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The Potential of ITS to Enhance Co-modality and Decarbonise Passenger Transport in Europe

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Abstract

Intelligent Transport Systems (ITS) are expected to provide valuable contributions to a more integrated and sustainable passenger transport system in the future. In this paper we studied the potential role three ITS applications (personalised travel information, car sharing schemes and mobile payment devices) could have in enhancing co-modality and decarbonising EU passenger transport. Based on a thorough review of existing and planned schemes, the mobility impacts of these ITS applications were estimated for single 'model' countries. To estimate the EU-wide decarbonisation potential of the options, a scaling methodology was developed, taking country specific aspects affecting the effectiveness of these schemes into account. The results of our analyses showed that particularly personalised travel information and mobile payment devices could significantly contribute to decarbonising the EU passenger transport system (1 - 3% and 0.5 - 1%, respectively) although the estimated CO_2 reduction figures are rather uncertain. Further research on this topic is for that reason highly recommended.

Keywords: *ITS, co-modality, personalised travel information, car sharing, decarbonisation of transport*

1. Introduction

Fighting climate change is one of the biggest challenges of the current society. The continuous accumulation of greenhouse gases (GHG) in the atmosphere – most notably carbon dioxide (CO_2) – leads to the slow warming of the atmosphere, which has severe consequences on ecosystems and eventually on societies as well. In order to limit the climate warming to 2°C - a threshold value where the negative impacts are still considered to be manageable - global GHG emissions need to be reduced.

Transport is responsible for a large part of the global GHG emissions; in Europe, about a quarter of the GHG emissions are emitted by transport, making transport the second biggest greenhouse gas emitting sector after energy [1]. Road transport accounts for almost three-quarters of these EU transport-related GHG emissions. While GHG emissions from most economic sectors are generally falling, those from transport have increased by 29% in the period 1990-2009 [1]. This increase has happened despite improved vehicle efficiency because the amount of passenger and freight transport has increased. Without additional policy intervention transport's GHG emissions in 2050 are expected to be around 25% above 2010 levels [49].

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Reducing transport's GHG emissions is one of the main objectives of the transport policy of the European Commission. In the White Paper on Transport [20] the European Commission set the objective of 60% CO_2 reduction in the transport sector in 2050 compared to the base year 1990. In order to achieve this target, while ensuring the mobility and economic benefit of European citizens and companies, new and innovative policies and technologies are required. Intelligent transport systems (ITS) should be part of these innovative technologies [18]. ITS could contribute to a decarbonisation of the European transport system in various ways; it could facilitate (differentiated) road charging schemes which are a way to influence transport demand, it could support fuel-efficient driving styles or it could enhance transport efficiency, *e.g.*, by stimulating co-modality. In this paper we will focus on the latter application of ITS.

This paper will present some relevant findings of the European 7th Framework project OPTIMISM (Optimising Passenger Transport Information to Materialize Insights for Sustainable Mobility). The main objective of this project is to provide stakeholders, e.g. policy makers and transport companies, with a set of strategies and recommendations for optimising passenger transport systems. As part of this project ITS applications that could be used to stimulate co-modality are assessed to identify the EU-wide decarbonisation potential of these applications. Given the expected growth in market penetration of these applications over the next decade, this assessment is very relevant from both a scientific and policy objective.

In the remainder of this paper we will first identify some best practices (in terms of contributions to realize an integrated and sustainable transport system) with respect to ITS applications that enhance co-modality (Section 2). Next, we will discuss the mobility effects that could be realized by applying these ITS options (Section 3). Based on a thorough literature review empirical evidence is gathered to quantify these effects. Due to the scope of most of the ITS schemes (regional or national) and the scarcity on empirical evidence, the mobility effects are only considered for one 'model' country per application. To estimate the decarbonisation potential of an EU-wide application of these options, a scaling method have been developed, taking country specific aspects affecting the effectiveness of ITS applications into account. This methodology and the results of the assessment of the EU-wide decarbonisation potential of the ITS options is discussed in Section 4. Finally, the main conclusions of our study are presented in Section 5.

2. ITS Options Promoting Co-modality

Intelligent transport systems (ITS) could be defined as '*advanced applications which – without embodying intelligence as such – aim to provide innovative services relating to different modes of transport and transport management and enable various users to be better informed and make safer, more coordinated and 'smarter' use of transport networks*'[19]. Various categories of ITS could be distinguished (based on [28]):

- Travel information systems; this category includes applications like real-time traffic information services, navigation systems, parking information systems, *etc.*
- Transport management systems; this category includes both applications related to transport management (*e.g.*, traffic operation centres, dynamic message signs) and applications related to demand and access management (*e.g.*, low emission zones).
- Mobility services; applications improving the quality of (integrated use of) transport modes. Examples are (multimodal) smart cards, integrated ticketing systems, rental services for public bikes, *etc.*

- Vehicle control and safety systems; advanced technologies in vehicles and infrastructure which helps transport users to control vehicles in order to improve traffic safety of fuel efficiency (*e.g.*, anti-collision warning and control systems, driving assistance systems).
- ITS-enabled transportation pricing systems; electronic toll collection, congestion pricing and variable parking fees are examples of applications which are part of this category.

Several of the ITS options mentioned above could be used to stimulate co-modality. In this paper we consider co-modality as an umbrella term in order to capture both the terms multi-modal and intermodal transport[1]. Multi-modal transport refers to the use of different modes of transport at different opportunities (trips/trip chains). Intermodal transport, on the other hand, refers to the combination of different transport modes within one route/trip [33]. Not all ITS options discussed above do affect co-modality, as is also shown in Figure 1. Vehicle control and safety systems are mainly single vehicle options and therefore will not stimulate co-modality directly. The same holds – to a smaller extent – true for ITS-enables transportation systems. On the other hand, travel information systems, transport management systems and mobility services all include some applications that stimulate co-modality (although they do also include single vehicle options, e.g. navigation systems for passenger cars). Since the objective of this paper is to assess the mobility impacts and decarbonisation potential of some ITS applications that enhance co-modality, we focus on the latter three categories of ITS options in this assessment.

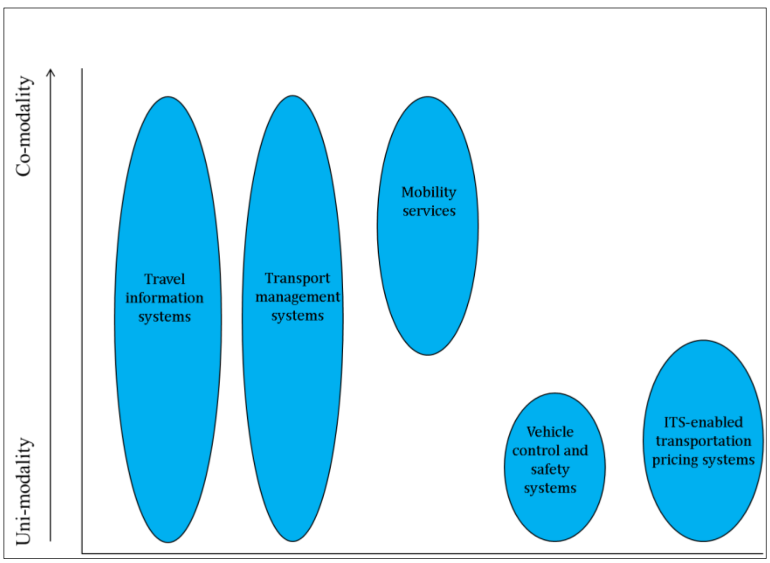

Figure 1. Relation between ITS applications and co-modality

2.1. Identifying ITS applications supporting co-modality

Based on a thorough review of the available evidence in the literature and the European countries on existing and planned ITS projects as well as about 20 semi-structured interviews

[1] This is a rather narrow definition of co-modality. Co-modality is also often defined as 'the efficient use of different modes on their own and in combination' (e.g. [17]). For example, driving assistance systems (which, for example, indicates the right moment to shift gear to reduce fuel consumption) are co-modality measures if the latter, broad definition of co-modality is applied, although these systems do not stimulate multimodal or intermodal transport and hence from a narrow perspective are not considered co-modality measures.

with experts/stakeholders in the field we identified 15 types of ITS applications enhancing co-modality that were already implemented or will be implemented in the short/medium term (up to 2020). These 15 types, which could be categorised in the three main categories defined above (travel information services, mobility services and transport management systems) are:

- Travel information services
    - Static route planners
    - Dynamic and real-time route planners
    - Personalised travel information services
    - Infrastructure bounded travel information for public transport
    - Infrastructure bounded travel information for road transport
    - In-vehicle travel information
- Mobility services
    - E-ticketing systems
    - Mobile phone ticketing
    - Multimodal smart cards
    - Mobile phone payments
    - Bicycle sharing services
    - Car sharing services
    - Demand Responsive Transport systems
- Transport management systems
    - Public transport management systems
    - General transport management systems.

2.2. Selecting three best practices

In the next step we selected three best practices, which have the most potential to contribute to an integrated and sustainable transport system. For these options we will estimate the mobility impacts and decarbonisation potential in the remainder of this paper. Here, we will only briefly describe the analyses carried out to select the best practices. A more elaborated description of the selection approach for the best practices could be found in OPTIMISM [47].

To select the three best practices we composed a set of indicators on which the various ITS applications were scored. Four groups of indicators were used for this selection procedure: mobility impacts (modal shift, travel time, safety, congestion, accessibility, (travel time) reliability), environmental impacts (climate change, air pollution, noise emissions), costs (investment costs, operational costs), transferability to other contexts (transport modes, countries/cities). All ITS applications were scored on these indicators using a semi-quantitative scale (-2, -1, 0, 1, 2). Preferably, we made use of ex-post and ex-ante evaluation studies to score the ITS applications on the various indicators. However, if these were not available we rely on the opinions of relevant experts or OPTIMISM partners. Finally, (unweighted) aggregated scores (based on the scores on the individual indicators) were calculated (see Figure 2). Although in general, the scores are rather comparable, four options scored highest: personalised travel information services (PTI), car sharing schemes (CSS), mobile phone payments and multimodal smart cards. Since the latter two options are closely related to each other, they are combined in mobile payment devices (MPD).

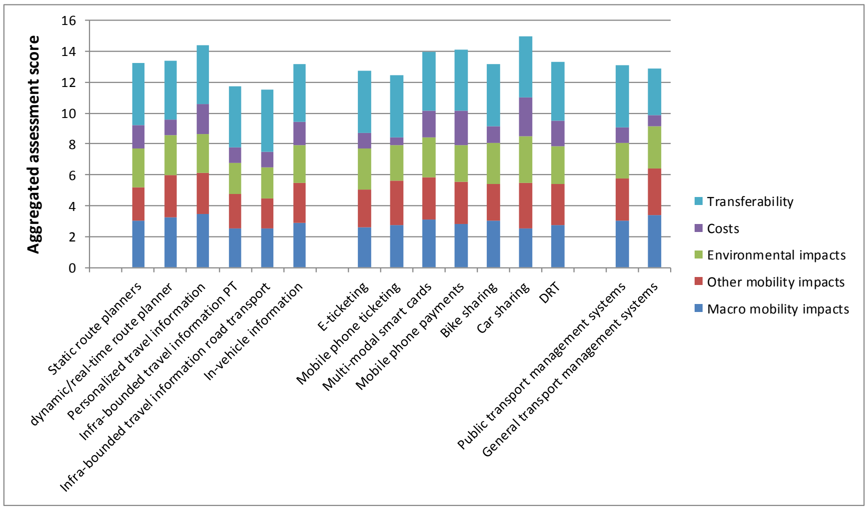

Figure 2. Results of selection process of best practices

2.3 A further introduction to the three best practices

In this section we provide a brief description of the three best practices. In section 3 and 4 the mobility impacts and decarbonisation potential for these ITS applications will be estimated.

2.3.1 Personalised travel information *services*: Dynamic and real-time route planners can be employed by the user to get information about travel times, routes, modes and associated disruptions or congestion *etc.*, based on personal preferences [8]. Personalised travel information services work at a similar level, but they provide the information automatically, so the user does not have to collect information manually. For the on-trip use, this provides certain advantages. In order to ensure the mobility of these services, they are often realised as smart phone applications.

Personalised travel information services have the potential to promote a modal shift, because delays can be anticipated beforehand and different modes are comparable with respect to travel time. The route or even mode of choice can be changed on-trip as well. For instance, if road users are informed about an accident on their route, they can switch to side roads and congestion at this point can be prevented.

2.3.2 Car sharing schemes*:* Car sharing schemes are organized arrangements, collectives or business ventures, where members can reserve cars when they need them and pay automotive expenses on a variable basis (per kilometer or per unit of time) [6]. This definition comprises the two different types of car sharing: station-based car sharing services are the 'traditional' service, where the vehicles are picked up and dropped off at fixed stations. 'Free floating' services on the other hand are often limited to one city and do not rely on stations, but vehicles are distributed randomly across the city and can be found and opened making extensive use of ICT (*e.g.*, smart phone applications).

2.3.3 Mobile payment devices*:* The operating principle of mobile device payment (both mobile phone payments and multimodal smart cards) is the use of Radio Frequency Identification (RFID) chips to enable contactless communication with other devices [4, 22]. Many public transport providers make use of smart cards on a regional or even national scale (*e.g.*, 'OV chipkaart' in the Netherlands) as a means of payment. For example, a prepaid smart card can be charged the fare to replace buying a paper ticket. Mobile phones can use a similar technology: Near Field Communication (NFC).

The appeal of mobile payment devices is that no time is lost for travellers determining the right tariff and buying paper tickets. In addition to this, this technology can be combined with systems that automatically calculate and charge the cheapest fare post-trip (taking into account budget prices, fare zones, *etc.*).

3. Mobility Impacts of Selected ITS Applications

The three selected ITS applications are scrutinised more thoroughly for potential mobility effects. The focus lies on the collection and analysis of quantitative information on the possible impacts related to the real-world implementation of these measures. For each of the measures, ample literature is available describing potential effects, expected outcomes and economical or environmental triggers for the application of said measures. However, more often than not, precise quantitative information as a result of consistent ex-post analyses of effects is lacking.

A significant part of the information available builds upon expected or potential outcomes of future projects or qualitative indications of current and future projects. Although tempting to use this information as indications for effects, this actually can pose some difficulties in the sense that expected outcomes are not verified despite being a necessary step towards the assessment of the successful implementation of any measure [38]. As a result the indicated figures remain questionable until verified. Although utmost care has been taken to verify available quantitative information, it is difficult to be absolute sure about the quality of estimations presented in literature. As a result, mobility impacts that are estimated in this section may be under- or overestimations. In order to avoid estimation mistakes, we focus on single 'model' countries for the different measures. Furthermore, this also means that impacts on total transport demand couldn't be quantified because of a lack of control over potential rebound effects. It should be noticed that these effects could be substantial; they are often estimated to be between 10% and 30% of the direct impact (*e.g.*, see [58]).

3.1 Applied methodology

The methodology that will be presented here is largely based on the methodology presented in the AMITRAN project [3]. The reason for selecting this approach are the inherent differences between the identified ITS applications. One measure focusses specifically on directly changing modal choice behaviour through the offering of alternative travel routes (personal travel information). The second measure focusses on facilitating the use of public transport (use of mobile payment devices). The third measure focusses on optimising the rate of use of passenger cars and reducing car ownership (car sharing). These measures focus on different aspects of transport behaviour: long term and short term trip planning as well as trip execution (timing, modal choice) In order to make a comparison of effects, a methodology needs to be followed that allows for a fair estimation of the impact on different aspects of the mobility question (route, timing, modal choice, vehicle choice, *etc.*).

A possible solution is presented by the AMITRAN project that specifically focusses on defining a reference methodology to assess the impact of intelligent transport systems on CO_2

emissions and aims to create a reference methodology for future projects, covering both passenger and freight transport through a comprehensive well-to-wheel approach. Distinctions are made between the pre-trip and on-trip choices that can be made by travellers. Furthermore, potential influences from transport infrastructure, long-term transport demand, and short-term transport decisions as well as specific parameters related to driving behaviour and vehicle conditions are included. As a result, a group of parameters was identified for which specific information in relation to potential effects was collected: trip information, modal split information, passenger and vehicle kilometres (per mode), network usage and transport capacity. These parameters were the focus of the collection of information that is presented below.

Three steps were undertaken to estimate the mobility impacts: (1) the collection of information on the three ITS applications from EU, national, regional or private projects was sought to add to the information collected earlier in the OPTIMISM project; (2) the analysis of quantitative information in relation to changes in mobility demand, modal shift and co-modality, also focussing on data validation; and (3) the identification of a model country for each of the three ITS applications, allowing for the quantitative estimation of the mobility impact associated to these measures in these countries. The outcome of these three steps is the creation of a consistent quantitative estimation of possible effects of the three ITS applications.

3.2 Quantified impacts from selected ITS applications on transport demand, modal shift and travel times

Although an extensive search of relevant literature was held, only a limited amount of quantitative information in relation to transport demand, vehicle kilometres ran, person kilometres, modal choice, modal split, *etc.*, was found for which the presented numbers could be validated. For two measures, Personal Travel Information and Car-Sharing, a coherent set of data could be composed. Quantitative information was mostly limited to relative changes in modal usage, vehicle kilometres or passenger kilometres. For Mobile payment devices, only very limited quantitative information could be found.

3.2.1 Personal Travel Information: For this measure, the literature search provided 9 validated information sources that present a set of quantitative information that could be used for further analysis. The following table presents an overview of the different parameters for which quantitative information was found and the main quantification.

As an example of the effect of the introduction of Personalised Travel Information, we present an estimation of the potential mobility effects for the United Kingdom. The basis for the effect estimation in the United Kingdom are the results presented by the Department of Transport in different reports [11, 12]. In these reports, the focus lies on the introduction of highly personalised measures where intensive campaigns are held to inform the public on alternative trajectories and made use for their daily commute. Reductions in yearly car usage range between 616 and 2,134 passenger kilometres per person. This range depends partly on the introduction of the measure in urban or rural regions but also the intensity of the communication campaign and target group.

Based on the statistics presented by the European Statistical Pocketbook [21], we can estimate the number of yearly car passenger kilometres. For the UK 687.3 billion passenger kilometres are reported for 63,182,000 inhabitants, resulting in an average of 10,878 car passenger kilometres per year, per inhabitant. This presents us with a reduction potential between 6% (616/10,878 pkm/year) and 20.6% (2,134/10,878 pkm/year). For the Lowestoft case, more detailed information is presented on the total daily trip distances. An average of

20.5 vehicle kilometres per day is reported, compared to 23 vehicle kilometres before the introduction of the measure (a 10.7% reduction), suggesting a preference for an effect size in the lower half of the estimation range.

In addition, relative reduction in modal split are reported in the Department for Transport reports [11, 12]. These suggest that a slight shift towards public transport for urban trips takes place (between 1% and 9%, depending on the region type). An average shift from busses to cars is estimated to be around 1.7% [11, 12]. More importantly, a consistent reduction in the car use as driver (between 3% and 14% reduction) takes place, while passenger car usage is more variable (between -5% and +10% usage ratio). Although these reductions in car use are slightly lower than the ones estimated based on the European Statistical Pocketbook, both figures show that a significant modal shift from car to public transport could be expected.

In the remainder of this paper we assume a reduction in car use (in terms of vehicle kilometres; vkm) due to a modal shift to public transport of 3 to 11%. The lower bound of this range is based on the lower value estimated by Department for Transport. The upper bound is based on the most representative value estimated by Department for Transport. Finally, also the reduction in bus usage (-1.7% in vkm) is based on the estimations provided by Department for Transport.

Table 1. Main findings on the mobility effects of personalized travel information

Parameter group	Main findings: relative impacts	References
Number of car trips	- A reduction between 0.3 and 0.4 car trips per day, per household. - A reduction between 7% and 15% in the number of car trips per day, per household for urban areas. - A reduction between 2% and 6% in the number of car trips per day, per household for regional areas.	[24], [11], [12], [50], [27], [51]
Number of vehicle (car) kilometres ran	- A reduction between 616 and 2,000 car kilometres ran (yearly basis). - A reduction between 6% (rural) and 12% (urban) in car kilometres ran (yearly basis)	[11], [12], [50], [51]
Modal change	- A reduction between 3% and 8% in car usage (urban trips). - A reduction between 2% and 20% in car usage (rural trips). - An increase between 1% and 3% in bus usage (urban trips). - An increase between 1% and 9% in bus usage (rural trips). - An increase between 1% and 9% in public transport usage (urban trips). - An increase between 1% and 6% in the use of slow mode (urban trips).	[7], [11], [12], [50], [51], [52], [57]

3.2.2. Car Sharing: For this measure, the literature search provided 21 validated information sources that present a set of quantitative information that could be used for further analysis.

The following table presents an overview of the different parameters for which quantitative information was found and the main quantification.

As an example of the effect of the introduction of car sharing schemes, we present an estimation of the potential mobility effects for Germany. The basis for the effect estimation in Germany are the results presented in several deliverables from the MoMo project [41, 42, 43, 44, 45]. In these publications, the focus lies on general collection of information of the state-of-the-art in car sharing in different EU Member States.

Based on the statistics presented by the European Statistical Pocketbook [21], we can estimate the number of yearly car passenger kilometres. For Germany 835.2 billion passenger kilometres are reported for 81.8 million inhabitants (Statistischen Ämtern des Bundes und der Länder portal [53]), resulting in an average of 10,843 car passenger kilometres per year, per inhabitant. This figure is used as a set-off for the estimation of the relative effect of the introduction of a car-sharing scheme to individual users on the number of car kilometres ran.

Table 2. Main findings on the mobility effects of car sharing schemes

Parameter group	Main findings	Reference
Penetration ratio	- C.S. Penetration levels between 0.5% and 1.5%	[15], [25], [31], [39], [42], [43], [44], [45], [46]
Number of vehicle (car) kilometres ran	- A reduction between 600 and 8,215 car kilometres ran (yearly basis, per user)	[10], [25], [26], [30], [35], [36], [42], [43], [44], [45], [46]
Modal change	- Car ownership reduction: up to 73.4% of car owners reported selling the vehicle under the condition that they became C.S. members. - No verifiable quantifications of modal split changes were found. For an unbiased population, an increased number of PT users between 11% to 12% was indicated (not necessarily modal shift).	[6], [10], [14], [26], [35], [40], [42], [43], [44], [45], [46], [48]

In practice, we estimate that a penetration rate of car sharing schemes between 1% and 1.5% at household level should be feasible for Germany. With an average of 2.36 persons per household in Germany, this means that the number of potential users in Germany lies between 1.9 and 2.9 million users. Based on the findings from the MoMo study, 73.4% of these potential users would consider only using car sharing services and public transport (with an indicated 973 driverkm/year, and a surplus of 1,500 other carkm ran/year [42] while 26.6% would make use of car sharing services in parallel to using their own car and public transport (973 car sharing carkm/year and 5,429 privately owned carkm/year). As a result, the reduction potential in carkm of car sharing for Germany would lie between 1.65% and 2.48%.

3.2.3. Mobile payment devices: Different formats of mobile payment device systems were reviewed, both for European as well as non-European use cases. Most information was available from: Hong Kong: Octopus, Singapore: EZ Link, Netherlands: OV Chipkaart, Rome (Italy): Metrobus card , Chicago: Plus I-Go, Dublin: LUAS, Schwäbische Hall (Germany): Kolibricard, Oslo (Norway): Skyss Travelcard, Japan: PiTaPa & LuLuLa card, Île-de-France (France): Navigo and London (UK): Oystercard [38, 39, 40]. However, verifiable quantitative information in relation to mobility effects was only available for the Navigo system (France), the Oystercard system (UK) and the Dutch OV Chipkaart system. We focus on the Navigo and Oystercard systems.

Although sizeable effects are reported over a longer time period, these are effectively the result of the implementation of a wide range of measures (infrastructure, transport availability, *etc.*). In case of the Navigo system, an increase of 11% usage of public transport systems was reported over the 2001 to 2010 period. However, in practice accessibility of the public transport system also significantly improved over that period of time as a result of separate measures introduced to the public transport network. An increase of11% more train vehicle kilometres and 21% more bus vehicle kilometres is reported as well as improved time schedules for public transport services [36, 37]. In case of the Oystercard system, a consistent decrease in car vehicle kilometres (-1.5% car vehicle kilometres [23]) was reported but that particular system was introduced at the same time as the London congestion charge. Overall, insufficient information was available to make a clear quantitative distinction between effects of the different associated measures. Based on the sparsely available information, we estimate that the effect magnitude of the introduction of a smart card system on car vehicle kilometres is relatively limited (between 1% and 2.4%).

3.3 Overview mobility impacts

A summary of the estimated mobility impacts for the three ITS applications is given in Table 3. All three options result in significant modal shift impact and hence support co-modality. It should be noticed that these mobility impact estimates are based on a rather small selection of empirical evidence and hence are quite uncertain. For that reason we apply ranges of impacts instead of point estimates. Two sources of uncertainty are the lack of evidence on the impacts on transport demand (rebound effect) and the assumed uniformity of passenger kilometres (pkm) among all transport modes. The latter implies that 1 pkm shifted from car equals 1 pkm added to bus. By applying this assumptions we may slightly overestimate the emission reduction, because passengers typically have to cover a larger distance when traveling by public transport than by car which allows driving directly without detours to the individual destination.

4. Environmental impacts of selected ITS applications

In order to assess the environmental impacts of the selected ITS applications, an emission model is developed and applied to the EU27 countries, Norway and Switzerland. This model includes all major modes of passenger transporter, *e.g.*, car, bus and train. Shipping is excluded due to the marginal significance for every-day passenger transport and the limited likelihood to be affected by the selected ITS applications. A time horizon between 2010 and 2030 is analysed. A quantitative projection beyond 2030 would be subject to high uncertainty. Furthermore, the maximum potential of the selected ITS applications options will already be realised within the next two decades.

Main focus of the emission model is the evaluation of the EU-wide CO_2 reduction potential. In addition the model also allows estimating nitrogen oxides (NO_x) and particulate matter (PM) emissions. For all types of emissions both tank-to-wheel (TTW) and well-to-tank (WTW) emission factors are integrated in the model.

Table 3. Effects of selected ITS applications on transport demand and modal shift

Option	Transport demand	Modal shift (relative change in vkm)		Long-term market penetration	Reference Country
		From	To		
PTI Personal Travel Information	Car: 0 % Bus: 0 % Train: 0 %	Car: -3 % to – 11%	Bus: 78 % Train: 22 %	2015: 20% 2020: 30% 2025: 50% 2030: 75% Market penetration: expected % of population that make use of system	UK
		Bus: -1.7 %	Car: 90 % Train: 10 %		
		Train: 0 %	Car: 0 % Bus: 0 %		
CSS Car Sharing Schemes	Car: 0 % Bus: 0 % Train: 0 %	Car: -1.65 % to – 2.48%	Bus: 90 % Train: 10 %	2020: 0.5 % 2030: 1-1.5 % Market penetration: expected % of population making use of system	Germany
		Bus: 0 %	Car: 0 % Train: 0 %		
		Train: 0 %	Car: 0 % Bus: 0 %		
MPD Mobile Payment Devices	Car: 0 % Bus: 0 % Train: 0 %	Car: -1 % to –2.4%	Bus: 92 % Train: 8 %	2015: 20% 2020: 40% 2025: 70% 2030: 100% Market penetration: expected % of population that make use of system	UK
		Bus: 0 %	Car: 0 % Train: 0 %		
		Train: 0 %	Car: 0 % Bus: 0 %		

4.1 Methodology for estimating the EU-wide decarbonisation potential

The CO_2 emissions from passenger transport depend on transport demand D for a certain traffic mode m, the specific energy consumption C and emission factor e of the respective mode. All values are variable over time [y], as for example the energy consumption in MJ/km is expected to decrease in future with improvements in energy efficiency. The total emissions E of a country in year y are calculated as:

$$E_{Country}^{[y]} = \sum_{m} D_{m}^{[y]} \cdot C_{m}^{[y]} \cdot e_{m}^{[y]}$$

Figure 3 illustrates the general structure of the data in the model.

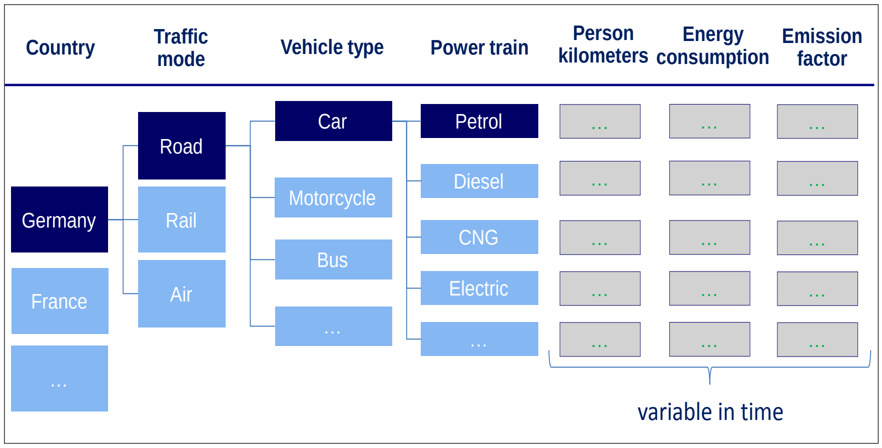

Figure 3. General data structure in the model

In order to analyse the potential emissions effect over time, a sound baseline scenario is required. For this purpose the *Integrated Scenario* from TREMOVE (version 3.3.2, [56]) is selected as it provides consistent data on the considered modes for all European countries by 2030 and is well established for policy assessments. The TREMOVE scenario is in line with the previous EU White Paper [16] and anticipates a number of new measures from the iTREN-2030 project. These measures comprise major relevant transport policies which are likely to be implemented in the future. The development of transport demand and the related GHG emissions is displayed in Figure 4 with respect to different transport modes.

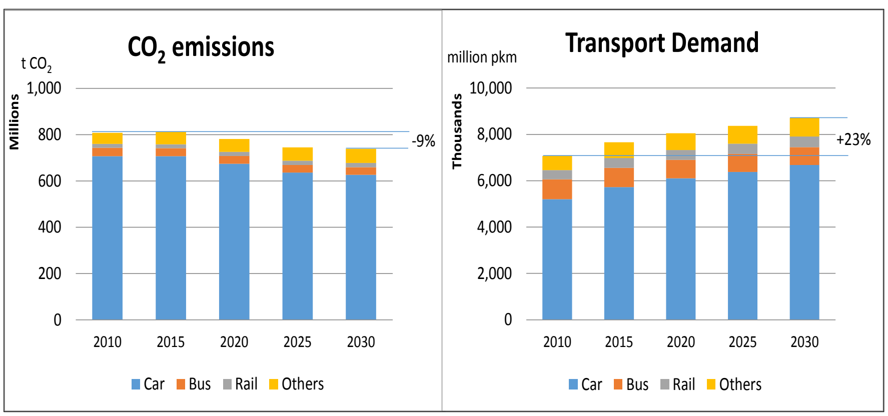

Figure 4. TREMOVE Integrated Scenario: Development of CO_2 emissions and transport demand of all passenger modes in Europe (including EU27, Norway and Switzerland)

The decarbonisation potential by ITS is country specific and depends on a magnitude of factors, *e.g.*, the willingness of the government to invest, the quality of the public transport system or the acceptance of information technologies by the customer. To account for the individual situation of a country, an assignability factor is introduced into the model. This factor allows scaling the impact level of an ITS application which has been observed in a reference case to an individual impact level for each considered country. The assignability factor is determined by a set of indicators related to the introduction of ITS applications. The selection of indicators and their relevance rating based on the expert option of the involved project partners is summarized in Table 4. All countries are benchmarked with regard to these indicators and their score is weighted with the corresponding relevance points. The outcome provides a relative ranking of how well the countries are likely to perform in achieving the possible impacts. Consequently, countries with a higher score than the reference country are expected to realise a higher (mobility) effect than displayed in Table 3.

Table 4. List of indicators and evaluation of relevance for selected ITS applications

Indicator	Unit	PTI	CSS	MPP
GDP per capita	PPP-€ / population	2	2	2
Investments per capita	€ investments / capita	3	2	2
Road network capacity utilization	pkm car / km roads	3	2	3
Rail network capacity utilization	pkm rail / km railway	3	3	3
Urbanisation	population in cities and agglomerations >100,000 inhabitants / total population	3	3	3
Modal share of public transport	% of pkm	2	2	2
Ownership of mobile phone with internet access	% of households	3	1	3
Rating: 0 (no relevance), 1 (low relevance), 2 (medium relevance), 3 (high relevance)				

The diffusion of ITS in the market happens gradually and the maximum impact potential is expected in the long run. Accordingly, the development of the decarbonisation effect over time is modelled and combined with the assignability factor. The estimation of the market penetration can be found in Section 3. For CSS, estimations were only available for 2020 and 2030 (mostly based on the Swiss example of CSS [5, 41]). The market penetration has therefore been modeled based on a logistic growth function. For all three ITS applications, the resulting market penetration over time is applied to the maximum potential impact and corrected by the country specific assignability factors to determine the effect for a certain country at a certain point in time.

4.2 EU-wide decarbonisation potential

In the next step the emission model is applied to the countries of the analysed European countries in the time frame from 2010 to 2030. For the estimation of the decarbonisation potential of the three selected ITS applications, the mobility effects (as discussed in Section 3) are implemented in the model. Table 5 shows the range of resulting CO_2 emission reductions of the three selected ITS applications in European passenger transport over time.

Table 5. CO_2 reduction potential by selected ITS applications (in thousand tons)

	Range	2015	2020	2025	2030	% of total transport CO_2 emissions in 2030
PTI	Min. potential	-2,550	-3,445	-5,089	-7,142	1.0%
	Max. potential	-9,871	-13,266	-19,537	-27,344	3.7%
CSS	Min. potential	-8	-30	-57	-68	0.01%
	Max. potential	-13	-44	-85	-102	
MPD	Min. potential	-907	-1,623	-2,506	-3,336	0.5%
	Max. potential	-2,178	-3,894	-6,014	-8,007	1.1%

As a result of the strong modal shift and an expected high market penetration, PTI have the largest decarbonisation potential of the three selected information technologies. In 2030, between 0.97% and 3.70% of passenger transport emissions could be avoided compared to the baseline scenario. MPD can contribute an emission reduction between 0.45% and 1.08%. CSS have a fairly low market penetration and also facilitate a small modal shift, so the decarbonisation potential is expected to be only 0.01% in 2030. In addition to this, both PTI and MPP require less infrastructure investments and also address people without a driving license, whereas CSS are solely used by car drivers.

Figure 3 illustrates the geographic distribution of the decarbonisation effects of PTI (in the best case).

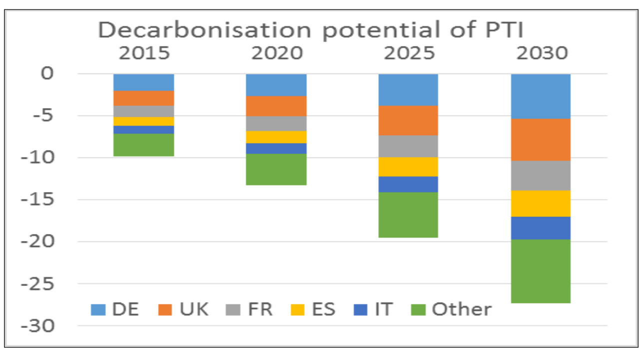

Figure 3. Maximum decarbonisation potential of PTI in different countries (in million tons)

As expected, the major decarbonisation share results from Germany, the UK, France Spain and Italy, accounting for 72% of the reduction. In the baseline scenario, these countries are responsible for 69% of CO_2 emissions in 2030. Reason for this is that the five countries in general rank high in the assignability and hence have a higher decarbonisation potential. The relative decarbonisation potential varies significantly between countries, mainly as a result of the differences in the assumed assignability factor. However, other country-specific aspects such as vehicle emission factors play a role as well. In 2030, the Netherlands are expected to reduce emissions by using PTI by 1.3% - 3.8%, and only Malta by merely 0.1% - 0.5%.

There was no empirical evidence available on transport demand reductions (see Section 3), so the decarbonisation effect just results from the shift from individual motorized transport to public transport. In the case of PTI CO_2 emissions from cars decrease by up to 49.6 million tons while emissions form buses and trains increase by 22.3 million tons as a consequence of the modal shift. This results in a maximum net CO_2 reduction of 27.3 million tons in 2030 (see Figure 4).

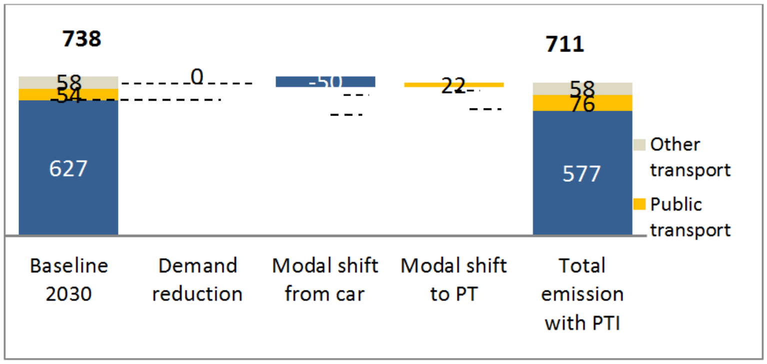

Figure 4. Composition of the decarbonisation effect (in Mton) of PTI in 2030 (maximum potential)

4.3 Other environmental impact

Aside from direct or indirect CO_2 emissions that accompany passenger transport, there are a number of co-benefits that can increase the attractiveness of the selected ITS applications. Of these co-benefits, air pollution is assessed in quantitative terms (based on TREMOVE data). In addition, the effects on traffic safety, congestion and noise are discussed qualitatively in the following.

4.3.1 Air pollution: The most common and relevant air pollutants arising from transport processes are nitrogen oxides (NO_x) and particulate matter (PM). Both are known to cause respiratory diseases; NO_x is also the cause of acidification and eutrophication. In order to limit these external effects and associated costs, the European Commission has set strict standards for new vehicles (Euro 1-6/I-VI standards). The modal shift resulting from the introduction of each of the three selected ITS applications will have noticeable effects on NO_x and PM emissions. Table 6 summarizes the potential resulting effects on NO_x emission by the three analysed ITS applications.

Table 6. Potential effect on NO_x emissions by selected ITS applications [in tons]

	Range	2015	2020	2025	2030
PTI	Min. potential	363	1,622	4,603	8,722
	Max. potential	1,455	6,295	17,719	33,422
CSS	Min. potential	1	14	52	84
	Max. potential	2	21	78	126
MPD	Min. potential	141	779	2,281	4,083
	Max. potential	339	1,871	5,474	9,800

In contrast to the decline of CO_2, nitrogen oxides emissions are expected to increase compared to the baseline scenario: in 2030 by 0.69% - 2.64% with PTI, 0.32% - 0.78% with MPD and about 0.01% with CSS. The increase can be attributed to the strong modal shift towards buses, which almost exclusively use diesel engines that have higher specific NO_x

emissions than the average car. The Euro emission standards only apply to new vehicles, so the effect is generally higher in countries with older rolling stock. The NO_x emissions of trains are strongly linked to the electrification of the railway network. In Switzerland, the country with the highest share of electrified railway[2], trains have specific NO_x emissions of 0.02g/pkm in 2010, whereas in Ireland this number is 0.52g/pkm. From an ecological point of view facilitating a modal shift towards rail is therefore especially worthwhile in countries with a high share of electrification (given that the power generation in the respective countries has low average NO_x emissions). In any case, the use of electric drivetrains shifts the source of NO_x emission out of residential areas. As a consequence the impact on health is reduced. In addition, the usage of renewable energy sources is enabled.

Table 7. Potential effect on PM emissions by selected ITS applications [in tons]

	Range	2015	2020	2025	2030
PTI	Min. potential	-384	-493	-707	-986
	Max. potential	-1,476	-1,887	-2,693	-3,750
CSS	Min. potential	-1	-4	-8	-9
	Max. potential	-2	-6	-12	-14
MPD	Min. potential	-135	-230	-344	-456
	Max. potential	-324	-552	-826	-1,095

As a result of the introduction of the examined ITS applications PM emissions are expected to decrease compared to the baseline scenario: In 2030 by about 0.78% - 2.96% with PTI, 0.36% - 0.87%% with MPD and 0.01% with CSS (see Table 7). The modal shift towards buses has a great potential to limit PM emissions effectively. Both specific TTW and WTW emissions are lower than cars'. The effect of the modal shift towards railway again strongly depends on the electrification and the power generation system of the respective country. In Ireland, the specific PM emissions of trains are around 3.5 times higher than cars' in 2010. In contrast, in Switzerland WTW emissions are virtually zero, because electric rail has no TTW PM emissions and there are almost no WTT emissions arising due to the high share of hydro and nuclear power in the country.

4.3.2 Noise: The effect of the selected information technologies on noise emissions is expected to be negligible. Empirical studies give no evidence of noise reductions. The modal shift connected to the introduction of ITS applications will decrease the number of private cars on the street in the short term. Accordingly, fewer sources of noise emissions will have a reducing impact on the overall noise level. However, the shift to buses may have a negative impact on noise levels, since the noise emissions of buses are significantly higher than for cars. Additionally, as a rebound effect the free road capacity will be filled with additional traffic, which also diminishes the positive effect on noise. The shift towards rail can offer some benefits: At any given sound pressure level, rail noise is typically perceived as less annoying than road noise.

4.3.3 Traffic Safety: In the evaluated studies no empirical evidence about the influence of the selected ITS applications on transport safety is reported. However, a positive effect is expected by the shift from individual to public transport. From a statistical point of view

[2] Measured in pkm travelled with electric drive trains / all rail pkm

traveling by train is significantly safer than traveling by car. In 16 of the 27 EU countries, no rail traffic fatalities were reported in 2010 [21]. Accordingly, there might be some potential for personal travel information and mobile payment devices to improve safety. The impact of car sharing on traffic safety is not clear. On the one hand, drivers travelling more kilometres per year typically have lower crash rates per kilometer than those driving fewer kilometres, suggesting an adverse impact of car sharing on traffic safety. On the other hand, people who do not own a car will drive less and use public transport more frequently. Lower overall miles driven by car will result in reduced overall crashes even if the crash rate per mile does go up. Furthermore, Keall *et al.*, [32] indicated that driving with a passenger is safer than driving without, although gender and age could have a strong mitigating effect. He argues that the responsibility drivers feel towards their passengers might outweigh any distraction from talking to them. Since the occupancy rate of shared cars is higher than for private cars, this may have a positive impact on traffic safety.

4.3.4 Congestion: The contribution of the ITS applications to lower congestion is expected to be limited. A modal shift to public transport should reduce congestion in theory, but hints for a positive effect on congestion could be found neither in the assessed ITS projects nor in the available literature. The most likely reason for this is a high latent demand for road infrastructure use by drivers, i.e. the new available capacity is immediately used by additional travellers. Due to this rebound effect the impact of the ITS applications to decongest transport infrastructure in the long term (on an economic scale) is supposed to be low. However, short-term decongestion (on an individual scale) is possible, especially for PTI: If users are able to anticipate traffic disruptions like accidents they can avoid these bottlenecks and effectively reduce travel time, cost and emissions.

5. Conclusions

In this paper we estimated the mobility and EU-wide decarbonisation potential of three ITS applications: personalised travel information (PTI), car sharing schemes (CSS) and mobile payment devices (MPD). It was found that for all three applications a significant shift from car use to use of public transport is expected, indicating that these options supports co-modality. Additionally, PTI and MPD could significantly contribute to the decarbonisation of passenger transport in the EU: about 1-3% and 0.5 – 1% in 2030, respectively. The EU-wide CO_2 reduction potential of CSS is expected to be significantly smaller, which is mainly the consequence of the smaller market penetration rate of this option.

The analysis carried out in this paper is characterised by various uncertainties and further research on this topic is needed. The main source of these uncertainties is the limited availability of ex-post (and ex-ante) evaluation studies on implemented (or planned) schemes, resulting in a limited amount of empirical evidence on the mobility impacts of these schemes. Particularly the impacts on total transport demand (rebound effects) are missing, although they are crucial to provide reliable estimates of the overall mobility and environmental impacts. Another issue on which further research is needed is the methodology to estimate assignability factors to transpose impacts of ITS applications from one country to another. More study on relevant indicators as well as relevance points could further improve this methodology.

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References

[1] AEA, CE Delft, TPER, "Developing a better understanding of the secondary impacts and key sensitivities for the decarbonisation of the EU's transport sector by 2050", Oxfordshire, (**2012**).
[2] AECOM Transportation, "Study on Public Transport Smartcards – Final Report", Published by AECOM Transportation, Birmingham, UK **(2011)**.
[3] AMITRAN, "CO_2 Assessment Methodology for ICT in Transport", Deliverable 4.1: Requirements and design of the methodology, (**2012**).
[4] M. Bak and P. Borkowski, "Integrated ticketing in passenger transport as a chance to improve interconnectivity", Proceedings of the 12th World Conference of Transportation Research (**2010)** July 11-15; Lisbon, Portugal.
[5] BFE, "Evaluation Car-Sharing: Schlussbericht", Bundesamt für Energie BFE, Switzerland, (**2006**).
[6] T. Briceno, G. Peters, C. Solli and E. Hertwich, "Using life cycle approaches approaches to evaluate sustainable consumption programmes – Car-sharing", Working Paper no. 2/2005, Norwegian University of Science and Technology (NTNU), (**2005**).
[7] S. Cairns, L. Sloman, C. Newson, J. Anable, A. Kirkbride and P. Goodwin, "Smarter Choices – Changing the Way We Travel. Final report of the research project: 'The influence of soft factor interventions on travel demand'", Printed by Department for Transport, London, **(2004)**.
[8] F. Cheung, "Real-time multimodal travel information in the Netherlands", Proceedings of the European Transport Conference (**2010)** October 11-13; Glasgow, Scotland.
[9] C. Chorus, E. Molin, B. van Wee, T. Arentze, Z. Sun and H. Timmermans, "Personal Intelligent Travel Assistants: Gebruik en Mogelijke Effecten", Tijdschrift Vervoerswetenschap, vol. 42, no. 2, **(2006)**, pp. 4-9.
[10] A. Cohen, S. Shaheen and R. McKenzie, "Carsharing: a guide for local planners", Published by Institute of Transportation Studies, University of California, Davis, **(2008)**.
[11] Department for Transport, "Operational Research Unit. Personalised travel planning: evaluation of 14 pilots part funded by DfT", **(2005)**.
[12] Department for Transport, "Making Personal Travel Planning Work: Practitioners' Guide", **(2008)**.
[13] Department for Transport, "Smart and Integrated Ticketing Strategy", Published by DfT, London, UK **(2009)**.
[14] Derbyshire County Council, "Carbon reduction strategy: road transport network", **(2011)** April.
[15] G. Doka and S. Ziegler, "Complete Life Cycle Assessment for Vehicle Models of the Mobility CarSharing Fleet Switzerland", Proceedings of the 1st Swiss Transport Research Conference, **(2001)** March 1-3, Monte Verità/Ascona, Switzerland.
[16] EC, White Paper - European transport policy for 2010: time to decide, COM (2001) 370, Brussels, (**2001**).
[17] EC, Keep Europe moving -Sustainable mobility for our continent Mid-term review of the European Commission's 2001 Transport White Paper, Brussels, 22.06.2006 COM(2006) 314 final (**2006**).
[18] EC, Communication from the Commission – Action Plan for the Deployment of Intelligent Transport Systems in Europe, COM (2008) 886, Brussels (**2008**).
[19] EC, Directive 2010/40/EU of the European Parliament and of the Council of 7 July 2010 on the framework for the deployment of Intelligent Transport Systems in the field of road transport and for interfaces with other modes of transport, Brussels (**2010**).
[20] EC, White Paper – Roadmap to a single European transport area – Towards a competitive and resource efficient transport system, COM (2011) 144, Brussels (**2011**).
[21] EU Transport in figures: statistical pocketbook 2012, **(2012)**.
[22] EMTA, Study on electronic ticketing in public transport – Final report, Paris **(2008)**.
[23] Forum for the future, "The sustainability business case for a South West smart card", Published by Forum for the future, London, UK **(2009)**.
[24] P. Gentile, "An Integrated Approach to Urban Traffic Management Mobility Telematics Applications in Turin – The 5T Project", Proceedings of the Joint Conference on Smart CO_2 Reduction, **(2000)** March 2-3; Turin, Italy.
[25] Ü. Haefeli, D. Matti, C. Schreyer and M. Maibach, "Evaluation Car-Sharing: Schlussbericht", Published by Interface Institut für Politikstudien, **(2006)**.

[26] C. Harmer and S. Cairns, "Carplus annual survey of car clubs 2011/2012 – London", Published by TRL, Wokingham, Berkshire, U.K and HIS, Berkshire, UK **(2012)**.
[27] H. Haydock, "Transport Direct Evaluation: Final Report for Department for Transport", **(2007)**.
[28] ITIF, "Explaining international IT application leadership: Intelligent transportation systems", Washington D.C. (**2010**).
[29] H. Iseki, A. Demisch, B. D. Taylor and A. C. Yoh, "Evaluating the Costs and Benefits of Transit Smart Cards", Published by the Institute of Transportation Studies, University of California, Berkeley, USA **(2008)**.
[30] K. Ito, H. Kato and N. Shibahara, "Life Cycle CO_2 emissions for Local Passenger Transport Modes of Different Passenger Flow Volume", Proceedings of the 9th International Conference on EcoBalance, **(2010)** November 9-12, Tokyo, Japan.
[31] E. Kamar and E. Horvitz, "Collaboration and Shared Plans in the Open World: studies of Ridesharing", Proceedings of the Twenty-First International Joint Conference on Artificial Intelligence, **(2009)** July 11-19, Pasadena, USA.
[32] M. D. Keall, W. J. Frith and T. L. Patterson, "The influence of alcohol, age and number of passengers on the night-time risk of driver fatal injury in New Zealand", Accident Analysis & Prevention, vol. 36, no. 1, **(2004)**, pp. 49-61.
[33] LINK, "Intermodal passenger transport in Europe", Passenger Modality from A to Z, LINK – the European Forum on Intermodal Transport Travel, (**2010**).
[34] E. W. Martin and S. A. Shaheen, "Greenhouse gas emission impacts of carsharing in North-America", Published by Mineta Transportation Institute, San José, **(2010)**.
[35] E. Martin, S. A. Shaheen and J. Lidicker, "Impact of Carsharing on Household Vehicle Holdings", Transportation Research Record, vol. 2143, **(2010)**, pp. 150-158.
[36] E. Matsoukis, "Congestion Charging / Carpooling / Carsharing: Solutions for Reducing Traffic Congestion, Pollution, and Vehicle kms traveled", Proceedings of the Greek Road Federation conference, **(2007)** July 8-9, Patras, Greece.
[37] N. McDonald, "Multipurpose Smart Cards in Transportation: Benefits and Barriers to Use", University of California Transportation Center Research Paper #630, **(2000)**.
[38] MEASTRO, "Monitoring Assessment and Evaluation of Transport Policy Options in Europe", Final Report, (**1999**).
[39] A. Millard-Ball, G. Murray, J. ter Schure, C. Fox and J. Burkhardt, "Car-Sharing: Where and How It Succeeds, Published by Transportation Research Board, Washington, USA **(2005)**.
[40] Mobility Genossenschaft, Geschäfts- und Nachhaltigkeitsbericht 2011, Published by Mobiliy Genossenschaft, Luzern, **(2011)**.
[41] MoMo, "More Options for Energy Efficient Mobility through Car-Sharing", The State of European Car-Sharing, (**2007**).
[42] MoMo project, "More options for energy efficient mobility through car-sharing", The environmental impacts of car-sharing use, **(2009)**.
[43] MoMo project, "More options for energy efficient mobility through car-sharing", Mobiliy packages- package offers of integrated sustainable urban mobility, **(2009)**.
[44] MoMo project, "More options for energy efficient mobility through car-sharing", Car-Sharing in Small Cities, **(2009)**.
[45] MoMo project, "More options for energy efficient mobility through car-sharing", Collaboration with Public Transport Operators, **(2009)**.
[46] M. Moses, "The moses guide: Keys to car-sharing", **(2005)**.
[47] OPTIMISM, "Identification of ICT options enhancing co-modality", Deliverable 4.1 of the OPTIMISM project (Optimising Passenger Transport Information to Materialize Insights for Sustainable Mobility), (**2012**).
[48] S. A. Shaheen and A. Cohen, "Growth in Worldwide Carsharing: An International Comparison", Transportation Research Record: Journal of the Transportation Research Board, vol. 1992, **(2007)**, pp. 81-89.
[49] I. Skinner, H. Van Essen, R. Smokers and N. Hill, "Towards the decarbonisation of EU's transport sector by 2050 – Final report", Oxfordshire, (**2010**).
[50] L. Sloman, "Less Traffic Where People Live: How local transport schemes can help cut traffic", Printed by Transport for Quality of Life, Machynlleth, **(2003)**.
[51] Socialdata, "TravelSmart Lowestoft – Final Report on the Individualised Travel Marketing Project in Lowestoft (2008-2009)", Report for Suffolk County Council and Waveney District Council, **(2010)**.
[52] Z. Sun, "Travel Information Impact on Activity-Travel Patterns", Printed by Technische University Eindhoven, Eindhoven, **(2009)**.
[53] Statistische Ämter des Bundes und der Länder: Statistik Portal.
[54] Syndicat des Transports d'Île-de-France, La mobilité en Île-de-France : enquête globale transport, Published by STIF, Paris, France **(2012)**.

[55] Syndicat des Transports d'Île-de-France, Diagnostic et orientations pour le nouveau plan de déplacements urbains d'Îls-de-France, Published by STIF, Paris, France **(2009)**.
[56] TML, TREMOVE economic transport and emissions model, http://www.tmleuven.be/methode/tremove/home.htm, (**2010**).
[57] Y. Yim and M.A. Miller, "Evaluation of TravInfo™ Field Operational Test: Final Report", **(2000)**.
[58] UKERC, "The Rebound Effect: an assessment of the evidence for economy-wide energy savings from improved energy efficiency", London **(2007)**.

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