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USING LIFE CYCLE
APPROACHES TO
EVALUATE SUSTAINABLE
CONSUMPTION
PROGRAMS

Car-sharing

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Using life cycle approaches to evaluate sustainable consumption programs: Car-sharing

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Abstract

Encouraging more sustainable consumption patterns offers an effective means of reducing the environmental impacts of individuals and households. In addition, many Product Service Systems (PSS) offer not only environmental benefits, but also social and economic benefits. In the evaluation of PSSs it is important to capture any indirect consequences of changed consumption patterns. For instance, a PSS that offers economic savings to the individual will inevitably be spent elsewhere. Any environmental assessment of a PSS must include an analysis of the consumers marginal expenditure. This article demonstrates how to apply Life Cycle Assessment (LCA) and economic Input-Output Analysis (IOA) to sustainable consumption patterns. Car sharing schemes and transportation choices are used as an illustrative example. It is shown that the way the rebound expenditure is spent makes a large difference to the overall environmental impacts. If the households marginal expenditure is spread uniformly across non-transport items the overall environmental impacts of different transportation choices only has small changes. However, if the marginal expenditure is spent on air travel, then the rebound emissions can negate any environmental savings of a transport choices.

Keywords

Car-sharing; Sustainable consumption; Life-cycle analysis; Input-output analysis; Product service system;

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1 Introduction

Unsustainable consumption patterns in industrialized countries are a reflection of the disproportionate scale of economic activity relative to the capacity of ecological systems to provide for our demands. Sustainable consumption programs cover an array of efforts to minimize our ecological impact. From technological efficiency to behavioral and social programs, all efforts are necessary to redirect the unsustainable paths of our societies (Halme et al., 2004). In particular, as distribution issues become more pressing and incessant pursuits for wealth continue, the dematerialization and sustainable management of energy and resources becomes ever-more important.

In this context, car-sharing schemes build a promising case for sustainable consumption programs. They are organized arrangements, collectives or business ventures, where members can reserve cars when they need them and pay automotive expenses on a variable basis¹ (per kilometer or per unit of time). The systems motivate a more efficient use of cars and other transport means, influencing consumer behavior through their organizational and cost structures. They induce less driving, increased use of public transport, walking and biking, and increase savings in transport budgets (Whitelegg and Britton, 1999).

In addition, car-sharing schemes serve as learning systems for consumers to engage in common-use of consumption goods, which encourages more sustainable consumption. As a Product Service System (PSS), car-sharing schemes advocate a shift away from private ownership to a managed provision of utility through a mix of products and services (Manzini and Vezzoli, 2002). Evidence shows that sharing, pooling resources, and efficient co-operation are key in the move to a more sustainable society.

1.1 Car consumption systems

Changes in consumption patterns can be very difficult to influence, particularly when the consumed good has been ingrained in everyday life. The symbols and social meanings attached to cars makes the move away from individual car ownership a challenging task. Normative institutions and existing infrastructure have been developing in favor of private cars for decades, making alternative modes of transport more difficult (Mont, 2004). In Norway, in spite of having one of the highest car costs in Europe (The Norwegian Public Roads Administration and SINTEF, 2004), private car-ownership has been increasing steadily while the average occupancy rate has been steady or decreasing in EU member states (European Environment Agency, 2003; Statistics Norway, 2001), see Figure 1 for Norway. The average distance of passenger car was 13,800 km a year in 2001 (Rideng, 2002).

Given the large environmental impact of the transport sector, and the private car in particular, these trends deserve special attention. The evidence so far shows that the use of the car is embedded in socio-cultural systems which car-sharing programs will have to overcome. Car-sharing schemes offer many advantages of a social, economical, and environmental nature. As transport consumers face costs from different options in variable

¹Here we distinguish from informal car-sharing, where friends or work colleagues may travel together on a shared basis.

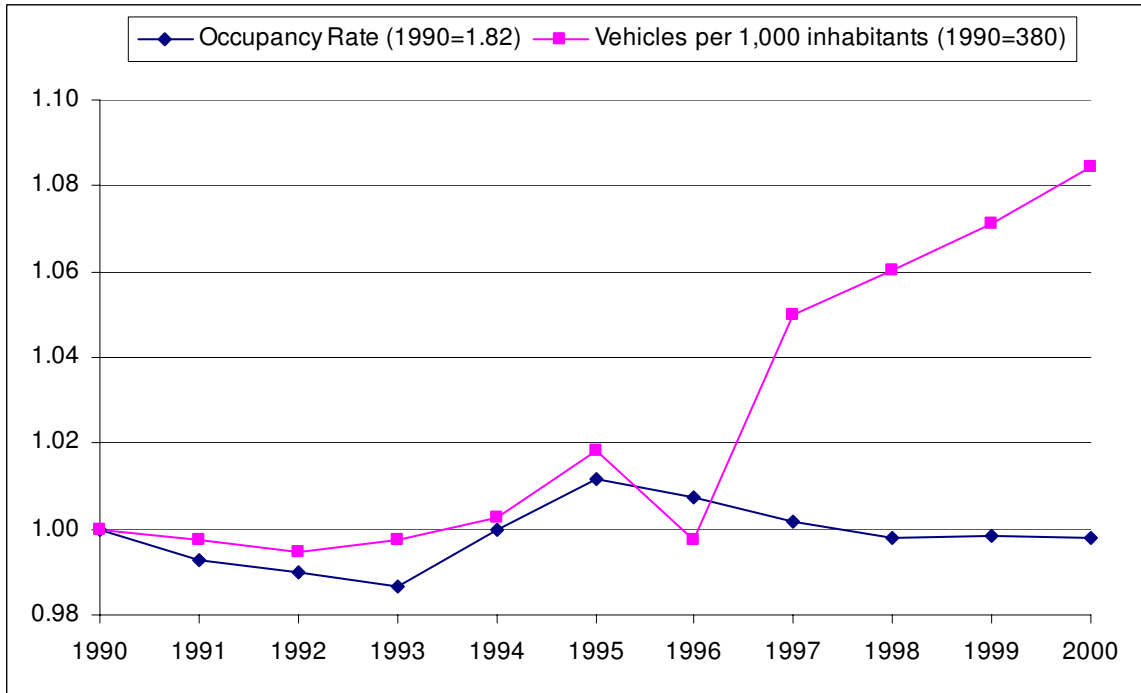


Figure 1: The normalized occupancy rates and number of vehicles per 1,000 inhabitants for Norway. Data from Eurostat.

terms (including car-use) they can make more suitable choices according to each need. The per-unit-cost also gives a more realistic picture of the cost of driving, allowing the consumer to make more informed decisions. In most cases, studies have found average car-use and distance traveled to decrease and many car purchases have been avoided (Whitelegg and Britton, 1999; Shaheen, 2004; Mont, 2004). At the aggregated level, less cars also means less traffic, less pollution, and more public space freed up from parking lots. Alternative modes of transport like bicycling and public buses also benefit from the increased use (Whitelegg and Britton, 1999).

1.2 Consumption of car sharers

Given the Norwegian experience and other surveyed schemes, most car-sharers have been found to be relatively young (between 25 to 40 years) with above average education, below average income, and with strong sensitivity for environmental and social concerns. The schemes have been attractive options for drivers who drive less than the average mileage and have drawn new members by making new transport mixes accessible. Break-even points for the cost-effectiveness of car-sharing as opposed to car-owners changes according to different countries and studies (see Whitelegg and Britton, 1999, pp. 42–45). Personal values and world views play an important role among car-sharing participants. Attitudes towards sharing programs in general have been found to be one of the most consistent characteristics of early adopters of the programs (Whitelegg and Britton, 1999).

Although membership is growing rapidly, sometimes at rates of 50% per year (White-

legg and Britton, 1999; Mont, 2004), car-sharing programs remain marginal to the overall automotive market. A critical mass is needed to generate many of the environmental benefits that occur at the aggregate level. A transport mix based on the available option of car-sharing should develop as a consumption system, improving not only the efficiency of these schemes but also other public transport modes. Therefore, much of the overall success of car-sharing programs depends on the rates of adoption.

So far, studies have shown significant changes in transport behavior as a result of car-sharing programs. They have been said to reduce the number of cars by about 40% and distances driven by 30-60% (Whitelegg and Britton, 1999; Shaheen, 2004; Mont, 2004). Some participants that did not own a vehicle before increase their driving distances, but this was more than offset by the reductions made by previous car owners (Whitelegg and Britton, 1999). Moreover, according to surveys conducted in United States, a large number of participants (about 30%) gave up their cars after joining a car-sharing scheme and reportedly, 60-70% of car purchases have also been avoided (Whitelegg and Britton, 1999; Shaheen, 2004). The utilization rate of the shared vehicles is also maximized as they tend to be driven more than twice the distance of a private car with almost double the occupancy rate (Whitelegg and Britton, 1999).

Another environmental benefit is the increased use of low environmental impact transport such as public transport, walking, and biking. According to a Swiss study, car-sharers increased their use of public transport, bicycle and foot from 63 to 75%. On the other hand, motorists were using the car for about 75% of their mobility needs. However, the behavior of former car-owners who give up their car as a result of the car-sharing schemes becomes remarkably similar to car-sharers who did not previously have access to a car (Whitelegg and Britton, 1999). Car-sharing has therefore had an impact both on making car-use more sustainable and improving the accessibility and efficiency of use of different transportation mixes.

1.3 The future of car-sharing

Car-sharing schemes have the potential for becoming mainstream alternatives for transport needs. Their growth rates have been impressive and in some cases, policy frameworks have begun to integrate incentives for their use. The European Commission has integrated car-sharing clauses into its transport policy and several European governments have promoted the schemes through research and infrastructure (Mont, 2004).

An important next step to improve the effectiveness of car-sharing as a sustainable consumption program is to include more life-cycle assessments of their use and impact. Working in co-operation with auto manufacturers can make car design more multi-user oriented and obstacles from normative institutions can be overcome (Mont, 2004). A combined effort with other forms of transport, such as rental cars and buses, has the potential to make the entire transport mix more sustainable. Moreover, given the lower cost of driving with a shared car, there is more room for manufacturers to introduce environmental innovations to vehicles that would otherwise be unmarketable. Most importantly, making driving patterns more sustainable requires a systemic approach that integrates technical as well as behavioral and social dimensions.

2 Evaluation of car sharing programs

Although the particular experience of car-sharing organizations in Norway has not been well documented, most studies on car-sharing schemes around the world have found consistent results that can be used as approximations to the Norwegian experience (Whitelegg and Britton, 1999; Shaheen, 2004; Mont, 2004). A life-cycle study of car-sharing schemes can further advise policy and the development of programs around the world. A quantitative study into changed consumption patterns must consider the complete consumption system—including the multitude of dynamics and various actors involved. A narrow focus can jeopardize the overall impact of a sustainable consumption program. For instance, when a household adjusts to the introduction of a sustainable consumption program, it may adopt accompanying activities with greater environmental impacts; known as the rebound effect (Hertwich, 2005). Therefore, a broad strategy to sustainable consumption programs is necessary given the complexity of our consumption choices, motivations, and dynamics.

In the remainder of this paper we demonstrate how to use life-cycle assessment (LCA) in combination with input-output analysis to evaluate the overall environmental impact of various car-sharing scenarios (Heijungs and Suh, 2002; Suh, 2004; Peters and Hertwich, 2004b). Given the lower costs of owning a car through a car-sharing scheme (Whitelegg and Britton, 1999) an analysis of the rebound effect is important (Hertwich, 2005). As an illustrative example, we look at car-sharing schemes as a mode of transport and, using Norwegian data, we compare them to other modes of transport in terms of their costs, changing budgets, and resulting global warming emissions. Scenarios are simulated to reflect the costs structure and life-cycle emissions of different transport mixes and the household's overall consumption levels are adjusted to reflect the new budget constraints and consequent emissions. Input-output analysis is used to derive the emissions from non-transport consumption. Although the available data is not detailed enough to make very concrete analysis, the main purpose is to demonstrate the use of the methodology and general dynamics involved.

2.1 Methodology

In the analysis we compare car-sharing schemes to other modes of transport in terms of their environmental impact, given total transport emissions and rebound emissions from the remaining household consumption. From the Norwegian Survey of Consumer Expenditure (SCE), we construct a consumption bundle for transport services and non-transport services for the average Norwegian household. Then, based on the Norwegian Travel Survey (NTS) (Denstadli and Hjorthol, 2002), we construct various household transportation scenarios and compare the resulting household environmental impacts. The environmental impacts for the transport services are determined using Life Cycle Analysis (LCA) (Heijungs and Suh, 2002), while the environmental impacts of non-transport consumption and the rebound effect are calculated using Input-Output Analysis (IOA) (Leontief, 1941; United Nations, 1999; Peters and Hertwich, 2004a). Global Warming Potential (GWP) is taken as the environmental impact indicator.

2.1.1 Data sources

The functional unit defines the parameters of the impact assessment and allows for a comparison to be made between the different consumption choices of modes of transport. We use the average Norwegian household size of 2.3 people to compare transport services for the household. Different occupancy rates were estimated according to the actual average rates for each mode of transport; most estimates were based on data from the NTS. Travel distances, costs, and modal distributions were derived from educated estimates. In most cases, averages were taken from transport and travel data sets from Statistics Norway² and the NTS.

The costs of owning and driving a car were based on the SCE where fixed and variable costs were separated to reflect differences in distances driven. The final cost was also comparable to other Scandinavian average costs of owning a car (Danish EPA, 2000). The cost of public transport bus use was based on the price of monthly bus tickets and company data. These costs were also compared to the SCE data and percentage of people using public transport. Travel distances and costs for car-sharing schemes were calculated from the data provided by the Trondheim Car Collective³.

All non-transport consumption expenditure data was taken from the SCE⁴. Since the SCE did not contain detailed information on transport usage, we considered the average Norwegian household—which had 2.3 occupants—as the functional unit.

2.1.2 Environmental Emissions: Calculations

Life Cycle Analysis (LCA) was used to derive transportation emissions since the tool gives a more precise environmental impact assessment than the input-output method. The environmental impact of the different transport choices was measured in terms of their Global Warming Potential (GWP) per person kilometer, calculated in kilograms of CO₂ equivalents. Emissions for transport were determined using life cycle emissions from the EcoInvent Database. The indicator included the production and operation of the transport vehicle as well as the construction, maintenance and disposal of roads for road vehicles and airport for air transport. It is important to keep in mind that GWP per person kilometer assumes an occupancy rate for each transportation mode. In this study it is assumed that for the public transport modes, the average occupancy rates remain the same; however, for the family car it is assumed that the same emissions occur regardless of the number of occupants in the car. Table 1 gives a summary of the LCA data.

Environmental impacts of the household’s non-transport activities were calculated using input-output analysis. The SCE data is tabulated in a different aggregation to the IO data and so a mapping was required between the COICOP and NACE classifications. If y is the consumption bundle of non-transport activities, in the NACE industry classification, then the impacts are given by

$$F(I - A)^{-1}y \tag{1}$$

²<http://www.ssb.no/english>

³<http://www.trondheim-bilkollektiv.no/>

⁴Most of the data can be obtained through http://www.ssb.no/english/subjects/05/02/fbu_en/. A report on an earlier version of the survey is also available (Lodberg-Holm and Mørk, 2001).

Transport Mode		GWP kg CO ₂ -e/p/km
Car	Family	0.291 kg/v/km
Bus	Regional	0.113
	Coach	0.0550
Train	Regional	0.0247
	Long distance	0.0118
Air	Europe	0.415
	Continental	0.252
	Weighted Average	0.303

Table 1: The Global Warming Potential (GWP) in kg CO₂-e/p/km for the different transport modes, except for the car which is in kg CO₂-e/v/km. All data is from the EcoInvent Database.

where F is the GWP per unit economic output and A is the interindustry requirements matrix (Peters and Hertwich, 2004a). The SCE data is evaluated in retail prices, while the IO data is in basic prices. Using information on taxes and margins the SCE was converted into basic prices for the environmental impact calculations. The GWP was calculated from three air pollutants; $GWP = CO_2 + 21CH_4 + 310N_2O$. Imports were assumed to be produced using Norwegian technology. This was sufficient for the comparative purposes of this study. For more details of the manipulations and calculations see Peters et al. (2004).

2.1.3 Rebound Calculations

The rebound effect was calculated to account for the change in the household's income spending given the different costs of each transport mode. Each transport scenario has different cost structures and the remaining household budget is assumed to be spent evenly across the remaining non-transport sectors. The overall rebound effect was then calculated in terms of GWP for the new expenditure patterns using the IO data.

Let the total household expenditure from the SCE data be given by y . Let the expenditure on all non-transport items be given by y_{nt} . Each transport scenario creates a vector of expenditure on transport y_t and so the total household consumption balances to give $y_t + y_{nt} + \Delta y = y$; the difference, Δy , is the rebound expenditure that can be spent on any desired product. We assume that Δy is distributed evenly over the vector y_{nt} until the total expenditure sums to y . Letting $\Delta y = \delta y_{nt}$ we have,

$$\sum y = \sum y_t + (1 + \delta) \sum y_{nt} \quad (2)$$

which gives

$$\delta = \frac{\sum y - \sum y_t}{\sum y_{nt}} - 1 = \frac{\sum \Delta y}{\sum y_{nt}} \quad (3)$$

The last equality shows that Δy represents the rebound expenditure. If $E(\cdot)$ represents the GWP for a given demand, then the GWP from the rebound effect is given by

$$E(\Delta y) = \delta E(y_{nt}) \quad (4)$$

	Car only	Bus & Car	Bus & Coach	Car share -light	Car share -intensive
Car - distance (vkm)	19,206	14,035	0	0	0
- cost (NOK)	46,740	40,910	0	0	0
Bus - distance (pkm)	0	7,477	22,552	22,552	16,621
- cost (NOK)	0	9,346	11,720	11,720	11,720
Coach - distance (pkm)	0	0	5,216	0	0
- cost (NOK)	0	0	3,406	0	0
Car share - distance (vkm)	0	0	0	2,268	6,371
- cost (NOK)	0	0	0	7,057	19,824
Total travel distance (pkm)	27,769	27,769	27,769	27,769	27,769
Total travel cost (NOK)	46,740	50,256	15,126	18,777	31,543
Non-transport GWP	7,934	7,934	7,934	7,934	7,934
Transport GWP	5,589	4,929	2,736	3,208	3,732
Rebound GWP	465	348	1,516	1,395	970
Total GWP	13,988	13,211	12,186	12,537	12,636

Table 2: The constant travel distance scenario. GWP in kg CO₂-e.

3 Scenarios

The emissions of car-sharers can be compared to car owners and non-car owners. The two reference points for car-sharers can be assumed to be either previous car owners or commuters previously limited to public transport for their transport needs. The transport mixes modeled for car-sharing scenarios continue to rely on public transport (regular buses) for daily travel, as studies have shown this to be the case for most participants (European Environment Agency, 2003). Traveling patterns vary according to different modes of transport. Although we do not have a clear break-down of traveling by purpose, we model total estimates for each mode. Profiles are based on the combined estimations of a transport mix. There are innumerable scenarios possible; the following are some representative examples that illustrate general tendencies.

3.1 Constant distance scenarios

In the first scenario we compare different transport profiles based on a constant number of passenger kilometers traveled. Although these scenarios may not always be realistic, a controlled comparison is possible by taking travel distance as given and comparing the different mixes of transport services. Using the Norwegian Travel Survey (NTS), the household travel distance estimated as 27,769pkm. For the average Norwegian this would involve a mix of most modes of transportation, including bicycle and walking. For the scenarios presented here, it is assumed that this distance is traveled all by car, car and bus, all bus, or by bus and car sharing; see Table 2.

The results in Table 2 show that the lowest transport GWP is for bus, car sharing, bus and car, then the car only. Due to decreased expenditure in shared transportation modes the rebound emissions are higher; although this does not change the overall ranking

of the different transport users. For car sharers we also have a win-win situation; even the intensive car sharers pay less than car owners for their transport services and their rebound emissions do not offset their environmental advantage over car owners. The fact that car-sharers do not drive as much as car owners accounts for most of this environmental advantage.

3.2 Variable distance scenarios

Whilst the previous constant distance scenario is informative, it is perhaps not overly realistic. Different transport users may behave differently; for instance, some transport users may ride or walk. A more realistic comparison of different transport profiles would reflect the fact that quantities of transport consumption change according to the mix of transport modes used. In particular, travel distances change considerably when comparing private car owners to car sharers or bus users. In fact, one of the main environmental attributes of car-sharing schemes is the decreased frequency of car use induced by the system.

The next scenario shows different quantities of transport consumed by the modeled household profiles; see Table 3. It is assumed that the car user still uses the car for all transport requirements. Car users are assumed to travel a greater distance in a given year and also have the highest environmental impacts. Despite the decreased use of bus services, all the scenarios involving bus transport have the same costs as the previous scenario. This is since the cost of bus use was based on the purchase of monthly bus passes; which is independent of travel distance. So overall, the bus users have lower transportation GWP, but the same rebound GWP. In this scenario the car share light user has the lowest transport emissions reflecting the lower overall distance; that is, it is assumed that they use a higher proportion of non-motorized transport services. Otherwise, the ranking of different users changes little from the previous constant distance scenario.

3.3 Variable distance with air travel

In this scenario the data from the previous section is taken, but it is assumed that the household spends surplus money allocated for transport on air travel, Table 4. In the previous scenarios this money was evenly distributed across non-transport expenditure. An average cost per kilometer was estimated for air travel and so the travel distance is proportional to the money spent on travel; continental and European trips are weighted together, Table 1.

The results in Table 4 show a considerable change; the results from the previous section are reversed. The transport users with the lowest costs associated with bus and car transport now have the highest emissions due to the use of air travel. For the bus only user, the amount of air travel represents a round-the-world trip, while of the car user the air travel represents a trip from northern to southern Europe. These numbers indicate that spending extra income on air travel leads to significant environmental impacts that likely overcome reduced emissions. The results illustrate potential rebound effects that may occur within the transport sector itself. Depending on how the rebound expenditure is spent, it may lead to very different environmental impacts.

	Car only	Bus & Car	Bus & Coach	Car share -light	Car share -intensive
Car - distance (vkm)	19,206	10,755	0	0	0
- cost (NOK)	46,740	37,212	0	0	0
Bus - distance (pkm)	0	10,492	15,787	11,276	13,297
- cost (NOK)	0	11,720	11,720	11,720	11,720
Coach - distance (pkm)	0	0	5,216	0	0
- cost (NOK)	0	0	3,406	0	0
Car share - distance (vkm)	0	0	0	2,268	6,371
- cost (NOK)	0	0	0	7,057	19,824
Total travel distance (pkm)	27,769	26,041	21,003	16,493	24,445
Total travel cost (NOK)	46,740	48,931	15,126	18,777	31,543
Non-transport GWP	7,934	7,934	7,934	7,934	7,934
Transport GWP	5,589	4,315	1,971	1,934	3,356
Rebound GWP	465	392	1,516	1,395	970
Total GWP	13,988	12,641	11,421	11,263	12,261

Table 3: The variable travel distance scenario. GWP in kg CO₂-e.

	Car only	Bus & Car	Bus & Coach	Car share -light	Car share -intensive
Car - distance (vkm)	19,206	10,755	0	0	0
- cost (NOK)	46,740	37,212	0	0	0
Bus - distance (pkm)	0	10,492	15,787	11,276	13,297
- cost (NOK)	0	11,720	11,720	11,720	11,720
Coach - distance (pkm)	0	0	5,216	0	0
- cost (NOK)	0	0	3,406	0	0
Car share - distance (vkm)	0	0	0	2,268	6,371
- cost (NOK)	0	0	0	7,057	19,824
Air - distance (pkm)	28,980	24,434	94,549	86,976	60,498
- cost (NOK)	13,972	11,781	45,586	41,935	29,169
Total travel distance (pkm)	56,748	50,475	115,552	103,469	108,127
Total travel cost (NOK)	60,712	60,712	60,712	60,712	60,712
Non-transport GWP	7,934	7,934	7,934	7,934	7,934
Transport GWP	14,370	11,719	30,619	28,288	24,307
Rebound GWP	0	0	0	0	0
Total GWP	22,304	19,653	38,553	36,222	32,241

Table 4: The variable travel distance with air travel scenario. GWP in kg CO₂-e. Note that the air travel distances are in units of person kilometers (pkm) and therefore 94,549pkm represents 41,108km with a ticket cost of 19,820NOK for household with 2.3 occupants.

	Cost (NOK)	Time (hours)	GWP kg CO ₂ -e
Car	963	8	146
Car share	1200	8	146
Bus	199	8.5	28
Train	299	6.5	6
Plane	605	3.5	180

Table 5: The cost, time, and GWP for a 500km trip between Oslo and Trondheim, Norway.

3.4 Travel between Oslo and Trondheim

This scenario considers the cost, time, and environmental impacts for a trip between Oslo and Trondheim; a distance of 500km. It represents a trip planned approximately one month in advance to capture the offers for booking early. The results are shown in Table 5. The car costs include a distribution of fixed costs, and not the marginal costs of using a car. The price and time for the plane includes getting to and from the airport.

For the Oslo to Trondheim case car travel is poor in terms of cost, time, and GWP; although there are perhaps other perceived benefits such as convenience. The bus and train both have low emissions, but take a long time. The plane is mid priced, fast, but has high emissions. Although, often occurs that the train and the plane have very similar prices for the case of Norway. The results indicate potential areas of monetary rebound, particularly if this type of trip occurs regularly. They also show a potential for a time rebound; particularly for the plane. This extra time may be used to travel a greater distance, and ultimately have higher environmental impacts.

4 Discussion and conclusion

Although this study was mostly illustrative, it showed that LCA and IOA in combination with consumer expenditure information have great potential to evaluate sustainable consumption programs at a broad level. With more extensive and detailed data, the tools used in this study could give more precise descriptions of the consumption dynamics expected with the introduction of a program like car-sharing. For instance, data correlating total household consumption and budgets with transport use would give more realistic scenarios and accurate calculations for each profile. Also more information on actual transport patterns would enrich the study. The scenarios used kilometers traveled, transport mixes, and expenditure patterns from averages and estimates. Actual differentiated data would have made the study more accurate.

The few simulated scenarios illustrate the general performance of different transport modes and the dynamics involved in relation to cost structures, emissions, and distances traveled. There are many more scenarios that can be simulated changing parameters and assumptions and with better data, more realistic models can be made. Nevertheless, the exercises in this case study highlighted some of the main aspects of consumer behavior that need to be considered in environmental assessments and sustainable consumption programs.

The results show considerable sensitivity to how the rebound expenditure is spent.

If money saved is used for increasingly affordable air travel then the emissions resulting from air travel become dominant. Perhaps an extreme conclusion is that the household occupants should only travel by foot or bicycle; however, justifying not owning a car by having annual intercontinental air travel leads to worse overall environmental impacts.

The household, as a decision-making agent in consumption decisions, is a crucial point of analysis. Budget allocation, use patterns, and preferences and concerns are important behavioral aspects evaluated at the household level. As shown in this study, transport decisions are of particular concern since they have a significant impact in the household's total global warming emissions. Looking at household consumption as a whole gives a more genuine picture of the actual environmental improvements achieved.

Car-sharing schemes promote more sustainable transport patterns through the economic incentives generated by their cost structures. The scenarios in this study accounted for the higher costs incurred by car owners, most of which was fixed in the purchase of the vehicle. Car-sharers, on the other hand, did not own a vehicle and incurred higher marginal costs for the collective ownership of the car, motivating less driving and greater use of other transport modes. Car sharers had high rebound emissions and if the rebound expenditure was spent on air travel, car-sharers had overall higher emissions than car owners. This clearly demonstrates that apparent moves towards more sustainable consumption patterns can have an overall worse environmental impact.

The observations that can be made with the analysis used in this paper can help to inform and improve efforts to implement sustainable consumption programs. As long as incomes continue to rise and more consumer products become available, sustainable consumption programs should remain cautious of the inevitable income rebound effect. With sectors such as transport, sustainable behavior needs to be promoted through overarching consumption systems that not only focus on car use but also on the whole transport mix of a household and the factors shaping their total consumption decisions.

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