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Future mobility and land use scenarios: impact assessment with an urban case study

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Abstract

In recent years the interest in urban mobility has grown considerably, not only due to the local increase in negative externalities generated by transport, but also because recent technological innovations are offering effective solutions especially in urban context. In particular, the introduction of Connected and Automated Vehicles (CAVs) could radically change the mobility scenario allowing, on the one hand, a widespread diffusion of shared vehicles that could feed the stations of the mass rapid transit network, improving the attractiveness of Public Transportation (PT), and on the other, the implementation of Travel Demand Management (TDM) measures on large areas of the most densely urbanized (and congested) territory of a city, without reducing accessibility and creating social exclusion. The present study aims at evaluating, through a system of Land-Use Transportation Interaction (LUTI) models, the impacts on transport demand and on population and activities location, of transportation policies oriented to both enhancing PT and restricting the individual use of the car. The case study analyzed is represented by the urban area of Rome. Several scenarios have been simulated and compared by means of sustainability indicators. Preliminary results show that the improvement of PT services, combined with the introduction of car use restriction and car free areas, do induce not only a significant modal shift towards more sustainable transportation modes, but also a limitation of urban sprawl.

Keywords: future mobility, land use, autonomous vehicles, travel demand management, LUTI models, urban sprawl, sustainable mobility

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1. Introduction

The renewed interest in urban mobility planning stems from the growing awareness of negative externalities generated by transport, but also due to the recent technological innovations that are offering effective solutions especially in urban contexts. The social and demographic changes (UN, 2016) (UN, 2017), the emerging new environmental sensitivities and criticalities (Ricardo-AEA, 2014), and above all of the digital and technological transformation of infrastructures and vehicles (Fig. 1) pose new challenges to transportation planners. In fact, transportation systems might be, in a short time, inadequate to meet the demand that will not only grow, but will become more complex and exigent, and will require high quality standards and customized transportation services. Owning a private vehicle seems to be no longer strictly necessary in some urban areas and users, especially those of the new generations, i.e. *millennials* and *generation z*, are more interested in having access to mobility services rather than having their own means of transportation (Cohen & Kietzmann, 2014). The transition from individual ownership to collaborative consumption seems imminent. Furthermore, the Information and Communications Technology (ICT) are favoring digitalization even in the well-established transportation industry, stimulating the optimization of transportation networks, the cooperation between infrastructure and vehicles, and a massive use of Intelligent Transportation Systems (ITS). At the same time, driven by such ongoing changes, new players are entering the market. These are offering new forms of mobility, such as shared mobility services and Automated Mobility on-Demand (AMoD) mode of transport, and are trying to accommodate users' new habits, even through innovative business models that provide for the integration of mobility services, which are currently offered in a fragmented manner by a vast number of different operators, in a single service aggregator, that is the concept behind the Mobility-as-a-Service (MaaS) platforms (Kamargianni & Matyas, 2017) (Audouin & Finger, 2017).

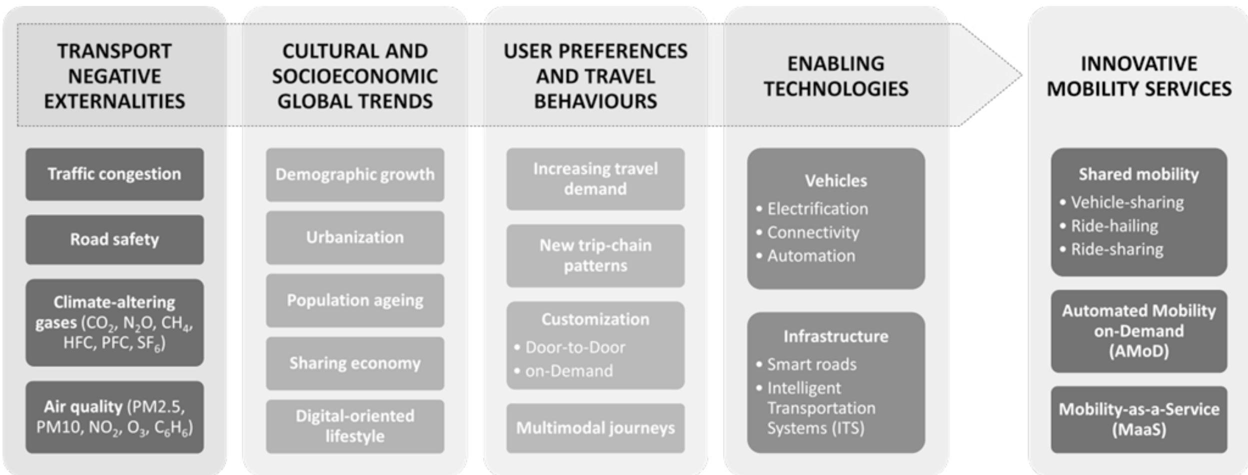

Fig. 1 - Key drivers of future transportation policies.

Under these circumstances, it is widely believed that the transportation of the future will be cleaner, more efficient and safer thanks to the contribution of electromobility, shared mobility, and to the diffusion of advanced vehicles equipped with the highest automation, connectivity and cooperation functions (Alonso Raposo & al., 2017). The penetration of the electric power in the automotive sector will bring significant benefits from the point of view of environmental sustainability, due to the localized reduction of greenhouse gas emissions and pollutants. Moreover, the gradual introduction of connected and automated means of transportation will increase safety; and advantages for air quality are not excluded, for a more efficient consumption of energy. However, the increase in vehicle performance may not be enough to solve the problems of urban traffic, indeed someone claims that it could aggravate them, because of the greater number of induced trips (Atkins, 2016) (Here, 2016). Especially if the introduction of self-driving vehicles will be at the expense of Public Transportation (PT), that is if these vehicles will affect part of the modal split that is now covered by PT rather than replace part of the modal share of private vehicles. In fact, in the worst case, traffic congestion will increase mainly due to the reduction of the value of time, for the possible consequent increase in distances between workplaces and residences, and for the distances traveled by empty vehicles.

In the past, the problem of diverting car trips towards PT modes has been addressed through increasing integrated PT services ("pull" policies) and by access restricting and/or pricing for private cars ("push" policies). The implementation of pricing policies that limit the access by car to some areas and streets in some cases has been seen as unfair, since it might create unequal accessibility opportunities, and in some cases segregation conditions (less advantages) for those population segments that cannot afford to own a private car or to pay for a taxi. However, the potential offered by advanced technology could allow (and increasingly in the future) to implement effective Travel Demand Management (TDM) measures to improve the quality of urban mobility, overcoming problems of social exclusion. In fact, it is widely believed that the deployment of electric Connected and Automated Vehicles (CAVs), will reduce significantly the operating costs of PT and car-sharing, thus allowing a widespread distribution of the service at affordable prices (also in areas with low-demand density). In the literature, preliminary studies have shown the potential impacts of autonomous driving, both on the supply of urban mobility services and on the demand side. However, it is not yet clear what impact the new supply of PT services (including shared mobility) and some disruptive TDM policies (e.g. large-scale car-free zones) could have on economic growth and urban form development (Cordera et al. 2017).

The new challenges for decision-makers and researchers in this domain would be that of identifying what policies to put in place in order to avoid that the technological shift will result, on the one hand, in increasing travel distances and increasing congestion level, and, on the other hand, in more disperse land-consuming urban development.

2. Research objectives and methodological approach

This research aims at testing the sustainability of integrated land use and transportation scenarios, characterized by the increasing capacity of PT and the diffusion of vehicle-sharing solutions combined with TDM measures. The work consists of the following steps (Fig. 22):

1) identification of the current and the future reference scenario, through the examination of strategic guidance documents regarding the study area;
2) design of future alternative scenarios, according to the different hypotheses of development of the transportation system;
3) simulation of the scenarios by means of an integrated LUTI model system (Coppola & Nuzzolo, 2011), the so-called STIT, which is based on a system of behavioral models that simulate: the travel choices made by the users of the transportation system; the location choices of the residential zone made by the population; the location choices of business made by economic subjects (private firms and commerce);
4) analysis of the results and comparison between the scenarios, using a set of economic, environmental and social sustainability indicators.

To this aim, an integrated system of mathematical models for the simulation of land-use and transportation interactions, named STIT, is used for the simulation of future land use and transportation scenarios. The models represent the behavior of both dwellers and transportation users and how they react to changing conditions (Nuzzolo and Coppola, 2005). It returns to output:

- the spatial distribution of the population, subdivided into five socio-economic categories of individuals, consistent with the national census classification (ISTAT), i.e. high-income worker, mid/low-income worker, high school student, university student, other (older than 14 years);
- the spatial distribution of economic activities, by a proxy of the jobs in commercial activities, jobs in private services, jobs in public services;

- the Origin-Destination matrix of the journeys by purpose of the trip (work, study, other) and by mode of transportation (cars, motorcycles, PT, walk/bike).

A set of indicators is, finally, defined to systematically evaluate and compare alternative future scenario and to assess to what extent different policies achieve sustainability in terms of transportation performances and environmental impacts.

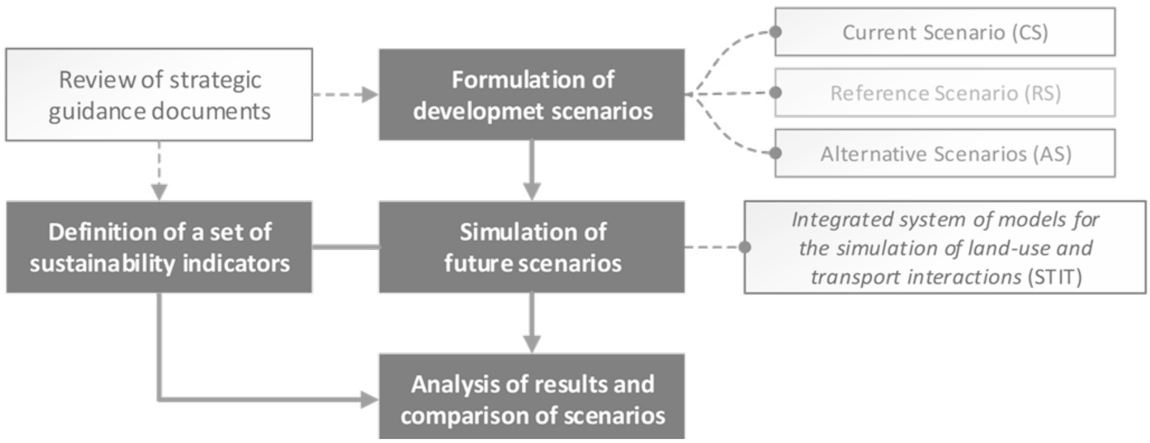

Fig. 2 - Methodological approach of the study.

3. Application to the urban area of Rome

The case study analyzed in this paper is the urban area of Rome. Several scenarios have been simulated and compared by means of (economic, environmental and social) sustainability indicators. Starting from the current scenario (CS), the reference scenario (RF) was built with a time horizon of 2030 using the following strategic guidance documents:

- the municipal urban masterplan "*Piano Regolatore Generale"* (PRG, 2008), which defines the transportation infrastructure system in a vision of close integration between urban planning policies and mobility policies in a long-term perspective;
- preliminary documents of the regional transportation plan *"Piano Regionale della Mobilità, dei Trasporti e della Logistica"* (PRMTL, 2014);
- the municipal transportation plan *"Piano Generale del Traffico Urbano"* (PGTU, 2015), which aims at optimizing the existing transportation system and regulating travel demand, thus providing guidelines for management interventions, rather than infrastructural ones, in the medium term;
- preliminary documents of the metropolitan transportation plan *"Piano Urbano della Mobilità Sostenibile"* (PUMS, 2017).

Based on the above documentation, in the reference scenario it is assumed an increase of the population up to about 3 million residents (STATUS, 2016) and the completion of the interventions on the housing stock proposed by the PRG. The PRG foresees an increase in Gross Floor Area (GFA) for residential use of 12% compared to the current scenario (CS), for a total of 11,642,183 m² of new houses. Interventions on the housing stock are concentrated mainly in areas outside the highway ring which surround the city, in fact around 80% of the new residences will be built in the outer ring (Area 5 in Figure 3).

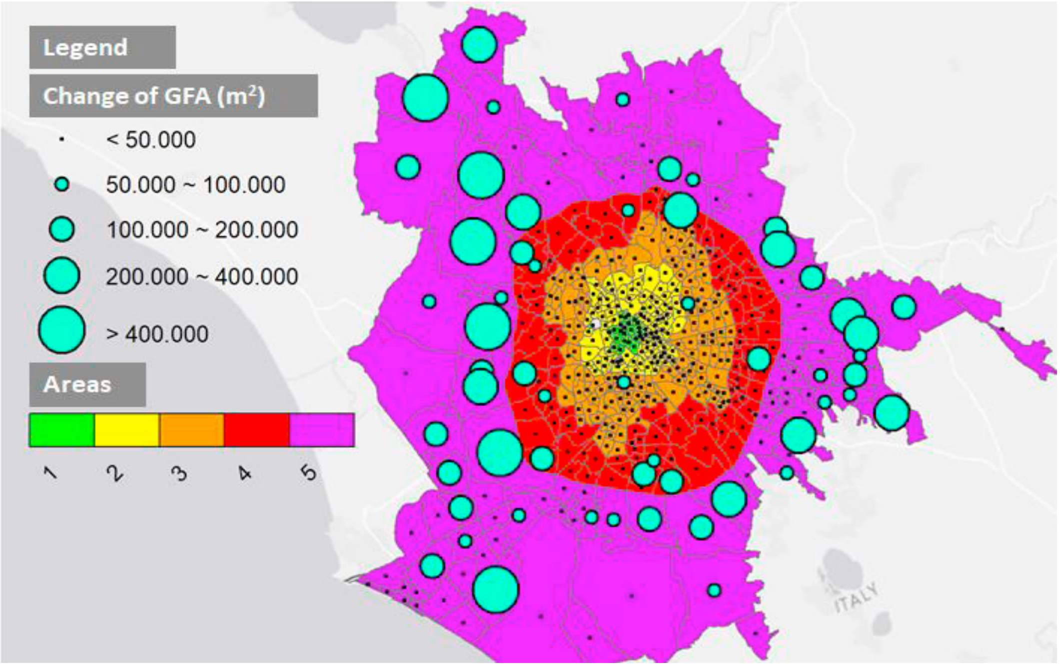

Fig. 3 - Variations of residential Gross Floor Area (GFA).

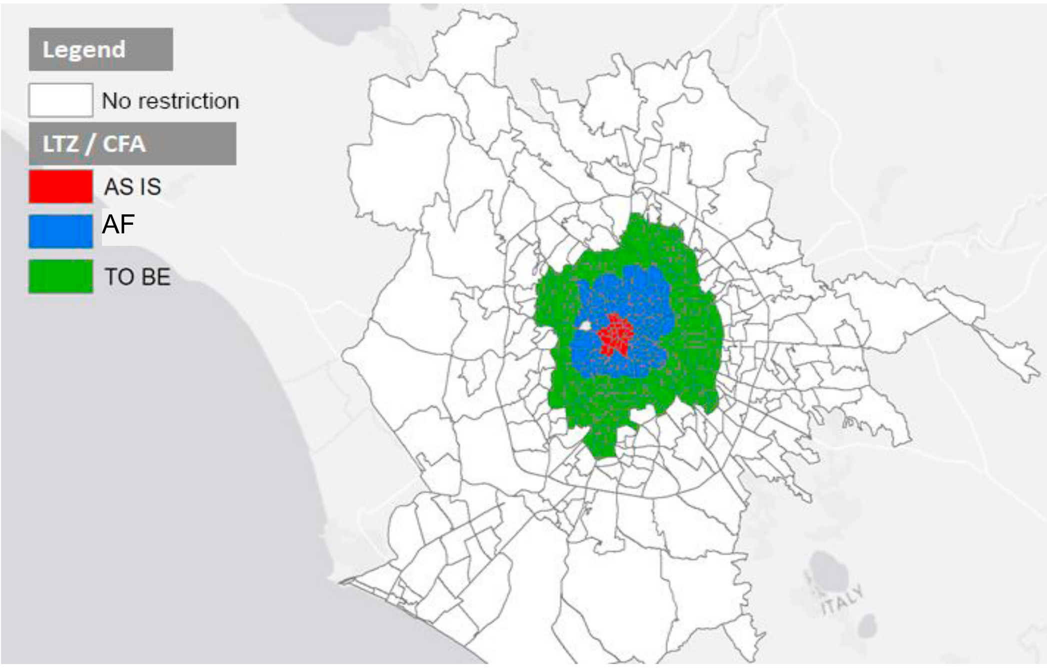

Fig. 4 - Areas of extension of TDM measures.

With respect to the interventions on the transportation system, not all the infrastructure projects included in the plans have been considered, both at the municipal and regional level, but only those that will be more realistically completed by 2030 and that will have a significant impact on the transportation supply system. In the Alternative

Scenarios (AS), some selected additional infrastructural intervention on the tram and metro networks have been assumed, in combination with the widespread deployment of Intelligent Transportation Systems (ITS) and electric CAVs in shared mode (including both driverless shuttles/minibus and driverless cars). These will serve as feeder service for the mass rapid transit (tram and metro) network from the areas with low demand density and/or to the areas in which a TDM measure is implemented. In particular, the effects of two different policies for moderating the individual use of private vehicles were examined: the Limited Traffic Zone (LTZ) and the Car-Free Area (CFA). The former provides the restriction to the incoming private cars (only) from other zones, while the latter extends the limitations to motorcycles and also to residents in the zones, i.e. incoming and outgoing private cars from the zones.

Different levels of extension of these two kinds of TDM are considered (Figure 4):

- the area “AS IS”, i.e. the LTZ currently in force in the historic center of Rome;
- the area “AF”, that considers the zones inside the railway ring (“*Anello ferroviario*”);
- the area “TO BE”, that consists in a larger portion of the most densely urbanized and congested territory.

The alternative scenarios have been formulated as a combination of the aforementioned different types of infrastructural and managerial interventions. This led to the creation of several alternative scenarios, identified from the possible intersections of the matrix reported in Figure 5. In the following of this paper only the results of the simulations of the scenarios highlighted in dark grey are reported, i.e.:

- Reference Scenario (RS),
- New PT infrastructure, with Limited Traffic Zone (LTZ) extended to Area 2 (INFR_LTZ_AF);
- New PT infrastructure + electric CAVs in shared mode, with LTZ extended to Area 3 (ITS_LTZ_TOBE)
- New PT infrastructure + electric CAVs in shared mode, with CFA extended to Area 3 (ITS_CFA_TOBE)

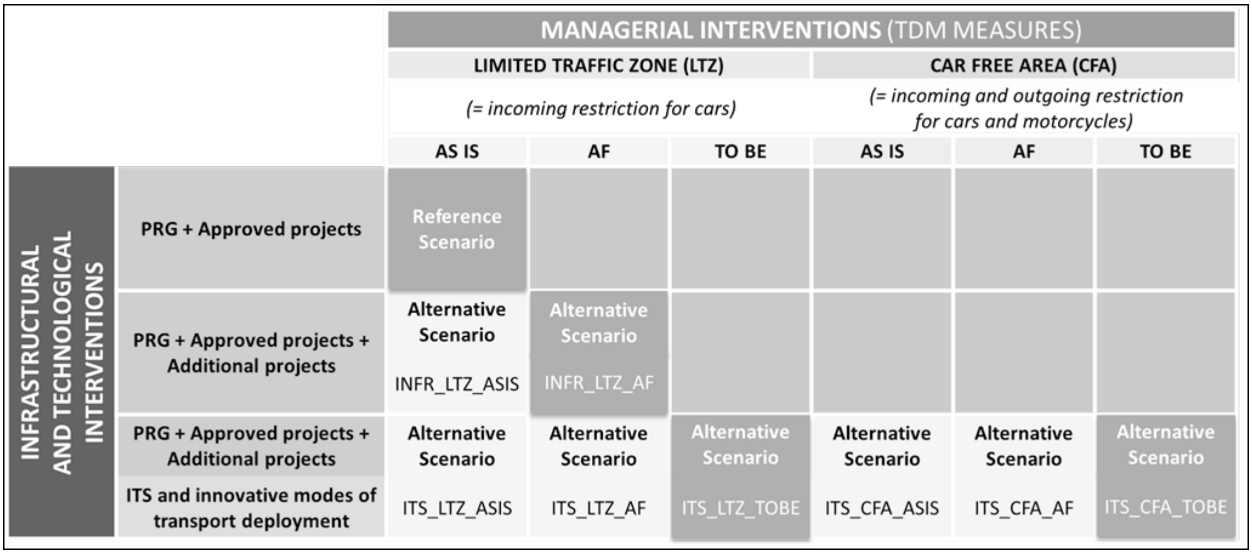

Fig. 5 - Matrix of interventions and scenarios to simulate.

4. Results

The reference scenario shows an uncontrolled spread of population and jobs in peripheral areas of the city (urban sprawl): the population in the inner areas declines compared to the current scenario, while it increases by 30,8% in the outer ring (Area 5 in Figure 3). The model therefore estimates that almost one third of Rome's population (931.498 out of 2.991.562 inhabitants) will reside outside the highway ring, mainly due to the new residential development scheme proposed by the PRG. Figure 6 shows the tendency of the population and jobs, to spread particularly in the west quadrant of the city, mainly due to the increase in the availability of new residential GFA.

Tab. 1 - Spatial distribution of population and jobs in the Reference Scenario.

Area	***Overall Population***	*High-income Workers*	*Mid/Low-income Workers*	***Overall Jobs***	*Jobs in Private Services*	*Jobs in Commerce*
1st	**57.036**	9.981	19.409	**114.901**	55.504	11.100
2nd	**432.994**	55.175	152.731	**395.979**	204.162	36.974
3rd	**977.188**	89.536	362.974	**370.590**	154.320	54.150
4th	**592.845**	58.644	234.694	**260.337**	101.070	37.700
5th	**931.498**	81.692	371.933	**294.963**	117.232	65.651
TOTAL	***2.991.562***	***295.028***	***1.141.741***	***1.436.769***	***632.288***	***205.576***

Tab. 2 - Percentage change of population and jobs in the Reference Scenario, compared to the Current Scenario.

Area	***Overall Population***	*High-income Workers*	*Mid/Low-income Workers*	***Overall Jobs***	*Jobs in Private Services*	*Jobs in Commerce*
1st	**-17,9%**	-18,6%	-10,6%	**-3,7%**	-8,6%	-9,1%
2nd	**-4,5%**	-2,2%	-6,1%	**+0,5%**	-1,7%	-1,4%
3rd	**-5,3%**	-3,3%	-6,3%	**+1,9%**	+2,6%	-5,8%
4th	**-2,3%**	+6,8%	-4,6%	**-2,4%**	-4,4%	-14,8%
5th	**+30,8%**	+21,5%	+33,2%	**+24,6%**	+41,2%	+42,6%
TOTAL	***+4,1%***	***+4,1%***	***+4,1%***	***+4,1%***	***+4,1%***	***+4,1%***

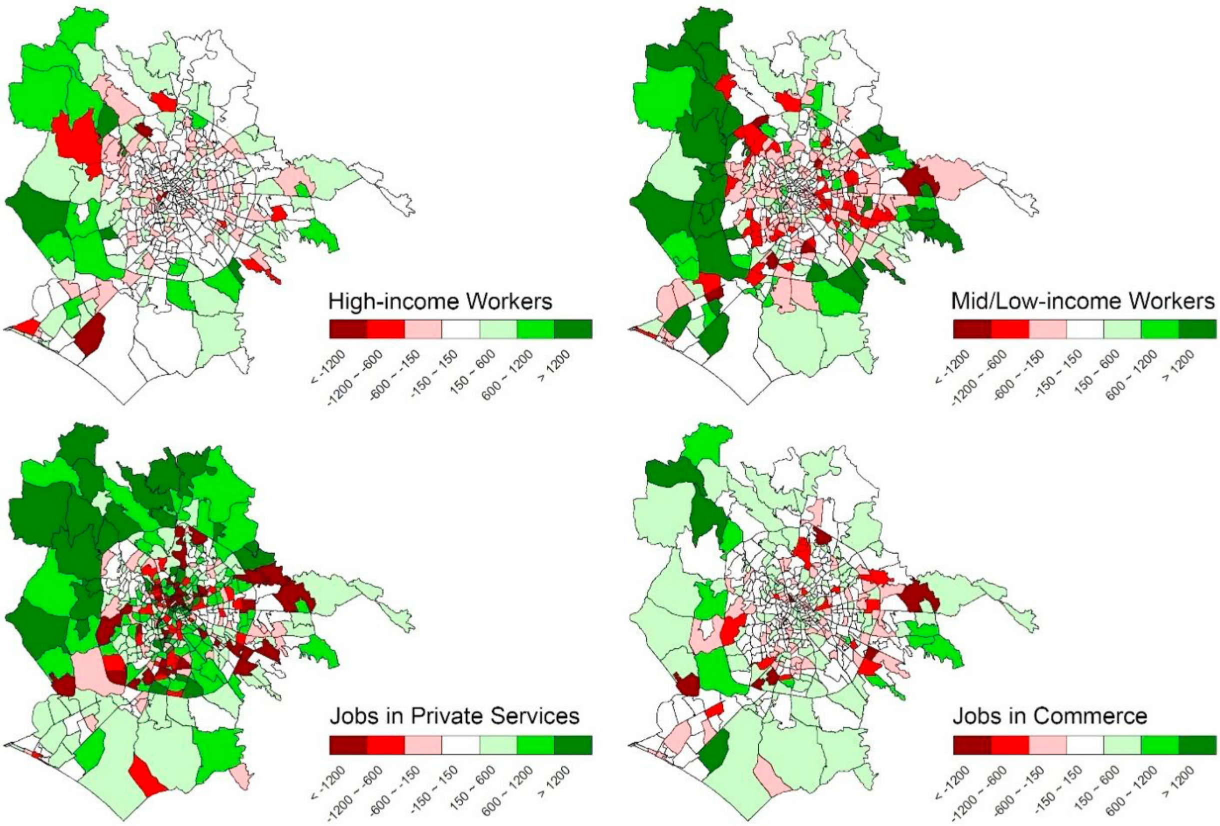

Fig. 6 - Map of variations of workers and jobs location in the RS, compare to the Current Scenario.

In the Alternative Scenarios (AS) the situation changes completely. In fact, the areas subject to TDM measures (Areas 1, 2 and 3 in Figure 3) become more attractive for residents, particularly for low-medium income, and partially also for jobs. The results of one of the simulated scenarios (i.e. "ITS_CFA_TO BE") are shown in Table 3 and Figure 7. These confirmed that the more attractive zones become those belonging to area 2 in which there is an increase of accessibility due to the increase of PT and shared-vehicle services and an higher availability of housing stock thanks to the migration of higher income residents towards outer zones (Area 5). These results reflect the fact that low-income population are more sensitive to changes in PT accessibility (Cordera et al. 2019), whereas high-income are more oriented to zones with high accessibility by car.

Tab. 3 - Percentage variations of population and jobs in the AS "ITS_CFA_TO BE", compared to the Reference Scenario.

Area	***Overall Population***	*High-income workers*	*Mid/Low-income workers*	***Overall Jobs***	*Jobs in Private Services*	*Jobs in Commerce*
1st	**+6,4%**	+8,2%	+5,2%	**+0,5%**	+0,4%	+3,4%
2nd	**+10,6%**	+0,6%	+13,8%	**+2,0%**	+2,4%	+7,6%
3rd	**+4,4%**	-1,6%	+6,3%	**+1,4%**	+1,5%	+5,2%
4th	**-2,6%**	+2,0%	-3,8%	**-0,6%**	-1,3%	-0,5%
5th	**-8,3%**	-1,1%	-9,7%	**-4,1%**	-5,3%	-8,8%
TOTAL	***0,0%***	***0,0%***	***0,0%***	***0,0%***	***0,0%***	***0,0%***

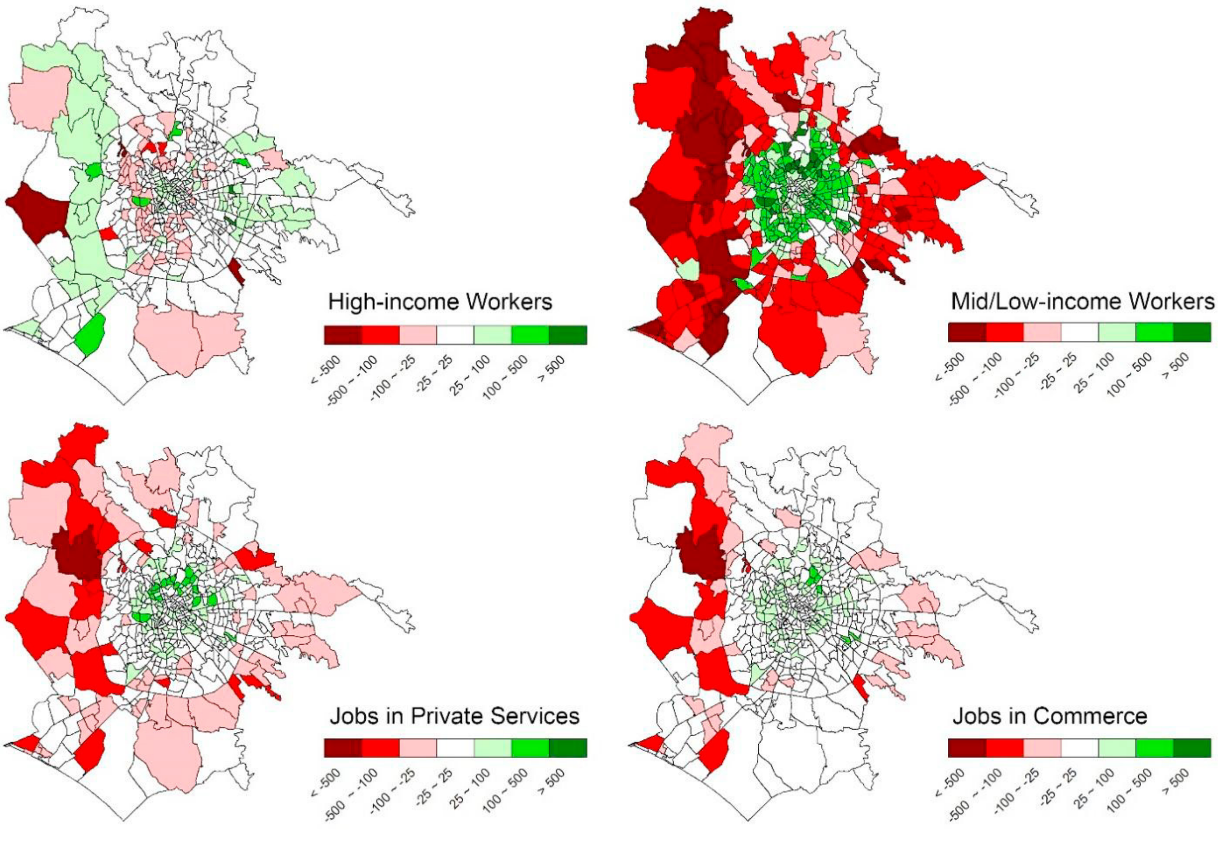

Fig. 7 - Map of variations of workers and jobs location in the AS "ITS_CFA_TO BE", compared to the Reference Scenario.

The direct comparison of the four simulated scenarios allows a better understanding of the settlement dynamics and the changes in the mobility patterns. With regard to the impacts on land use, it emerges that in the AS there is a reduction in the population density of area 4 and area 5, in favor of the central areas, i.e. the sprawl of the population is significantly reduced, compared to what occurs in the RS (Figure 8).

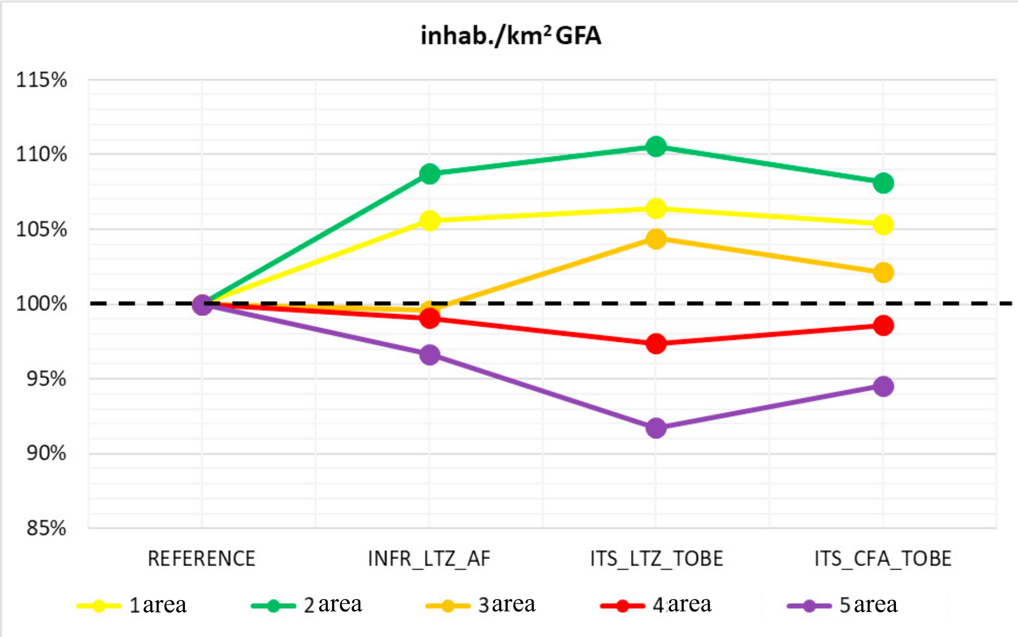

Fig. 8 - Index number of population density in all four future analysis scenarios.

As regards the modal split of travel demand, it can be observed (Figure 9) that: in the "INFR_LTZ_AF" scenario, where only infrastructural interventions are assumed, Car remains the most used mode of transport, even under the assumption (in scenario "INFR_LTZ_AF") of extending the LTZ to the entire Area 2 (AF); in the other two alternative scenarios, in which the extension to Area 3 (TOBE) of a LTZ (i.e. scenario "ITS_LTZ_TOBE") and of a CFA (i.e. scenario "ITS_CFA_TOBE") are assumed in combination with the widespread distribution of electric CAVs services, the use of the car decreases from the reference value of 54% to 32% or 22% respectively. In these scenarios, in terms of environmental sustainability, it can be achieved also a reduction of energy consumption and CO_2 emissions in a range of 43%-54% (Table 4).

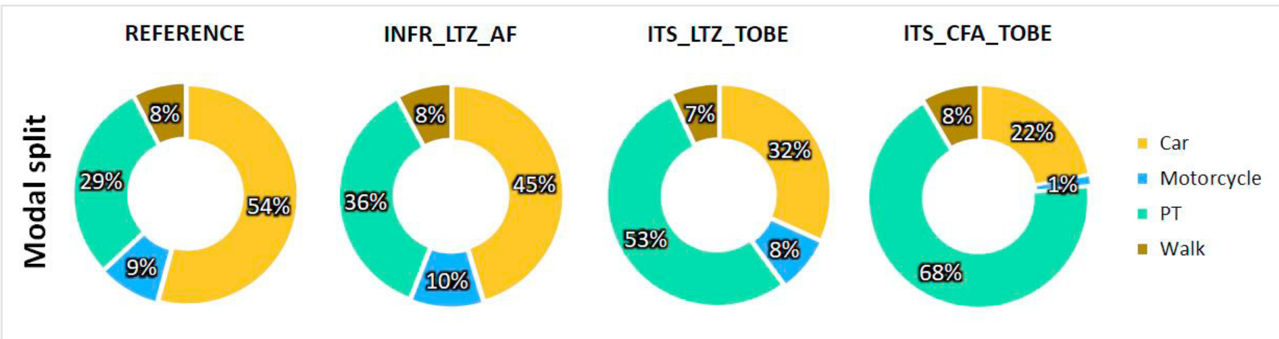

Fig. 9 Modal split variations in the alternative scenarios.

Tab. 4 - Environmental sustainability indicators (values per peak hour).

Scenario	***Mileage*** vehicles-km	***Energy consumption*** GJ	***CO_2 emissions*** tonns	***Change*** %
Reference scenario	3.562.479	16.459	312	-
INFR_LTZ_AF	3.003.994	13.879	263	*-15,7%*
ITS_LTZ_TOBE	2.026.092	9.361	178	*-43,1%*
ITS_CFA_TOBE	1.643.584	7.593	144	*-53,9%*

5. Conclusions

The urban masterplan (PRG) of the city of Rome, which foresees a significant housing stock development in the peripheral zones of the urban area, appears to be not aligned to the transportation infrastructural interventions. From our analysis, it resulted to be inadequate in terms of access to the urban and regional mass rapid transit network, and lead residents and city-users to unsustainable travel choices. Moreover, simulation shows an increase of the urban sprawl with increasing travelled distances between residence and workplaces without access to the mass rapid transit network (tram and metro), which favors a car-oriented mobility with a consequent increase of pollutants emissions.

In the simulated alternative scenarios, additional infrastructural interventions have been assumed, aimed at improving accessibility and reducing the general cost of travel by public transport. This allows for a slight reduction of the urban sprawl; however, the analysis shows that there is not a substantial reduction of the negative externalities generated by transport: private vehicles remain the most used mode of transport, even assuming an extension of the Limited Traffic Zone (LTZ) for non-residents' vehicles to a certain extent. On the other hand, a profound change in the modal split occurs when a widespread deployment of new technologies coupled with the implementation of very strict TDM policies, such as the institution of a Car-Free Area (CFA), is assumed for more extended areas. In fact, the widespread diffusion of CAVs in shared mode and as feeder to PT services encourages a more intensive use of collective transportation modes, even in areas with low demand density, from the reference value of 54% to 32% and 22% respectively with LTZ or CFA, and tends to limit the migration towards peripheral areas of the population (particularly low income) and jobs.

In conclusion, the improvement of PT services combined with large-scale restricted traffic areas and pedestrian areas, allowed by the innovative and shared mobility solutions, may induce a significant modal diversion from private vehicles towards more sustainable modes of transport, and induce a limitation of the urban sprawl.

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