Research activities on sustainable and inclusive transport systems carried out at the Politecnico di Torino - DIATI

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Research activities on sustainable and inclusive transport systems carried out at the Politecnico di Torino – DIATI

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Transport systems are one of the cornerstones of any environmentally sustainable and socially inclusive modern society. It is therefore of critical importance to improve their performances under both these viewpoints. This contribution is presenting a selection of recent research activities carried out by the Transport research group at the Politecnico di Torino – Dept. DIATI that touch at some of these key issues: starting from a closer look at the opportunities and challenges of electrification and the use of shared vehicles the paper lands to a broader view on how transport planning processes can be supported by researchers to limit environmental impacts and promote inclusiveness.
Keywords: *electrified vehicles, car sharing, mobility plans, gender studies.*

Attività di ricerca sui sistemi di trasporto sostenibili e inclusivi svolte presso il Politecnico di Torino – DIATI. *I sistemi di trasporto sono uno degli elementi fondanti di ogni società moderna che sia sostenibile sul piano ambientale ed inclusiva sul piano sociale. E' perciò d'importanza fondamentale migliorare le loro prestazioni considerando entrambi questi aspetti. Il presente contributo descrive una selezione di recenti attività di ricerca svolte dal gruppo "Trasporti" del Politecnico di Torino – Dip. DIATI che indagano alcune di queste tematiche: a partire da un approfondimento sulle opportunità e le sfide poste dall'elettrificazione e dalla mobilità condivisa, l'articolo approda ad un allargamento della prospettiva su come la ricerca può assistere i processi di pianificazione dei trasporti nel limitare gli impatti ambientali e promuovere l'inclusività sociale.*
Parole chiave: *veicoli elettrificati, mobilità condivisa, piani della mobilità, studi di genere.*

1. Introduction

Transport systems are one of the cornerstones of any environmentally sustainable and socially inclusive modern society. It is therefore of critical importance to improve their performances under both these viewpoints, where many progresses have been made in past decades and are undergoing though sometimes only partially meeting the high level of ambition and expectations from decision makers, stakeholders and the general public. It is generally acknowledged by researchers in this area that there is a need to more effectively tackle the transforming problems of transport systems, tacking stock of new technologies from different sectors, better exploiting mobility data that are available nowadays and, more in general, developing new inter- and trans-disciplinary research approaches. This contribution is presenting a range of recent research activities carried out by the Transport research group at the Politecnico di Torino, Dept. DIATI, that touch at some of these key issues, starting from a closer look at the opportunities and challenges of electrification and the use of shared vehicles in road transport to a broader view on how transport planning processes can be supported by researchers to limit environmental impacts and promote inclusiveness.

2. Sustainable road transport: how far electrification is pursuable?

According to Eurostat, the impact of transport systems in Europe (EU-25) on the overall energy consumption in EU countries was around 33% (2008-2019, EIA, UP/UNEM); as concerns CO_2, transport systems account for almost a quarter of the total emissions from human activities. Globally, according to the IEA (International Energy Agency) WEO (World Energy Outlook) 2020, for 2019, in terms of World Energy Demand, more than 90% of the world's transport-related energy demand is met by crude-oil. In addition, of the total percent of the world's energy demand for oil, 59% comes from the transport sector; of the total primary energy demand, 20% comes from transport. A decade ago, light-duty vehicles were considered responsible for approximately 13.5% of global CO_2 emissions, and considering extraction and the supply chain, the percentage reached 15%; these values are almost conservative in the last years.

On the other hand, it is necessary to consider the constraints imposed on transport systems, focusing on the European ones: pursuit of the partial independence of urban mobility from oil-derived fuels, effects of emissions at global level, containment of urban pollution, the competitiveness of the automotive sector and related industry.

Secondly, the European legislation on air quality (Directive 2008/50/EC) is based on precise principles: as regards the emissions generated by transport systems, it is important to underline the difference between global aspects (carbon dioxide emissions), implying a Well-to-Wheel analysis on the life-cycle, and local ones, linked to Tank-to-Wheel efficiency (Dalla Chiara and Pellicelli, 2016).

Thirdly, the European Community has set ambitious emission performance levels for newly manufactured automobiles and light-duty commercial vehicles, which are consistent with EU commitments under the Paris Agreement. So, to what extent transport research may contribute to these three main purposes?

At first, both studies from ISFORT, at Italian level, and from Politecnico di Torino, at an international one (Dalla Chiara *et al.*, 2019; Caballini *et al.*, 2021), found that more than 60% of daily trips take place within a distance of 10 km whereas only approximately 3% exceed 50 km.

Car driving habits were detected using a dataset obtained from automobiles in use in Europe (Dalla Chiara *et al.*, 2019). A very aggregated analysis of demand trends is not yet sufficient to understand the actual daily mobility of people. To this end, recent researches have been developed with real data from the automotive industry. An analysis was conducted on real trips undertaken in Europe by more than 1,000 vehicles and more than 200,000 automobiles, referring to an extended period that lasted more than one year; the obtained results are an example of the information that can be extracted from rough data to support future decisions of stakeholders and end users (e.g., car makers, authorities, drivers).

The main scope of such study was to investigate whether hybrid and electric powertrains can represent suitable alternatives to traditional engines to pursue abovementioned environmental aims, taking into account available battery ranges, idle times for recharging and charging alternatives. Long distance trips were analysed to better understand whether they could be covered by pure electric cars. In the extensive sample analysed, it would be necessary to increase the driving range to 400 km/day in order to satisfy 99.9% of trips, however not satisfying the queuing issues for recharging. This aspect can be alleviated by adopting a PHEV (plug-in), given box their flexible recharging and less energy requesting batteries. The study provided a quantitative analysis of the energy needs, considering a wide range of road vehicles usage, and the chance for recovering energy during vehicles idle times.

The driving analysis was conducted in two phases. The first step was devoted to identify the most frequent car usages and the structure of the most representative trips; more specifically in this phase single trips were considered, classified according in relation to their length, duration, idle time and frequency of use. The second step aimed at providing an overview of the daily usage of vehicles, considering all the trips performed each day. This second step showed how different trips comprised the entire daily usage, and provided the daily travelled length and duration with reference to a 24h driving cycle.

The frequency of the daily distance for all trips is shown in Figure 1. Extended daily trips are relevant because, although 99% of

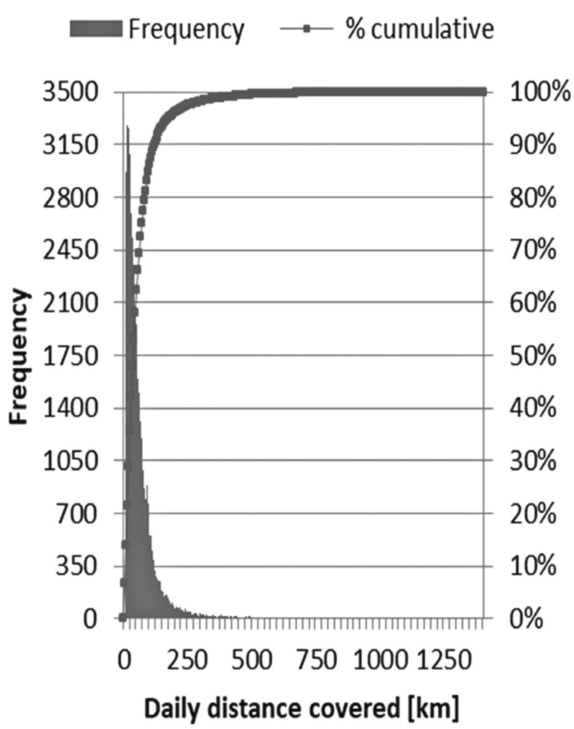

Fig. 1 – Frequency [#days] of the daily distance covered over all the driving cycles (contexts) for all the trips.

the days per user involves at most 400 km/day, only 60% of the days per user involves less than 50 km/day. Instead, this range was observed in 99.9% of the days for an urban context.

The idle time after concluding a journey, was depicted for the entire dataset; all the contexts (urban, extra-urban and motorway) were included (Figure 2).

As it can be seen, in approximately 50% of the cases, the total idle time after finishing a journey is less than 1 hour, 10% is between 1 to 2 hours, 10% is between 2 to 4 hours, 10% is between 4 to 9 hours, and it is more than 9 hours for the remaining cases (20%). The obtained results point out again that the most flexible automobile is the PHEV; yet, for drivers who cannot afford it, BEV-sharing (i.e., a car sharing of plug-in automobiles) may be a good solution, at least during a transitional phase.

Another issue faced by our research was to propose a methodology, unexplored in the literature, aimed at comparing battery recharging scenarios with differently electrified plug-in vehicles (hybrid and full electric, i.e. BEV, with different levels of energy storage). The obtained results have provided interesting insights about both the operability of different types of domestic recharging and the potentiality of recharging architectures that involve the use of larger installed structures, for example at work places.

The results related to a generic simulation day show that PHEVs are much more flexible than the other considered vehicles and have the characteristics necessary to travel with zero local emissions within an urbanised context, with obvious benefits for the environment and for the quality of life of citizens. In addition, their recharging times are compliant with the periods of night rest, as they would be for regular daily work in a stable place. Furthermore, they also show much greater compliance with the electric grid, since the limited capacity allows them to use a slow recharging, also competitive in terms of unit costs when compared to traditional fuels, without penalising the available driving range. Fast and rapid charging not only shows higher costs of energy per kWh, even higher than an equivalent refuelling, but also frequently does not comply with the required time and expected queues, having to deal with shared areas and spots available on public soil; fast and rapid charging also facilitate battery aging. With slow charging, more compliant with a typical daily scheduling of the driver if overlapping with night rest or a daylight physically stable work, PHEVs represent a winning choice to eliminate exhaust gas emissions in urban centres and cities, where the dispersion of pollutants is problematic and the health of citizens is at risk, without sacrificing the benefits associated with ICE (Internal Combustion Engines). As far as BEVs are concerned, their charging times, which are usually approx. four times longer than those of a PHEV charged at home, unless supply contracts are modified, require more attention, but offer the advantage of being able to be connected to the grid in a V2G configuration.

The spread of electrified vehicles with an average distance driving range in pure electric mode (8-12 kWh, indicatively), particularly suitable for covering medium-short

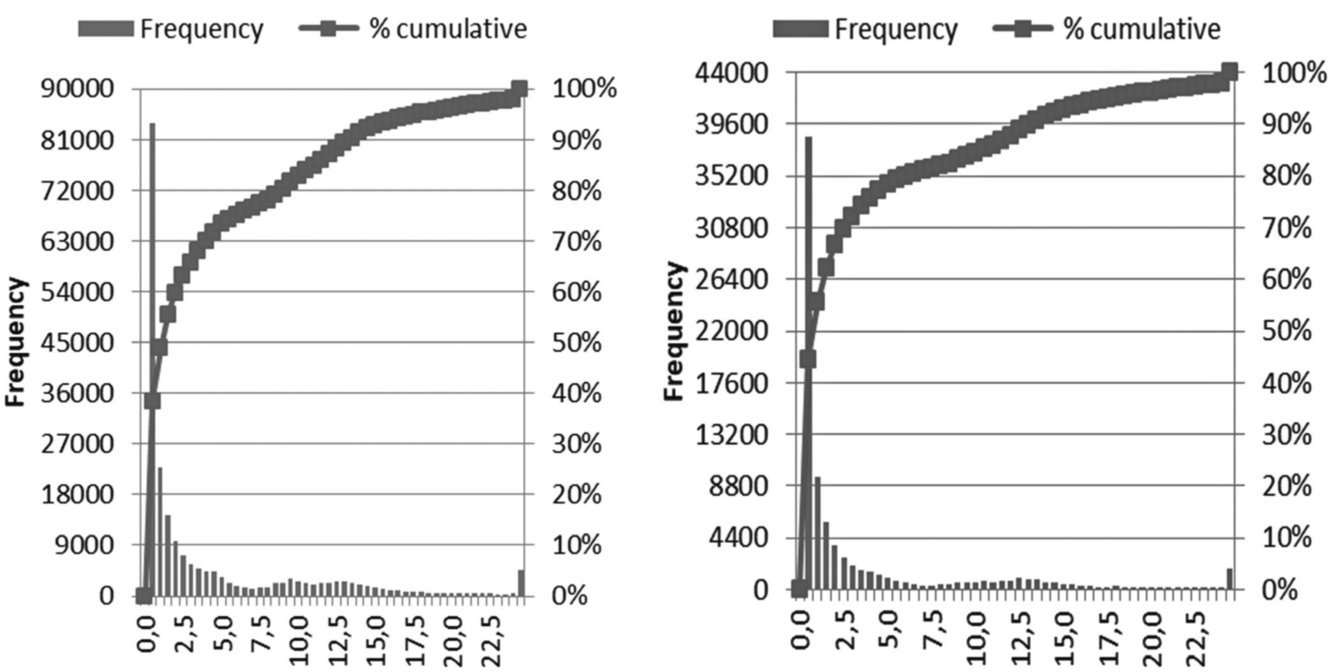

Fig. 2 – Idle time after finishing a trip [h] for all the driving cycles (left) and in an urban driving cycle (right).

distances, such as those from home to work places, or traveling in urban and sub-urban environments, could also benefit from the availability of extended facilities, such as public car parks equipped with recharging points.

Concluding, urban areas have a technological solution at disposal for the next one-two decades, suitable to satisfy both demand of drivers – according to analysed data – and supply of automobiles by carmakers. Meanwhile, extra urban area require much more ambitious and financially brave perspectives if BEV – and not a flexible PHEV – was deemed to be supported at all costs for any environmental reason, as detailed below.

3. *Traffic simulation to analyse innovative solutions for charging electric vehicles*

The majority of fully electric vehicles (BEV or FEVs) currently satisfy the electric energy requirements for their motion with on-board batteries. Extensive literature on their limitations focuses on battery problems, particularly on limitations in size and power, battery weight, life and recharge time, and the lack of a wide network of electric charging points. These problems are even more relevant for freight distribution services, where the vehicle masses and daily distances are much greater compared with those of passenger cars (12-20 times higher). In this case, a stationary recharge could require many charging stations not only located at depots, but also distributed in the service area, to provide more charging opportunities during the delivery routes. For this reason, the charging-while-driving (CWD) system or dynamic wireless charging could provide a technology to contain the battery sizes and recharging infrastructure costs without impacting on the vehicle autonomy, while investing on the "technological infrastructure".

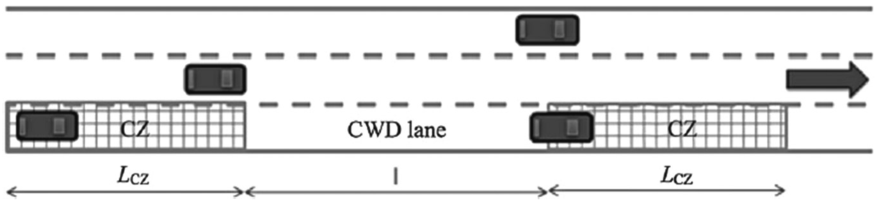

Fig. 3 – Scenario layout for CWD in a road with three lanes.

Figure 3 shows a CWD lane scheme, with two charging zones (CZs) represented. The EVSE (Electric Vehicle Supply Equipment) includes inductive coils placed under the pavement surface, at a relative distance, which generate a high frequency alternating magnetic field to which the coil on the car couples and power is transferred to charge the battery. A proper design procedure should consider both the service provider's need to minimize the installation and maintenance costs and the users' acceptance of the time required for a proper recharge in the CWD lane.

3.1. Traffic and energy assessment

A method for analysing the performance of the wireless inductive charge-while-driving (CWD) electric vehicles, from both traffic and energy points of view is presented in Deflorio *et al.* (2015). To accurately quantify the electric power required from an energy supplier for the proper management of the charging system, a traffic simulation model is implemented. This model is based on a mesoscopic approach, and it is applied to a freight distribution scenario. Lane changing and positioning are managed according to a cooperative system among vehicles and supported by Advanced Driver Assistance Systems (ADAS). From the energy point of view, the analyses indicate that the traffic may have the following effects on the energy of the system: in a low traffic level scenario, the maximum power that should be supplied for the entire road is simulated at approximately 9 MW; and in a high-level traffic scenario with lower average speeds, the maximum power required by the vehicles in the charging lane increases by more than 50 %.

The implemented dynamic traffic simulator in Deflorio and Castello (2017) adopts a mesoscopic approach by updating traffic and energy data only for the simulated vehicles at defined nodes along the road, generally spaced in hundreds of metres. The traffic simulator operates according to a cooperative driving behaviour among vehicles, for both the overtaking manoeuvres and the entries management. Primary traffic parameters can be estimated in the CWD lane, such as vehicle count, average speeds, and delays, which are time dependent and significantly changed along the road. The model also allows the implementation of a speed control strategy to manage temporary incidents, for example due to extraordinary maintenance operations. This strategy could also be applied in the case of high traffic volumes to facilitate the entries of vehicles from on-ramps. The traffic model is able to manage queuing conditions and delays caused by the strategy, when headways in the CWD lane are required to be higher than an established value. With respect to conventional dynamic traffic models, the current vehicle energy requirements affect the drivers' behaviour.

3.2. Dynamic charging along urban arterial roads

A method based on traffic micro-simulation to support feasibility studies on CWD systems for fully electric vehicles in urban environments is presented in Deflorio and Castello (2015). The examined CWD solution is deployed by charging zones (CZs), which are installed before the stopping lines at signalised intersections. The opportunity to charge an electric vehicle en route is provided for almost stationary vehicle conditions, when it may be in queue for junction control requirements. The analysed scenario refers to a 2 km urban arterial with eight signalised intersections, where 10% of the traffic is assumed to be electric vehicles. CWD performance results are reported from the viewpoints of both driver and energy provider. The estimated stop time for electric vehicles at any section can vary and is often below 30 s. However, the entire stop time for a vehicle along the arterial is higher: ~50% of the vehicles can charge in a range of 10-65 s. From the energy operator's viewpoint, a support analysis for the CZ location was performed by observing the charging opportunities at various sections. Finally, the total electric power provided for the entire system is estimated.

3.3. Simulation for the daily energy to dynamic charge electric vehicles on motorways

An application for motorway scenarios of charge while driving (CWD) also known as dynamic charging systems for fully electric vehicles (FEVs) is investigated with three lanes, where the right-hand lane is reserved for charging at defined speeds for FEVs. The input traffic flow for the motorway is simulated according to an hourly time profile along the day. To generalise the simulation for various traffic levels, the traffic flow for any time interval is estimated on the base of the traffic density, known from available data. The FEVs are only a part of the whole traffic and their input traffic is estimated as a percentage. The principal aim of this study is to estimate the daily energy provided to electric vehicles by the CWD system, which can be used, together with other data if available, to build possible business models and help stakeholders configure charging services. For this reason, the total energy provided is estimated by simulation for different scenarios.

3.4. Travel Patterns from Floating Car Data in Electric Mobility Scenarios

Understanding the potential of electric vehicles in current car mobility scenarios is crucial to plan a realistic deployment of charging stations and vehicle features. In the Incit-EV project, daily travelled distances are analysed to understand if the observed car usage can be satisfied with the expected range of electric vehicles (EVs). Moreover, idle times between trips are studied for assessing the vehicle needs for electric charging stations (ECSs) infrastructure to support EV travel. The datasets are derived by floating car data recorded for 365 days and contain more than 30 million trips crossing Turin Metropolitan City. Approx. 70,000 km are daily observed for more than 10,000 vehicles (up to 18,000) in each day of 400 different vehicle models, to identify daily activities, considering electric vehicles can be preferably recharged for long periods overnight. This assumption can be considered a reference scenario, in synergy with the battery range, to plan ECSs in road networks. Results show that 97% of daily VKT (vehicle kilometres travelled) is less than 200 km, over a year of observation for the whole set of vehicles. Cars are also classified according to their market segment to identify specific vehicle usage. Indeed, daily VKT values estimated for segment A (i.e. mini cars) have an average of 34 km, whereas for segment E (i.e. executive or large cars) the average is 75 km. The idle times analysis reveals a higher number of shorter breaks in the city centre compared to peripheral districts, suggesting that recharging solutions should be adapted to zones according to how they are used by vehicles.

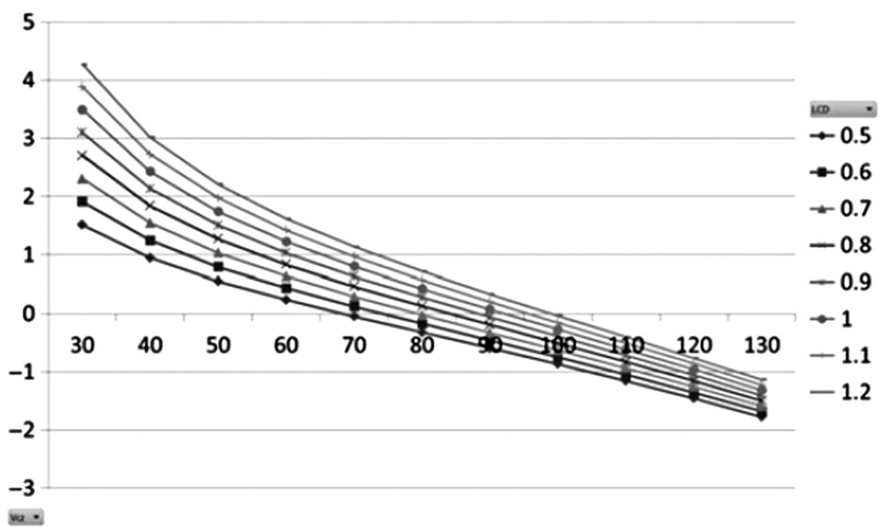

Fig. 4 – Gain of energy [kWh/km] at various speeds [km/h] for different lengths of the charging device [m].

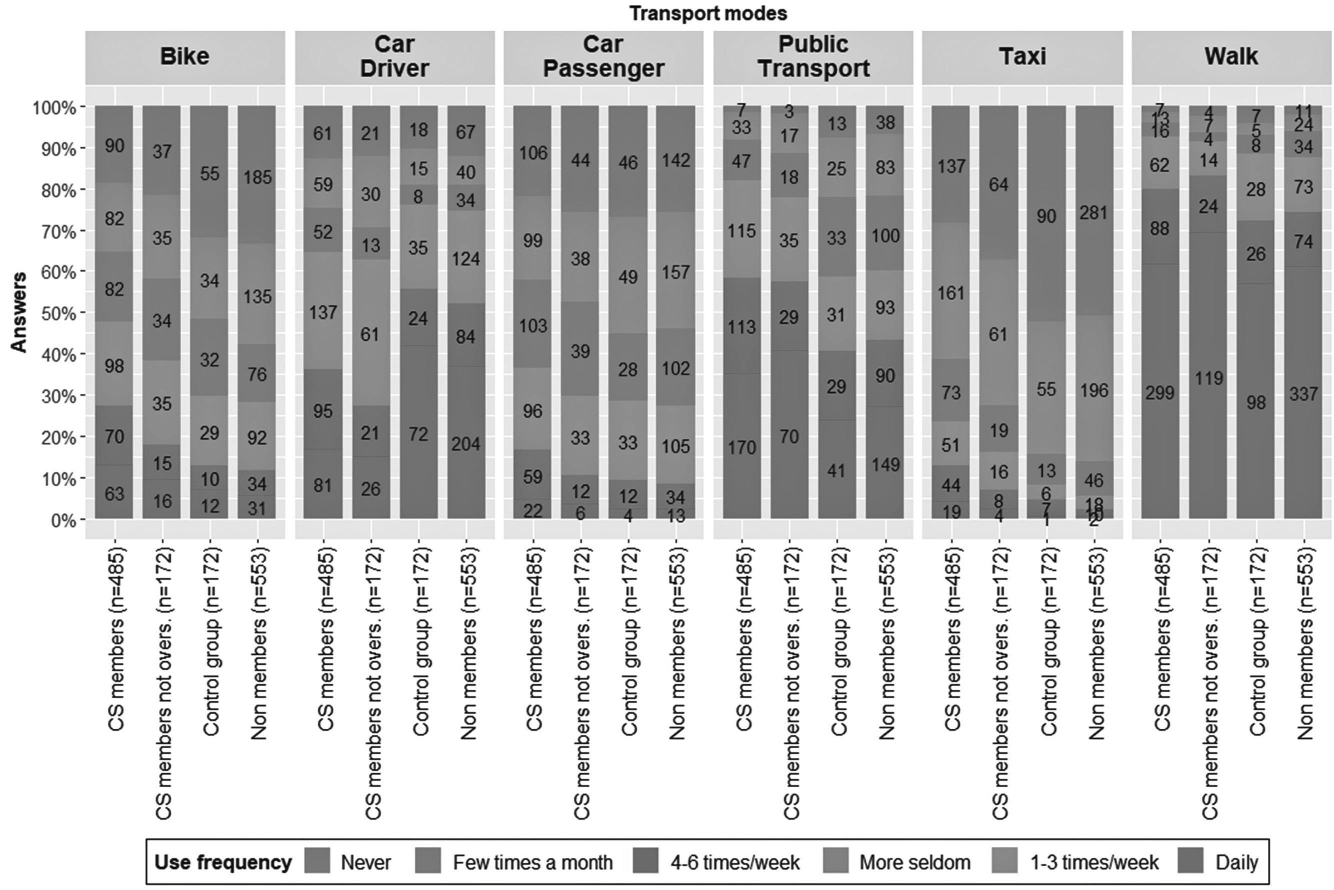

Fig. 5 – Use frequency of different travel modes – car sharing members and non-members – source: http://stars-h2020.eu/wp-content/uploads/2020/04/STARS-5.1.pdf.

4. Car sharing services impacts on urban mobility scenarios

Beyond electrification issues that have been discussed in the previous sections – that, in some cases, can be satisfied by placing car-sharing before the technological affordability of new powertrains – a wider change of paradigm in the ownership and use of private vehicles is another promising avenue to improve the sustainability and the inclusiveness of transport systems. The STARS project aimed at understanding the potential benefits of shared vehicle services that are steadily expanding in urban areas and their impacts in terms of congestion mitigation, environmental footprints and social inclusion.

Acting both as project coordinators and technical delivery partners, the DIATI transport research group was involved in many research activities, starting from an inventory of existing car sharing systems in Europe. Data collected through desktop research were used to develop a multidimensional classification of CS services with a bottom-up approach that considered service operational characteristics, vehicles type, pricing, and subscription fee. Then we collaborate in the distribution and analysis of a questionnaire mainly developed by the University of Gothenburg to understand the profiles of both users and non-users of car sharing in European cities concerning their travel patterns and psychological aspects (e.g. attitudes, acceptability of car sharing, personal norm). Five distinct mobility styles were identified and furtherly characterized by sociodemographic variables and by the motives for making use of car sharing (Ramos, Bergstad, Chicco, & Diana, 2020).

Another activity led by our group consisted in the design and distribution (at least in Italian cities) of a mobility questionnaire targeted to car sharing users and non-users of different European cities (from Germany, Italy and Belgium) aimed at evaluating the car sharing impacts on personal long-term mobility choices (such as car ownership) and how these changes are influencing the use of different travel modes and everyday mobility decisions. In this perspective, we evaluated car sharing's potential role in satisfying the current travel demand by looking at the substitution and complementary patterns that may change the travel demand for all competing modes (motorized individual means, taxis, active means, and public transport). The questionnaire consisted of four main sections: travel behaviour and mobility habits (where the use frequency of different travel means was investigated), a compact travel diary about the last trip performed with any mode (non-users) and with car sharing (users), changes in car ownership, and sociodemographic characterization of the respondents.

Descriptive person-level analyses about changes in the use of different transport modes and changes in car ownership levels after car sharing registration showed that car sharing users tend to own fewer cars, more public transport passes and bike-sharing membership than non-users. Consequently, car sharing users are more multimodal (Figure 5). Among car sharing users, however, differences were found according to the variants they are registered for. In particular, when modelling the car shedding among German car sharing users living in inner cities areas (where all main car sharing variants were available, namely roundtrip station-based, one-way free floating, and combined), albeit all car sharing users reported significantly lower levels of car ownership than before registering to the service, roundtrip station-based users were about 15 times more likely to reduce car ownership than free-floating unique users.

Besides, in order to predict the switch from the current mode used to car sharing for a specific trip and personal characteristics of respondents (the potential travel demand that can be attracted by car sharing as mentioned above), trip level analyses were carried out. Binomial logit models calibrated on a previously collected dataset (Ceccato, Chicco, & Diana, 2021; Ceccato & Diana, 2021) were applied to the non-users data that were collected in Italy and different mobility scenarios were identified. Related emissions of pollutants and greenhouse gases were quantified and monetized through unit costs to understand how to maximize car sharing's positive environmental impacts.

According to the switch models' explanatory variables, the configuration that determined the lowest externalities – the planning scenario – was obtained by changing car sharing and private car costs. In this way, car sharing should substitute trips currently performed by private cars rather than trips performed with more sustainable modes (PT and active ones).

Modal switch models' results showed that one-way car sharing has the potential to cover up to 10% of the daily travel demand in the planning scenario (Figure 6). Although the diverted travel demand was mainly subtracted from private cars, the environmental benefits were partially offset by switches from public transport and active modes. Concerning the externalities related to the whole transport system's emissions, the planning scenario would lead to a reduction of 1% in terms of social costs. Such benefits can be increased up to 3.6% by promoting electric car sharing fleets (Figure 7) (Chicco & Diana, 2021).

5. Supporting local authorities in sustainable transport planning

Sustainable transport planning is a fundamental requirement for cities that want to improve their citizens' mobility and freight significantly. Although larger authorities are relatively well equipped

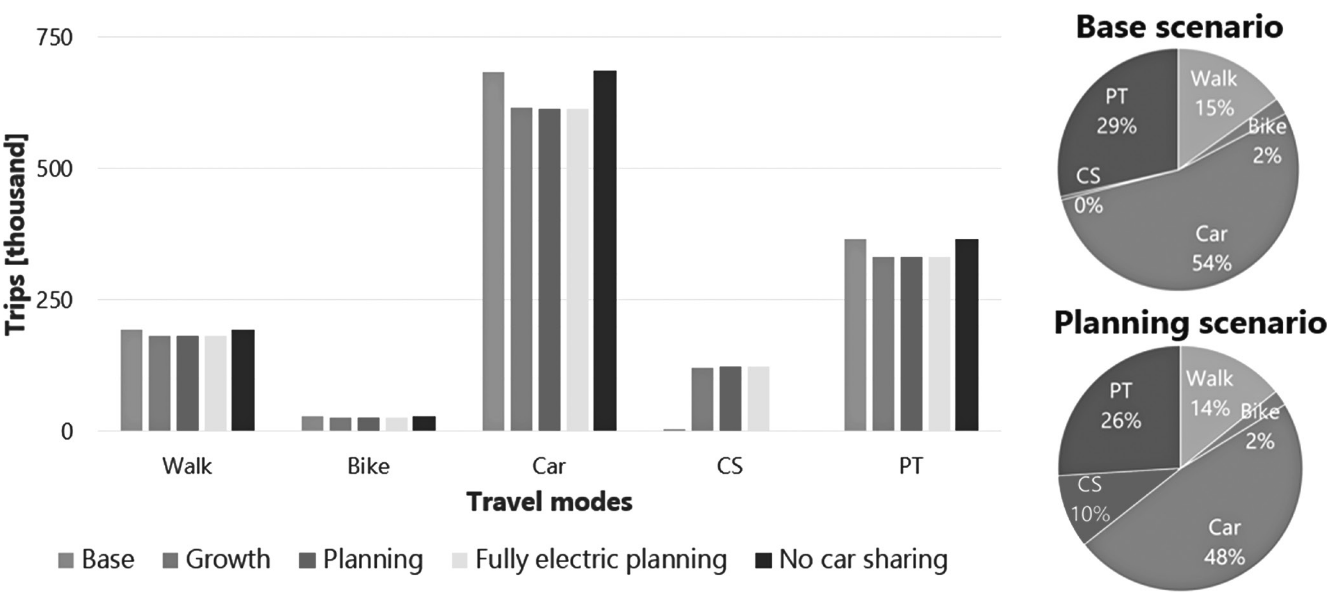

Fig. 6 – Diverted daily trips and market share in scenarios – source: Data retrieved from (Chicco & Diana, 2021).

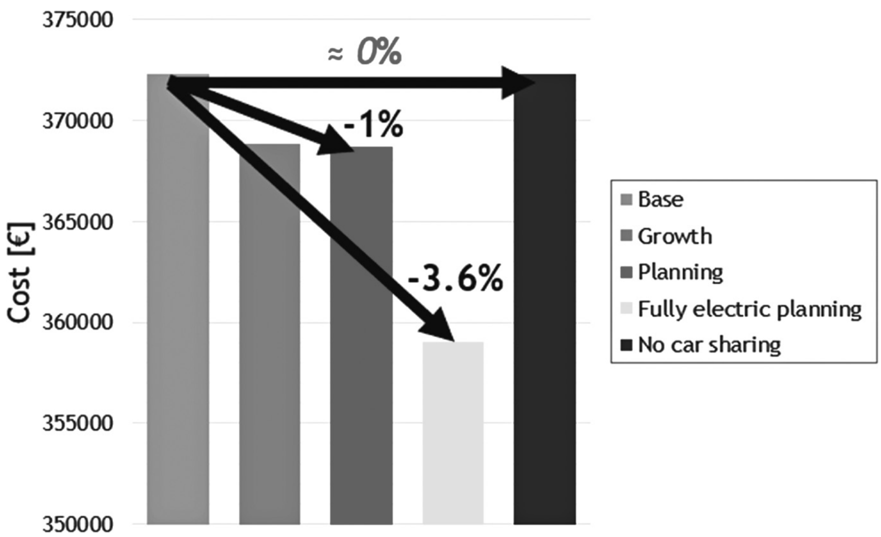

Fig. 7 – External costs of pollutants and GHG emissions in scenarios – source: Data retrieved from (Chicco & Diana, 2021).

to face these challenges, smaller, more traditional Local Authorities (LAs) may lack the knowledge and capacity to plan and implement innovative and sustainable transport measures. The H2020 European project SUITS aimed at supporting the capacity building of small – medium local authorities in developing sustainable transport measures. The project adopted a socio-technical approach and focused its first activities on understanding how nine European LAs were addressing the challenges associated with developing sustainable transport measures, the use of real-time mobility and more interdepartmental and technologically supported ways of working (Diana *et al.*, 2018). The larger LAs had more time to engage with the project and piloted the tools and methods developed, thanks to their larger departments. Their experiences and practices were transferable to the follower cities who could learn from the larger LAs and benefit directly from the proven outputs.

Data collection is known to be a fundamental step for the observation of passenger and freight movements at the city level. Furthermore, data analysis is a priority in developing proper sustainable measures and planning and implementing solutions at the city level. However, as found in the project's preliminary activities, an absence of an appropriate focus on data collection and modelling is observed in most of the LAs. Within SUITS, a pilot activity based on the freight data gathering in Turin (Italy) has been conducted to inform the implementation of new measures to meet congestion problems and the level of know-how needed to extract useful data.

The methodology is developed to help cities investigating a specific aspect characterising and influencing their mobility, namely the observation of freight flows from the demand side, through the exploitation of existing datasets such as Global Position System (GPS) vehicle traces. This latter information was combined with another kind of data derived from the infrastructure, namely traffic flows characterizing the road network. The innovative combination of these two kinds of data aims at identifying the most congested areas, thanks to the creation of a highly disaggregated Key Performance Indicator (KPI) based on the time lost in congestion by each vehicle in each road segment (Pirra & Diana, 2019). This KPI can be used to inform a wide range of policy actions within the transport sector, both from the viewpoint of a municipality and from that of an individual actor in the transport system. For example, the analysis provided information about the most congested points of the city in terms of the total amount of time wasted by vehicles in traffic (Figure 8).

The assessment of how urban deliveries affect various areas in the city, mostly those commonly affected by congestion, is a further challenging point while dealing with urban freight policies. Starting from the GPS vehicle traces dataset, spatial analysis is then conducted through a specific GIS-based data mining technique to find the most significant clusters (groups) of service stops in Turin (Diana *et al.*, 2020). Then, a specific area in the Limited Traffic Zone in the city centre was selected as the most suitable where running a survey designed to collect information on the dynamics of freight deliveries and pickups at these locations: operators usually delivering, where the vehicles are parked, exploitation of the available unload/load areas, duration of stops, the number and dimension of packs supplied, and the final destination of such deliveries. This tool can be used to inform a range of policy actions at the municipality level, mainly on the freight delivery side.

As highlighted previously, LAs are starting to deal more and more with managing data collected from different stakeholders involved in urban freight transport. Another challenging point is the evaluation of the city accessibility for freight distribution services. Pirra *et al.* (2019) proposes an innovative approach that starts from the previous GPS vehicle traces data available in Turin and evaluates the accessibility to the city. It is ba-

Fig. 8 – Value of the mean indicator computed for all the arcs of the road network, zoom in the Turin city centre (Reproduced from Pirra and Diana (2019) under the licence https://creativecommons.org/licenses/by/4.0/legalcode).

sed on the travel time estimations along the most frequently used routes that connect relevant areas and their average speed through a simplified road network model. The results obtained confirm the value of this kind of data in assessing the accessibility of different zones interested in delivery operations and provide a fruitful monitoring function to urban logistics operators and LAs while managing urban freight flows.

6. Gender-related contemporary challenges for smart and inclusive mobility ecosystems

Nowadays, when dealing with sustainable transport systems, it is relevant to focus on a buzzword of the beginning of the 21st century: Smart Mobility (SM). This innovative concept involves four main contents: vehicle technology, intelligent transport systems, data, and new mobility services (Carboni *et al.*, 2021). Smart Mobility is seen as a means of delivering key benefits such as containing local pollution, global emissions, traffic congestion, and noise pollution, while increasing safety and improving transfer speed. However, substantial gender inequalities are seen in current transport provision, with SM being a way of opening exciting opportunities for social inequity reduction; an inequity that includes also other aspects, as that of ageing of the population, with possible digital divide, that the SM itself brings with it.

The ambition of the H2020 project TInnGO – Transport Innovation Gender Observatory – is to address contemporary challenges, such as employment, education, and prevalent male-dominated Science, Technology, Engineering and Maths (STEM) cultures and future mobility scenarios in EU transport strategies, in a gender and diversity sensitive way.

The project operates through the development of a pan-European Observatory that leads, coordinates and is fed by 10 Hubs across EU providing leadership, innovation and critique of SM innovations.

Having these concepts in mind, the project considers women not merely as passive users of SM, but also as providers – designers, engineers and innovators. Thus, the project activities move on several fronts. On one side, a modelling approach that embraces multiple methods for understanding women's mobility needs is adopted. The preliminary steps include investigating the literature on the topic and proceeded with focus group activities in the Hubs, intending to explore the thoughts and feelings related to their travel behaviour (Pirra *et al.*, 2021). This approach was the basis for identifying the most pertinent aspects of gendered mobility experience and helped in designing a survey proposed in the 10 Hubs. Data collected will help transport planners and mobility operators to identify needs and differences between men and women, to measure the impact of new services and transport features on gender-equal mobility opportunities.

A pilot data collection activity started in September 2020, intending to collect the first wave of a limited number of responses investigating how the COVID emergency has affected mobility choices (Carboni *et al.*, 2021). Preliminary results reveal that public transport is the mode that has been most affected by the changes in mobility due to the spread of the pandemic, probably being perceived unsafe in terms of infection. Women, found to be the primary users of this transport solution, are indeed the ones who report the main changes, especially for work-related trips. In general, a shift to more sustainable modes of transport, such as walking and biking, is observed.

While dealing with women as users, it is worth investigating their attitude towards new paradigms in the transport offer, such as sharing vehicles and means, being these potential answers of SM to environmental sustainability problems. Shared mobility is one of the focus of the Italian Hub. Some preliminary Hub activities were based on the analysis of a dataset collecting 2934 responses to a survey addressed to both car-sharing users and non-users. Results revealed that, when women and men are considered as different kinds of users, the main characteristics of various clusters of respondents using this service are rather similar despite the gender (Chicco *et al.*, 2020).

As highlighted previously, the project considers women not only as SM users but also as providers. This would require highlighting how a lack of diversity in STEM professionals has contributed towards a fractured and gender-biased transport ecosystem (embracing education, employment, operation, data collection, and innovation) that does not allow a gendered Smart Mobility transport provision. A low number of initiatives for encouraging and supporting women in the transport sector are found in TInnGO countries, so the project will try to fill this gap by yielding new knowledge and proposing innovative ways to tackle this topic. Moving on to a higher level in the provision of innovation, further analyses investigate the research footprint of female transport researchers, revealing that women working in research environments are subjected to similar discriminatory practices as their sisters in industry, indicative of a broader malaise in the sector.

7. Final remarks

This paper has presented an array of recent researches dealing with sustainable and inclusive transport systems. Through the heterogeneity of disciplinary perspectives, research methods and outcomes that have been showcased, it is clear that a radical improvement of such systems cannot come from a single approach or discipline. Through a diversity of backgrounds, research interests and personal experiences, the Transport research group at Politecnico di Torino, at Dept. DIATI, is actively seeking to give contributions in this sector that are at the forefront of international research, thanks to a relatively wide portfolio of funded projects mostly at the European level.

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