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Energy, environmental and mobility impacts of car-sharing systems. Empirical results from Lisbon, Portugal

Patrícia Baptista*[,a], Sandra Melo[a], Catarina Rolim[a]

[a]*IDMEC - Instituto Superior Técnico, Universidade Técnica de Lisboa,*
Av. Rovisco Pais, 1 - 1049-001 Lisboa – Portugal

Abstract

The dominance of road transport, both on passenger and freight movements, has reached alarming levels for society due to their negative environmental impacts as well as societal and economic costs. To reverse this trend, many approaches have been applied, but without significant effects on mobility patterns and on the sustainability of the transport system. Fairly promising results have recently been reported in Europe with car-sharing. This research confirms, as hypothesized by prior research, that car sharing contributes to a more efficient and rational mobility (with lower number of vehicles per capita among members, lower demand for parking space, lower fixed costs and a complement to public transport). Additionally to the lower consumption of physical and economic resources, car sharing can also contribute to the reduction of energy and environmental impacts (added to the direct ones from the changes on vehicle ownership and usage patterns). A case study was carried out in Lisbon, Portugal, to estimate car sharing impacts and the effects of a possible technology change. The results demonstrate that those benefits can represent reductions of 35 or 47% in terms of energy consumption and 35 and 65% for CO_2 emissions, if a shift to Hybrid vehicles (Sc.1) or to Electric vehicles (Sc.2) is promoted, respectively. The impacts of reducing vehicle ownership, in a 1 to 6 ratio, due to the implementation of car-sharing were also estimated. Additionally, a simplified fleet based NPV analysis was performed and the break-even point for which the system would become economically feasible was estimated. The most relevant variables influencing the economic feasibility of the car sharing the cost related variables, reducing the break-even timeframe from 36 to 57%.

Keywords: car-sharing; Lisbon case-study; energy and envionmental analysis; economic feasibility.

* Corresponding author. Tel.: +351218419555
E-mail address: patricia.baptista@ist.utl.pt

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1. Introduction

The dominance of road transport, both on passenger and freight movements, has reached alarming levels for society due to their negative energy and environmental impacts as well as societal and economic costs. In fact, the road transportation sector in Portugal was responsible in 2010 for 35% of the final energy consumption (corresponding to 70% of the crude oil products consumption) and approximately 30% of CO_2 emissions (EUROSTAT, 2012). To address this issue, two main approaches have been followed. On one hand, actions have been carried out to promote alternative mobility solutions (such as car-sharing), that induce a more efficient transportation system. On the other hand, a technology driven approach, based on improving vehicle's efficiency, promoting alternative vehicle technologies and energy sources, has been pursued (Baptista et al., 2012; IEA, 2010). The use of alternative fuels such as hydrogen and electricity is regarded as an opportunity to reduce significantly the amount of CO_2 emitted by the transportation sector and increased renewable energy penetration (Pina, 2008). Along this paper, the authors analyze both approaches, estimating the impacts of car-sharing, in the specific case-study of Lisbon, Portugal, and assessing the effects of possible vehicle technology changes.

1.1. Car Sharing Concept

Car-sharing is a membership-based service that offers the user short term vehicle access, when other modes of transport are not available or are not convenient. Members can reserve one vehicle from a fleet, parked at central locations across the city, usually near other transportation hubs, such as metro and train stations. Traditionally, to access the systems, the payment of a membership fee and a usage rate based on time and distance travelled is required. Besides vehicle usage, the membership fees can include parking, fuel, insurance, cleaning, and maintenance and inspection expenses. Car-sharing systems usually target two types of groups: individual and business members. Individual members are customers who pay a monthly or yearly fee, which guarantees the access to car-sharing vehicles within the network. Business members correspond to companies that pay a membership fee giving access to previously named employees to use the service. This last service corresponds to a fleet sharing system, which allows an organization to have exclusive use of car-sharing vehicles at particular times (most business members use the regular car-sharing network in the same way as other members.). Fleet sharing certifies that the company's access to the vehicles is guaranteed, and is monetarily better for the operator since it assures a profit flow. It can be compared to a short time renting system in which companies have the assurance that a car sharing vehicle will be at their disposal close to the facilities of the company.

The main public of car-sharing is generally lower-income drivers who sporadically need a vehicle or households and companies with more than one driver. As a result, one of the main advantages of car-sharing is the decrease on fixed costs associated to vehicle ownership. These fixed costs are the expenses the vehicle owner must pay independently of its usage, including costs such as vehicle depreciation, insurance and taxation. Considering these fixed costs, privately owned vehicles pay higher costs per VKT than car-sharing vehicles. In car-sharing systems, from the user point of view, these facts modify the cost structure of car availability by changing most of the costs into variable ones, in particular for low driving mileage (Steininger et al., 1996). A study for San Diego (IBI, 2009) estimates that the average car expense for car-sharing individual members is of $50 per month, when compared to the $600-$700 per month for car ownership. Consequently, car-sharing analysis requires a direct consideration on how much each trip costs (Duncan, 2011), making car-sharing members drive considerably less after they become members of the service (Katzev, 2003; Meijkamp, 1998; Steininger et al., 1996).

In terms of vehicle ownership, several studies indicate that the use of a car-sharing service usually results in a reduction in vehicles per capita among members (Table 1). Such evidence leads the authors to explore whether car-sharing allows users to have the same mobility patterns using less resources.

Table 1. Effects of car-sharing systems on vehicle ownership and usage and on kilometres travelled.

References	Influences on vehicle ownerships and usage patterns
(MOMO, 2010)	• A car-sharing vehicle replaces four to eight vehicles.
(MOSES, 2005)	• As a result of the decrease in private car need, one car-sharing car replaces 7-10 private cars and 4-6 cars, respectively (study conducted in Bremen and in Belgium).
(Cervero and Tsai, 2004)	• 30% of the households that joined the City CarShare (San Francisco, USA) have either sold a car or delayed purchasing one, and the use of alternative transports, like bicycling and walking has also increased.
(IBI, 2009)	• The same pattern of selling the old car or delaying the purchase of a new one was observed in members of Chicago's I-Go Car Share program.
(Katzev, 2003)	• Members increased their use of public transport and of alternative travel modes, such as walking and bicycling.
(Shaheen et al., 1998)	• Reductions of 33 to 50% of car kilometres travelled and an increase on public transportation usage after joining the car-sharing organization were observed in Switzerland.
(Meijkamp, 1998)	• A decrease in vehicle kilometres travelled by former car owners was of 33% and a more frequent use of bicycles (+14%) and train (+37%) was also observed in the Netherlands.
(Prettenthaler and Steininger, 1999)	• A mileage reduction due to car-sharing system between 42 and 50% was observed in Germany.

The impacts summarized in Table 1 refer to direct impacts on individual mobility patterns. Besides these, there are also other positive effects for the general public. Decreasing vehicle ownership results in lower demand for parking space, less congestion, increased road safety due to reduced vehicle crashes, and reduced local pollutants emissions and energy consumption (IBI, 2009; MOSES, 2005). The State of European Car-Sharing report states that, when comparing private car fleets with car-sharing fleets, the latter can present 15 to 25 percent lower specific CO_2 emissions (MOMO, 2010). Additionally, the Environmental Assessment Report states that car-sharing has the potential to reduce emissions by 40 to 50 percent (MOSES, 2005). Furthermore, car-sharing also works as a complement to public transport, biking and walking (Duncan, 2011). In this sense, car-sharing can be considered a contributor to a more socially sustainable transport system by offering affordable mobility and enhancing energy and environmental efficiency for the society. Several studies have addressed the possible impacts of car-sharing, either to understand if a car-sharing system is adequate to specific urban environments (Seik, 2000), or to quantify its possible environmental impacts (Firnkorn and Müller, 2011; Musso et al., 2012). Following the existing literature on the topic, this research paper presents a broader analysis on the current energy and environmental impacts of the car-sharing system operating in the city of Lisbon, Portugal, estimating the effects of introducing different vehicle technologies, as well as analyzing possible variables that can make these types of systems succeed economically.

1.2. Worldwide car-sharing review

To understand the deployment status of car-sharing systems worldwide and to characterize them, information on car-sharing systems across the world was collected. More than 400 cities with car-sharing systems were identified, mostly located in Europe (around 80%), followed by North America (approximately 18%) and by Oceania (approximately 2%). The following characterization of car-sharing systems is based on this major data collection.

Car sharing systems have experienced a wider deployment in the 2000's, despite some prior initial trials in Switzerland, UK and USA. In 2011 and 2012, more than 25 new systems were created, confirming the recent increasing acceptance of this mobility solution. The most widely known operators also reveal this growing tendency. Autolib in Paris has 1750 Electric Vehicles, offers 4000 charging points and has more than 65000 registered subscribers). Zipcar (that started in the US but has expanded worldwide) reached 777000 members and offers nearly 10000 vehicles. Hertz on demand started in 2008 with a vast distribution both in US, Europe and Australia, and has reached 150000 users. Car2Go started in Germany in 2008 and has expanded to 18 cities worldwide with over 350000 customers and offering 6000 conventional and alternative vehicles. These 4 operators are the bigger systems with more than 100 vehicles per city, representing 47% of the total system and have been promoting the use of alternative vehicles on their fleets. Moreover, the collected information on car-sharing systems across the world allowed identifying several variables on car sharing systems to be accounted and normalized to the cities' size and population, as presented in Table 2.

Table 2. Car-sharing systems characterization variables.

Characterization variables	**Average values**
Parks per 10 km^2	2.4
Parking spaces per 10 km^2	4.8
Vehicles 10000 inhabitants	2.5
Members per total population (%)	3.5%

In terms of car-sharing systems parking infrastructure, the average number of parks and parking spaces per 10 km^2 is of 2.4 and 4.8, respectively. As for member's adoption of car-sharing systems, an average of 3.5% of the cities' population enrolls in these systems and an average of 2.5 vehicles per 10 000 inhabitants is provided. When analyzing the price associated to these systems, they normally provide long term memberships (rounding 60 per year), monthly fees (with an average 15 pe r month value). For less frequent usage, a daily fee is also provided reaching values of 25 per day or 5 per h our. Other systems charge their vehicles usage per minute or/and kilometer travelled.

In terms of vehicle technology, car-sharing systems traditionally deploy internal combustion engine vehicles (predominantly gasoline running vehicles). However, in recent years, electricity powered vehicles such as fully electric vehicles (EV) and plug-in hybrid electric vehicles (PHEV) have been used in car-sharing systems. Considering that car-sharing systems usually cover urban city trips, electricity powered vehicles have several local advantages such as noise reduction, zero local tail-pipe emissions and improved vehicle efficiency. Table 3 presents the vehicle technology distribution for the considered car-sharing systems, showing that electricity powered vehicles, despite of their higher purchase cost, are starting to achieve a sizeable importance in this context.

Table 3. Vehicle technology distribution for the considered car-sharing systems.

Type of technology	**Percentage**
Conventional	89%
EV	9%
PHEV	2%

2. Methodology

2.1. Car-sharing characterization in Lisbon, Portugal

The Lisbon car-sharing operator system, MobCarsharing, was launched in October 2008. This system provides 12 vehicles in 9 locations across Lisbon. This corresponds to 0.22 vehicles per 10000 inhabitants and 1.1 parks per 10 km^2, which are lower values compared to the average 2.5 and 2.4 values presented in Table 2, respectively. Since its beginning, approximately 300 members have registered (70% private users and 30% company users), representing 0.05% of the city's population, also a low number compared to the average 3.5% value presented in 2. Such low usage (illustrated in Fig. 1) can result of a small city coverage, with few vehicles deployed. Nevertheless, Mobcarsharing presents an increasing yearly trend both in terms of total number of usages (average 81% per year) and the total vehicle kilometers travelled, which has increased on average 116% per year (MobCarsharing, 2013).

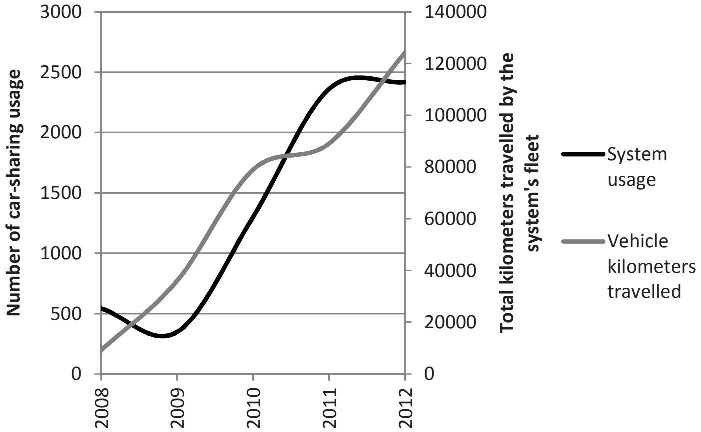

Fig. 1. Lisbon car-sharing system usage from 2008 to 2012 (MobCarsharing, 2013).

The tendency illustrated in Figure 1 seems to indicate that there is still an unexplored potential market for car sharing in Lisbon. In fact, the authors analyzed individual and business members' profiles and respective mobility behavior changes and identified the maximum share of members to whom the membership is economically beneficial and more probable to occur. After a detailed characterization of current car-sharing services and a deep socio-economic characterization of the population of Lisbon, estimated maximum shares of 8% and 15% of population and companies were obtained for individual and business members in Lisbon, respectively (Melo and Rolim, 2011). According to that, a 10% penetration scenario, corresponding to the maximum potential scenario is tested and reported along the next section.

2.2. Changes on mobility patterns and user's behavior

The quantification on mobility changes was obtained through a survey conducted online to both individual and business members of the car sharing system in Lisbon (Melo and Rolim, 2011). The survey sent to 241 members of the service was composed by 30 closed-ended questions and covered aspects such as users' personal characterization, their mobility patterns, motivation to become members, impacts of the service in their travel behavior, their preferences concerning the service use, objectives of service use and its benefits and disadvantages. Members were also questioned about their travel modes use frequency, as well as their kilometers travelled.

2.3. Energy and environmental impacts

Along this paper, in a first approach, three scenarios are tested to estimate the effects of car-sharing: the BAU scenario with car sharing running mostly with conventional vehicles characterizing the current situation, a full hybrid vehicles scenario (Sc.1 - HEV scenario) and, lastly, a full electric vehicles scenario (Sc. 2 - EV scenario), as presented in Table 4.

Table 4. Considered scenarios for the Lisbon's car-sharing fleet evaluation.

Scenario	Description	Modeling tools used
BAU	Current fleet	Macro-simulation, COPERT 4
Sc.1 - HEV scenario	Replacing current fleet with HEV	Macro-simulation, COPERT 4
Sc. 2 - EV scenario	Replacing current fleet with EV	Micro-simulation, ADVISOR

In order to estimate the energy and environmental impacts of a car-sharing fleet in the fuel tank-to-wheel (TTW) stage (which accounts for the emissions and fuel consumption that result from moving the vehicle through its drive cycle), the Lisbon car-sharing fleet was studied (MobCarsharing, 2013). It is composed by 10 gasoline internal combustion engine and 2 gasoline hybrid vehicles (all Euro 4 standard), which are used approximately 1400 times a year. This fleet's presents an annual average of ≈5000 km travelled per vehicle.

The following assumptions were made regarding the driving context of the car-sharing fleet (see Table 5).

Table 5. Driving context characterization for Lisbon car sharing fleet.

	Driving context		
	Urban	**Rural**	**Highway**
Average speed (km/h)	50	90	100
Percentage of driving time (%)	85	10	5

For estimating the TTW impacts (BAU and Sc. 1), a macro-simulation software was used, the COPERT 4. It is based on the MEET methodology (EEA, 2009; Hickman, 1999), that establishes a framework to calculate energy consumption and emissions of conventional (and nowadays including HEV and NG) vehicle technologies. It was defined within the EMEP/CORINAIR Emission Inventory Guidebook, developed by the UNECE Task Force on Emissions Inventories and Projections (under the UNECE Convention on Long-Range Transboundary Air Pollution and the EU directive on national emission ceilings). For Sc. 2, micro-simulation tools were used to calculate the TTW results of this alternative technology (Baptista et al., 2012).

As for the Well-to-Tank (WTT) impacts, that result from the expended energy and emissions from bringing an energy vector from its source until its utilization stages, reference factors were used for each of the different energy pathways considered (in this case, gasoline production and electricity production in the Portuguese electricity mix) (Baptista, 2010; Baptista et al., 2012). The combination of the TTW and the WTT stages account for the Well-to-Wheel (WTW).

Moreover, a second analysis was performed for the BAU scenario, estimating the avoided energy and environmental WTW impacts of the vehicles replaced by the car sharing vehicles, as indicated by the literature review in Table 1. These impacts refer to the society energy consumption and CO_2 emissions gains of not having the replaced vehicles running (assuming a low usage profile of 4000 km per year based on typical Portuguese usage patterns), due to having a car sharing system implemented minus the impacts of the car-sharing system. In terms of purchase and running costs, it refers to the global society gains of avoiding the purchase and operation of those replaced vehicles minus the purchase and operational cost of the car sharing vehicles.

2.4. Economic feasibility of car-sharing

To perform an analysis on which variables are more important to the economic feasibility of car-sharing, a fleet based Net Present Value (NPV) was calculated. The Net Present Value (NPV) is the difference between the present value of cash inflows and the present value of cash outflows. NPV is used in capital budgeting to analyze the profitability of an investment or project and is defined by:

$$NPV = C_0 + \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} \quad (1)$$

where t is the time of the cash flow, r is the discount rate, T is the total number of periods, C_t is the net cash flow (i.e. cash inflow – cash outflow), at time t. (Brealey et al., 2011). This analysis includes vehicle or fleet related variables, but does not consider other fixed costs associated to the structure of deploying a car-sharing system (e.g. administrative costs). As a result, in the cost variables, fuel (DGEG, 2013a), insurance, maintenance and circulation tax costs (Nina, 2010) are accounted and, in the revenues, profits related to membership and usage of the system (according to prices available online) are included. An 8 year period was considered, since it corresponds to the average lifetime of a vehicle and a 5% discount rate was included.

3. Results

3.1. Changes on mobility patterns and user's behavior

Based on a response rate of 17% and a confidence level of 90%, the following information was obtained from the survey carried out to members. Based on the declared mobility patterns and respective behavior, it was possible to conclude that individual members use car-sharing vehicles mostly for shopping (excluding groceries) with 12% and for health appointments (8%). Car-sharing replaces taxi use (17%) for both shopping (excluding food products) and health issues, substitutes private car for private trips (visiting parents) (13%) and subway (8%) for shopping and personal activities. Car-sharing also has a considerable effect on the member's behavior. Over the last 6 months, 42% of individual members started managing trips in a different way, 21% started using other transport modes and 8% no longer own a vehicle. In the near future, 21% intend to start using alternative transports, 25% to make better trip management and 4% have mentioned a desire to stop owning a private vehicle. The reduction on car-sharing ownership, which corresponds to a replacing ratio of 6:1, has direct energy and environmental impacts, which is estimated along section 3.2.

3.2. Energy and environmental impacts of car-sharing

For the first analysis, the WTW energy consumption and CO_2 emissions for the 3 technology-based scenarios are presented in Fig. 2. The current situation scenario leads to 126 GJ of yearly WTW energy consumption, which can be reduced by up to 35 or 47%, if scenarios 1 and 2 are introduced. For CO_2 emissions, the current BAU leads to a yearly emission of 9.5 ton, with a reduction potential of 35 and 65% when scenarios 1 and 2 come into place.

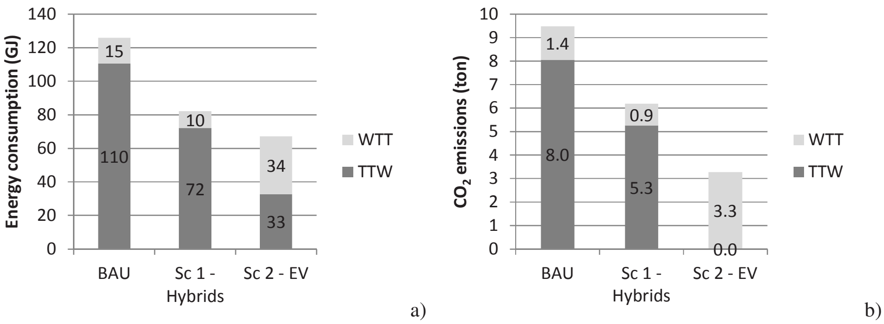

Fig. 2. WTW energy consumption and CO_2 emissions impacts resulting from the Lisbon car-sharing system usage for the 3 considered scenarios.

In terms of local pollutants emissions resulting from changing the vehicle technology of the fleet (Table 6), for scenario 1 (Hybrid) an average of 56% WTW reduction if observed. However, scenario 2 (EV) leads to a shift from the TTW to the WTT stage. Since it regards the introduction of electric vehicles, the local tailpipe emissions are eliminated, and shifted to the electricity production sites. This corresponds to a delocalization of emissions, which in an urban context are positive due to zero TTW emissions.

Table 6. Local pollutants emissions for the considered scenarios.

Local pollutants emissions (kg)	LCA stage	BAU	Sc 1 – Hybrids	Sc 2 – EV
NO_x emissions	TTW	1.98	0.72	0.00
	WTT	4.75	3.10	7.14
CO emissions	TTW	12.84	1.65	0.00
	WTT	0.56	0.37	0.00
HC emissions	TTW	1.60	0.66	0.00
	WTT	24.31	15.87	0.00
PM emissions	TTW	0.05	0.00	0.00
	WTT	0.24	0.16	0.69

Finally, the purchase and running costs for this fleet were also assessed. By considering an average vehicle lifetime of 8 years (ACAP, 2010), the total purchase and energy running costs of the fleet are presented in Fig. 3. Switching to hybrid vehicles (Sc. 1) or to EV (Sc. 2) considerable increases purchase costs are observed (82 and 150%, respectively). On the contrary, energy running costs are lower with 35% and 76% reductions for scenarios 2 and 3, respectively.

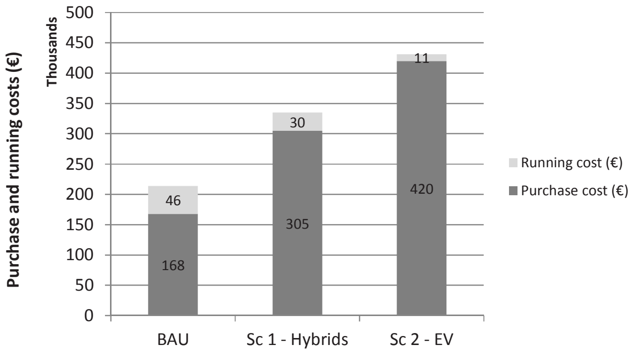

Fig. 3. Purchase and running costs for the 3 considered scenarios assuming a vehicle lifetime of 8 years.

In terms of the second analysis, considering the market dimension associated to the car-sharing system, the BAU and the maximum potential scenario (defined in section 2.2) were considered in order to understand the current and the possible future impacts of car-sharing in the Lisbon case-study.

According to the previous literature review (Table 1) and the previous characterization of car-sharing in Lisbon (Melo and Rolim, 2011), the assumption that a car-sharing vehicle would, on average, replace the ownership, of 6 vehicles was made. This 6:1 ratio means that, in the BAU, 72 vehicles (with typical Portuguese utilization patterns) would be replaced and, in the maximum potential scenario, around 30000 vehicles would not be used. As a result, the yearly balance between conventional vehicles that are replaced with car-sharing vehicles can be estimated for the two market dimensions considered, as presented in Table 7. The results indicate reductions of 0.003% and 1.28% in the yearly TTW energy consumption of light-duty vehicles in the Lisbon area, when considering the BAU and the maximum potential scenarios (DGEG, 2013b). The local TTW emissions of CO_2 would also be reduced, as well as the societal purchase and running costs due to the reduction in the number of vehicles.

Table 7. Impacts global balance from shifting to car-sharing.

Impacts considered	Reduction from shifting to car-sharing (car-sharing – replaced vehicles impacts)	
	BAU	**Maximum potential scenario**
TTW Energy consumption (GJ)	-473	-199 891
TTW CO_2 emissions (ton)	-35	-14 713
Purchase costs (thousand)	-749	-181,427
Running costs (thousand)	-409	-183,370

This analysis allows estimating a car-sharing CO_2 footprint for the Lisbon case-study, reaching a value of 0.6 kg of CO_2 saved per kilometer travelled in the car sharing system.

3.3. Variables influence on economic analysis of car-sharing

In order to assess which variables mostly influence the economic feasibility of a car-sharing system, a fleet based NPV was calculated for the BAU scenario and for the maximum potential scenario, as presented in Table

8. Considering this fleet approach the car-sharing system would reach its break-even point after 6.8 years, having a positive NPV after the 8 year period proportional to the fleet size.

Table 8. Fleet based NPV and break-even point for the BAU and maximum potential scenarios.

Scenario	Break-even point (years)	NPV (after 8 years)
BAU	6.8	37,098
Maximum potential scenario		15,626,692

In order to understand which variables influence more the economic feasibility of the car-sharing system, a sensitivity analysis was performed to some of the variables of the model applying a factor of 2 to the BAU variables in order to estimate their impacts on the fleet's NPV. These results are presented in Table 9.

Table 9. Variables influence on economic analysis of car-sharing.

Scenario	Break-even point (reduction compared to the BAU)	$NPV_{SCENARIO}/NPV_{BAU}$ (after 8 years)
Double membership fee price	-19.6%	2.8
Double number of members	-19.6%	2.8
Double VKT by total fleet	-31.2%	5.2
Double price per km	-36.5%	6.7
Half purchase vehicle cost	-35.5%	3.2
Half vehicle insurance, maintenance and tax costs	-41.2%	4.0
Half fuel cost	-56.8%	10.2

Both revenue and cost related measures were assessed. The results demonstrated that cost related measures are more effective on improving the car-sharing system economic analysis. However, it should be noted that the costs of hypothetically implementing these measures are not being accounted. The number of members and the membership fee price has similar results by reducing the break-even point in 20%. Doubling the number of VKT of the total fleet (by having more intensive vehicle usage or more available vehicles) leads to a 31% reduction in the break-even point. Having a higher price per kilometers allows reducing the break-even point by 37%. When analyzing the cost related measures, reducing the vehicle purchase cost would allow decreasing the break-even point by 36%. Having lower insurance, maintenance and tax costs would be reflected in a 41% reduction, while having lower fuel cost would represent a 57% reduction in the break-even point time. This demonstrates that cost related variables have higher influence on the final results.

Finally, a cost efficiency factor was estimated, with globally results in investing 9.8 to save one G J energy (in TTW) for the BAU Lisbon case-study in this 8 year period timeframe.

4. Conclusions

In all, an in-depth analysis was performed to a car-sharing system case-study, proving and quantifying its energy and environmental local and global impacts at a city scale, as well as to better understand the variables that influence its economic feasibility. The estimation of effects in terms of mobility behavior and patterns indicates a reduction of 0.003% and 1.28% in the TTW energy consumption of light-duty vehicles in the Lisbon area, when considering the BAU and the maximum potential market scenarios, respectively. Secondly, the Lisbon case-study was also used to assess the impacts of shifting to more efficient vehicle technologies. While the current BAU scenario leads to 126 GJ of yearly WTW energy consumption, these can be reduced up to 35 or 47% if scenarios 2 (Hybrids) and 3 (EV) are introduced. The same happens for CO_2 emissions, with the BAU leading to yearly 9.5 ton emissions, which can be reduced by 35 and 65% when scenarios 2 and 3 come into place. The drawback associated to this technology shift is the increased vehicle purchase cost (82 and 150% for scenarios 2 and 3 respectively compared to the BAU), in spite of lower energy running costs (35% and 76% reductions compared to the BAU). Additionally, a simplified fleet based NPV demonstrates the car-sharing system would reach its break-even point after 6.8 years, having a positive NPV after the 8 year period proportional to the fleet size. Moreover, a sensitivity analysis to the economic model was performed showing that the variables with higher influence were cost related ones (reducing the break-even timeframe from 36 to57%), such as vehicle purchase cost, insurance, maintenance and tax costs and fuel cost.

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