

A SELECTION OF INDICATORS FOR MONITORING SUSTAINABLE URBAN MOBILITY POLICIES

Francesca Mamei^{*}, Gerardo Marletto^{*}

^{} Dipartimento di Economia, Impresa e Regolamentazione (D.E.I.R.), University of Sassari, Italy; and CRENoS, Italy.*

Abstract

In reaction to an increase over time in population, city sizes, movement of people and goods, transport systems and infrastructures have been gradually expanded, contributing to the decline in quality of life and environmental degradation in urban areas all over the world. Traffic congestion, air emissions, noise pollution and accidents are just few of the numerous side effects of urban transports systems which strongly impact on individuals living in cities. Within this scenario, developing an effective and sustainable transport system is a prerequisite for a sustainable economic growth. But what is meant by sustainable urban transportation and how progresses towards sustainability can be measured? A research project has been co-funded by Isfort (Istituto Superiore di Formazione e Ricerca per Trasporti) and the University of Sassari to answer these questions and operationalize the concept of sustainability for the governance of urban mobility. Preliminary results of this research are presented here together with an extensive literature review on the topic. In particular, adopting an expert-led ‘top-down’ methodological approach this article recommends a small number of key indicators that could be used for measuring the sustainability of urban transport policies.

Keywords: Urban mobility indicators; Sustainability; Transport policies

1. Introduction

The concept of sustainable transportation¹ has gained its relevance in reaction to the increase over time in population, city sizes and movement of people and goods, which caused a gradual expansion of transport systems and infrastructures. Transports have in fact significant implications in term of environmental degradation, pollution, use of resources, human health and safety, which dramatically affect the quality of life of individuals. This is particularly evident in the observed increased private car dependency, which is a major contributor to air pollution problems and global climate change (EEA 2007). Despite the technological improvements registered in the last twenty years to reduce the emissions, an increased number of private vehicles has in fact counterbalanced

¹ In this work we will alternatively use the terms “sustainable transport” and “sustainable mobility”, always referring to the latter. A comprehensive discussion on the difference between the two terms goes beyond the purpose of this paper. Generally speaking, though, “mobility is a broader concept than transport, as it refers not only to actual movement, but also to a potential to move and thus to the spatial, economic and social context of movement. Sustainable mobility is by analogy a more encompassing term than sustainable transport” (Gudmundsson 2003, p.215).

these gains (EEA, 2008). Further undesired effects include noise, accidents and occupation of space (i.e. a reduction of pedestrian and cycling areas).

On the other hand, measuring the sustainability of urban mobility policies still remains a difficult task for policy makers. What is urban transport sustainability and which dimensions have to be considered when undertaking mobility policy evaluations? Which indicators have to be used in the assessment? Trying to answer these questions, this paper provides an extensive review of the numerous national and international sustainable transport initiatives which have directly and indirectly analysed these issues. In particular, thanks to a cooperation with Isfort experts, a core set of urban mobility indicators is suggested as a tool for monitoring the sustainability of urban mobility.

1. The different dimensions of sustainable transportation

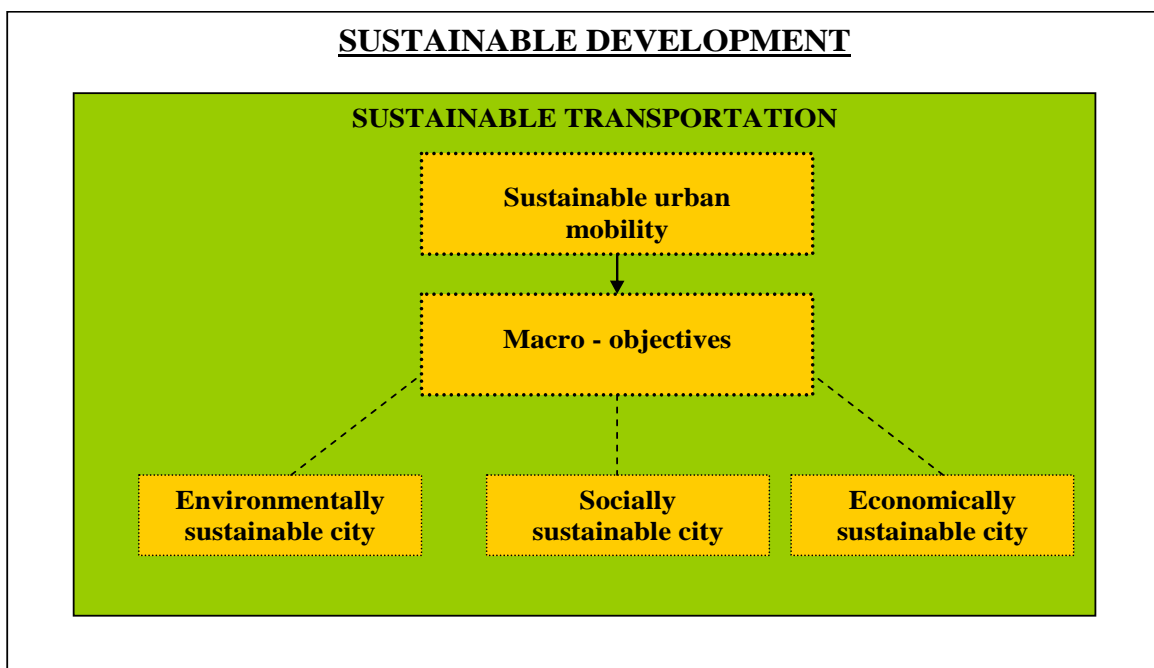
Despite its relevance for policy agendas, there is yet no standard way in which transport sustainability is considered (Mebratu 1998, Gudmundsson 2003, Jeon and Amekudzi 2005). As suggested by Jeon and Amekudzi (2005), studies tend in fact to “develop appropriate indicators for measuring sustainability in terms of particular needs identified and captured in unique definitions of sustainability” (p.33). Three reasons are adduced (Gudmundsson, 2003) for explaining the vagueness of the sustainable mobility concept: 1) the difficulty in identifying the critical limits for a sustainable use of the environment (*environmental sustainability problem*); 2) the difficulty in defining the optimal contribution of each sector of the economy to solving each sustainability problem (*economic allocation problem*); 3) the difficulty in independently assessing the sustainability of mobility, due to the links of transport activities with other activities, location choices and lifestyles (*social inter-linkage problem*). Further, it has to be considered that any sustainable transport consideration may cause a conflict between collective and individual interests. What is sustainable for someone may not be sustainable for others. What is considered as being a collective improvement in the quality of life, might not match all individual interests, causing a problem in balancing the two forces. Not everyone might agree to adapt its lifestyle in order to reach sustainability goals. As an example, many individuals might prefer using cars (for their convenience in terms of independence, speed and comfort) and tolerating pollution, congestion and noise, rather than using public transportation.

On the other hand, “while the definitions of sustainable transportation reveal there is no standard way in which transportation is being considered, there seems to be a consensus that progress must occur on at least three fronts: economic development, environmental preservation,

and social development” (Jeon and Amekudzi 2005, p. 33). The concept of sustainable transportation tend therefore to be framed as a tripartite framework that simultaneously balances and accounts for these different dimensions of sustainability (WCED 1987, OECD 1997, Litman 2005, Isfort 2006, Nicolas *et al.* 2003). This means that any sustainable transportation evaluation should consider the possible impacts of mobility on the environment (e.g. noise, air and water pollution, resources depletion, habitat loss and global warming), the economy (e.g. in terms of direct and indirect transportation costs impacting on the community) and society (e.g. human health impacts, accessibility, equity, and security problems). These three dimensions have an equal relevance for measuring progresses towards a sustainable transportation. Connections between issues and integrated solutions might not be in fact easily found when adopting a narrowly defined sustainability (Litman, 2005). For example, if this is considered only in terms of air pollution emissions, decision-makers could decide to solve pollution problems by imposing the use of more efficient vehicles. On the other hand, this solution would not reduce congestion or mobility problems faced by non-drivers which, in turn, could result increased (Litman, 2004).

The same multi-dimensional framework has to be adopted when analysing sustainability of transport systems at the urban scale. It is for this reason that we suggest evaluating urban mobility policies by means of macro-objectives which encompass environmental, social and economic qualities (see Fig. 1).

Fig 1: Sustainable urban mobility dimensions



2. Development and implementation of sustainable urban mobility indicators: a literature review

2.1. Sustainable urban mobility indicators within the scientific community

Despite its relevance, we have found a very limited scientific literature specifically dealing with the development of sustainable mobility indicators at the urban scale. On the whole, these works tend to be structured as independent case studies which, departing from existing data sources or ad hoc data collection, describe the sustainability of transport systems in selected cities.

Nicolas et al. (2003) apply the theme of sustainable development to study urban transport and daily mobility in the city of Lyons (France). The sustainability of the urban travel system is analysed with a set of indicators constructed from household travel survey data, and complementing this information with other minor data sources. Indicators are developed by taking into account their potential relevance (they must cover essential issues), their coherence with the statistical database (and with the mobility issue) and their simplicity (i.e. easy to be used). This study adopts a top-down integrated approach, which classifies the indicators along different dimensions of economic, social and environmental sustainability. Measuring mobility costs for the community (households, companies and public authorities), the economic indicators are meant to reflect transport cost-efficiency within the conurbation. A set of social indicators is used to represent equity issues such as distances travelled, vehicle ownership, and the level of public transport expenditures. Finally, environmental impacts are taken into account with the following indicators: the level of local and global transport air-pollution emissions, space consumption from travelling, parking and infrastructures. Different levels of analysis are used when computing the indicators: place of residence (urban centre, neighbouring municipalities and further outer areas); transport mode used (car, public transport, other); income level (low, medium, high) and zone of emission. Lacking the data, road safety and noise pollution measures are not computed in this study.

With the objective of synthesizing a set of mobility indicators for medium sized urban centres (with a population between 100-500 thousands), Frei (2006) pays a special attention to the relation between pedestrians, cyclists and the use of private cars. In particular, he develops the so called 'Sampling Mobility Index', which is computed as the sum of several indicators representing the following urban features: 1) sidewalk width; 2) free walking pass; 3) vertical and horizontal signalling; 4) safety belt use; 5) respect for traffic light; 6) presence of pedestrian traffic lights; 7) presence of cycling lanes; and 8) the number of vehicles with more than one person on board. Taking Assis (Brazil) as a case study, the mobility index is computed by carrying out ad-hoc surveys in different homogeneous zones of the city (identified through cluster analysis by means of

10 socio-economic indicators drawn from the most recent national census). Measurements are either taken on a set of blocks randomly chosen within each homogeneous zone of the town, or on the 10 busiest roads with traffic lights. Results for Assis indicate a critical situation in terms of mobility. On the whole, Frei's approach does not explicitly consider the multi-dimensionality of transport sustainability. It reflects some aspects of mobility, such as the administration concerns over transport accessibility and driver's behaviour in relation with current legislation, but it neglects some other important issues. No indicator is in fact provided for measuring the quality of public transportation or the possible socio-economic-environmental impacts of mobility.

Aiming to assess the sustainability of urban transport in Lahore, Imran and Low (2003) suggest using a set of indicators belonging to the following categories: environment, society, economy, and transport-related (each domain is disaggregated in a number of sub-categories). According to data availability and the compliance with a number of assessment criteria (e.g. indicators should meet access needs of individuals, minimise consumption of non-renewable resources, and should be consistent with human health), a global evaluation of the situation in Lahore is provided (a table summarises this information by means of varying degrees of shading, showing how bad the situation is for each indicator). On the other hand, missing any figure, it is not clear which indicator is available or whether the evaluation is simply made under the provided criteria. On the whole, results show a critical situation for the transport system in Lahore with respect to sustainability.

Barker (2005) evaluates the sustainability of transportation system in San Antonio, Texas, using per capita miles-vehicle-travel (VMT) as a key indicator. Displaying high levels of this variable, several implications are considered for this city in terms of commuting-time (i.e. congestion), transport-related costs, traffic fatalities, energy consumption and pollution emissions. On the whole, San Antonio is found to be less sustainable compared to other cities. Several general strategies for increasing sustainability are then identified (e.g. a higher provision of public transit and pedestrian/bicycle facilities), and a comparison is made with the existing programs and plans developed in the city. This study suffers from several shortcomings. Although Baker emphasizes VMT as a key measure which affects a number of other 'unsustainability' variables, a list of indicators that should be generally used for measuring the sustainability of a transport system is not provided. The choice of indicators used is not motivated in any way, giving the impression of being based on data availability. Moreover, even if the various dimensions of transport sustainability are graphically displayed in the manuscript, the variables analyzed reflect just a few of the elements listed in this framework without being specifically ascribed to the different dimensional categories. It has also to be remarked that the evaluation is based on data elaborations provided by other studies

and not from on own computations. Lastly, as suggested by Litman (2005), the use of VMT (as well as similar measures) as a sustainability measure can be controversial: while motorized travel reduces sustainability for being resource-intensive and environmentally harmful, it also provides some economic and consumer benefits.

By means of multicriteria analysis, Costa et al. (2005) identify a set of indicators for monitoring sustainable urban mobility conditions of selected cities in Brazil and Portugal. The indicator selection process has involved several steps. By scrutinizing a wide range of national and international systems of sustainability indicators (and scanning official Internet pages of municipalities in both countries), the authors have first created an extensive list of mobility indicators (465). After classifying them by categories and themes, and taking into account potential similarities and adequacy to the urban scale, this has allowed selecting a smaller number of indicators (115). All elements (categories, themes and indicators) have been next weighted by a group of Brazilian and Portuguese experts, which assessed their relative importance for urban mobility monitoring. Using an Analytical Hierarchy Process (AHP) and pairwise comparisons, the experts have been able to identify a final set of 24 indicators belonging to the following categories: transport and environment, urban mobility management, spatial planning and transportation demand, socio-economic aspects of transportation. The main drawback of this work is that it does not include a table with the original list of indicators (being an extension of Costa's university dissertation, we guess this information might be found there) nor it does explain the clear-cut criteria used for removing indicators from the list (it is only specified that indicators with low weights have been removed, but no threshold value is provided).

Rather than proposing new sets of indicators/indices for monitoring the sustainability of urban mobility, Zhang and Guindon (2006) recommend new methodologies for computing existing indicators suggested by policy/transportation experts. Considering that urban travel patterns are strongly linked to the form of urban areas, they recommend to derive urban land-use data from satellite remote sensing imagery and employ this information for quantifying sustainability indicators. Urban form features (e.g. compactness, land-use, population density, distribution of population and employment) have in fact a significant impact on transportation activity and should be adequately considered when assessing transport sustainability. In the authors' words, "for urban transport sustainability, urban form is recognized as one of its most influential components" ... "through its impact on travel patterns and travel mode feasibility, can influence transport-related energy consumption" (p.151). On the other hand, the methodology proposed by Zhang and Guindon is quite complex and quantifies indicators by using basic statistics, spatial analysis and modelled processes derived from geo-spatial data. It involves the extraction of information on the features of

urban form (density, land use and compactness) from satellite data and the use of algorithmic formulations and dedicated software to analyse its impacts on transportation, environment and land use efficiency. On the whole, four indicators are derived for the cities of Ottawa-Gatineau and Calgary (Canada): 1) population density in urban land (excluding rural areas, water bodies and conservation land); 2) travel mode - an index measuring the impacts of land-use mix and urban form structure (i.e. the fraction of build-up land that is non-residential) on the feasibility of different transport modes (walking, cycling and motorized vehicles use); 3) city compactness (i.e. urban concentration); and 4) probability of travel distance.

2.2 Urban mobility indicators developed by other research initiatives

In order to better address the urban transport policies and improve the quality of life of people living in cities, specific urban mobility indicators systems have been developed in the last decade by international institutions, national and international initiatives.

Operationalizing sustainability by helping cities to optimize their use of land and transport networks and reducing problems such as traffic congestion, pollution and urban sprawl is in fact one of the greatest challenges facing policy-makers. It is with this aim than numerous projects have been developed within the Fifth European Union Framework Programme² (under the *Energy, Environment and Sustainable Development* thematic belonging to the *City of Tomorrow and Cultural Heritage Key Action*) to promote Land Use and Transport Research (LUTR)³. PROPOLIS, for instance, is a European Community research project⁴ aimed to develop integrated land-use and transport policies, tools and methodologies able to support sustainable long-term urban strategies. As discussed by Lautso et al. (2004), this project evaluates the sustainability of several policy options (investments, car pricing, regulation, public transport, land use and policy combinations) in seven European cities: Helsinki, Dortmund, Naples, Vicenza, Inverness, Bilbao and Brussels. This is achieved by means of urban land-use and transport models that simulate the effects of the policies on location behaviour of households/firms and account for the subsequent mobility patterns in the metropolitan region. Policy sustainability is assessed in terms of environmental, social and economic impacts, using different set of indicators to represent these dimensions. Indicators are chosen by taking into account their general relevance, representativity and policy sensitiveness, as well as avoiding double counting and trying to be consistent with other

² This programme “sets out the priorities for the European Union's Research, Technological Development and Demonstration (RTD) activities for the period 1998-2002” (http://ec.europa.eu/research/fp5/fp5-intro_en.html).

³ The following projects are part of LUTR: ASTRAL, ARTISTS, CITY FREIGHT, ECOCITY, ISHTAR, PLUME, PROPOLIS, PROMPT, PROSPECTS, SCATTER, SUTRA, TRANSPLUS.

⁴ PROPOLIS approach builds on a previous EC funded project, called SPARTACUS.

sets of urban indicators (especially the ones produced by the European Environmental Agency). A composite methodology is adopted for processing the output produced by the land-use transport models and computing the indicators values. Employing different ‘indicator modules’, a dedicated software performs spatial data disaggregation, economic cost-benefit analysis and social evaluations. In order to calculate their relative contribution to sustainability and aggregating them into different sustainability themes, indicator values are also processed via multicriteria analysis (the weights used are the outcome of an internal expert survey). At the end of the process, single aggregate environmental, social and economic indices describe the alternative policy options. Policy effects are assessed over the long-term (20 years) by varying zonal activities (such as variations in population/ employment localization) and mobility patterns of transport demand (different modal splits). On the whole, this study shows which types of policies are likely to give positive results (and therefore merit further study), demonstrating that best results are usually achieved by using policy mixes (combining pricing, investment and land use policies). The main drawback of this approach concerns the data, difficult to obtain for the costs involved and the highly spatially disaggregated level required. Moreover, this type of analysis simultaneously uses many tools and it is probably too complex for being applied at a large scale.

Departing from the idea that urban mobility is one of the critical elements influencing the sustainable development of a city, ISFORT⁵ (2006) identifies a core set of indicators (18) suitable for assessing the effectiveness of urban mobility policies. In order to be easily used by policy makers, indicators are disaggregated by thematic categories. In particular, ISFORT employs an innovative framework which tries to integrate the logic of decoupling/performance indicators and the well-known D-P-S-I-R (Determinants-Pressure-State-Impacts-Response) model. This new framework considers in fact both the direct and positive impacts of urban mobility (measuring the performance of the system in terms of increased accessibility) as well as the indirect and negative effects of the transport system on the environment and the human health. Reflecting various aspects of urban mobility, these central themes are further divided into sub-categories (measuring for instance the efficiency of the local public transportation system and resource consumption), each of which is represented by a small set of indicators. The core set of indicators has been selected with a top-down approach, departing from indicators listed in existing projects and applying a number of ‘established criteria’ for reducing indicator numerosness. Although an exhaustive list of the criteria used is not displayed, the choice of indicators has been made by taking into account: 1) their policy relevance (with respect to the Italian context and urban mobility concerns); 2) their use in other international and European systems of indicators; and 3) data availability. On the whole, as

⁵ Istituto Superiore di Formazione e Ricerca per Trasporti

the explanation provided are very shallow, it is not clear how this selection procedure has allowed defining the key set of indicators. The original list of indicators is not provided, nor it is specified their initial number. A further limitation of this study is the lack of any social and economic indicators. Moreover, despite mentioning the existence of multiple dimensions of sustainability, these are not taken explicitly into account in the indicator framework.

In order to help decision makers in Asian cities to evaluate the sustainability of their urban transport systems and better address local transport policies, a specific program (PSUTA, Partnership for Sustainable Urban Transport in Asia), was launched in 2004 by ADB (Asian Development Bank), CAI-Asia (Clean Air Initiative for Asian Cities) and EMBARQ (the World Resources Institute Center for Transportation and the Environment). The project involved (ADB and EMBARQ, 2006) three representative cities across Asia: Pune (India), Hanoi (Vietnam) and Xi'an (China). With the help of local stakeholders, each city had to gather the data and develop a set of indicators for monitoring transport sustainability by taking into account the following factors: access, safety, governance, environmental, economic and social externalities. As a result of this partnership, it has been possible to measure the sustainability of the transport systems in the selected urban areas as well as understand which information was lacking and how improving it in the future. Differently from the other cities, Pune (PSUTA, 2005) has developed its own set of indicators by taking into account local stakeholders expectations with respect to the transport system. On the whole, among the different stakeholder categories, commuters seemed mostly concerned over access problems and economic issues, while citizens in general were more worried for security and environmental impacts. This project suffers from two major drawbacks: 1) indicator sets are not homogeneous in the different cities (which do not allow making comparisons); 2) there are no details on how stakeholder expectations are investigated, nor how groups are formed and their information evaluated.

2.3. *Measuring urban development sustainability*

Lists of mobility indicators can also be found in studies and projects meant to evaluate overall city sustainability, which marginally deal with the transportation theme. Departing from an original list of more than 1000 indicators, for instance, Ambiente Italia (2003) has identified 10 local and urban sustainability indicators (European Common Indicators) belonging to different areas of analysis. Eight of these have a transport-related component. Indicators have been developed with a bottom up approach, involving local authorities as main actors in the process and improving synergies with existing indicator sets. They are in fact the result of numerous and extensive

consultation rounds with towns and cities, which were based on a number of common sustainability concerns (equality and social inclusion, local governance/empowerment/democracy, local/global relationship, local economy, environmental protection and cultural heritage/quality of the built environment). Urban mobility is directly and indirectly represented by the following indicators: 1) citizen satisfaction with regard to public transport; 2) transport contribution to global climate change; 3) local mobility and passenger transportation; 4) average population living at a close distance of public transports; 5) quality of the air; 6) children's journeys to and from school; 7) noise; 8) sustainable land use. Data gathering has been carried out with the help of local administrations in different EU countries. The main limitation of this initiative is that indicators are not homogeneous in terms of the number of responding cities. Moreover, none of the indicators listed is meant to measure economic issues.

A system of indicators aimed at surveying sustainable development in Italian provinces has been annually provided by Legambiente (the main Italian environmentalist association) since 1994. In its last report *Ecosistema Urbano 2008* (Legambiente, 2008), urban sustainability is represented by a set of variables belonging to the following themes: transports, water, air, energy, environmental policies, waste, space and urban green areas. Within the suggested set of indicators, fifteen of these can be ascribed to the urban mobility category. Some are directly related to transport activities and are meant to capture public transport offer/demand, the rate of motorization, the use of environmental friendly vehicles, fuel consumption, the extension of bike paths, pedestrian and limited traffic areas. Other indicators are just indirectly related to transports (they also reflect other activities) and measure air quality, green areas and eco-management issues. Based on indicators performance with respect to some pre-defined national and international targets, a ranking of Italian provinces is provided for each indicator. In addition, a general ranking of the provinces shows the general level of urban development in relation to the aggregate scores obtained in all indicators (a panel of expert has weighted the different themes and indicators). On the whole, there are some drawbacks in the approach used by Legambiente. Although the ranking criterion provides an immediate and clear picture of the performance of each location, it does not take into account the structural differences among provinces. This problem has been just partially corrected for the variables measuring public transport offer/demand, where different targets are used to distinguish between small and big cities. Moreover, the performance of each province can be simply assessed over the years in terms of different ranking positions in the various editions of the report (bearing in mind that the weighting scheme has changed over time).

TISSUE (*Trends and indicators for monitoring the EU Thematic strategy on sustainable development of urban environment*) is an important research project undertaken⁶ in 2004 to support the European ‘Thematic Strategy on the Urban Environment’. Urban transport sustainability is one of the five themes specifically considered by this project (dealing also with urban design, construction, management and environment), which aims to produce a harmonised set of indicators for monitoring the sustainable development of urban areas. Indicators are identified by screening the indicator systems developed within national, international and European initiatives and by taking into account a number of urban development related concerns (e.g. environmental pollution, consumption of resources) and trends (e.g. urban sprawl). The assessment is done in terms of usability and validity criteria. On the whole, 42 sustainability indicators are suggested in this study, out of which 8 are used for measuring urban transports features. Transport demand, safety, modal splits, the quality of public transport and the level of non-motorized infrastructures are the sustainable urban transport indicators explicitly proposed. Being indirectly linked to transport activities, a number of variables (9) belonging to the themes of sustainable urban environment, design and management can also be considered in the list of the transport-related indicators developed within the project. Each indicator is individually described and defined in terms of measurement, policy relevance, consensus (its shared use), and feasibility (if readily accessible in the short-term with a reasonable effort from the institution concerned, or not yet feasible due to shortcomings in data availability and other practical aspects and obtainable in the medium/long-term). This project suffers from the following limitations: 1) indicators are just disaggregated by theme, and not by economic, social and environmental dimensions of sustainability; 2) it focuses on environmental aspects of sustainable urban development without considering any socio-economic issues.

2.4. Leaving the urban dimension: general sustainable transport indicators

Urban mobility indicators are usually indirectly represented in the documents from international organisations. A general transport-specific approach (not necessarily urban) is in fact preferred by these institutions, which tend to focus on the transport sector as a whole and to develop indicators centred around environmental issues. This is the case, for instance, of the Transport and Environment Reporting Mechanism (TERM), developed in 1998 from the European Environment Agency (EEA), the European Commission and Eurostat. The aim of these institutions was in fact to produce a comprehensive set indicators apt to monitor the sustainability of the transport sector as

⁶ Within the 6th Framework Programme ‘Integrating and Strengthening the European Research Area’.

well as the integration of transport and environment strategies in EU countries. TERM reports have been annually published since 2000 by the EEA and currently consist of 40 indicators covering the most important aspects of the transport and environment system (following the well-known D-P-S-I-R framework). Each report is structured around seven qualitative policy questions, aiming to investigate, for instance, whether the EU is optimising the use of existing transport infrastructure capacity and moving towards a better-balanced intermodal transport system. Most indicators are centred around environmental issues and are measured at the national and EU level (i.e. they are computed for each country or as aggregated cross-country values). It has to be noticed though that they are not disaggregated by sustainability dimensions and, due to data availability problems, not all of them are published every year (15 indicators have been published in the last report, EEA 2008). Out of the 40 indicators, 34 could be computed for measuring transport sustainability at the urban scale.

A similar transport-oriented approach is also shared by OECD which, however, focuses its attention on road transport activities (2001, 2007). Numerous environmental pressures are in fact generated by road transportation, such as environment restructuring, consumption of natural resources (land, materials and energy), pollution, noise, congestion and accidents. In order to account for these potential negative externalities, the OECD has collected time-series data at the national level (from 1970s for OECD countries) on a set of parameters measuring road transport demand, supply, energy consumption, fuel prices and taxes. On the other hand, all these variables represent mobility and economic features of the road transport system and none of them measures the environmental impacts directly generated by transport activities.

Numerous national research initiatives have been undertaken in the recent years to develop sets of indicators able to evaluate progresses towards (or away from) sustainability in the transportation system (for a review see Jeon and Amekudzi, 2005⁷). Employing the EEA reporting mechanism, APAT⁸, for instance, has recently collected a series of transport and environment indicators for Italy (2005, 2006). Another valuable example is the Sustainable Transportation Performance Indicators Project jointly developed by the Centre for Sustainable Transportation and the Government of Canada (see Gilbert and Tanguay 2000, and Gilbert *et al.* 2002).

A general guidance on the selection of sustainable transport planning indicators is provided by Litman (2005). After listing various examples of indicator sets used by previous studies, Litman

⁷ The authors provide an extensive list of indicators used in 16 national and international initiatives. Information is provided whether the adoption of an indicator is shared by different initiatives and indicators are disaggregated by sustainability dimensions. On the other hand, since this latter information is often not provided in the studies scrutinised, this classification is based on a discretionary choice of the authors (e.g. within TERM indicators, the 'real change in the cost of transport is considered a transport-related parameter and not an economic one). A review can also be found in Litman (2005).

⁸ Agenzia per la protezione dell'ambiente e per i servizi tecnici.

suggests a number of best practices for selecting and applying sustainable transport indicators. Whenever possible, indicators have to be useful, easy to understand, comparable, suitable for establishing performance targets, as well as being available or readily collectable with the existing resources. In addition, indicators should reflect all the relevant economic/social/environmental planning objectives. A recommended list of sustainable transportation indicators (disaggregated by dimensional category) is provided by Litman together with information on their relevance⁹. Within the set of indicators considered as being the most important, economic issues are mostly represented. Despite the usefulness of prioritizing indicators, information is though lacking on the reasons why some indicators should be more important than others.

2.5. Literature overview

In the previous sections we have reviewed the specific scientific literature that deals with sustainable urban mobility as well as indicator systems proposed by numerous national and international organisations. Studies meant to analyse ‘sustainable urban development’ in general and the ‘sustainability of the whole transportation system’ (not necessarily at the urban scale) have been also considered. In order to draw some conclusions on the main features shared by these studies we have reported them in a single table (see table 1). Each study is briefly summarized and information is provided on the:

- **Study type:** applied, methodological or theoretical;
- **Focus of the analysis:** sustainable development, sustainable transport/mobility, or sustainable urban transport/mobility;
- **Approach adopted:** approaches are divided into two main categories: expert-led “top-down” approaches or participatory-based “bottom-up” methods¹⁰. The former makes use of quantitative indicators and statistical tools, it derives indicators from general principles, existing indicator sets and is generally defined by ‘experts’ (local, regional or national bodies with little or no input from the community). The latter approach emphasises stakeholder involvement: in this perspective local communities are the ones choosing a set of indicators according to their needs and perceptions.
- Eventual **weighting system** and **composition of evaluation panel**;
- **Geographical scale** of the analysis;

⁹ Indicators are classified into different groups: ‘Most Important’ (should always be used), ‘Helpful’ (used if possible) and ‘Specialised’ (used for reflecting particular objectives).

¹⁰ A suggested by Reed *et al.* (2006), “top down” approaches draw on the reductionist paradigm typical of many scientific fields (e.g. ecology, biology, economics), while “bottom-up” approaches are rooted in the social sciences (e.g. psychology, anthropology, etc.).

- **Key transport-related indices/indicators:** number of indicators recommended, sustainability dimensions explicitly considered and categories mostly represented;
- **Data sources** used.

Looking at the table below, we notice that the majority of the studies reviewed are empirical papers applied on a small number of urban areas which make use of existing data. Moreover, the sets of indicators suggested are typically developed by using top-down approaches. This means that they could lack legitimacy in the eyes of local stakeholders and may be inadequate for representing specific local issues. In order to define indicators that are closer to the needs and contexts of the specific localities, indicators should be in fact preferably complemented by the consultation of local actors/experts (as in PSUTA 2005, Costa et al 2005).

Another feature of the studies reviewed is that they tend to recommend small sets of indicators for measuring urban transport sustainability (the maximum number of indicators is 47). Interestingly, not all studies explicitly disaggregate the indicators by sustainability dimensions, and the transport-related (mobility) indicators seem to be the most represented category. On the other hand, despite the literature suggests to consider sustainability in terms of environmental, social and economic impacts, these dimensions are not homogeneously represented in the empirical studies reviewed.

In conclusion, what can be inferred from revising the literature on sustainable mobility in general as well as its urban counterpart, is that it seems virtually impossible measuring all aspects of sustainability, even when specifically focussing on the economic, social and environmental dimensions. This is probably linked to the vagueness of the sustainability concept and the difficulties in its measurement, as discussed in section 1. What can be done, though, is evaluating eventual progresses towards a more sustainable urban transport system without pretending to give a precise measure of sustainability. This requires the identification of key indicators apt to measure specific macro-policies developed by keeping in mind the three-dimensional framework of sustainability.

Tab. 1: Comparison between studies

Author	Study type	Focus	Approach	Weighting system	Composition of the evaluation panel	Geo. Scale	Key transport-related indices/ indicators			Data Sources	Brief description
							Tot.	Sustainability dimensions/categories			
								Explicitly considered	Mostly represented		
<i>Nicolas et al. (2003)</i>	Applied local	Sustainable urban mobility	Top-down	- ^a	-	Urban	19	Economic, Social, Environmental, mobility.	Economic/mobility	Existing data	Develops a set of indicators for measuring the sustainability of Lyon's urban travel system (estimations are mainly based on households' travel survey data). It discusses the conditions for reproducing this approach on other urban areas.
<i>Costa et al (2005)</i>	Applied – national/international level	Sustainable urban mobility	Bottom-up (multicriteria)	Analytical Hierarchy Process (pair-wise comparison)	Experts	Urban	24	Transportation and environment, mobility management, Infrastructure and transportation technologies, Spatial planning and transportation demand, Socio-economic	Environmental	-	Employing multicriteria analysis, this study identifies a set of indicators (and their relative importance) suitable for monitoring the urban mobility conditions of selected cities in Brazil and Portugal.
<i>Zhang and Guindon (2006)</i>	Methodological	Sustainable urban transport	Top-down	-	-	Urban	4	-	-	Existing data	Suggests a methodology for quantifying land-use/urban-form based indicators based on remote-sensing technology, basic statistics, spatial analysis and modelled processes.
<i>Frei (2006)</i>	Applied local	Sustainable urban mobility	Top-down	-	-	Urban	8 (= 1 index)	Mobility	Mobility	Ad-hoc	With the aim of monitoring mobility conditions in medium-sized cities, this study develops a so called "Sample Mobility Index" (composed of indicators related to walking, vehicle-use and cycling). The index is compute for the city of Assis (Brazil).
<i>Imran and Low (2003)</i>	Applied local	Sustainable urban transport	Top-down	-	-	Urban	47	Economic, social, environmental, transport activity.	Environmental	Existing data	Reviews the adequacy/deficiency of transport planning in Lahore (Pakistan) and recommends some measures for developing a more sustainable urban transport system.
<i>Barker (2005)</i>	Applied local	Sustainable urban transport	Top-down	-	-	Urban	1	Mobility	Mobility	Existing data	Evaluates the sustainability of the transportation system in San Antonio (Texas) using 'vehicle travel miles' as a key indicator.
<i>Lautso et al (2004)</i>	Methodological	Sustainable urban transport	Combined top-down and bottom-up (multicriteria, cost-benefit analysis)	Direct weighting method	Experts	Urban	35	Economic, social, environmental	Social	Existing data	Describes 'PROPOLIS', an EU project that evaluates the sustainability of different transport policy options in 7 EU urban regions. It employs an integrated approach based on land-use transport models, spatial disaggregation of the data, economic/social evaluations, and multicriteria analysis.
<i>ISFORT</i>	Theoretical	Sustainable	Top-down	-	-	Urban	15 18	Mobility (accessibility),	Mobility	-	A core set of indicators (disaggregated by

(2006)		urban mobility						environment and health			themes and sub-themes) is suggested as a tool for assessing the effectiveness of urban mobility policies. Indicators are meant to measure: 1) progresses towards a more sustainable urban mobility system; 2) negative impacts of the transport system on health and environment.
<i>PSUTA (2005)</i>	Applied local	Sustainable urban mobility	Bottom-up	-	citizens, service providers, energy providers, infrastructure providers, regulators, vehicle manufactures and government	Urban	31 ^e	Mobility (accessibility), economics, environment and health, safety, governance	Mobility	Existing data	Application of the PSUTA project to the city of Pune (India). The sustainability of the local transport system is evaluated by developing a set of indicators that take into account local stakeholder expectatives.
<i>TISSUE (2005)</i>	Theoretical	Sustainable urban development	Top-down	-	-	Urban	17 ^c	Urban transport, urban design, urban management, urban environment	Mobility	-	Describes 'TISSUE', an EU project aimed to produce an harmonized set of indicators that could be generally used for assessing the sustainability of an urban environment. Indicators are identified from the analysis of several national, international and European initiatives, and by taking into account a number of urban development-related concerns
<i>Ambiente Italia (2003)</i>	Applied at the EU level	Sustainable urban/local development	Bottom-up	-	Experts	Urban	8	-	-	Ad-hoc	With the help of local authorities, a short list of indicators (the Common European Indicators) is used for defining the sustainability profile of numerous EU cities.
<i>Legambiente (2008)</i>	Applied at the national level	Sustainable urban development	Bottom-up	Direct weighting	Experts from local administrations	Urban	15	-	-	Existing data	A set of indicators is used by Legambiente to evaluate the sustainable development of Italian provinces. A ranking of localities is provided according to the performance obtained for each indicator as well as for aggregate values of the parameters.
<i>Litman (2005)</i>	Theoretical	Sustainable transport	Top-down	-	-	-	16 ^d	Economic, social, environmental	Economic	-	Litman suggests a number of best practices for selecting sustainable transport indicators, describes examples of indicators sets used in previous studies and provides a list of recommended indicators disaggregated by relevance and dimensional category.
<i>EEA (2000-2007)</i>	Applied at the EU level	Sustainable transport	Top-down	-	-	National	34 ^e	Transport, environmental	Environmental	Ad hoc and existing	Annual reports describing TERM, an indicator-based reporting mechanism developed by the EEA for monitoring the

										data	integration and effectiveness of transport and environment strategies in the EU.
OECD (2007)	Applied at the national level	Sustainable development	Top-down	-	-	National	13	Transport, environmental	Transport	Existing data	As road transport activities generate noticeable pressures on the environment, the OECD provides a set of road-transport indicators (measured at the national level) that could potentially reflect these externalities.
^a - : not applicable; ^b ns: not specified; ^c indicators indirectly linked to transports are also included; ^d indicators grouped as the 'Most Important'; ^e excluding indicators with low significance with respect to transport system sustainability; ^e excluding indicators inapplicable at the urban scale;											

3. Indicator selection

Indicator selection has followed two steps. We have first defined a conceptual framework enabling us to link each parameter to a specific urban policy objective. This scheme is organised as a set of urban policy Macro-objectives representing the different dimensions of sustainability highlighted by the literature, which encompass environmental, social and economic urban mobility concerns (see Table 1). Each of these dimensions is articulated in a different set of transport policy objectives. In particular, attaining a more environmentally sustainable city implies reducing greenhouse gas emissions from motorized vehicles, transport waste and land consumed by transport infrastructures. Achieving social sustainability requires improving city accessibility (i.e. creating alternatives to mobility and facilitating urban travel) and liveability (i.e. through a greater availability of public space, silence, safety and cleaner air). Progresses towards economic sustainability can be made instead through a reduction of mobility costs for households, firms and public authorities.

Table1. Macro-objectives and objectives of sustainable urban mobility policies: the three dimensions of sustainability

MACRO-OBJECTIVES		OBJECTIVES
1. Socially sustainable city:	<i>Accessibility:</i>	1.1. Alternatives to mobility
		1.2. Ease of movement
	<i>Liveability:</i>	1.3. Availability of public space
		1.4. Silence
		1.5. Clean air
		1.6. Security
2. Environmentally sustainable city		2.1. Reduce greenhouse gas emissions
		2.2. Reduce land consumption
3. Economically sustainable city		3.1. Mobility costs reduction

This framework has two major advantages. Firstly, it is a tool that can assist in operationalizing the sustainability concept, which facilitates decision-making by local public administration authorities (the ones responsible for the development of the urban transport system and for monitoring its sustainability). Rather than being structured as an extensive list of unmanageable indicators, it provides instead a clear and intuitive format for evaluating and comparing different urban policy decisions. Secondly, this structure can be easily used for weighting the mobility objectives according to their relevance via multicriteria analysis¹¹ (e.g. weights can be attributed by experts on the basis of policy priorities or involving local stakeholders and citizens).

¹¹ See Munda (2004), Stagl (2006) and chapter 12 in Vatn (2005).

Departing from the research initiatives described in the previous section (and consulting Isfort researchers¹²), the next step involved the selection of a core set of mobility indicators apt to measure the sustainability of urban transport systems. In particular, adopting a top-down methodological approach, the choice of indicators has been carried out on the basis of their comprehensiveness and efficiency. According to the first criteria, indicators are selected by trying to represent all dimensions of sustainability, simultaneously reflecting economic, social and environmental concerns. Being difficult and costly to measure at a highly spatially disaggregated level, the second criteria respond instead to the necessity of avoiding redundant indicators. The number of indicators is therefore kept to a minimum, trying to associate a restricted number of clear and distinctive parameters to each urban mobility objective.

Table 2 lists a core set of indicators suitable for measuring the urban mobility policy objectives described above. All indicators are based on the assumption that private motorized vehicles represent a source of negative externalities, while walking and cycling are the most sustainable means of transport. The *Availability of public and private services accessible via telephone and computer* is the indicator chosen to approximate the ‘alternatives to mobility’ objective of social sustainability. The logic behind this indicator is that a ‘virtual mobility’ reduces the use of private motorized vehicles. Improvements in city accessibility can be also achieved through an ease of movement objective, measured with distinct indicators according to the modal split of trips (i.e. variety of travel choices): motorized transportation is measured with a road *Congestion* indicator; slow-mobility is approximated with two indices of *Walkability* and *Cycling*; while public transport is represented by the *Quantity/quality of public transport services*. The ‘availability of public space’ can be measured with the *Number of motorized vehicles per km²*, and *Kilometres of vehicle travel density*. Improving city liveability requires also reducing transport noise, having a cleaner air and increasing safety. The first objective is measured with the *Percentage of population exposed to transport noise levels exceeding the national standards*, the second is approximated by *Transport emissions* (the levels of PM10, COVNM, NOX, CO generated by transport activities), while the latter is measured with the number of *Death and injuries from transports*. Turning to the measurement of environmentally sustainable transport objectives, we suggest using the following indicators: *CO2 emissions from transports*, *Land occupied by transport infrastructures* and *Transport waste*. Finally, the ‘mobility cost reduction’ objective can be measured with the *Annual average mobility expenditure from households*,

¹² Isfort is one of the main organisations studying urban mobility in Italy. With the aim of monitoring the sustainability of urban mobility policies, since 2005 Isfort has in fact undertaken an urban mobility research project, named OPMUS (*Osservatorio per le Politiche della Mobilità Urbana Sostenibile*).

companies and public authorities (including investments in transport infrastructures, vehicles operating costs and transport service costs).

Table 2. Recommended indicators for monitoring sustainable mobility policies

OBJECTIVES	INDICATORS
1.1. Alternatives to mobility	Public and private services accessible via telephone and computer
1.2. Easy mobility	Congestion
	Walkability index
	Cycling index
	Quantity/quality of public transport services
1.3. Availability of public space	No. of motorized vehicles per km ²
	Kilometres of vehicle travel density (Vehicles*distances travelled per km ²)
1.4. Silence	Percentage of population exposed to transport noise levels exceeding the national standards
1.5. Clean air	Transport emissions: PM10, COVNM, NOX, CO
1.6. Safety	Death and injuries from transports
2.1. Reduce greenhouse gas emissions	CO ₂ emissions from transports
2.2. Reduce land consumption	Land occupied by the transport infrastructures
2.3. Reduce transport waste	Waste generated by transport activities
3.1. Mobility costs reduction	Annual average mobility expenditure from households, companies and public authorities

Indicators have been selected independently from data availability. On the other hand, a major problem in Italy (as well as for many other countries) is the availability of local data on urban mobility, which hampers any sustainability monitoring initiative. One of the most important data frequently missing is the average travel distance of motorized vehicles, disaggregated by vehicles type (i.e. two-wheelers, automobiles, trucks, buses) and vehicle performance (e.g. engine power, emissions, etc.). This data is in fact crucial for computing the majority of indicators listed in Table 2: the level of road congestion, noise exposure, greenhouse gas emissions, transport waste and local air pollutants generated by transport activities; and private mobility costs. The situation is also critical for other minor parameters. Pedestrian and cycling data are in fact generally unavailable, as well as the information on the quality of public transportation and on the services accessible via telephone and computer. On the whole, it is still necessary in Italy to set national guide-lines and laws for promoting a ad-hoc data collection from local government.

4. Future research

The next step of this research project will involve a better definition of some indicators suggested in Table 2. We still need in fact to investigate how to measure the walkability and cycling indices, the services accessible via telephone/computer, the quantity/quality of public transport

services and congestion. Furthermore, after collecting the required data (involving local administrations), we want to conduct an empirical evaluation of transport sustainability policies in selected Italian cities. The analysis will be developed by taking into account the urban transport macro objectives framework identified in the previous section. In choosing our case studies, preference will be given to those cities which have already gathered data that are normally lacking at the national urban level (e.g. the average daily distances of motorised vehicles, noise). In order to understand the relative importance of the different policy objectives for sustainable urban mobility, in the future we also aim to use multicriteria analysis (MCA) tools. With the help of Isfort's trimestral survey on mobility (Audimob) we have already started to gather households' opinion, but we also aim to weight the policy objectives by setting up a panel of national experts on urban transportation systems.

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