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Transportation Research Procedia 72 (2023) 1934–1941

Transportation Research Procedia

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Transport Research Arena (TRA) Conference

Carbon Footprint Reduction with Car-Sharing Service – A Case Study

Valtteri Ahonen[a*], Jussi Lassila[b], Jani Karjalainen[b], Pekka Leviäkangas[a]

[a]*University of Oulu, PL8000, Oulu 90014, Finland*
[b]*Sitowise Oy, Voudintie 3, Oulu 90400, Finland*

Abstract

This paper reviews how much a car-sharing service can reduce CO2 emissions. Based on literature and a case study, an estimation of CO2 emissions is made. The studied vehicle fleet consists mostly of vehicles with an internal combustion engine (ICEV), and hence the potential reduction of CO2 emissions with this kind of fleet is very limited. Propositions for more sustainable vehicle fleet are made and the potential of car-sharing service in Finland is discussed. The results show that users are replacing sustainable transport modes (walking, cycling) with car-sharing services. Replacing ICEVs with battery electric vehicles (BEV) would allow 31 % decrease in CO2 emissions. However, this would require major changes to the fleet.

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Peer-review under responsibility of the scientific committee of the Transport Research Arena (TRA) Conference

Keywords: Multimodal transport; Clean mobility options; Sustainable cities and communities; Environment sustainability; Sharing economy; Carbon footprint;

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1. Introduction

1.1 Car-sharing and emissions

Car-sharing services have both positive and negative impacts on CO2 emissions. The most effective features of car-sharing services that potentially reduce CO2 emissions are i) the newer and more energy-efficient vehicle fleet and (Chen & Kockelman, 2014) ii) the decreased need to manufacture cars (Jung & Koo, 2018). In addition, well-implemented car-sharing services reduce car ownership and vehicle kilometres traveled (e.g. Shaheen et al., 2012; Nijland & Meerkerk, 2017). However, when changing from the use of private cars to shared cars a modal shift effect is witnessed: some of the mobility done by private cars is replaced by other modes of transport (i.e. public transport). This effect is to some extent offsetting the benefits of reduction in emissions enabled by shared cars (Amatuni et al,

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* Corresponding author. Tel.: +358 504732195
E-mail address: valtteri.ahonen@oulu.fi

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10.1016/j.trpro.2023.11.673

2020). On the other side, some of the mobility made previously by public transportation might be replaced by car-sharing services, thus increasing the total emissions (Jung & Koo, 2018; Vélez & Plepys, 2021). Finally, reduced car ownership can also cause a rebound effect in CO2 emissions if the money formerly consumed to own a car is directed to other affairs that increase CO2 emissions (Ottelin et al., 2017).

The differences in the use patterns (average speed, driving environment, driving style, utilization, etc.) of the shared vehicle may affect the vehicle's lifecycle. This is called the lifetime shift effect and it mainly derives from the phenomenon that the annual vehicle mileage of shared cars is usually higher and hence the service life is shorter than privately-owned cars. In other words, the adoption of shared cars is not equally lowering the manufacturing rate of passenger cars (Amatuni et al., 2020). The positive impact of the lifetime shift effect is that technical aging-related causes such as corrosion do not affect the service life of the shared car if the usage is intensive enough (Meijkamp, 1998).

1.2 The aim of this paper

This study is developing a more realistic method to estimate the CO2 emission reduction made with the implementation of car-sharing services. The individual CO2 footprint is estimated based on a pilot study data collected in Kuopio by a group of consulting and service companies (Sitowise, 2021). The case study contains a user survey and some user data collection. Results of the user survey are discussed and the implications of the aforementioned effects of car-sharing are examined. Implications include car ownership, reduced vehicle kilometers, and the potential reduction of carbon footprint. In addition, the reduction of carbon footprint is estimated between different car alternatives in the vehicle fleet.

2. Data and methods

Car-sharing service of PlanBil has currently 36 cars available in Finland. Sharing model is round-trip which means that car has a certain spot where it can be rented and need to be returned. Most of the cars are leased by businesses and then rented forward (B2P) but some of the cars are leased by private persons and rented forward (P2P). The owner of the car fleet and platform is PlanBil (PlanBil, 2022)

2.1. Data

The case study was conducted in the city of Kuopio, Finland, in 2020 consisting of the following tasks:

- a survey for registered users of the car-sharing service in Kuopio
- an analysis of user data of the car-sharing service during the case study in Kuopio

A report of the results of the case study is publicly available only in Finnish (Sitowise Oy, 2021). The survey for the registered users had 68 participants, of which approximately a third had not used the service. The pilot in Kuopio had three cars and 85 users and it lasted for 6 months. In addition, data for reservations in the car-sharing service were extracted from the platform. It contains the number of kilometers driven during the reservation of the vehicle. Data contains all reservations made on the car-sharing platform from January 2021 to January 2022.

2.2. Life-cycle estimation models

Emissions of the car-sharing service are calculated with the coefficients available in the literature. Estimation of the emissions is focused on the primary effects of the car-sharing service on CO2 emission. The user survey implied there is a possible negative modal shift from sustainable modes to private driving (which is a secondary effect) of the car-sharing service. However, it was not taken into account in this study. The magnitude of this negative change on the entire transport system is unknown.

Other secondary effects such as car ownership and reduced vehicle kilometers traveled are not acknowledged either. To compare the different types of fleet scenarios that could potentially exist, it was assumed that shared cars are used instead of privately owned cars that typically are older and thus have higher CO2 emissions.

Road infrastructure life-cycle emissions are not considered in this study. The reason for this settlement is that most of the studies concerning car-sharing have been done in North America, where road infrastructure differs significantly from that of Finland.

Passenger car life-cycle emissions are typically considered to cover the manufacturing of the vehicle, operation of the vehicle, and fuel production and transport to the gas stations (WTT). Bieger's (2021) values for estimating the life-cycle emissions of shared cars are used in this study (Table 1). Life-cycle emissions per kilometre are calculated with formulas (1), (2), (3), (4), (5), and (6) where E_{Ma} is emissions from vehicle manufacture, E_{BMa} is emissions from battery manufacture (45 kWh battery capacity), E_{Op} is emissions from the operation of the battery electric vehicle (BEV) or internal combustion engine vehicle (ICEV) including maintenance, and E_{Fp} is emissions from the fuel production (WTT). E_{sum} is the total emissions of a vehicle per kilometer.

Table 1. Coefficients used in CO2 eq. emission calculations (reworked from Bieger, 2021)

Source of CO2 eq. emissions	Coefficient	Unit	Variable
Vehicle manufacturing (ICEV)	5.2	t $CO_{2eq.}/t_{vehicle}$	Ma
Vehicle manufacturing (BEV)	4.7	t $CO_{2eq.}/t_{vehicle}$	Ma
Battery manufacturing (45 kWh)	2.7	t CO_{2eq}	BMa
Operation of the vehicle (ICEV)	2.24	kg $CO_{2eq.}$/l	Op
Maintenance of the vehicle (ICEV)	5	g CO_{2eq}/km	Mt
Maintenance of the vehicle (BEV)	4	g CO_{2eq}/km	Mt
Fuel production (WTT)	0.68	kg $CO_{2eq.}$/l	Fp
Fuel consumption (small ICEV)	6.5	l/100km	Fc
Fuel consumption (medium ICEV)	7.1	l/100 km	Fc
Electricity consumption (medium BEV)	20.6	kWh/100 km	Ec
Vehicle lifetime	18	Years	LT
Lifetime mileage (small vehicle)	198000	km	LTM
Lifetime mileage (medium vehicle)	243000	km	LTM
Life-cycle carbon intensity of electricity consumption (STEPS)	199	g $CO_{2eq.}$/kWh	LCCI
Life-cylce carbon intensity of electricity consumption (Renewables)	23	g $CO_{2eq.}$/kWh	LCCI
Mass (small vehicle)	1155	kg	m
Mass (medium vehicle)	1382	kg	m

$$E_{Ma} = \frac{Ma \cdot m}{LTM} \quad (1)$$

$$E_{BMa} = \frac{BMa}{LTM} \quad (2)$$

$$E_{Op}(ICEV) = \frac{Fc \cdot Op}{100} + Mt \quad (3)$$

$$E_{Op}(BEV) = \frac{Ec \cdot LCCI}{100} + Mt \quad (4)$$

$$E_{Fp} = \frac{Fc \cdot Fp}{100} \quad (5)$$

$$E_{sum} = E_{Ma} + E_{BMa} + E_{Op} + E_{Fp} \quad (6)$$

3. Results

3.1. User survey

Fig. 1. (a) and (b) show the results from the survey that are significant to the scope of this paper. The survey shows that car-sharing service is replacing mostly modes of transport that are considered environmentally sustainable and only 8.5 % of the responders say that car-sharing reduced the usage of a personal car. 20.9 % said that car-sharing replaced trips that would be otherwise made by intracity public transport. 14.9 % said that intercity trips by train or bus were replaced by the car-sharing service. In addition, 10.4 % responded that walking and bicycling were replaced by car-sharing and for 26.9 % of the respondents, car-sharing enabled trips that they would not otherwise make.

It needs to be noted that during the period the pilot was conducted traveling by public transport was reduced by 30 % in Kuopio due to the Covid-19 pandemic. Fig. 1. (B) shows that only a small amount of respondents use the car-sharing service for daily trips to school or work. Generally, for trips related to everyday life like shopping or hobbies car sharing is used less than for trips that are not that regular such as visiting relatives or longer leisure trips. Approximately a third of the respondents used car-sharing for transporting people and freight. Fig. 2. (A) and (B) show that registered users of the car-sharing service typically don't own a car and are using public transport for traveling.

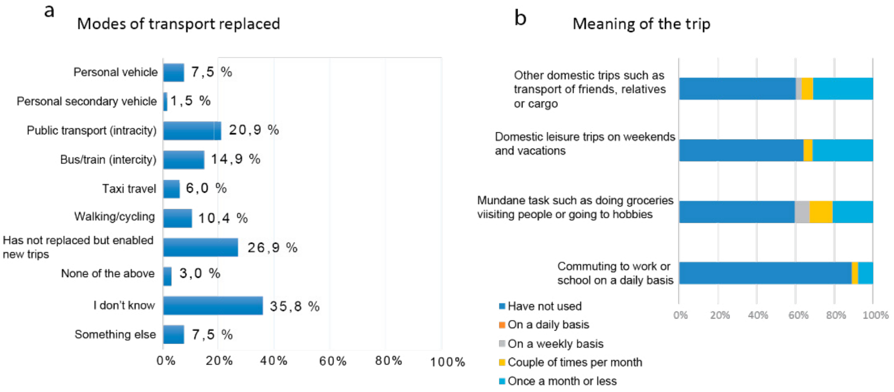

Fig. 1. (a) Modes of transport replaced by car-sharing service; (b) Meaning of the trips made with car-sharing service.

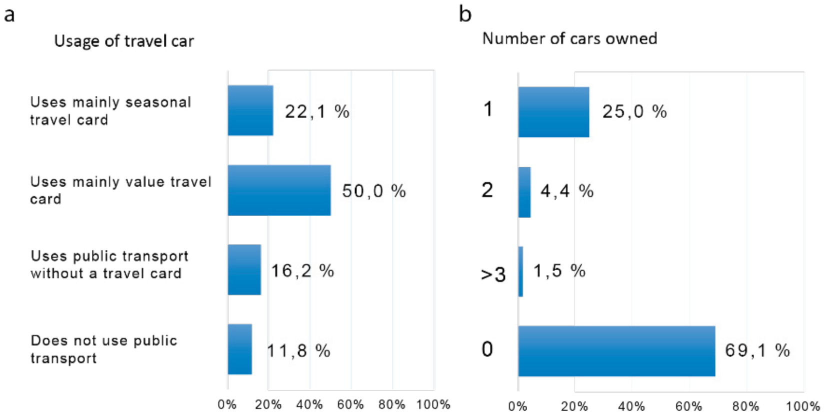

Fig. 2. (a) Usage of travel card of registered users of car-sharing service; (b) Car ownership of registered users of car-sharing service.

3.2. Data from car-sharing fleet

Fig. 3. Illustrates the typical trip made with the vehicles during reservation. Four cars are missing from the figure because they had too few trips driven during the observation period. The maximum length for reservations on the platform is 7 days, but for some vehicles, reservations have been limited to smaller periods. This explains the variations in kilometers driven during the reservation. Car number 7 is a hybrid car and cars 8, 9, and 10 are battery electric vehicles (BEVs), which explains the shorter mileage during reservations. In addition, BEVs are reserved at an hourly cost which limits the longer trips. During most of the reservations under 200 km are driven (74.2 % of the reservations). Altogether 412 338 kilometers were driven and 2217 reservations were made with the vehicle fleet during the observed period. The mean distance driven during reservation for the whole fleet was 186 km and the median 70 km.

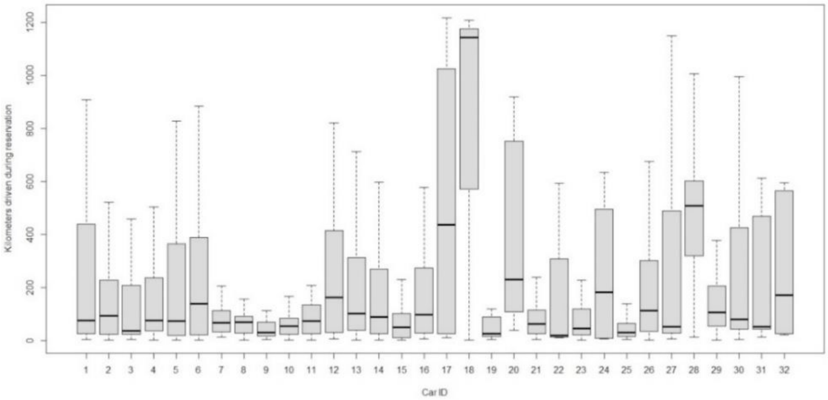

Fig. 3. Boxplot of kilometers driven during the reservation of different cars in the fleet.

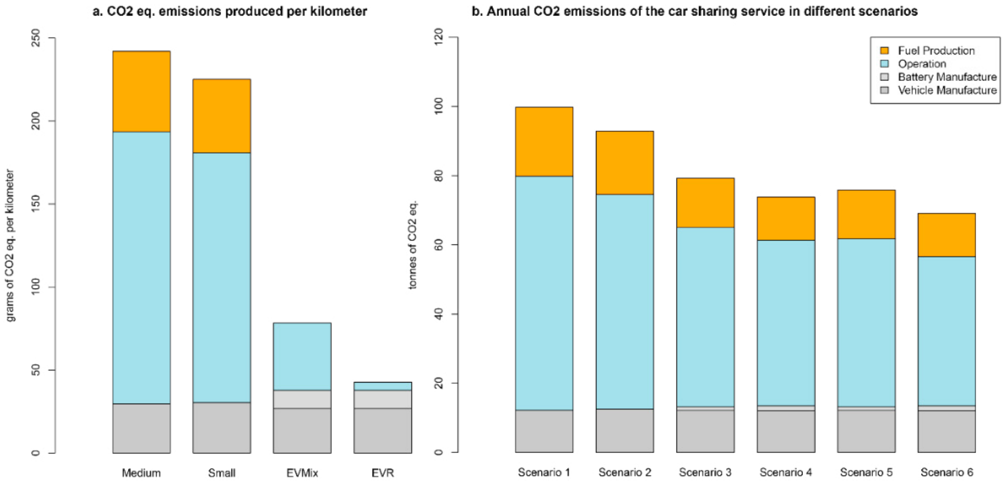

Fig. 4. (a) $CO_{2\,eq.}$ emissions produced per kilometer by different types of vehicles; (b) Annual $CO_{2\,eq.}$ emissions of the vehicle fleet in different scenarios.

3.3. CO2 emissions of the vehicles in service's fleet

Annual emissions of the car-sharing service were calculated with four different scenarios. Fig. 4. (a) shows the emissions per kilometer calculated for different types of vehicles. The coefficient used in the calculation is presented in Table 1. *A medium* car is similar to an average car used in Finland (Traficom, 2022) and almost all of the vehicles in the car-sharing service's fleet are smaller than that. In fact, the cars in the service fleet have smaller weight and fuel consumption than the ones used for the *small* vehicle type. *EVmix* type is BEV with an energy mix of electricity based on the Stated Policies Scenario (STEPS) (IEA, 2022). To emphasize the relevance of the source of the electricity, a BEV that is running completely with wind and solar energy (*EVR*) is illustrated for comparison. With these emission factors, six scenarios have been created and illustrated in Fig. 4 (b).

The scenarios are:

- Scenario 1: The vehicle fleet is operated completely with medium-sized cars (*medium*) that are comparable to the average vehicles used in Finland
- Scenario 2: The fleet is operated with small cars (*small*) which are close to the configuration the current fleet has
- Scenario 3: All reservations which have less than 200 kilometers driven are traveled by electric car (*EVmix*) and the rest of them with small cars (*small*)
- Scenario 4: All reservations under 300 kilometers driven are driven with BEV (*EVmix*) and the rest of them with small cars (*small*)
- Scenario 5: All reservations under 200 kilometers are driven with BEV running on solar and wind energy (*EVR*) and the rest of them with small cars (*small*)
- Scenario 6: All reservations under 300 kilometers are driven with BEV running on solar and wind energy (*EVR*) and the rest of them with small cars (*small*)

A vehicle fleet with small cars cuts CO2 emissions by 7 % compared to a vehicle fleet with medium cars. In scenario 3 decrease in emissions is 21 %, in scenario 4 it's 26 %, in scenario 5 it's 24 %, and in scenario 6 it's 31 %. In scenarios 3 and 5, 74.2 % of the reservations are replaced with electric cars, and in scenarios 4 and 6, 80.9 %. However, reservations under 200 km consist of 22.5 %, and reservations under 300 km 31.5 % of the kilometers driven annually. This means that even in the best scenario (scenario 6) over two-thirds of the kilometers driven is traveled with ICEV.

3.4. CO2 footprint of individuals in the pilot study

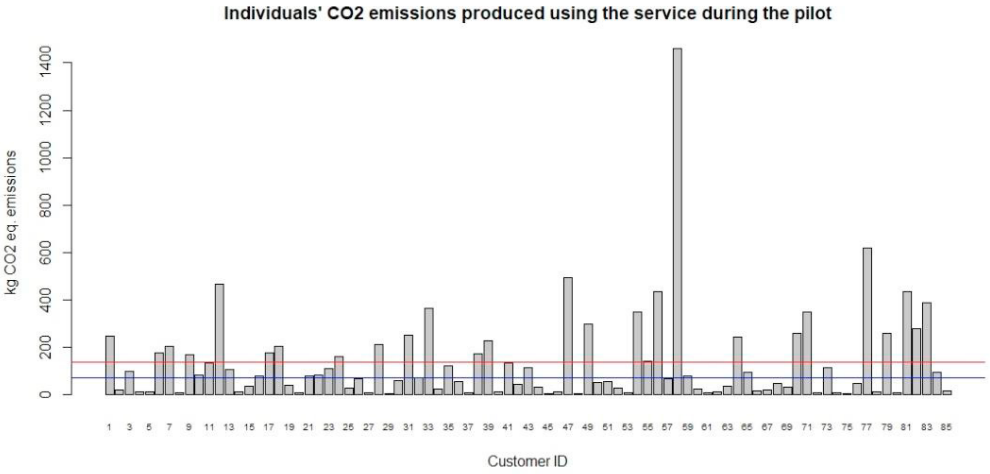

Fig. 5. CO2 emissions produced by individual users during the pilot.

Individuals' CO2 emissions during the pilot study were calculated with the coefficients of *small* type of car (Fig. 4. (a)). During the Kuopio pilot, there were three cars on disposal and 85 users used the service. 65 % of the users used only one car and the rest two or three cars during the pilot. The average distance driven during the reservation was 176 km and the median was 50 km, these numbers are smaller than the whole fleet's mean (186 km) and median (70 km). Fig. 5. Shows the CO2 emissions that users were producing by using the car-sharing service. The red line represents the average emissions during the pilot and the blue line median. There was a lot of variation in the kilometers driven between the users, the shortest distance driven was 12 km, and the longest 6484 km. Hence, the amount of CO2 released into the atmosphere by the users varied a lot.

4. Conclusion and discussion

The estimations of CO2 emissions represented in this study are generally optimistic because of underlying assumptions. Only primary emissions of car-sharing are taken into account and it is assumed that the option for traveling with a car-sharing service would be a private car that is medium-sized with higher emissions than cars in the car-sharing service's vehicle fleet. Scenarios 1-6 in chapter 3.3 show that changing the fleet has a very limited effect on the annual emissions of the car-sharing service. This is because of the very limited range of BEV at the moment. Also, the source of electricity does not affect as much as the range that can be driven with BEVs (compare scenarios 4 and 5). Even with scenario 6 where all the reservations under 300 km are replaced with BEVs with very low emissions only 31 % of the CO2 can be cut compared to scenario 1. In scenario 6, most of the emissions are still produced with ICEVs. In this scenario, the majority of reservations are driven with BEVs which would mean major changes to the vehicle fleet when most of the cars would be needed to change to BEVs. This raises the question of whether that kind of vehicle fleet is possible in this state of technology. Good charging infrastructure would increase the range on BEVs and especially longer reservations with higher distances driven could be replaced with BEVs which would then decrease annual emissions of the car-sharing service.

More accurate data on usage of the vehicles is needed (e.g. average speed, trips made during reservation) to have a better estimation of vehicle fleet CO2 emissions. For example, COPERT method could be used to estimate CO2 emissions more accurately, if data on average speeds and type of road traveled could be obtained (Ntziachristosa et al., 2009). In addition, vehicles in the service's fleet should be in the future examined individually to calculate more accurate CO2 emissions of the vehicle fleet based on the vehicle's fuel consumption, peak motor power, and weight, for example with coefficients provided by Buberger et al. (2022). Individuals' direct CO2 emissions in the pilot study vary a lot as well as the distances driven during the reservations. To estimate the effects of usage of the car-sharing service on an individual's total emissions sample size need to be larger and more data is needed for example on the meaning of the trip, the number of passengers.

The results of the survey represented in this study implicate that the users are replacing sustainable modes of transport with the car-sharing service and in that way carrying through a negative modal shift (rebound effect), which is a similar phenomenon to what Amatuni et al. (2020) conclude in their paper. Moreover, reduce in car ownership is according to Ottelin et al. (2017) causing a rebound effect where the money freed by saved costs in car ownership is directed to average consumption causing CO2 emission.

However, based on the survey of the users of the car-sharing service the responders already use public transport in some manner and most of them don't own a car. Considering this and the studies (e.g. Shaheen et al., 2012; Nijlanf et al., 2017) that suggest that car-sharing services are allowing to get rid of private vehicles and avoid buying one, the replacement of private car usage is presumably higher than in the survey. Having said that, according to Ramos et al. (2020) non-users of the car-sharing service have a strong habit of using private vehicles and not public transport, which suggests that their emissions are a lot higher than the typical users of car-sharing services. To solve this divide between the users and non-users car-sharing services need to be so well implemented that owning a car is not necessary.

The results of the survey show, that car-sharing service is used for trips that the round-trip model is suitable for. For the trips to work or school, the free-floating model would be suitable but it is currently available only in the largest cities in Finland. The round-trip model can replace only a small number of daily trips, and for scaling up the service free-floating model would be needed. In this particular fleet, meeting the needs of the user is challenging because the usage of the vehicles differentiate from the typical car-sharing services used in case studies that are operating in urban areas (e.g. Nijlanf et al., 2017; Migliore et al., 2020) as the fleet studied here has reservations with variable distances and some of them can't be replaced with BEVs or public transport. The sample size needs to be bigger for further evaluation of the impacts of reservations with different distance driven.

Because only a few cities in Finland have a viable public transport system (Rinta-Piirto et al., 2019), the user needs in Finland differentiate from what they are in North America or Central Europe. Making car-sharing available in other than the most urbanized areas has the potential on reducing CO2 emissions but has its challenges as studied by Illgen et al. (2018).

The modal shift from the sustainable modes of transport is increasing individuals' CO2 emissions, but it is unclear what is the scale of the increase and its effect on the entire transport system. Also, new trips enabled by car-sharing services are increasing individuals' net CO2 emissions. Moreover, car-sharing should be integrated into a Mobility-as-a-Service platform, which would increase multimodal traveling and offer choices for sustainable modes of transport. It would also bring this particular car-sharing service closer to shared mobility which has greater potential on reducing CO2 emissions than just sharing vehicles (Tikoudis et al., 2021).

There were some limitations with the three data sets that were available for analysis. For example, the differences in mobility needs and habits of users traveling different lengths of trips (short, urban trips - medium long, peri-urban trips - long, inter-urban) and examining the effects of modal shift and rebound effects in the different traveler and trip categories. Larger and more uniform samples are needed for future research.

Author contribution and acknowledgments

The case study was conducted and reported by Mr. Lassila and Mr. Karjalainen. Mr. Ahonen authored most of the paper. Prof. Leviäkangas oversaw and reviewed the work. This research has been supported by the European Union H2020 program's AURORAL project, grant agreement ID: 101016854 (Auroral, 2022).

References

Amatuni, L., Ottelin, J., Steubing, B., & Mogollon, J. M. 2020. Does car sharing reduce greenhouse gas emissions? Assessing the modal shift and lifetime shift rebound effects from a life cycle perspective. Journal of Cleaner Production, 266.

Buberger, J., Kersten, A., Kuder, M., Eckerle, R., Weyh, T. & Thiringer, T. 2022. Total CO_2-equivalent life-cycle emissions from commercially available passenger cars. Renewable and Sustainable Energy Reviews, 159 (2022).

Chen, D. T., & Kockelman, K. M. 2014. Carsharing's life-cycle impacts on energy use and greenhouse gas emissions. Transportation Research Part D, 47 (2016).

International Energy Agency (IEA). 2022. Available at: https://www.iea.org/reports/world-energy-model/stated-policies-scenario-steps, retrieved 04-27-2022.

Illgen, S. & Höck, M. 2018. Establishing car sharing services in rural areas: a simulation-based fleet operations analysis. Transportation, 47 (2020).

Jung, J., & Koo, Y. 2018. Analyzing the Effects of Car Sharing Services on the Reduction of Greenhouse Gas (GHG) Emissions. Sustainability, 10 (539).

Meijkamp, R. 1998. Changing consumer behaviour through eco-efficient services: an empirical study of car sharing in the Netherlands. Business Strategy and the Environment, 7 (1998).

Migliore, M., Gabriele, D. & Camiti, D. 2020. The environmental benefits of carsharing: the case study of Palermo. Transport Research Procedia, 48 (2020).

Nijlanf, H. & van Meerkerk, J. 2017. Mobility and environmental impacts of car sharing in the Netherlands. Environmental Innovation and Societal Transitions, 23 (2017).

Ntziachristosa, L., Gkatzofliasb, D., Kouridisb, C. & Samaras, Z. 2009. COPERT: A European Road Transport Emission Inventory Model. Information Technologies in Environmental Engineering.

Ottelin, J., Heinonen, J. & Junnila, S. 2017. Rebound effects for reduced car ownership. Nordic Experiences of Sustainable Planning: Policy and Practice, 2017.

PlanBil. 2022. Mikä on PlanBil?. Available at: https://planbil.fi/planbil, retrieved 04-26-2022.

Ramos, E. M. S., Bergstad, C. J., Chicco, A., & Diana, M., 2020. Mobility styles and car-sharing use in Europe: attitudes, behaviours, motives and sustainability. European Transport Research Review.

Rinta-Piirto, J. & Weiste, H. 2019. Saavutettavuusselvitys – Tarkastelumallin kehittäminen valtakunnallisen henkilöliikenteen saavutettavuudelle. Finnish Transport and Communications Agency (Traficom).

Shaheen, S. A., Mallery, M. A., Kingsley, K. J. 2012. Personal vehicle sharing services in North America. Research in Transportation Business & Management, 3.

Sitowise Oy, 2021. Yhteiskäyttöautojen vaikutukset liikkumiseen ja pysäköintiin Kuopiossa. Available at: http://publish.kuopio.fi/kokous/2021796328-4-1.PDF, retrieved 04-26-2022.

Tikoudis, I., Martinez, L., Farrow, K., Bouyissou, C., Petrik, O. & Oueslati, W. 2021. Exploring the impact of shared mobility services on CO2. OECD Environment Working Paper no. 175.

Traficom. 2022. Open data from vehicles. Available at: https://www.traficom.fi/en/news/open-data?toggle=Open%20data%20for%20vehicles, retrieved 04-08-2022.

Velez, A. M. A. & Plepys, A., 2021. Car Sharing as a Strategy to Address GHG Emissions in the Transport System: Evaluation of Effects of Car Sharing in Amsterdam. Sustainability, 13 (2418)