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Car-sharing (CS) System as a Sustainable Mobility-as-a-Service (MaaS) Model Solution for Metropolises

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Abstract

The exponential growth of privately owned vehicles in urban India has led to alarming levels of air pollution, traffic congestion, and energy consumption. This research investigates the viability of car-sharing as a sustainable mobility alternative to private vehicle ownership, focusing on Delhi, one of India's most polluted and densely populated cities. Drawing exclusively from empirical data and modeling presented in the original study, the paper employs a two-pronged methodology: linear regression analysis to estimate car sharing (CS) adoption and COPERT5.5 software to quantify vehicular CO_2 emissions and energy consumption.

The study reveals that substituting seven privately owned vehicles with one shared vehicle can significantly reduce environmental burdens. Between 2014 and 2018, carbon dioxide emissions from vehicles dropped by 8.57% to 25.71%. Energy consumption trends mirrored CO_2 emission reductions, indicating economic and ecological benefits.

The demographic and infrastructural characteristics of Delhi, combined with comparative data from European cities, underscore the potential for scalable CS systems, as a Mobility-as-a-Service model (MaaS), in India. The findings advocate for policy interventions, public awareness campaigns, and integration of electric vehicles into shared fleets to enhance sustainability.

This paper contributes to the discourse on urban mobility by demonstrating the tangible benefits of CS in mitigating climate change and promoting efficient transportation. The implications extend beyond Delhi, offering a replicable model for other metropolitan regions grappling with similar challenges.

Keywords: *Car-sharing; Sustainable mobility; Traffic congestion; Vehicular CO_2 emissions; COPERT5.5; MaaS; Delhi; Climate change*

INTRODUCTION

Background

Urban transportation systems are increasingly recognized as major contributors to greenhouse gas emissions, particularly in developing countries like India. The dominance of road transport, both for passenger and cargo movement, has led to severe environmental degradation, with CO_2 emissions from fuel combustion accounting for 25% of global totals (IEA, 2019). In India, road transport contributes 90% of the transport sector's CO_2 emissions (MoEFCC, 2020). Delhi, as a megacity, exemplifies these challenges due to its high population density and rapid growth of vehicles.

Car-sharing (CS), a Mobility-as-a-Service (MaaS) model, offers a promising alternative. It enables users to access vehicles on a subscription basis, reducing the need for private ownership. Globally, car sharing has gained traction since the 1980s, with Europe and North America leading adoption (Shaheen and Cohen, 2007). Compared to Europe and North America, India has a very high population density and a huge number of privately owned cars; thus, CS can be a predominant alternative for passenger transport. In India, companies like Zoomcar, BlaBlaCar, and Quickride have begun to popularize the concept.

Objectives of the Study

The study aims to achieve the following main objectives as outlined hereunder –

- Estimation of CS users in India;
- Developing a linear regression model to estimate potential CS vehicles in India and in Delhi using suitable impact parameters;
- Estimation and analysis of vehicular CO_2 emission and energy consumption trends in Delhi using COPERT5.5 software; and
- Recommend future mobility strategies.

Significance of the Study

Car-sharing (CS) is not just a business model—it's a transformative approach to urban mobility as a MaaS model. It addresses environmental concerns by reducing emissions and congestion, and it offers social benefits by making transportation more accessible and affordable. In Delhi, where air pollution regularly exceeds safe limits, CS could play a pivotal role in improving public health and quality of life.

The study aligns with national goals outlined by NITI Aayog (Bhandari *et al.*, 2018) and supports the transition to sustainable transport systems. It also complements existing policies like the Odd-Even scheme (Thakur and Qamar, 2020) and promotes integration with electric vehicle (EV) initiatives.

Statement of the Problem

Despite its potential, CS remains underutilized in India. Barriers include a lack of awareness, insurance constraints, and limited infrastructure. There is also a need for more empirical studies to validate its environmental benefits in the Indian context. This research addresses these gaps by providing a data-driven analysis of CS impact in Delhi.

LITERATURE REVIEW

Conceptual Framework

Car-sharing (CS) has the potential to serve as a major alternative to private vehicle ownership worldwide, delivering substantial benefits in terms of reducing air pollution and alleviating traffic congestion. As a form of Mobility-as-a-Service (MaaS), car-sharing presents a viable substitute for private cars on the road. It represents a shift in lifestyle from ownership to service-based usage, requiring a subscription or membership for access (Prettenthaler and Steininger, 1999).

This service allows individuals to utilize a common vehicle for personal purposes, akin to short-term rentals. Users can access vehicles for travel within the city or for journeys to other locations. Subscription models typically charge based on time or distance travelled and may include additional fees for maintenance, cleaning, insurance, parking, inspections, fuel, and more. This convenient option is especially beneficial for users with occasional transportation needs, as vehicles can be dropped off at different locations for use by others.

In many parts of the world, CS – MaaS model is a well-established practice, yet in India, it remains more common among low-income individuals who require a vehicle infrequently. Promoting awareness and enhancing infrastructure for car-sharing can facilitate its growth and adoption in the Indian market.

CS reduces emissions by replacing inefficient private vehicles with shared alternatives. However, it may also increase emissions if users shift from public transport to shared cars (Chen and Kockelman, 2016). The net impact depends on user behaviour, vehicle type, and operational models.

Adoption Factors

Demographic characteristics play a key role in the adoption of a CS system in a city and/or region. In North America, users are typically aged 25–35, educated, and environmentally conscious, and the majority of users (72%) are members of homes without other automobiles (Burkhardt and Millard-Ball, 2006).

Insurance of the drivers and on-street parking remain two of the most significant barriers to the adoption of the CS system that need to be addressed. Whereas technological integration and electric vehicle (EV) fleets enhance acceptance and improve flexibility.

Empirical Studies

Several CS studies have been reported from all over the world (Shaheen and Cohen, 2007; Shaheen and Cohen, 2009; MOMO, 2010; Musso *et al.*, 2012; Baptista *et al.*, 2014; Jung and Koo, 2018; Amatuni *et al.*, 2020). A random utility model analysis by Catalano *et al.* (2008), using data resulting from the SP (stated preference) experiment of Palermo city (Italy), highlighted the growth of car club market share and car-pooling share in the future. Dissanayake and Morikawa (2010) tested the Nested Logit model using data from the Bangkok Metropolitan Region, Thailand. This study reported that trips to the Central Business District (CBD), long-distance journeys, income level, process popularity, traveller age, and the presence of faculty children in families were the critical elements in household travel decisions.

Firnkorn and Mullar (2011) examined the environmental consequences of the CS model that operated with a free-floating fleet of vehicles wherein customers are allowed for discretionary one-way usage generally based on fixed stations for the Ulm city in Germany. The study concluded a lowered requirement of the number of motor vehicles in the municipality, and a reduction in CO_2 emissions even in the worst-case scenario.

The study of Lisbon, the capital and largest city of Portugal, conducted by Baptista et al. (2014), concluded that vehicle sharing can help reduce energy consumption and environmental implications, in addition to consuming less physical and monetary resources. In terms of mobility behaviour and patterns, the study suggested a reduction of 0.003% and 1.28% in the TTW (Tank to Wheel) energy consumption of light-duty cars, respectively, when considering the BAU (Business-as-Usual) and maximum potential market scenarios.

Chen and Kockelman (2016) investigated the influence of prospective visitors adopting CS in the USA settings on various energy use and greenhouse gas (GHG) emissions using a life-cycle inventory. The findings revealed that modern CS participants reduce their typical man or woman's transportation energy use and GHG emissions by roughly 51% after joining a CS company.

Jung and Koo (2018) study, in South Korean settings, concluded that rather than supporting car sharing per se, a proliferation of fuel-efficient EV CS vehicles is a more effective means of reducing GHG emissions through car-sharing services.

Amatuni et al. (2020) considered three different regions, namely the Netherlands, San Francisco (USA), and Calgary (Canada), and reported a 3-18% reduction of mobility-related life-cycle GHG emissions caused by B2C car-sharing participation by the average member. Further, in all three case studies, the behavioural change in driving had the most significant magnitude of change on the total emissions.

All the above-reviewed studies validate the environmental benefits of CS but emphasize context-specific outcomes.

MATERIALS AND METHODS

Study Area

Delhi spans 1,483 km² and had a population of 31 million in 2021. It ranks third globally in urban population. The city's climate varies seasonally, affecting vehicular performance and emissions. Fig. 1 illustrates the major road structure of the study area - Delhi.

Data Sources and Software Tools Used

The study primarily utilizes data from several key sources, including European Car Sharing Data (MOMO, 2010) of the development and operational dynamics of CS programs across various European cities; the Indian Meteorological Department (IMD) for climate related variable; and the Delhi

Fig. 1: Major road structure of Delhi.

Statistical Handbooks 2018, 2019 and 2020 (DESOCR, 2020) for information pertaining to demographic, transportation infrastructure, and trends in vehicle ownership and usage in Delhi. Additionally, the penetration rates of various mobility services, including CS systems across different regions, from Statista website (https://www.statista.com/), and parameters such as population, GDP per capita (USD), vehicles/1000, fuel price (USD/litres), Pollution Index, etc., are also collected from the world's official websites. These diverse data sources collectively enrich the study's analysis, enabling a comprehensive understanding of the feasibility and impact of car-sharing as a sustainable mobility solution in the context of the Delhi metropolitan.

The software used for analysis and graphical representation includes COPERT5.5 for energy consumption and emission modeling; and MS Excel for liner regression analysis and plotting graphs.

Methodology

The investigative analysis of the study is a combination of two parts, in which the first part is supportive of the second one. Firstly, the CS users and the number of shared cars in Germany are used to estimate the number of CS users in India. Germany was taken into consideration because in the year 2017, the number of CS users in Germany and India was almost similar, counting 1.72 million for Germany and 1.4 million for India.

Microsoft Excel was then used to create the linear regression (LR) plot. The design gave the behavioural change of the number of shared vehicles with respect to the number of CS users for different countries of Europe, like Austria, Belgium, Denmark, Finland, France, Germany, the United Kingdom, Ireland, Italy, the Netherlands, Portugal, Spain, Sweden, and Switzerland. Different cases were studied with respect to different parameters to identify the best possible results of CS vehicles. The five cases are briefed below, considering parameters per iteration:

1) Only based on CS users.
2) Based on CS users and population.
3) Based on CS users, population, fuel price, urban population and Environmental Pollution Index (EPI).
4) Based on CS, population, fuel price and EPI.
5) Based on customer, population and fuel price.

From the above five cases, it was understood that the regression was more efficient for case number 1, as it gave the precise results when cross-checked with the known data from other countries as well. So, based on case number 1 (i.e. only based on CS), results were drawn out.

CS is immensely popular in eight metropolitan cities of India, which include Bangalore, Hyderabad, Chennai, Pune, Kochi, Delhi, Mumbai and Coimbatore. Mumbai and Delhi have the most CS vehicles among these eight cities. Different weightages were determined based on the number of privately registered vehicles in these eight cities. The finding is further used in the analysis by the COPERT5.5 software.

The average kilometer travelled by a commuter per day, the average kilometer travelled by a commercial vehicle per day (as CS is included in the commercial sector, the same parameter is kept under consideration), estimated CS vehicles by the LR model, car sharing users of the city, and an assumption of what percentage of people use CS are some of the possible factors that aid in the estimation of the number of CS using a single car per day. From the outcomes of this statistical study, three different scenarios were obtained, which are as mentioned below:

Scenario I: Substitution of single passengers' cars with one.

Scenario II: Substitution of two passengers' cars to one.

Scenario III: Substitution of three passengers' cars to one.

The total CS users using one car per day is computed by using Eq. (1) as under:

$$Total\ CS\ users\ using\ one\ car\ per\ day = \frac{\{(Avg.\ kms\ travelled\ by\ commuter\ per\ day) \times (CS\ users) \times (0.75)\}}{\{(Avg.\ kms\ travelled\ by\ commercial\ vehicle) \times (Calculated\ CS\ vehicles)\}} \quad (1)$$

In the above eq. (1), it is assumed that 75% of car users use CS vehicles per day, hence the factor 0.75. Further, Scenario III has been considered as the most suitable for Delhi as the city is highly populated and high participation can be expected and desired. With this scenario, the computed ratio to substitute the number of privately owned vehicles with the CS vehicles is 1:7, which means substituting 7 privately owned vehicles for 1 CS vehicle. Further, different scenarios were also generated with the help of statistical methods to know how to substitute the shared vehicles with the privately owned vehicles and in what ratio. The exception is that not all the vehicles can be substituted with the shared vehicle, so a definite penetration rate was set per year for the CS vehicles, which are referred to from the survey conducted by Statista website (https://www.statista.com/). The penetration rate was chosen with respect to the penetration rate of users entering the CS market per year in India.

RESULTS AND ANALYSIS

Car Sharing Users in India

The CS users in India during the years 2017 and 2018 are reported to be 1.4 and 1.5 million, respectively. To estimate the CS users in India for the years 2014 to 2016, the percentage change in CS users in Germany during the same period has been used (Table 1). The reference data of Germany was used because the number of users as well as the rate of increase in CS users in India during 2017-2018 was the closest to the German data out of the available data of other European countries.

Table 1: Year wise CS users in India and Germany.

Year	Number of CS Users (in millions)		%age Increase from 2014	
	Germany	India	Germany	India
2014	0.76	0.70		
2015	1.04	0.96	36.84	33.33
2016	1.26	1.17	65.79	62.50
2017	1.72	1.40	126.32	94.44
2018	2.11	1.50	177.63	108.33

Linear Regression Modeling to Compute CS Vehicles in India

The CS users and CS vehicles data of European countries, 25 observations of two years (2009 and 2014), was used to develop the linear regression (LR) model. The developed LR model, represented by Eq. 2, has high coefficient of determination ($\boldsymbol{R^2}$ = 0.96), low standard error (572.15), and reasonable scattering (Fig. 2). The scattering is also attributed to the fluctuation in the CS users to CS vehicles in the European countries.

$$y = 0.0182x + 338.07 \quad (2)$$

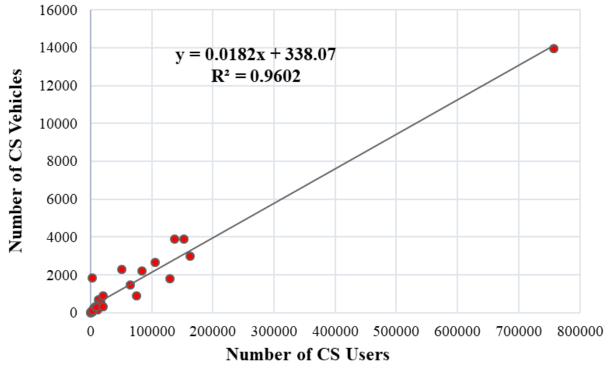

Fig. 2: LR model for the number of CS users vs. CS vehicles.

Using the LR model (Eq. 2), the CS vehicles in India are computed for the years 2014 to 2018, as tabulated in Table 2.

Table 2: Computed CS vehicles in India using LR model.

Year	CS Users	Computed CS Vehicles
2014	701,760	13,500
2015	960,000	18,000
2016	1,170,000	22,000
2017	1,400,000	26,000
2018	1,500,000	28,000

City Weightage Analysis for Delhi

Presently, there are eight major cities in India where CS is prevalent. Of these, Delhi has the highest number of privately owned vehicles numbering 3,493,540. However, in percentage terms, Delhi has the second-highest percentage (29.5%) of all the privately owned vehicles, only superseded by Mumbai (32.9%). Thereby, using a 29.5 per cent weighting, the CS users and CS vehicles for Delhi are computed (Table 3) and being used in further analysis for Delhi metropolitan.

Estimation of Daily CS Users using a Single CS Vehicle

Table 3: Computed CS users and CS vehicles in Delhi.

Year	CS Users	Computed CS Vehicles
2014	210,528	4,050
2015	288,000	5,400
2016	351,000	6,600
2017	420,000	7,800
2018	450,000	8,400

On the basis of the characteristics provided in the methodology, the number of users utilizing a single CS vehicle per day was computed. The average daily kilometer travelled by commuters was found to be 35 kilometers; whereas, the average daily kilometer travelled by commercial vehicles was determined to be between 100 and 150 kilometers, which was approximated to be 120 kilometers for this study. The data was surveyed by the Economic Times of India. The factor of 0.75 is taken into account in the calculations done with the appropriate methodology. With these factors in mind, the total number of users was determined to be 12 people who will utilise a single car per day. Furthermore, using this information, it was possible to replace seven privately owned vehicles with one. As a result, the 1:7 ratio is employed to calculate various contaminants' emissions.

COPERT5.5 Emission Outputs

After estimating the CS users and CS vehicles, along with the other computed and/or assumed parameters, the CO_2 emissions, energy consumption and other gaseous emissions are estimated by using COPERT5.5 software for both the scenarios – without car sharing and with car sharing. The results are analysed and discussed hereunder.

Carbon dioxide (CO_2) Emissions

Fig. 3 depicts the year wise CO_2 emissions by the private vehicles without CS and with CS as estimated from the COPERT5.5 output. The results suggest that if CS sharing becomes commonplace at the current penetration rate, the concentration of CO_2 emissions will stabilize over time. The reduction that was about 8.57% in 2014 could reach to 25.71% in 2018 in just five years with the adoption of CS as a MaaS model. Further, with this model, CO_2 emissions can not only be reduced, but also brought to a point where the emissions remain almost unchanged regardless of increasing number of vehicles. CO_2 being the most significant GHG emitted by automobiles that cause global warming and in turn affect climate change and thus needs to be reduced and managed. Further, high quantity of CO_2 emission indicates that vehicle energy consumption is equally significant that results in an economic burden individually and nationally.

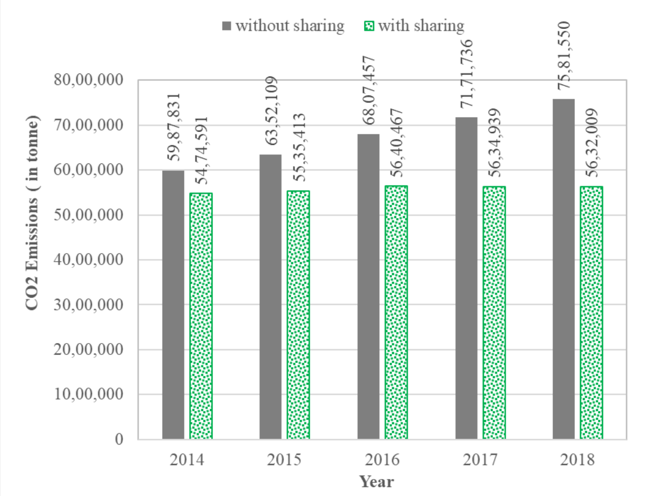

Fig. 3: Year wise estimated CO_2 emissions by the vehicles – with car sharing and without car sharing.

Energy consumption

The trend in energy consumption is analogous to the trend in CO_2 emissions by automobiles. The consumption of fuels is gradually increasing in demand (about 5,050 TJ annually) without the CS model being adopted (Fig. 4). However, if the CS sharing model is adopted in the Delhi metropolitan area, the trend remains relatively consistent with a slightly decreased slope post-2016. Thus, by implementing a CS model, energy usage can be lowered to some extent. Further, the increasing difference between the two line graphs clearly demonstrates that the suggested CS model is beneficial in terms of energy consumption as well.

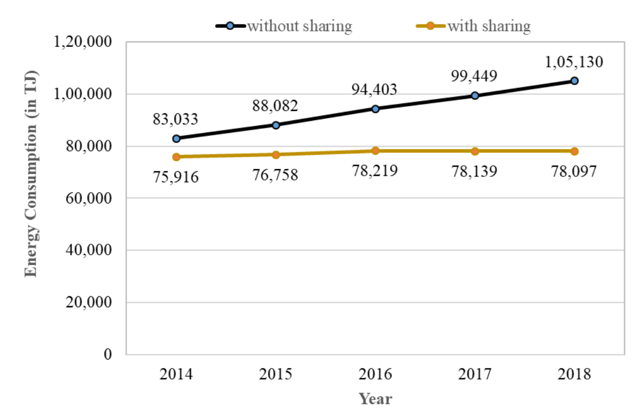

Fig. 4: Year wise estimated energy consumption by the vehicles – with car sharing and without car sharing.

Conclusion

The study concludes that car sharing presents a viable solution to Delhi's mobility crisis. The 1:7 substitution ratio aligns with global benchmarks and demonstrates significant reductions in CO_2 emissions and energy use. COPERT5.5 modeling confirms environmental benefits, while regression analysis validates adoption trends. The study supports integrating CS as a MaaS model into urban transport policy.

Considering the limitations of the present study, recommendations for future study are –

- include hybrid and EV in future modeling;
- conduct demographic surveys to assess awareness;

- role of public-private partnerships for infrastructure; and
- use COPERT5.5 for EV impact analysis.

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The present research did not receive any financial support.

Conflict of Interest

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

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