluation methods, classified based on the time frame in which they can be used, in line with the distinction described above. It can be noticed in Figure 2 that some of the categories appear in both time frames, as they can be employed either for the ex-ante or the ex-post evaluation of the impacts of shared mobility.

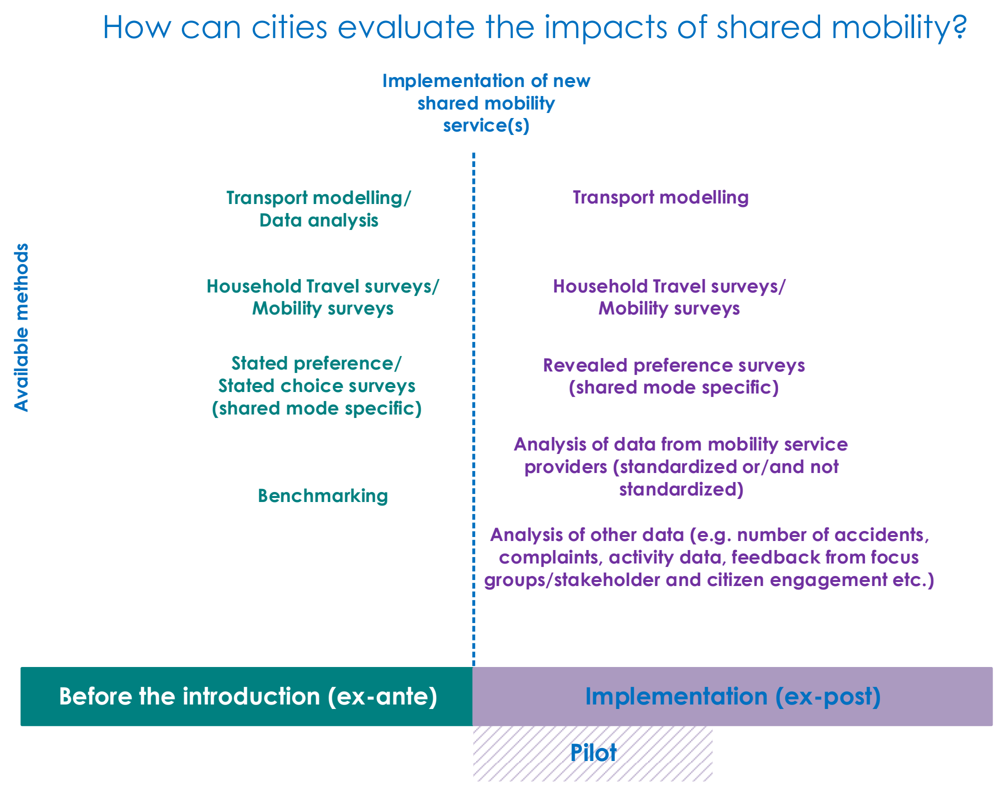

Figure 2. Classification of the main available methods for the evaluation of the impacts of shared mobility.

3.4 Main findings from the state-of-the-art and state-of-the-practice and the need for a comprehensive evaluation framework

We can conclude that there is a large pool of different methods that have been developed by academics and researchers aiming to assess how shared mobility affects a city. These methods vary a lot; some of them, such as the survey-based methods (SP and RP surveys, household/mobility surveys), have been around for decades already in transport-related research, while others, such as the analysis of data from shared mobility service providers have recently gained more attention, as their potential is magnified by the continuous technological progress of our era. We also detected variations in terms of the geography of the methods; using data from shared mobility service providers in a standardized format started in the U.S. and it is more widely used in cities there. Some cities in Europe have started exploring the possibilities that such a method opens for them, but there are still issues related to personal data protection that need to be considered before a wider implementation can become a realistic scenario.

We explained earlier that currently, cities all over the world are struggling in navigating their citizens in the new era of urban transport characterized by electrification, automation, the declining importance of vehicle ownership, and the growing role of ICT innovations; and all these amidst a global pandemic which poses additional challenges and unprecedented restrictions to transport planners and decision-makers. Besides the common urban challenges, the literature review we performed showed that each city has also its unique challenges to consider. Selecting thus the evaluation method(s), the output of which suits better the actual needs of the city is very important and can lead city authorities in making better-informed decisions.

We provided a map and classification of the existing main evaluation methods for shared mobility and at the same time we identified a critical gap in the existing literature, which is the lack of a comprehensive, multi-perspective, evaluation framework that can be applied to assess the full range of impacts that urban shared mobility entails. It is noteworthy that none of the existing methods for the evaluation of shared mobility that have been classified and discussed herein is flawless, for different reasons.

From our findings, it is clear that future research in the field of shared mobility should focus on exploring efficient ways to use these evaluation methods to design frameworks that utilize the strengths of each one while minimizing the downfalls. Some attempts in this direction have already began to be developed in recent years, being mostly U.S.-based initiatives with a focus only on American cities.

The detailed results of the critical review and classification of evaluation impacts of shared mobility that we performed and which we describe above has been published in an open access peer-reviewed journal paper in *Sustainability* journal:

Roukouni, A.; Correia, G. Evaluation Methods for the Impacts of Shared Mobility: Classification and Critical Review. *Sustainability* 2020, 12, 10504.

The published paper can be found on the following link:

https://www.mdpi.com/2071-1050/12/24/10504

4. Development of an evaluation tool to calculate the impact of shared mobility on decarbonization of cities

4.1 Motivation and objectives

As explained in section 3 of the report, there is undoubtedly a wide range of impacts of shared mobility, some of them such as the impact on society (e.g. transportation equity of citizens) more difficult to quantify than others. From our communication with the representatives of the cities – members of the SuSmo project network, Sofia, Bologna and Stockholm - we confirmed the main findings from our desk research, that cities in Europe often struggle with evaluating the impacts of shared mobility modes and services on their territory.

We had detailed discussions with the representatives of these three cities during the bi-weekly scheduled SuSMo project partner meetings and also during the several SuSMo events that have taken place (online workshops and webinars), in which of other cities outside the SuSMo network had also the opportunity to participate. The lack of an evaluation tool emerged from these discussions, which ideally would have the following key characteristics: simple, fast, user friendly and flexible, to give them the opportunity to estimate what would be the impact of introducing different combinations of shared modes in their attempts to decarbonize their city. Considering these characteristics, we developed a tool, that estimates the magnitude of the impacts on CO2 emissions, of different urban mobility scenarios when shared modes are introduced in a city. The following section presents the methodological approach we followed to develop this tool.

4.2. Methodological approach

In the diagram of Figure 1 the main categories of impacts of shared mobility on an urban system were presented. It is noteworthy that these categories are not standalone, but very much interrelated; the impact on the environment for instance is a direct consequence of the changes observed on the travel behaviour of the citizens, which is reflected among others on modal shift and vehicle kilometres travelled (VKT). When citizens change the way they used to travel as a result of the introduction of a new shared mode, this alteration of travel behaviour results in changes in the transport – related CO2 emissions.

We included in our calculations three types of urban shared mobility: car sharing, bike sharing and e-scooter sharing. We also took into account the electrification of (part of) the shared cars fleet.

For the CO2 calculations, we had a strong preference to use data from studies based on European cities (when available), although there is many studies available for cities in the U.S. and Asia. The reason behind this decision is that the differences in structure, density, scale, function of the cities outside Europe affects parameters such as the average distance travelled daily for urban trips and therefore also the average VKT. We considered tailpipe emissions of CO2, as well as the emissions due to electricity production related to electric vehicles (cars and scooters).

When travellers switch from private cars to shared modes, this results in fewer CO2 emissions; however, especially in the case of car sharing, this might not be the case when the shared mobility users were previously using public transport for the same trip, or were performing the trip by walking or cycling. Therefore, in order to calculate the impact of shared mobility on CO2 emissions, first we need to know which modes were being used previously, so that one knows what modes are being replaced by car sharing. After we have estimated this, then we can calculate the amount of CO2 emissions that would have been emitted under this scenario (when the shared mode is not an option) and compare it with the CO2 emissions resulting from the use of the shared mode.

We follow the same approach for the three shared modes we examine; we use as input the current modal split of the city in the three broad categories of: private car, public transport and active modes (walking and cycling) and then we assumed that the number of trips generated with one of the shared modes was previously realized using one of the three aforementioned options. E.g. if the modal split in a city is currently 40% private car, 45% public transport and 15% active modes, we assume that the 40% of the shared trips were previously being done by private car, the 45% by public transport and the rest by active modes. The following sections provide more details about the calculation process for each one of the shared modes we examine.

4.2.1. Car sharing

The calculation process that we follow for the estimation of the impact of car sharing on CO2 emissions is presented in the diagram of Figure 3. The colour coding of the diagram is as follows: The pink cells contain values that are taken from the literature, the purple cells include information that are requested by the cities as input to the evaluation tool, the orange cells entail country-specific factors deducted from EU databases or values

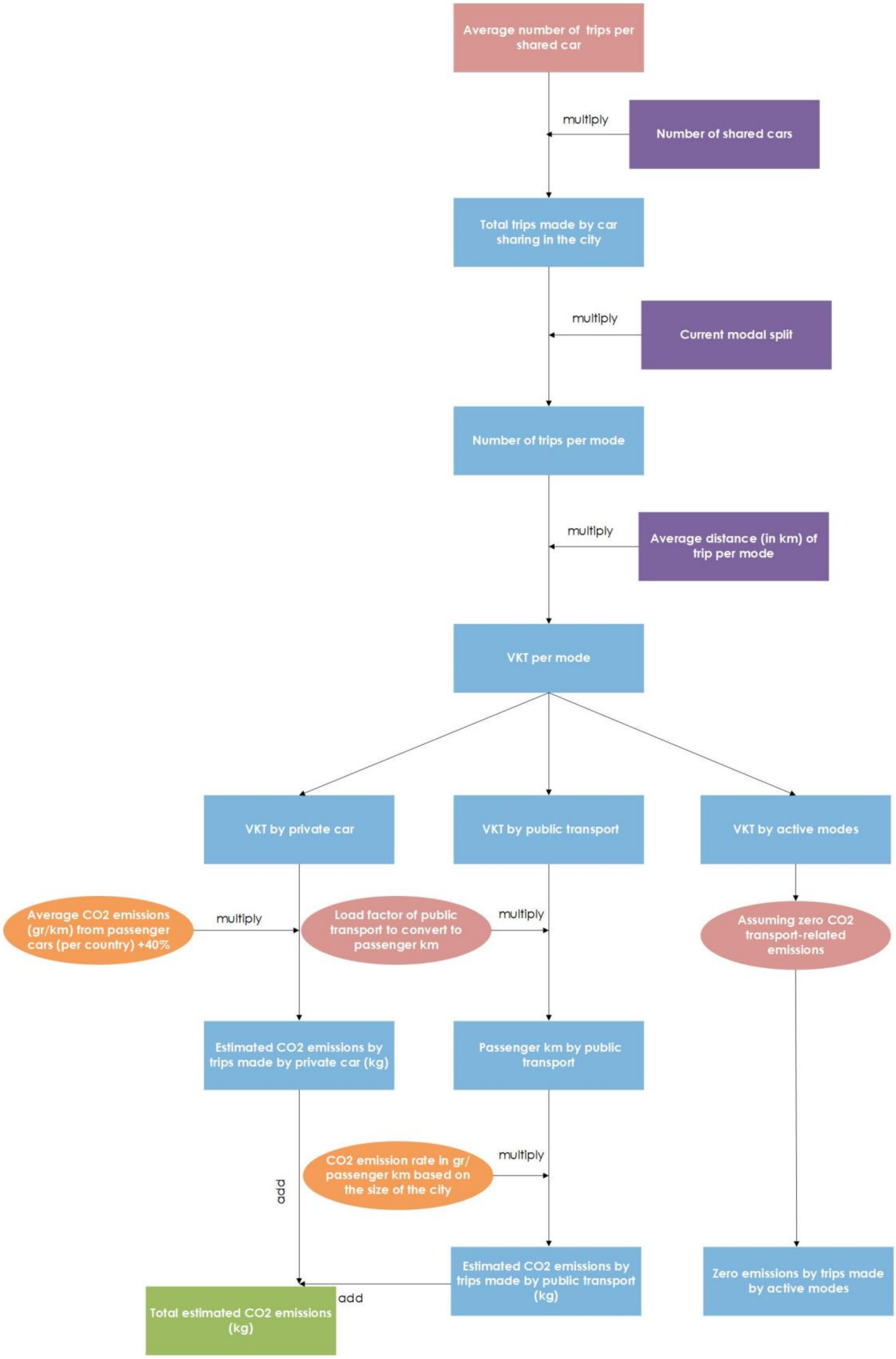

Figure 3. Calculation process of CO2 reductions that result from the impact of car sharing on modal shift.

that change based on the scale of the city (e.g. in the case of public transport estimations as it will be explained below), the blue cells correspond to the intermediate calculation results and finally the estimated CO2 emissions are presented in green colour. The same colour coding is used in all the diagrams included in this deliverable report. The time unit we use is the day, so all the numbers are referring to daily trips.

To begin with, we use the average number of trips per shared car per day (Habibi et al., 2017) and the number of shared cars to estimate the total number of trips made by car sharing in the city. After that, in line with the assumption we presented in section 4.2., we use the current modal split of the city to calculate the number of trips per mode; our aim is thus to see how would the trips have been made if car sharing was not an option. Following that, and using the average distance per trip per mode in that specific city, we can calculate the VKT per mode (private car, public transport, active modes). The next step is to calculate the CO2 emissions that correspond to the VKT by the first two categories (as we assume zero transport-related CO2 emissions for the active modes category).

To calculate the amount of CO2 emissions from private cars, we use the country-specific indicator of the average CO2 per km from passenger cars. We select which year's factor to use based on information each city provides regarding the average age of the private cars' fleet. All the factors were derived from the Eurostat database (Eurostat, 2020). It is worth noticing that according to the International Council on Clean Transportation, there is a significant difference between the CO2 emissions measured in the lab experiments and the real-world emissions. The real emissions tend to be around 40% higher when the New European Driving Cycle (NEDC) method is used (Dornoff et al., 2020). With the recent introduction of the Worldwide Harmonized Light Vehicles Test Procedure (WLTP) which started being used in 2017, this gap is expected to close to approximately 14% discrepancy between lab and real-world (Dornoff et al., 2020). We added 40% to the CO2 factors used here to account for this difference (see also Fromm et al., 2019), as the latest available values for CO2 emissions per km per country is for 2017. For future use of this evaluation tool, we recommend adapting this value if necessary to the WLTP standards.

In the case of public transport, we first need to convert the VKT to passenger-km travelled, as the CO2 emission rate for public transport is measured in this unit, and for this reason, we multiply with an average load factor derived from the literature. For the CO2 emission rate we adopted the classification of the methodological guide of Medde (French Ministry of Ecology, Sustainable Development, and Energy) and ADEME (Environment and Energy Management Agency) (2012) (p. 159) that suggested using the following factors based on the population of a city:

Under 100000 inhabitants -> 171 g CO2/passenger km

Between 100000 and 250000 inhabitants -> 154 g CO2/passenger km

Over 250000 inhabitants - > 144 g CO2/passenger km

After having calculated the estimated CO2 emissions from the trips that would come from private cars and public transport, their sum is the total volume of CO2 saved by car sharing.

The next step is to calculate the CO2 emissions of the car sharing fleet itself, taking into account that part (or in some cases the total) fleet can consist of electric cars. The calculation process for this is described in Figure 4.

In addition to the number of shared cars in a city, the evaluation tool requires as an input the percentage of the car sharing fleet that consists of EVs. So, we can calculate based on that, the number of cars with conventional combustion engines and the number of EVs, and the corresponding emissions. For the typical shared car models for conventional engine cars and for electric ones we use a representative widely used model for each category, as follows:

Combustion engine: Volkswagen up! -> 117 gr CO2/km

Electric car: Mitsubishi iMiev/Peugeot Ion/Citroen C-zero -> 171 Wh/km

We use the CO2 emission intensity of electricity generation (gCO2/KWh) per country, available from the database of the European Environmental Agency (EEA) (EEA, 2020) as presented in Table 1.

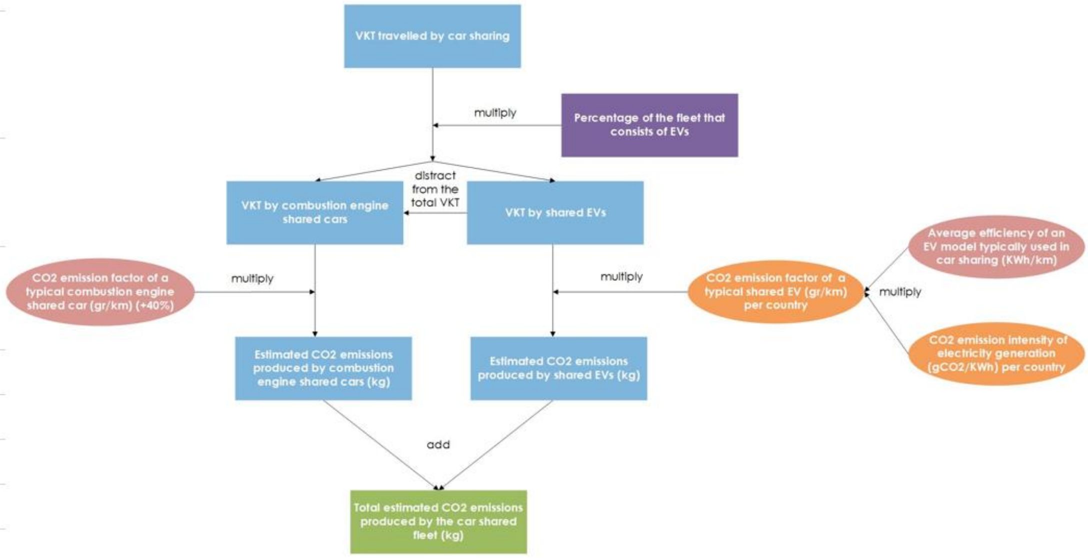

Figure 4. Calculation process of CO2 emissions produced by the car sharing fleet.

Table 1. CO2 emission intensity of electricity generation per country (gCO2/KWh) (EEA, 2020).

EEA 2017 CO2 emission intensity of electricity generation (gCO2/KWh)	
EU Country	**2017**
Belgium	176.07
Bulgaria	486.21
Czechia	437.85
Denmark	147.66
Germany	418.82
Estonia	922.41
Ireland	392.53
Greece	657.31
Spain	304.3
France	67.23
Croatia	187.95
Italy	258.8
Cyprus	660.69
Latvia	49.16
Lithuania	63.69
Luxembourg	65.18
Hungary	252.96
Malta	441.77
Netherlands	452.63
Austria	103.98
Poland	103.98

Portugal	349.78
Romania	262.52
Slovenia	248.26
Slovakia	107.31
Finland	82.79
Sweden	9.27
United Kingdom	268.52
Iceland	0.02
Norway	18.92
Switzerland	294.21
EU Average	294.21

The last step after calculating the total emissions from the car fleet itself is to calculate the difference between the two values, and this number is the net expected CO2 emissions reduction.

4.2.2. Bike sharing

For bike sharing, as shown in Figure 5, the same process that has been already described for car sharing, with two differences: First, we do not need to calculate the net emissions in this case, as we assume zero transport-related emissions for walking and cycling as already stated previously in this report. Therefore, the output of the calculation process of Figure 5 corresponds to the final estimated CO2 emissions reduced as a result of bike sharing. Second, to have a more realistic result, for the VKT calculations, we use the average distance of the active modes trips in the city, because assuming that a shared bike can replace the full length of an average private car trip could sometimes be too optimistic and not reflect the reality of the city; we hence choose to remain on the conservative side in our assumptions.

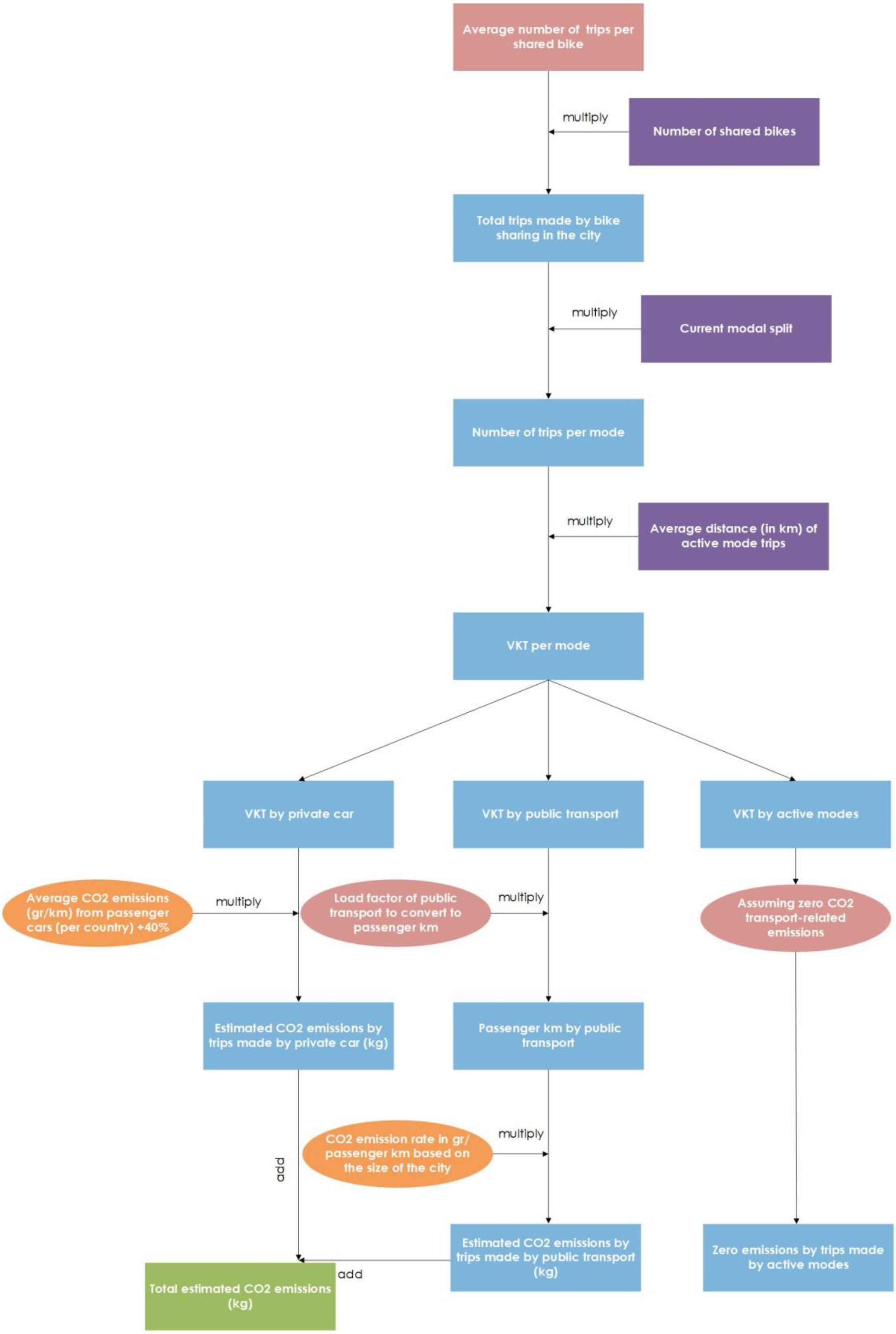

Figure 5. Calculation process of CO2 reductions that result from the impact of bike sharing on modal shift.

4.2.3. E-scooter sharing

Regarding e-scooter sharing, the calculation process we followed which is depicted in the diagrams of Figures 6 and 7, lies in between the one followed for car sharing and bike sharing. We did calculate the emissions generated by the e-scooter fleet based on the electricity generation emission factors per country, but we used also for the VKT calculation a shorter distance than the average distance per mode (either the average distance of the active modes trips can be used or it can be increased by a small percentage to reflect the usually rather bigger length or radius of the trips made by e-scooters). The reduction of CO_2 is, as in the case of car sharing, the difference between the two values; the green cell of Figure 6 minus the green cell of Figure 7.

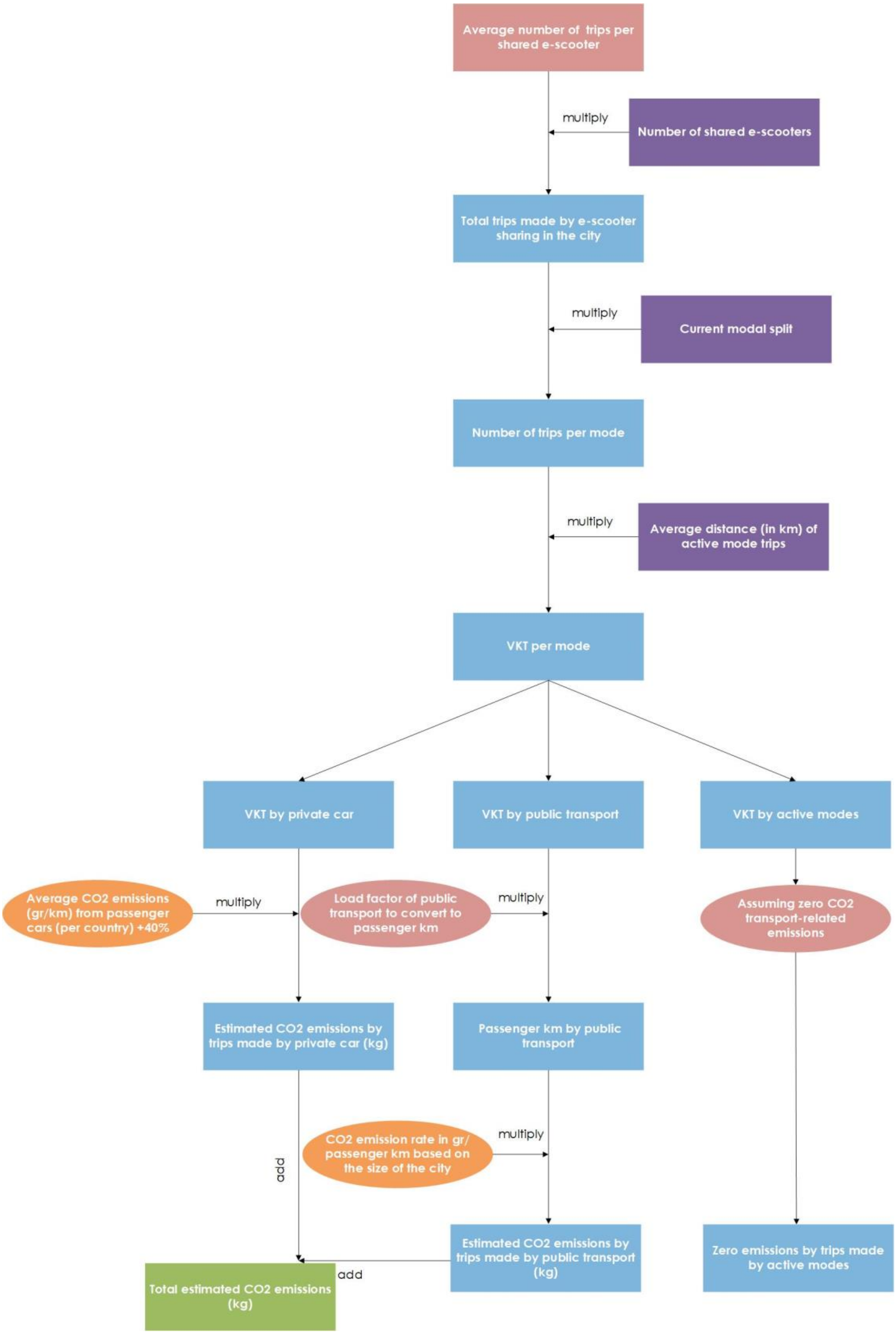

Figure 6. Calculation process of CO2 reductions that result from the impact of e-scooter sharing on modal shift.

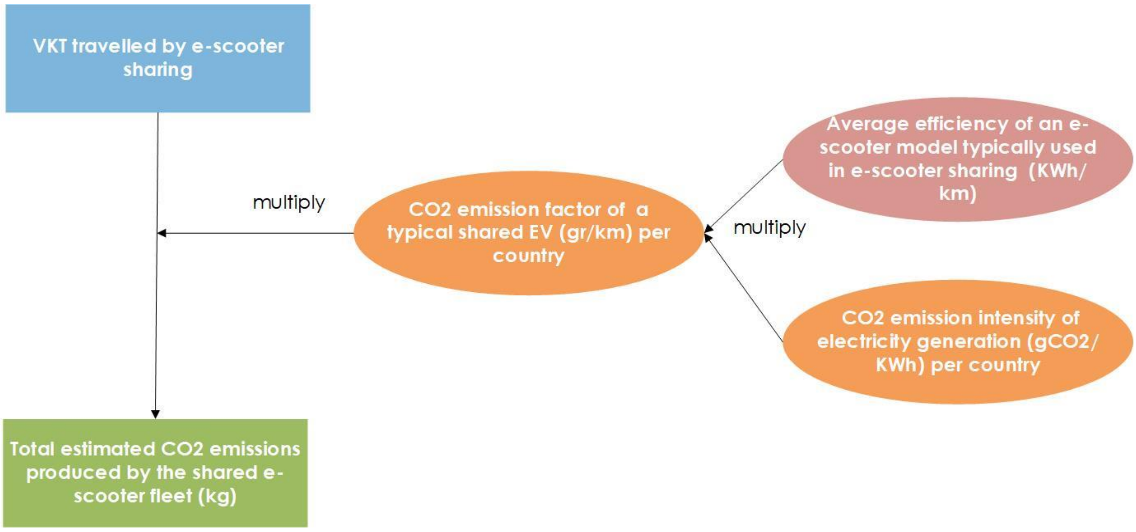

Figure 7. Calculation process of CO_2 emissions produced by the e-scooter fleet.

4.2.4. Evaluation tool screenshots

The tool was programmed in an excel file. Figure 8 presents an example of the input screen of the evaluation tool and Figure 9 the corresponding output screen.

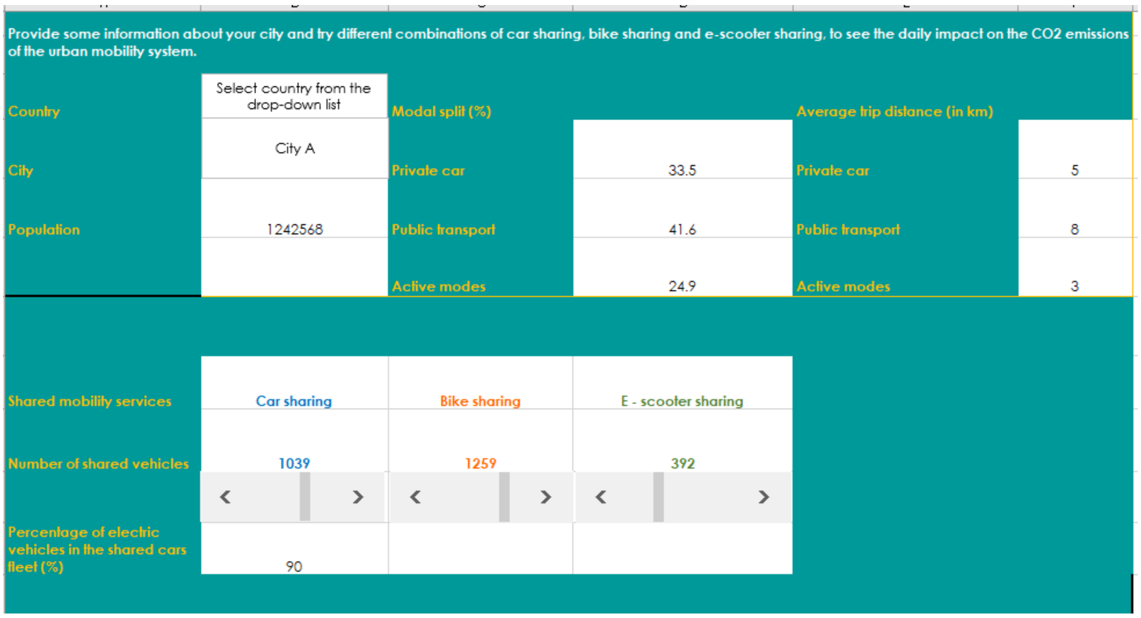

Figure 8. Input screen – Example of an application

Estimated reduction of CO2 emissions (in kg) per mode	From car sharing	From bike sharing	From e-scooter sharing
	47753.35	28492.20	1306.592748
TOTAL estimated reduction of CO2 emissions (in kg)	77552.15		

Figure 9. Output screen of the same application

5. Conclusions

The scope of this work done in the context of the SuSMo poject is to look at the evaluation process of the impacts of shared mobility from a city perspective, in the direction of assisting decision-makers in the challenging process of selecting the most suitable method or combination of methods to apply to assess the impacts of shared mobility. We classified the main categories of options that can be used to evaluate the impact of shared mobility in a clear format to be helpful to city authorities and decision-makers; the people who often face the difficult decisions regarding the implementation of shared mobility programs.

The tool developed afterwards and presented herein aims at providing city authorities and decision-makers with a simple, user-friendly, and flexible way to explore different future scenarios and the associated impacts that shared mobility can bring to their city, by trying out different combinations of shared modes and how these combinations influence the CO2 footprint of their city. The urgent need for a tool that can be tailored-made to each city but also easily adaptable to a case-by-case basis emerged from our desk literature review research but also from the contact with the SuSMo partners cities. Being aware of certain limitations of the tool, we believe that it can act as an important first step towards the development of a comprehensive, multi-perspective evaluation framework that can be applied to assess the full range of impacts that urban shared mobility entails in cities in Europe.

Such limitations include for instance, that there is the possibility that some of the trips made by shared mode users, would not have been made at all if the shared mode was not an available option, and currently, our assumptions do not cover this specific case of shared mobility-induced trips. Also, some values obtained from the literature such as the conversion factors from VKT to passenger km travelled and the average number of trips per shared car per day can vary a lot across different European cities and countries, therefore taking one average value for all cases may not necessarily fully reflect the local circumstances. Last but not least, other types of shared modes such as ride sharing and ride sourcing is not included in our calculations so far.

In future versions of this tool, we would like to explore how we can include - in addition to the three shared modes the impacts of which we are investigating currently – telecommuting, as it is a phenomenon that dominated the way people are (not) travelling to work in 2020, and there is an on-going discussion that it could continue from 2021 and eventually working from home could be established as the "new normal" situation for a significant percentage of citizens that were used to daily commute before the COVID-19 pandemic. Therefore telecommuting can have a major impact on the overall transport – related carbon footprint of cities and it would be very interesting to examine its potential synergies with shared mobility.

The workplan for year 3 of SuSMo (2021) focuses on dissemination of these outputs. SuSMo is therefore at a critical stage. It is important that this work is completed in order to maximise value for money for Climate-KIC and EIT by ensuring the SuSMo messages and outputs reach a wide audience. Without this dissemination taking place, the overall project objectives will not be fully achieved. Successful dissemination will lead to more cities adopting sustainable shared mobility, greater impacts in terms of carbon emissions reduced, and a growing ecosystem of engaged cities (municipalities, citizens and the private sector).

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