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# Urban Form and Sustainability: the Case Study of Rome

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**Abstract**

This paper investigates the relation between sustainability and urban form. To this aim a system of Land-Use and Transport Interactions (LUTI) models has been designed and applied to the metropolitan area of Rome, to understand the interdependence of key variables such as travel behavior, transport supply, property values, jobs and residential location. The models represent the behavior of both dwellers and transport users and how they react to changing conditions. A system of assessment indicators has been defined to systematically test and compare alternative scenarios of urban form and to evaluate to what extent different locations and density distributions of activities achieve sustainability in terms of transport performances, social and environmental impacts.


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Keywords: Urban form; Sustainability; LUTI

## 1. Introduction

A number of studies in literature dealing with the influence of urban form on travel behavior have not been conclusive in identifying determinants for sustainable city form. In particular some literature supports that urban form can have a direct impact on travel behavior, whereas in others it has been concluded that there is virtually no effect. In some studies urban density has shown to be a key factor since it has the potential to reduce the need to travel and, therefore, improve the overall sustainability of the urban fabric (Steiner, 1994). Nevertheless, the

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available literature provides mixed results on the effects of urban form and density distribution on travel patterns and on related environmental impacts.

In order to provide empirical insights to this debate, this paper presents a methodology for sustainability assessment of urban forms, with an application to the urban area of Rome. To this aim a system of Land-Use and Transport Interactions (LUTI) models has been designed and applied to understand the interdependence of key variables such as travel behavior, transport supply, property values, jobs and residential locations. The models represent the behavior of both dwellers and transport users and how they react to changing conditions. A system of indicators has been defined to systematically test and compared alternative urban development options and to assess to what extent different urban structures achieve or not sustainability in terms of transport performances and environmental impacts.

The paper is organized as follows. In Section 2 we refer to the existing literature and the debate on the relations between urban form and sustainability. Section 3 describes the methodological approach of the research. In Section 4 we discuss the results of the application to the empirical case study of Rome. Conclusions are drawn in Section 5.

## 2. Background

The new millennium challenge of sustainable development will be played, in the next years, in urban and metropolitan areas, where most of world population has been constantly keeping placed. In order to prevent negative social and environmental impacts of uncontrolled growth, spatial planners agree on the issue that a new cultural and scientific approach to urban development is necessary. This should be based on integrated policies in the attempt to overcome the antithesis between economic development, on the one hand, and environment and resources protection, on the other (Nuzzolo et al., 2010).

The debate whether a particular shape, density average and distribution of activities can have an impact on the mobility behavior and on cities sustainability is still undergoing (Williams et al. 2000; Echenique et al. 2012). In fact, a number of studies dealing with such issues have not been conclusive in identifying determinants for sustainable urban forms of cities.

Many researches have been produced focusing on the impacts of the urban form on mobility behavior and the relative environmental and social impacts (Boarnet & Crane 2001; Handy, 1996). In particular three specific urban structures have been assessed and studied with different approach and methodologies: the compact, the polycentric and the sprawl urban forms.

As regards the compact urban form, since the EU Green Paper of the Urban Environment, this model was advocated as the most sustainable for urban development (Commission of the European Communities, 1990). In fact, according to several researches (Newman and Kenworthy, 1999; Næss, 2013), compact cities can promote sustainability by limiting the losses of surrounding natural and agricultural areas; reducing the amount of travel, car dependency and energy use for transport; reducing energy use; limiting the consumption of building materials for infrastructure; and maintaining the diversity and possibilities for choice among workplaces, service facilities and social contacts, Other studies stated, on the other hand, that compact developments can cause severe congestion in transport network, increase land and dwelling prices and create social exclusion (Breheny, 1997). Furthermore dense urban environments are often more exposed to noise and local pollution from traffic, with direct negative health impacts.

Also polycentric urban model, in which the location of activities are located in and around dense and mixed sub centers, is a much debated issue in current urban planning. In the Netherlands context, Schwanen et al. (2001) show that polycentric urban structures encourage car use whatever the travel purpose, because public transport networks are mainly intended for radial trips. Some authors assert that polycentric developments is the most able to reduce car use and travel distances and conserving land, but credible supportive evidence remains limited. Some studies (Gordon and Richardson, 1997; Levinson and Kumar, 1994) suggest that a polycentric structure tends to reduce commuting distance and commuting times. Finally, other authors (e.g. Ewing, 1997) refute this positive view of the effect of policentricity on travel behavior. Other empirical studies show that when sub centers are located near metro station, according to TOD principle, they generate less trips by car (Pivo, 1993).

As regard the sprawl urban structure, most studies agree that this urban form induces auto-oriented lifestyles and higher urban management costs (e.g. energy distribution, waste collection, etc.) and is accompanied by intensive travel movements and associated environmental effects (Camagni et al. 2002; Travisi et al. 2010; Westerink et al. 2013).

**The methodological approach**

The research method we propose is based on the following four steps (Figure 1):

1. Definition of spatial and transport development scenarios;
2. Scenarios simulation;
3. Design of performance and sustainability indicators and scenarios assessment;
4. Analysis of the results.

As regard the first phase, three spatial development scenarios categories were defined, according to different distributions of residents and jobs, but maintaining the same number of city-region-wide totals of residents and jobs. The different development options correspond to three different urban patterns to which appropriate transport policies at the city-wide (strategic) scale are related: "Compact" scenario, characterized by a new clustering of high density activities in the city center; "TOD Transit Oriented Development" scenario, characterized by new activities developments around rail and metro station areas; "Sprawl" scenario, characterized by a the market-led dispersal of new activities.

Two more scenarios were developed to be used as benchmarks in the assessment phase: the "base" scenario (BS) referred to the year 2011 and the "City Master Plan" scenario (CMP), which includes the new activities location and the interventions on transport networks planned by Master Plan of Rome (2008).

The second phase is the scenarios simulation, developed by means on a LUTI models system, that simulate the behaviour of dwellers and transport users and how they react to changing conditions.

The third phase is the design and computation of key performance indicators. The assessment framework here does address economic, social, environmental impacts and energy consumption criteria.

Finally, the fourth step is the analysis of the results and the interpretation of the quantitative results, to identify the more sustainable land-use transport city form.

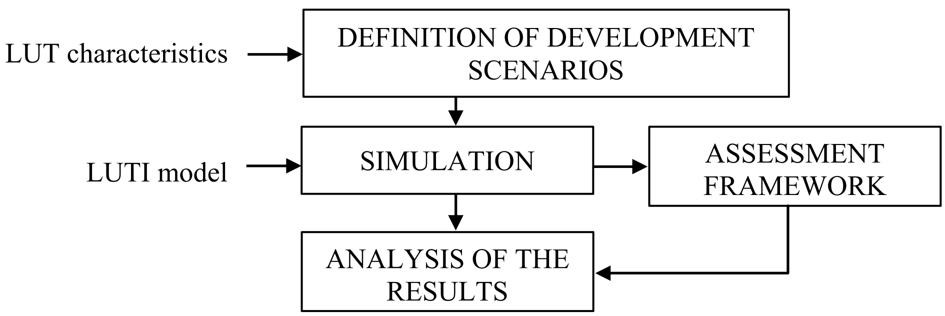


Fig. 1. The steps of the research method.

## 3. Application

### *3.1. The empirical case study of Rome*

The urban area of Rome has about 2.8 million inhabitants in 1,285.3 km2 and 1.1 millions of jobs, contributing to about 552,000 trips in the morning peak hour. The structure of the city is strongly mono-centric and it can be split into circular rings with increasing densities approaching the city center (Figure 2).

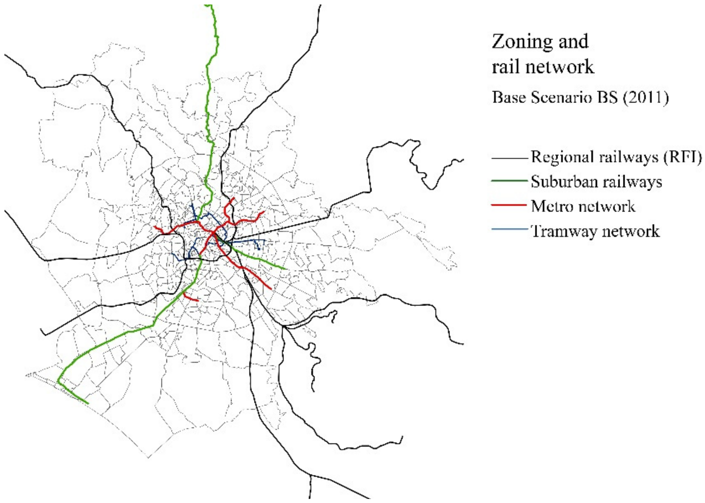


Fig. 2. Zoning and urban rail network in the Base Scenario BS (2011).

The “Grande Raccordo Anulare” GRA, i.e. the circular freeway of approximately 68 km of length, delimits the most dense and populated area of the metropolitan area, with an average density of population of about 70 inhabitants/ha and an average density of job of about 75 employees/ha. Inside the GRA, population and activities are mainly concentrated along radial roads to/from the city center (i.e. the old access roads to the ancient roman town). The transit system consists of two (as well radial) metro lines extending for a total of 36 km, with a single interchange in the very city center (“Termini” central station). Other seven regional rail lines connect the surrounding urban areas to the city center. As regards the car use, Rome has a very high level of automobile ownerships (more than 700 for 1,000 persons) and the road network is highly congested. In large part of the historical center, access by car is allowed only to the residents.

### *3.2. Scenarios setting*

The scenarios settings phase required different sources of information and several assumptions.

For the Base Scenario (2011) we used the following Census data that were aggregated into 463 traffic zones (Figure 2):

- XIV Census of Population and Housing 2011;
- XIII Census of Industry and Services 2001;
- XIV Census of Population and Housing 2011 and documents and previous research produced by the City of Rome.

The activities system was schematically subdivided into three subsystems as follows:

- the subsystem of the "Population", segmented by employment status and professional condition (i.e. high, medium and low);
- the subsystem of the "Economic Activities", consisting of the employees by economic sector (e.g. service, commerce, industry);

- the subsystem of the "Real Estate", consisting of building space available in each traffic zone divided by type (residential areas, service and retail) with the relative property values.

The setting up of future development scenarios (Table 2) required some assumptions on the evolution of the above subsystems as well as of the development of transport networks. For the subsystems “Population” and “Economic Activities” projections have been carried out for the year 2031, consistent with the demographic development of Rome forecast by the Italian National Statistical Institute (ISTAT). With regard to the subsystem "Real Estate" several assumptions have been made, depending on residential density, accessibility, and the development of the road and rail networks. It is assumed that the total number of additional built-up area (i.e. square meters of new housing) keeps constant in each development scenario (i.e. equal to 11.6 million square meters as forecast by the City Master Plan).

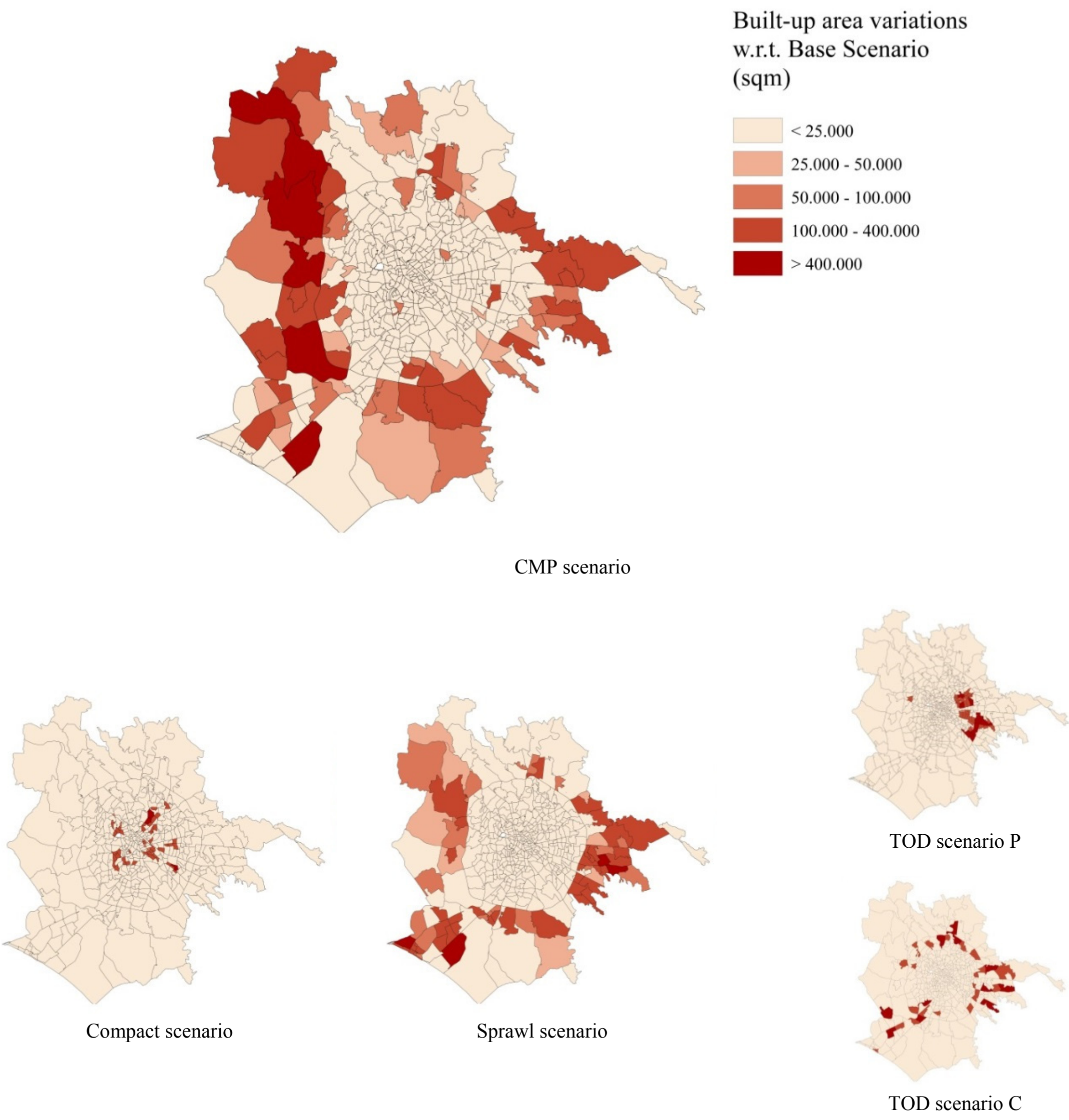


Fig. 3. Built-up areas variation w.r.t. Base Scenario in the CMP compact, TOD and sprawl scenarios

According to the three different urban patterns and the Master Plan interventions, different spatial development scenarios were defined (Figure 3):

- City Master Plan (CMP), locating the new built-up areas according to the City Master Plan approved by the Municipality Council in year 2008;
- Compact scenario, locating the new built-up areas in few zones in the central areas;
- Sprawl scenario, scattering the new built-up area in the urban peripheral area; two different sprawl scenarios have been defined (Sprawl_P and Sprawl_C) which slightly differ in the density values;
- Transit Oriented-Development (TOD) scenario, concentrating the new built-up developments in some catchment areas of the new and existing stations of the rail network. Two different TOD scenarios have been defined (i.e. TOD_P and TOD_C), in particular in the scenario TOD_P new development are located in proximity of the new rail corridor in the west part of the city, while the scenario TOD_C consist into the location of new developments in different station areas on the west and east sides of the urban area.

As regards the development of the transport network two main hypotheses were made:

- Complete network (C), including all interventions suggested by the City Master Plan;
- Partial network (P), including a subset of the complete network, assuming a more "realistic" hypothesis of the transport infrastructures development, consistent with the ongoing and financed interventions.

From the intersection between the spatial development scenarios and the transport networks, ten scenarios of future spatial development were designed (Table 2) and for each of them a database was built, containing the data necessary for the simulation. Each database has also been associated with a shape file in order to produce in GIS environment thematic maps of the main outputs.

Table 1. Spatial development scenarios.

| | | **transport network characteristics** | | |
|---|---|---|---|---|
| | | Base network (2011) | CMP partial network | CMP complete network |
| **land use characteristics** | Base scenario (2011) | BS | | |
| | City Master Plan CMP | | CMP_P | CMP_C |
| | Compact | | COMPACT_P | COMPACT_C |
| | Sprawl | | SPRAWL_P | SPRAWL_C |
| | TOD | | TOD_P | TOD_C |

### *3.3. Simulation*

The LUTI model STIT (Coppola & Nuzzolo, 2011) has been used for the simulation of the interactions between transport and Land Use systems. This model simulates the location choices of the residents and of private and commercial businesses through random utility theory, and their interactions with the transport system as shown in Figure 4. The model allows to forecast the impacts that transport policies have on the spatial distribution of economic activities (such as services and retail) and on the population, as well as on real-estate property values. On the other hand, it allows assessing the impact of urban development plans on demand flows and on transport networks performance.

The model was calibrated upon the Base Scenario (BS) consisting of the network infrastructure and transport services and the socio- economic and demographic characteristics at the year 2011. Model validation was performed by comparing the distribution of population, facilities and retail workplaces provided by the model and the "observed" values by Census. In addition, we compared the Origin-Destination demand flows (OD matrices) estimated by trip purpose and mode, with the data supplied by the Agency for Mobility of Rome.

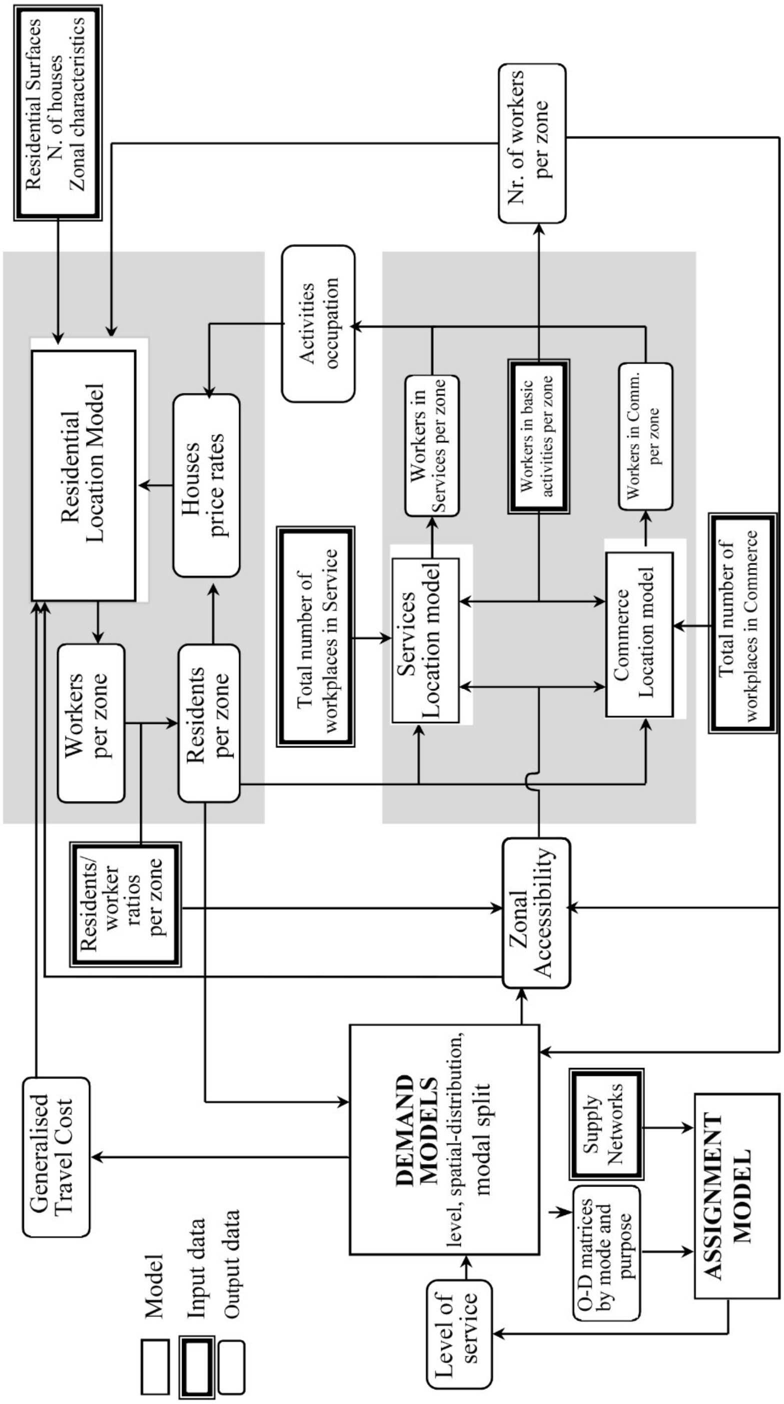


Fig. 4. Schematic representation of the LUTI models system (Coppola and Nuzzolo, 2011).

### 3.4. Assessment

In the final step the application, the LUTI models were applied to the 9 scenarios previously defined. The results of these applications have been used to carry out a sustainability analysis of different scenarios of urban development.

For each scenario, maps and tables were built up for the description of the results. As an example, Figure 5 shows the changes of workplaces in the service sector for the spatial development scenarios CMP City Master Plan with the partial transport network.

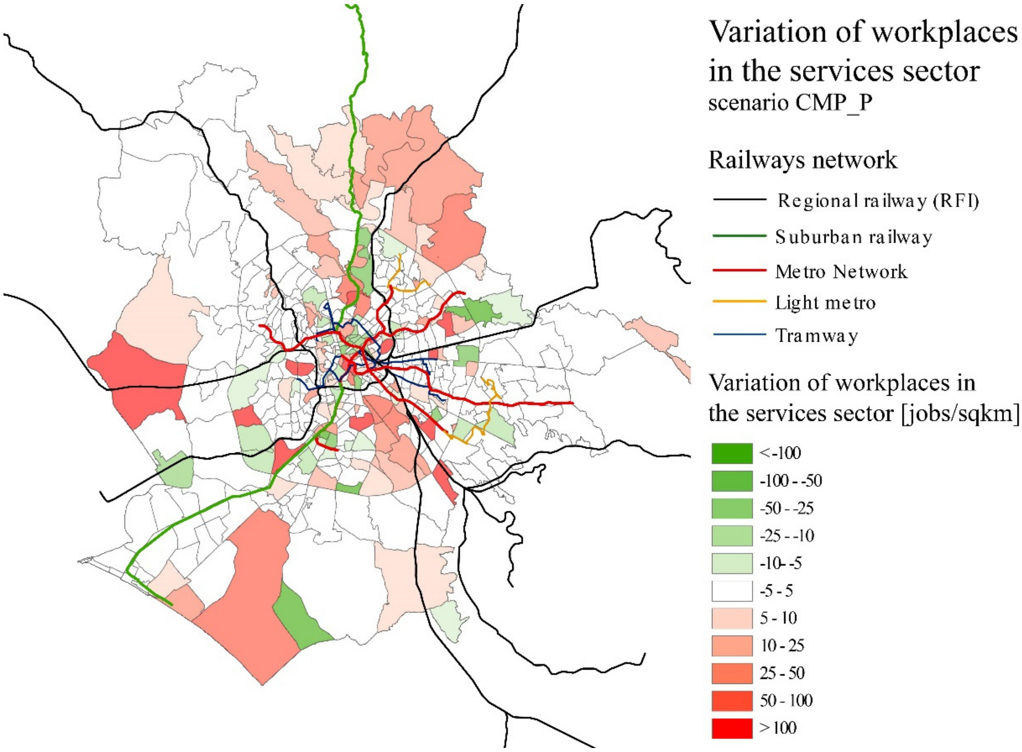


Fig. 5. Variation of workplaces in the services sector in the City Master Plan scenarios with partial transport network CMP_P.

For the scenarios assessment, a system of indicators grouped into four distinct areas was developed:

- Mobility;
- Land Use;
- Environment;
- Energy.

Mobility indicators have been used to assess the impacts on modal share and on the performances of transport networks in terms of the variations of time and cost of average number of trips as well as in terms of travelled distances.

The indicators of land use were exploited to assess the impacts on the spatial distribution of socio-economic activities, the degree of use of the existing and the new built-up areas.

The assessment of the impacts resulting from the implementation of different urban development scenarios simulated was also carried out with a focus on energy and environmental issues, due to the importance that these issues have taken on within the scientific debate on urban sustainability. Similarly we proceeded to evaluate the negative externalities related to vehicular traffic both in terms of fuel consumption, and emissions of carbon dioxide, one of the most representative parameters for the assessment of atmospheric pollution.

Table 3, 4 and 5 show some synthetic indicators aggregated for the whole urban areas in the different scenarios and the variation percentages of land consumptions and CO2 emissions.

Table 2. Average commute time, total number of trips and modal shares.

| **Transit network** | **scenarios** | **Modal shares** | | | |
|---|---|---|---|---|---|
| | | car | PT | moto | foot |
| | | % | % | % | % |
| **Base network (2011)** | BS | 50.9% | 30.3% | 10.0% | 8.8% |
| **P Partial network** | CMP_P | 56.1% | 27.6% | 8.7% | 7.6% |
| | Compact_P | 48.1% | 33.9% | 8.6% | 9.4% |
| | Sprawl_P | 55.6% | 27.7% | 8.5% | 8.2% |
| | TOD_P | 51.3% | 30.7% | 8.4% | 9.6% |
| **C Complete network** | CMP_C | 56.5% | 28.3% | 8.6% | 6.6% |
| | Compact_C | 50.4% | 32.7% | 8.6% | 8.3% |
| | Sprawl_C | 56.4% | 28.5% | 7.8% | 7.3% |
| | TOD_C | 50.7% | 31.7% | 8.4% | 9.2% |

Table 3. Percentage variation of land consumption and CO2 emissions related to car use with regards to the CMP_P scenario.

| **Partial network scenarios** | **Δ% Land consumption w.r.t CMP_P scenario** | **Δ% CO2 emission w.r.t. CMP_P scenario** |
|---|---|---|
| Compact_P | -51,83% | -16,52% |
| Sprawl_P | 7,12% | -0,71% |
| TOD_P | -29,35% | 5,39% |

Table 4. Percentage variation of land consumption and CO2 emissions related to car use with regards to the CMP_C scenario.

| **Complete network scenarios** | **Δ% Land consumption w.r.t CMP_C scenario** | **Δ% CO2 emission w.r.t. CMP_C scenario** |
|---|---|---|
| Compact_C | -51,83% | -16,00% |
| Sprawl__C | 7,12% | -2,08% |
| TOD_C | -14,60% | 7,59% |

The Compact scenario shows in both the partial and complete network extension the highest values of public transport use, with the modal share of 33.9% and 32.7% and also the highest values of commute trips made on foot of 9.4% in the partial transport network and 8.3% in the complete transport network. In TOD scenarios on the contrary the percentage of car trips increases with regards to the City Master Plan partial and complete scenarios.

## 4. Conclusions

Based on integrated land-use and transport modeling architecture, the research provides empirically based insights on the relation between urban form, sustainability and travel behavior. Different scenarios of urban development have been assessed for an empirical case study, with respect to transport network performance as well as social and environmental impacts. Preliminary results show that at the city level different urban forms (i.e. compact, sprawl, TOD) have found to differ in their sustainability, and in particular the compact development appears to better off others form of spatial development. However, compact development imply an increase of urban congestion level and also an increase of dwelling prices which in some cases create social exclusion and segregation of peripheral areas. These impacts are not reported on here and will be investigated in future research.

Moreover, the results of the simulations carried on, have been here discussed using average values for the entire urban areas, whereas more noticeable impacts and different trends could be estimated at a smaller scale. Further research will thus focus on impacts at the scale of single neighborhood, and will take into account also other environmental and energy consumption indicators.

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