Urban mobility and degrowth strategies: A note on the role of shared transportation modes

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Abstract

This paper investigates the mechanisms through which shared modes lead to degrowth strategies and help reduce major spatial and environmental issues related to mobility in urban areas, namely road congestion, rivalry of use for parking spaces and air pollution, as well as the number of goods in the economy. In this article, I use gross space consumption estimations for different transportation modes as a basis and integrate the service provided by the modes. Results indicate that in terms of time-space consumption and service provided shared modes are intermediate modes between private modes and mass transit. Therefore, shared modes constitute key components of a sustainable, comprehensive and efficient transportation system in urban areas. The present analysis provides guidance for local transportation authorities.

Keywords: mobility, shared modes, spatial issues, time-space consumption
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1 Introduction

Degrowth strategies, even often not called so, can be associated with strategies tackling both spatial and environmental issues related to mobility in urban areas, where these issues are indeed exarcerbated. Road congestion, rivalry of use for parking spaces and air pollution are major issues regularly at the heart of local transportation policies. They have been dealt with through various approaches. Mass transit have recently been fostered as a solution against road congestion and rivalry of use. These spatial issues relate to the space consumed by transportation modes. Private cars are assumed to consume larger quantities of space than mass transit, while offering similar services, namely origin-to-destination trips. Similarly, cars are the most polluting mode and transportation policies fostering bicycles have thrived in order to reduce air pollution, in particular CO_2, and NO_X emissions and PM.

However, private cars remain the leading transportation mode for commuting trips (except in some large cities, such as Paris where mass transit is the leading mode). In this article, I focus on shared modes, namely vehicle-sharing and self-service vehicles. The contribution is twofold. First, I explore the mechanisms through which shared modes lead to degrowth and help reduce road congestion and rivalry of use for parking spaces, as well as air pollution, compared to private modes. Second, I highlight the fact that transportation modes do not provide similar services to users. Therefore, gross comparisons in terms of time-space consumptions between modes (Marchand, 1993) are oversimplifying. I suggest to put these gross estimations into perspective accounting for additional services provided by transportation modes. Refined measures of time-space consumptions are presented. When the service provided is accounted for, the gap between mass transit and private cars is reduced. More importantly, the results show that car-sharing and self-service cars constitute relevant alternatives to private cars in terms of time-space consumption per unit of service provided. Shared modes thus constitute a credible alternative for urban mobility in a degrowth strategy.

The analysis provides guidelines for decision-makers since it clearly indicates orders of magnitude for time-space consumptions from various transportation modes. Furthermore, I mention the limits of the present organization for shared modes. More precisely, the need for institutionalizing is highlighted for car-sharing, and network expansion required for self-service vehicles. The study reveals that both types of shared modes lead to degrowth and help reduce spatial and environmental issues related to mobility in urban areas and as such constitute key components of a sustainable, comprehensive and efficient transportation system.

The article is organized as follows. Section 2 briefly presents the major spatial and environmental issues related to transportation in urban areas, namely road congestion, rivalry of use for parking spaces and air pollution. Section 3 investigates the mechanisms through which shared modes help reduce the aforementioned issues and lead to degrowth. Then, the concept of time-space consumption from transportation modes is explored and gross estimations of time-space consumption are refined accounting for the service provided. Section 4 provides guidance for transportation policy-makers. Section 5 concludes.

2 Major spatial and environmental issues related to mobility

Both spatial and environmental issues are associated with mobility, namely road congestion and rivalry of use for parking spaces, as well as air pollution. The present section explains each of these issues and the measures generally implemented to address them. However, these issues are strongly correlated with each others and require a comprehensive approach of the transportation system.

Road congestion occurs when demand for mobility (e.g., the number of vehicles in traffic) is higher than supply (e.g., road capacity). Congestion issues relate to the demand in road space. It can be caused or made worse by traffic incidents or road work. Yet, in city centers, congestion is often recurring, especially during peak hours, due to the increasing number of vehicles on roads. The cost of road congestion is estimated up to 2% of GDP in Europe (European Commission, 1995). Moreover, road congestion exacerbates air pollution by extending the engine running time. More cars on roads also induces higher needs for parking spaces and worsens rivalry of use. Road congestion is a major issue addressed by local authorities. First measures have aimed to expand road space, such as widening existing roads or building new road infrastructures. However, increased traffic flow leads to induced demand that generates road congestion. Second, local authorities have fostered modal shift to mass transit, bicycles or walking, in particular through increased supply. Finally, measures combine various strategies from low-carbon transportation incentives to restricting demand for private cars (road pricing, parking restrictions), and include city planning and urban design.

In densely built-up urban areas, road users compete to park their cars. Conflicts are especially intense for on-street parking, considered as more convenient than off-street parking. Land devoted to transportation in general, and public parking spaces in particular, can be considered as common resources available to road users on free access. Common resources as well as free access resources are prone to conflicts in their allocation. Parking spaces are non excludable but rivalrous: any agent can park her car on public roads, but this prevents another agent to park her car at the same place. Rivalry of use for parking spaces increases road traffic, therefore contributing to road congestion. Moreover, increased road traffic results in increased air pollution. Rivalry of use for parking spaces has been exacerbated by parking restrictions aimed at reducing demand in road transportation. Parking fees are generally applied in city centers and the number of spaces decreases in favor of parks, dedicated lanes for buses and/or bicycles, and self-service vehicles. Parking issues are also related to the demand in road space, which does not match the supply.

Another major issue related to transportation in urban areas is air pollution. Transportation, and in particular road traffic, generates various air pollutants. Air pollution is exacerbated by both road congestion and rivalry of use for parking spaces, which results in longer engine running times. Moreover, very low speeds of vehicles trapped in road congestion result in higher levels of emissions. Vehicle exhausts release large quantities of CO_2, a greenhouse gas which is a leading contributor to climate change. In OECD countries, transportation accounts for 27.5% of total CO_2 emissions, with road transport accounting for the larger share of emissions (89%) (IEA, 2011). Local air pollutants such as carbon monoxide (CO), nitrogen oxide (NO_X) and particulates (PM_{10}, $PM_{2.5}$ and $PM_{1.0}$) also arise from transportation. They have significant effects on the environment (acide rain, contribution to ozone pollution and to climate change) and the health (asthma, lung cancer, heart diseases and strokes). In France, 19% of CO emissions can be attributed to the transportation sector (CITEPA, 2013). NO_X emissions result mainly from transportation due to the exhaust of diesel vehicles. In France, 61% of NO_X emissions are released by transportation[1], among which 93% from road transportation (CITEPA, 2013). Moreover, the transportation sector releases around 15 to 20% of the total particulates in France (CITEPA, 2013), mainly from vehicle exhausts and the wear of roads, tires and brakes. Local authorities regularly warn against pollution peaks in large cities and against their effects on health. Measures to reduce air pollution have long been technical responses (catalytic converters, reduced CO_2 emissions), and are now increasingly directed to road demand management. Transportation policies mainly aim to foster low-carbon or no-carbon modes (mass transit, bicycles, walking). Shared modes, such as car-sharing and self-service cars or bicycles, are often overlooked, though they offer a credible alternative to private vehicles.

Spatial issues overlap each others and they also overlap environmental issues. The different transportation modes form a complex system. Crucial interactions occur between commuters. Every commuter impacts the accessibility of a territory through congestion effects and rivalry of use for parking spaces. Therefore, accessibility must be addressed taking into account each user and the transportation system as a whole. An efficient transportation system requires to consider collective needs, not only individual ones. On one hand, private vehicles may best respond to individual needs (comfort, flexibility, availability), but may overlook collective needs such as the global accessibility of a territory. Due to their relatively high space consumption and given the limited road space available in urban areas, private vehicles may generate road congestion and rivalry of use for parking spaces. On the other hand, mass transit may best respond to collective needs related to accessibility, but may leave out of consideration individual needs. While mass transit helps reduce road congestion and rivalry of use for parking spaces, it usually provides much less services than private vehicles and may not meet all individual needs. As such, they have a significant role to play within an efficient transportation system. Shared vehicles constitute an intermediate transportation mode, both in terms of reduction in spatial issues and services provided.

3 The key role of shared transportation modes

Goods in general and vehicles in particular require space, in a strictly physical sense. Space scarcity may be felt in densely built-up city centers. Shared use of goods is realistic and attractive when goods are barely used by a single agent and when they are bulky. In urban areas, private passenger vehicles are generally sub-optimally used for mobility[2] and could then be pooled. Two different systems of shared vehicles can be distinguished.

[1] In France, more than half of the fleet (61.3%) is made up of diesel vehicles in 2013 (CCFA, 2012).

[2] Household travel surveys carried out in France (CERTU, 2004) reveal that cars are parked on average 96% of the time, i.e., unused for mobility.

First, vehicle-sharing systems, such as car-sharing, generally refer to a single vehicle shared simultaneously by several users. Second, self-service systems, such as self-service cars and self-service bicycles in urban areas, refer to a fleet of vehicles used sequentially by different users.

What is highly interesting with shared vehicles is the potential for reduced congestion and rivalry of use for parking spaces. Shared use in general allows for a reduction in the total number of vehicles in the economy, and thus on a particular geographical area, for instance a city. Reducing in absolute terms the number of goods needed, used and manufactured conveys a clear-cut degrowth strategy. More precisely, car-sharing mostly helps reduce traffic congestion through higher vehicle occupancy rates. Fewer vehicles are needed to move the same number of users. Moreover, fewer vehicles would then be parked, reducing rivalry of use for parking spaces. Rens Meijkamp (2000) reports a 44% reduction in the number of cars used by car-sharing members. On the other hand, self-service schemes lead to higher use rates and therefore primarily help reduce rivalry of use for parking spaces. Due to their higher use rate, pooled vehicles are parked on-street for a shorter time. Cabanne (2009) estimates that a self-service bicycle in Lyon, France, performs on average five trips a day. Therefore, shared bicycles show far higher use rates than private bicycles. However, their occupancy rate is similar or even lower than that of private vehicles, which has consequently no impact on road congestion.

Both types of shared modes allow to reduce the per-person space consumption required for a trip by the transportation mode. Vehicle-sharing systems mostly help reduce space consumption for traffic and therefore road congestion, while self-service schemes predominantly help reduce space consumption for parking and therefore rivalry of use for parking spaces. Yet, road congestion and conflicts for parking spaces are strongly correlated with each others. The more cars on road, the more cars would need a parking space at the end of their trip. Similarly, the more cars trying to park, the more congestion on roads. Therefore, addressing spatial issues related to mobility requires both vehicle sharing structures.

From an environmental perspective, pooling is especially interesting when products have high material or energy content. Reduced environmental impacts arise primarily from a decrease in the number of units manufactured. This is made possible not only by maintenance and re-use, but also mainly by shared use. Both higher use rates and recycling slow down resource flows in the economy (Scott, 2009), as well as emissions generated by raw material extraction and manufacturing. Moreover, as explained above, shared vehicles help reduce spatial issues which in turn contributes to curtail vehicle polluting emissions. In addition, vehicles offered in self-service schemes are generally less polluting than private vehicles. Self-service cars are most often electric cars which do not release CO_2 or NO_X and which cut down PM emissions.

Road congestion and rivalry of use are issues related to the space required by transportation modes. The above section evidences that shared modes reduce the per person space consumption required for a trip. The next section gives measures of the space required per trip per person for various transportation modes. Gross time-space consumptions are indicated, before I account for the service provided by the different transportation modes to refine time-space consumption estimates.

3.1 Gross time-space consumption estimations

Generally, a trip generates two types of space consumption: a consumption associated with the movement of individuals or vehicles (traffic), and a consumption related to the parking of vehicles. Let's call the former a dynamic consumption and the latter a static consumption (after Marchand, 1977). The two types of space consumption can be aggregated when expressed in a common unit, namely 'time-space consumption' (m^2.h) which combines surfaces (m^2) and duration of the consumption (h) (Marchand, 1993).

On the one hand, there is a consensus on the calculation method used to assess static space consumption. Both the vehicle's dimensions and the type of parking infrastructure (off-street or on-street parking) are considered. On the other hand, several methods have been used to measure dynamic space consumption (CERTU, 2007). Road capacity measures give estimates of the necessary road width required for a given flow of vehicles, according to transportation modes. This oversimplified measure of space consumption ignores the speed of vehicles and the duration of road occupancy. The speed of vehicles impacts the flow of transportation infrastructures, the distance between vehicles[3], the road occupancy time and the width of rights-of-ways[4]. The underlying idea is that higher speeds enable to cover a given distance in a shorter period of time, therefore consuming less time-space than slower vehicles. Time-space consumption depends therefore highly on the speed of vehicles. Moreover, higher speeds increase the road capacity. However, as the distance between vehicles increases more than proportionately with the speed, dynamic space consumption rises with the speed. In addition, higher speeds require larger right-of-ways, in particular for unguided modes such as cars. According to the capacity-speed curves by Cohen (2006), a speed of around 60 to 90 kmph allows for maximal road capacity. The length of vehicles is also accounted for in dynamic space consumption, despite its negligible impact.

The method developed by Marchand (1993) entails both static (parking) and dynamic (traffic) space consumptions, and accounts for the speed of vehicles. Both time-space consumptions are expressed in m^2.h and given by, respectively (Marchand, 1993):

$$TSC_i^{parking} = \frac{1}{n_i}\left(S_i * h_i\right)$$

and

$$TSC_i^{traffic} = \frac{1}{n_i}\left(l_i * d_i\left(V_i\right) * \frac{L}{V_i}\right)$$

or

$$TSC_i^{traffic} = \frac{1}{n_i}\left(\frac{l_i * L}{Q_i\left(V_i\right)}\right) * 1000$$

with TSC_i the time-space consumption of transportation mode i, n_i the occupancy rate of transportation mode i, S_i the surface in square meters required to park transportation mode i, h_i the length of stay (parking) in hours for the transportation mode

[3]Distance between vehicles corresponds to the stopping distance, i.e., both the reaction distance and the braking distance.

[4]Right-of-ways are lateral safety distances on both sides of vehicles and roads, sometimes combined with median strips or emergency lanes.

i, l_i the road width where transportation mode i moves, d_i the distance between vehicles of transportation mode i which depends on their speed V_i and can be summarized by $Q_i(V_i)$ the road capacity where transportation mode i moves, L the length of the trip in kilometers, and 1000 to obtain m^2 instead of km^2.

Marchand (1993) gives estimates of time-space consumptions for several transportation modes (car, two-wheeler, bus, subway and walking) and several trip purposes (work, shopping and leisure). Parking length varies strongly according to trip purposes, from 9 hours for work trips to 1.5 hours for shopping trips. Table 3 in appendix summarizes the results from Marchand. For a 10 kilometer return commuting trip, time-space consumptions per person range from 90 m^2.h for cars to 1 m^2.h for subway and include 2 m^2.h for walking, 21 m^2.h for two-wheelers and 3 to 12 m^2.h for buses. These estimations reveal that car commuters consume up to 90 times more time-space than subway commuters. Results are strinking and claim for increasing use of mass transit to reduce congestion issues in cities.

Nevertheless, these results can be considered as gross estimations. First, the underlying assumptions are strong and sometimes unclear (see Table 4 and Table 5 in Appendix). Second, transportation modes are compared without accounting for their generalized costs and the utility they provide to users. Transportation modes cannot be compared so simply since they do not provide similar services to commuters and have different generalized cost. Commuters make the final decision about transportation modes, and for this reason the determinants of mode choice should be explored. The service provided by the transportation mode, as well as its generalized cost, are leading determinants of mode choice. In the next section, I refine time-space consumptions accounting for the service provided by the mode and including other transportation modes, namely shared modes.

3.2 Accounting for the service provided

Gross estimations from Marchand (1993) rely on the oversimplified assumption that the only service provided by transportation modes is the origin-to-destination trip. In this paper, I assume that transportation modes do not provide similar services to commuters and neither have similar generalized costs. Accounting only for gross time-space consumption of transportation modes allows to meet collective needs, while ignoring individual needs. For this reason, time-space saving modes may remain empty despite regular incentives from local authorities. Users choose the cheapest transportation mode from which they derive a given level of utility (Hicksian utility function). Therefore, their choice depends on the services provided by the mode and on its generalized cost. The optimization program of a representative user according to transportation mode j can be written as follows:

$$\min_{t_j,x} R(t,x) = p_t t_j + p_x x \tag{1}$$

$$s.t. \left\{ \; U_j \geq U_0 \right.$$

with

$$U_j \geq \alpha \ln \left(T + \sum_{i=1}^{n} t_j \right) + \ln x$$

and

$$p_t t_j = GC\left(j\right) = v^h.h_j + v_j$$

Let's R be the revenue the user wants to minimize. With this revenue, she buys two goods: transportation with mode j, t_j, at price p_t, and a composite good x at price p_x. The representative user wants to reach a level of utility, noted U_j, equal to or greater than U_0. The utility function is the sum of the utility derived from transportation and from composite good. The user has a preference α for transportation compared to composite good. Transportation with mode j provides the core service T or origin-to-destination trip, and additional services $t_1, ..., t_n$ provided by the mode j. The cost of transportation mode j can be approached by its generalized cost, $GC(j)$, which is a combination of the time value and monetary value entailed by the mode. The time value is the length of the trip in hours, h_j, multiplied by the hourly average value, v^h. The monetary cost, noted v_j, is usually made up of the fuel cost for cars, the cost of tickets for mass transit, etc. Measures of generalized cost may also encompass measures of comfort.

The aim is not only to find which transportation mode is the more likely to reduce spatial issues theoretically, but also to assess which modes would be practically operated by users. To give an illustration of the impact of the service provided and generalized cost on the final choice of users, let us take a simple but concrete example that considers the service provided by transportation modes only - not the generalized cost.

The utility derived by commuters results from several services, including the origin-to-destination trip but also services such as carrying heavy loads, driving people with reduced mobility (children, the elderly or those without a driving licence), avoiding road congestion, making physical efforts or not, providing symbolic functions, offering private space for discussion, covering more than 5 kilometers, being available immediately, etc. Other services could be added to the list. I attribute weights to these services and aggregate them to the core service, namely the origin-to-destination trip. Let us arbitrarily set 1 for the core service and 0.2 for each additional service provided by a given transportation mode[5]. Note that physical efforts can be viewed either as a positive or as a negative attribute. In the latter case, the weight -0.2 is applied. A list of services and weights is provided in Table 1. The weights for each service associated with a given transportation mode are then aggregated and the time-space consumption of the mode is weighted by this value. This allows us to get time-space consumptions per person and *per unit of service provided*. Therefore, previous gross estimations are put into perspective. Furthermore, I add transportation modes not previously considered by Marchand, in particular private bicycles and shared modes (car-sharing, self-service schemes for cars and bicycles, taxi).

Table 2 summarizes the various transportation modes and the aggregated weights derived from the services they provide. Time-space consumption per unit of service provided extends and refines the work from Marchand (1993).

[5]Different weights could be set according to the importance of the service considered. However, we prefer to limit the arbitrary nature of the weight setting and set similar weights for all services.

Table 1: Services provided by transportation modes

Service provided	Weight
Origin-to-destination trip	1
Carrying heavy loads	0.2
Driving people	0.2
Avoiding road congestion	0.2
Physical efforts (positive)	0.2
Physical efforts (negative)	-0.2
Symbolic functions	0.2
Private space for discussion	0.2
Covering distances > 5 km	0.2
Immediate availability	0.2

Table 2: Time-space consumption (TSC) per person for a 10 km return commuting trip

Transportation modes		Use rate	W	TSC			WTSC
				Dyn.	Stat.	Total	Total
Private modes	Cars	1.1	2.2	20.5	81.8	102.3	46.5
	Motorized two-wheelers	1	1.6	7.5	13.5	21	13.1
	Bicycles	1	1.2	3.8	6.8	10.6	8.8
			1.6	3.8	6.8	10.6	6.6
Shared modes	Car-sharing	2.5	1.2	9	36	45	37.5
	Self-service cars	1 (5/day)	2	22.5	16.4	38.9	19.5
	Taxis	1.1 (5/day)	1.8	20.5	14.9	35.4	19.7
	Self service bicycles	1 (5/day)	1.2	3.8	1.4	5.2	4.3
			1.6	3.8	1.4	5.2	3.3
Mass transit	Bus with dedicated lanes	1,500/h/day	1.4	12	0	12	8.6
	Bus without dedicated lanes	1,500/h/day	1.2	3	0	3	2.5
	Subway	10,000/h/day	1.4	3	0	3	2.1
Other	Walking	1	1.2	2	0	2	1.7
			1.6	2	0	2	1.3

Note: W: Aggregated Weight; WTSC: Weighted Time-Space Consumption; Dyn.: Dynamic; Stat.: Static

Private cars are defined as cars owned and used by a private user. Car occupancy rate for commuting trips is about 1.1[6]. Therefore, both static and dynamic space consumptions are first weighted by the occupancy rate, and then by the aggregated weights associated with this transportation mode. Private cars rank highest in terms of service provided. In addition to the origin-to-destination trip, private cars can be used to carry heavy loads, to drive people and to cover long distances, they provide symbolic functions (mainly social status through the type of vehicle, and self-expression through customization) and private space for discussion. Moreover, private cars are available immediately, since they are owned by a single agent and generally parked close to residences.

Two different systems of shared cars can be distinguished: car-sharing and self-service cars. Car-sharing occupancy rate is logically much higher than that of private cars. In a high-hypothesis case, let us assume that shared cars move on average 2.5 people. Therefore, both static and dynamic space consumptions are weighted by 2.5 and thus reduced compared to private cars. In addition to the origin-to-destination trip, car-sharing allows to cover distances greater than 5 kilometers. Self-service cars allow not only to cover long distances, but also to carry heavy loads, to drive people, and they provide private space for discussion and possibly symbolic functions. Their occupancy rate is assumed to be lower than that of private cars: 1 people per trip. However, while cars shared simultaneously stay parked between outward and return trips, cars shared sequentially can perform up to 5 trips a day (high-hypothesis case). Therefore, while dynamic space consumption of self-service cars is divided by 1, their static space consumption is divided by 5.

Taxis provide functions similar to those offered by self-service cars. The difference is that they do not provide private space for discussion, but they allow to avoid road congestion through dedicated lanes. Commuting trips generally occur during peak hours and avoiding congestion leads to precious time saving. Taxi occupancy rate is assumed to be similar to that of private vehicles when the driver is not accounted for.

Private motorized two-wheelers allow to cover distances greater than 5 kilometers, and are immediately available to the user. Moreover, they may help avoid congestion in urban areas. Symbolic functions are usually not associated with motorized two-wheelers. Their occupancy rate is estimated to 1.

Private bicycles allow to avoid congestion through dedicated lanes and are available immediately. Symbolic functions are usually not associated with private bicycles. Furthermore, they require physical efforts to move from origin to destination, which can be viewed either as a positive (health benefits) or a negative (tiredness, perspiration, weather-sensitivity, need for suitable clothes) feature. Bicycle occupancy rate is 1.

Shared bicycles are usually part of a self-service scheme. They have the same characteristics as private bicycles, except the fact that they are not immediately available to the user. In addition, they may provide symbolic functions, in particular expressing environmental awareness of users. Their occupancy rate is 1, but they can perform up to 5 trips a day.

[6]Occupancy rates for all transportation modes are given for France.

Buses are of 2 types: buses on non-exclusive lanes and buses on exclusive lanes (30 vehicles per hour). They all allow covering more than 5 kilometers. In addition, dedicated lanes help avoid congestion. Bus occupancy rate amounts to 50 (high-hypothesis case rather suitable to large urban areas). Moreover, it is assumed that mass transit vehicles are constantly moving, especially during peak hours. When they park, they park outside city centers, where rivalry of use does not occur. Static time-space consumption for buses is therefore zero.

A subway has characteristics similar to buses, except its occupancy rate which is estimated to be much higher: 10,000 commuters per hour (hypothesis for large cities).

Walking allows to avoid congestion during peak hours, and is immediately available. Walking requires physical efforts, considered either positively or negatively.

Although the estimations from Marchand are subject to many criticisms, I use them as a basis to introduce the notion of service provided by transportation modes. Figures should be treated cautiously; the order of magnitude is far more informative in this analysis.

The underlying idea is that mass transit occupies far less time-space than private vehicles and notably than cars. Gross estimations reveal that private cars used for commuting trips require up to 90 times more space than the subway. However, I emphasize that mass transit provides far less services to users than private cars. For instance, the weight associated with the service provided by the subway is 1.4, against 2.2 for private cars. Weighted time-space consumptions remain in favor of mass transit, but the relation decreases from 1 to 90 to 1 to 22 when assumptions are modified and the service provided by the mode accounted for. This order of magnitude shows that the additional time-space consumption of private cars is not fully offset by the additional services they provide. Therefore, they remain time-space consuming modes.

Due to their intermediate position between mass transit and private modes, one may expect better results from shared modes. Indeed, self-service cars provide almost as many services as private cars, while they strongly reduce per person time-space consumption. However, effects from car-sharing are not so significant. Time-space consumption from self-service cars is divided by more than 2 compared with private cars, while that of car-sharing is divided only by 1.2. This is due to the fact that cars require high static time-space consumption for parking which can be reduced only when increasing the use rate of vehicles.

Let us also note that private bicycles perform worse than most mass transit, even when bicycles provide more services. Shared bicycles allow to reduce the time-space consumed, but still perform worse than most mass transit. Only buses with dedicated lanes have an advantage over bicycles, either shared or private (when physical effort is viewed negatively). Furthermore, it is worth noting that private bicycles perform better than self-service cars. Shared cars' use rate should increase exponentially so that self-service cars rank higher than bicycles - which is practically impossible. The first results allow us to make policy recommendations to help local transportation authorities address spatial and environmental issues.

4 Policy implications

Degrowth strategies and spatial issues related to transportation can be approached by the time-space consumption required by transportation modes. In this sense, policy makers should favor transportation modes that are less time-space consuming and that imply fewer goods in the economy. Mass transit has long been considered as the only solution to road congestion, rivalry of use for parking spaces and to slowdown the increasing number of cars on the road (and manufactured). Gross estimations reveal the very low time-space consumption of mass transit compared to other modes. Moreover, mass transit is generally far less expensive than private cars. Hence, one can wonder why private cars remain dominating, even for commuting trips. In this article, I show that other needs and functions are overlooked. For instance, mass transit does not allow to carry heavy load, to drive a relative, to enjoy private space for discussion or to be available immediately. The need for these additional functions may explain the mitigated success of mass transit.

For this reason, shared vehicles constitute a credible alternative to private vehicles. They provide additional functions to mass transit and allow to save time-space compared to private vehicles. Moreover, they imply a reduction in absolute terms of the number of vehicles in the economy, without impairing urban mobility. Car-sharing and self-service cars are relatively new transportation infrastructures and they have many caveats. First, the institutional framework governing car-sharing remains confused. Car-sharing is most often based on private initiatives from neighbors or offered to non-neighbors for occasional trips, mainly inter-urban trips. It entails costly coordination costs that may discourage users to join car-sharing groups. Coordination platforms are set up on the Internet to bring car drivers and car passengers together. Lack of institutionalization contributes to confine car-sharing to sporadic uses. Car-sharing should be better regulated, with the help of a legal framework giving guarantees to both drivers and passengers. Coordination platforms should be encouraged to be comprehensive and flexible. Second, self-service cars have been introduced in some large cities. They remain however too sparse to constitute flexible alternatives to users. Moreover, the outskirts and many places in the countryside have potential to host self-service car stations. The network should be enlarged and incentives given to private car users to quit their cars and use shared cars. Third, using shared modes would discourage some users to buy private cars if their needs can be fully met with shared cars. Hence, complementary offers should be developed, such as family car rentals for several days or weeks at attractive prices. The car rental market is generally disconnected from the transportation providers within a city. In addition, the relatively high prices discourage from regular uses, since then buying a car remains cost saving. Therefore, regular car rental for long period is currently not competitive with private cars. Incentives to integrate car rental with other transportation services should be done to build a sustainable, comprehensive and efficient transportation system in which shared modes are a key component.

Transportation policies fostering the use of taxis is uncommon but should be reconsidered in light of the time-space consumed per service provided. Taxis are shared modes rather similar to self-service cars, in terms of service provided and time-space consumed. However in countries with high labor costs, the monetary cost of taxis remains higher than that of other shared modes, due to the need of a driver.

Furthermore, the size of the city and its transportation infrastructure are major elements to account for when discussing the local transportation policy. Results from Table 2 indicate that subway commuters need less time-space than either private of self-service bicycles. Nevertheless, subways and similar light-rail mass transit are implemented in large cities only. Medium-sized cities would rather have buses with dedicated lanes. In this case, results show that private bicycles (when physical effort is viewed positively) and to a larger extent shared bicycles perform better than mass transit in terms of time-space consumption. This is especially true because buses occupancy rate will fall in medium-sized cities, leading buses to perform worse than in larger cities. Consequently, shared bicycles seem to represent a rational compromise to address spatial issues in medium-sized cities.

Environmental issues related to transportation can also be approached by time-space consumption. Traditionally, policy makers encourage low-carbon modes such as mass transit, as well as active modes (walking and cycling) in order to reduce air pollution resulting from transportation. Mass transit releases far less air pollutants than private cars (for instance, rail transport releases 0.0026 kg of CO_2 equivalent per kilometer against 0.07 for a private gasoline vehicle (ADEME, 2006)). Walking and cycling do not release any air pollutant during their use phase. Nevertheless, mass transit has been criticized for its lack of flexibility and limited functions provided to users. Walking and cycling require physical efforts which can be considered negatively by users. In addition, mass transit vehicles and bicycles necessitate materials during the manufacturing phase. Producing vehicles contribute to pollution and resource depletion. On the contrary, shared modes help reduce the number of vehicles in the economy and therefore the number of vehicles manufactured. This is particularly interesting for bicycles whose environmental impact can be fully attributed to the manufacturing phase. In addition, time-space saving transportation modes such as mass transit, shared modes and walking are also low polluting modes. For these reason, shared bicycles should be favored by local transportation authorities rather than private bicycles, especially as the service they provide is similar.

5 Concluding remarks

Shared modes such as taxis, car-sharing and self-service cars or bicycles are often overlooked in transportation policies. The analyses conducted in this article helps service providers or local authorities consider the impact of shared modes on time-space consumption and related spatial issues, especially in the context of a degrowth strategy. The analysis clearly indicates that shared cars help reduce road congestion, rivalry of use and air pollution, as well as the number of vehicles, compared to private cars, while providing additional functions to users compared to mass transit. Indeed, shared modes are intermediate modes between time-space consuming modes such as private cars and time-saving modes such as mass transit. Moreover, shared low-carbon modes, such as self-service bicycles, have the potential to reduce simultaneously both spatial (congestion and rivalry of use) and environmental (air pollution) issues in medium-sized city. Both vehicle-sharing and self-service vehicles constitute credible alternatives to private cars when investigating time-space consumptions per service provided. Shared modes contribute to address spatial and environmental issues related to transportation and should be favored as a leading component of a comprehensive transportation system, especially in a degrowth strategy. As such, this study provides guidance for policy-makers.

References

ADEME (2006) *Chiffres clés Transport*, Report.

Cabanne, I. (2009) "Dossier d'évaluation sur les vélos en libre-service", in *Les comptes des transports en 2008* (vol. 2), Les dossiers d'analyse économique des politiques publiques des transports.

CERTU (2004) *Les chiffres clés des enquêtes ménages déplacements ; Méthode standard CERTU, principaux résultats*, official documents.

CERTU (2007) *Quelle est la consommation d'espace par les transports et par l'urbanisation ?,* Summary Report, september.

CCFA (2012) *L'industrie automobile française, Analyse et statistiques 2012*, september.

CITEPA (2013) *Rapport SECTEN*, April.

Cohen, S. (2006) Considérations sur les courbes débit-vitesse, in *Séminaire vitesse. Apports récents de la recherche en matière de vitesse*, Actes INRETS n°105, p. 57-66.

European Commission (1995) *Towards Fair and Efficient Pricing in Transport Policy - Options for internalising the external cost of transport in the European Union*, Green Paper.

International Energy Agency (2011) *IEA Energy Statistics – Energy Balances for World*, IEA report.

Héran, F. and Ravalet E. (2008) *La consommation d'espace-temps des divers modes de déplacement en milieu urbain - Application au cas de l'Ile de France*, PREDIT, Groupe Opérationnel 1 : mobilité, territoires et développement durable, juin.

Marchand, L. (1977) Qu'est-ce que la mobilité, *METROPOLIS*, Vol. 3, n°24-25, p. 51-54.

Marchand, L. (1993) *Du bon usage de l'espace de voirie dans les centres urbains*, ENPC, Cycle Transport de Voyageurs - module 2 : l'économie des transports, Paris.

Meijkamp, R. (2000) *Changing Consumer Behaviour Through Eco-Efficient Services: an empirical study on car sharing in the Netherlands*, Delft University of Technology: Delft, The Netherlands.

Scott, K. (2009) *A literature Review on Sustainable Lifestyles and Recommendations for Further Research*, Stockholm Environment Institute, Project Report.

Appendix

Table 3 presents the gross estimations from Marchand (1993) related to the time-space consumptions per person in m^2.h for a 10 km return commuting trip with different transportation modes. Table 4 and Table 5 present the underlying assumptions for Marchand's dynamic and static time-space consumption estimations, respectively. Finally, Table 6 presents the services provided by each transportation modes.

Table 3: Time-space consumption per person for a 10 km return commuting trip

Transportation modes	Time-space consumption		
	Dynamic	Static	Total
Cars (1.25 people/vehicle)	18	72	90
Two-wheelers	7.5	13.5	21
Bus with dedicated lanes	12	0	12
Bus without dedicated lanes	3	0	3
Subway	1	0	1
Walking	2	0	2

Source: Marchand (1993)

Table 4: Assumptions for Marchand's dynamic TSC estimations

Transportation modes	Distance d_i (m)	Width l_i (m)	Speed V_i (kmph)	Occupancy rate n_i (people/veh)	Road capacity Q_i (veh/h)	Trip length L (km)	Dynamic TSC (m^2.h)
Cars	15	2.7	18	1.25	1200	10	18
Two-wheelers	6	1.5	12	1	2000	10	7.5
Bus with dedicated lanes	500	3	25	50	30	10	12
Bus without dedicated lanes	50	3	15	50	200	10	3
Subway	500	3	25	600	50	10	1
Walking	1.4	0.7	5	1	3571	10	2

Source: Derived from Héran (2008)

Table 5: Assumptions for Marchand's static TSC estimations

Transportation modes	Surface S_i (m^2)	Stay duration h_i (h)	Occupancy rate n_i (people/veh)	Static TSC (m^2.h)
Cars	10	9	1.25	72
Two-wheelers	1.5	9	1	13.5
Bus with dedicated lanes	N.D.	0	50	0
Bus without dedicated lanes	N.D.	0	50	0
Subway	N.D.	0	600	0
Walking	N.D.	0	1	0

Source: Derived from Marchand (1993) and Héran (2008)

Table 6: Services provided by transportation modes

	Origin-to-destination trip	Carrying heavy loads	Driving people	Avoiding road congestion	Physical efforts	Symbolic functions	Private space for discussion	Covering distances > 5 km	Immediate availability
Private cars	✓	✓	✓			✓	✓	✓	✓
Private motorized two-wheelers	✓			✓				✓	✓
Private bicycles	✓			✓	✓				✓
Car-sharing	✓							✓	
Self-service cars	✓	✓	✓			✓	✓	✓	
Taxis	✓	✓	✓	✓				✓	
Self-service bicycles	✓			✓	✓	✓			
Bus with dedicated lanes	✓			✓				✓	
Bus without dedicated lanes	✓							✓	
Subway	✓			✓				✓	
Walking	✓			✓	✓				✓