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Evaluating the role of land use and transport policies in reducing the transport energy dependence of a city

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A B S T R A C T

In this paper a land use and transport model is presented to calculate an indicator of "Transport Energy Dependence" (TED) in order to support the delivery of sustainable urban and transport plans. The model is based on a mathematical description of the transport system, where transport mode choice follows ideal simple rules based on distance from origin to destination and transit network accessibility. For each transport mode unit energy consumption, capacity and load factor are considered. Flows of trips are optimally assigned between origin and destination zones in such a way that transport energy is minimised. Energy ideally required for home-to-school/university travel is assessed as these journeys contribute a significant number of daily trips within a city. In particular, the model was applied to the urban area of Catania, a medium-sized town in Italy, for different scenarios, including improvements in the transit system and in pedestrian/cycling accessibility. The methodology proved to be suitable to evaluate the potential impact of land use and transport policies in terms of transport energy dependence, separating it from behavioural considerations.

1. Introduction

70% of the EU's population lives in urban areas. These generate 85% of the Union's GDP (EC, 2009) and produce 25% of all CO_2 transport-related emissions (EEA, 2013). In 2011 transport used one third of all energy and 70% of all oil in the EU (EC, 2013). Meeting climate change targets and reducing oil dependency are dual challenges facing cities and local communities. To meet the aim of improving environmental sustainability and reducing transport related energy use, cities joining the Covenant of Mayors[1] are adopting Sustainable Energy Action Plans (SEAPs). However, these often lack suitable methods to estimate the impact of the proposed measures in terms of transport energy reduction.

The transport energy use of a city depends on the dimension, density, design and transport level of service of the city, as well as by socio-economic features. Travel Demand Management (TDM) includes strategies to reduce the use of cars and related energy consumption (Ignaccolo, Caprì, Giunta, & Inturri, 2006; Ison & Rye, 2008; Litman, 2003). These strategies are effective in reducing transport energy by acting on the demand and, therefore, changing users' behaviour (Gerike, Hülsmann, & Roller, 2013). An effective way of reducing car dependency of our cities and the related energy consumption is to properly integrate land use and transport planning (La Greca, Barbarossa, Ignaccolo, Inturri, & Martinico, 2011; Caprì, Ignaccolo, Inturri, & Le Pira, 2015). Newman and Kenworthy (1989) found that transport related fuel consumption is reduced by urban density. The idea is that higher density increases the probability of shorter trips and the attractiveness and feasibility of walking and using public transport. This leads urban planners to favour mixed use, transit oriented compact cities as opposed to low density, car dependent and sprawled cities. Some authors (Neuman, 2005) however question whether compact and high density cities are a form of sustainable urban development.

A comprehensive review of the main ideas and opinions about travel behaviour and land use and socio economic variables can be found in Hickman and Banister (2007). Several indexes have been proposed to evaluate actual transport energy consumption (Boussauw & Witlox, 2009; Reiter & Marique, 2012). The Commute-Energy Performance (CEP) index (Boussauw & Witlox, 2009) was applied to assess the transport energy related to workers in Belgium, at a regional scale, using statistical data. Some interesting results show that distance is much more relevant than

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[1] http://www.covenantofmayors.eu/.

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mode choice and that the relationship between density and energy consumed described by Newman and Kenworthy (1989) is well respected (in terms of CEP). Following a similar approach, Reiter and Marique (2012) used the Energy Performance Index (IPE) to assess the energy consumed for home-to-work and home-to-school trips in the urban area of Liège. They showed that building energy consumption is about 6 times more than transport energy and that the energy consumed for home-to-work journeys is about 8 times higher than ones undertaken for study purposes.

The Transport Energy Specification (TES) introduced by Saunders, Kuhnimhof, Chlond, and Rodrigues da Silva (2008) is quite different from previous studies as it is not an estimate of the actual transport energy consumption but a calculation of the transport energy dependence of a neighbourhood. It calculates the minimum transport energy used if everyone selected the most energy efficient mode of transport available according to simple rules based on the distance between land use locations. Despite its simplicity, the TES represents an interesting approach to exploring the relationships between the transport system, land use patterns and the transport energy demands of a neighbourhood.

Analogous to the TES, we use a model to calculate the transport energy of a city which is dependent on the spatial distribution of land use destinations, transport network connectivity, transit quality, vehicle energy standards and idealized users' travel behaviour. The model allows us to separate the impacts of the planning choices on land use and transport variables from the actual transport demand patterns and travel habits of citizens (Inturri, Ignaccolo, Le Pira, Mancuso, & Caprì, 2014). It calculates a "Transport Energy Dependence" (TED) indicator at the level of a single traffic zone and of the whole urban area which measures the potential effectiveness of the adopted policies, rather than the actual consumed energy. TED is an ideal indicator that can be used as a baseline from which to understand the maximum (ideal) extent to which urban planning can modify the travel patterns. Even if the effect of transport policies is clearly conditioned by travel behaviour, the present methodology is an attempt to disentangle land use and transport strategies from behavioural implications to try to evaluate the extent to which the "urban and transport settlement" of a city is energy efficient, apart from the actual citizens' travel choices.

2. Methodology

The methodology has been applied to evaluate the transport energy dependence of commuting (home-to-work) in the city of Catania (Inturri et al., 2014). In this paper, we assess the transport energy dependence of education (school and university) mobility, being a huge part of the daily trips in the city (McDonald, Brown, Marchetti, & Pedroso, 2011) and highly dependent on many factors, such as urban form and destination distances (McMillan, 2007; Schlossberg, Greene, Phillips, Johnson, & Parker, 2006). The results are compared with home-to-work trips and the impacts of land use and transport policies are discussed.

Urban transport energy use is a function of three main factors:

- the land use distribution, which influences the amount of transport activity, that is how many kilometres people travel;
- the efficiency of the transport system, determining the number of people sharing a vehicle, that is the capacity of the vehicle multiplied by the load factor;
- the energy intensity of vehicles, that is the unit energy to move a vehicle one kilometre.

The three factors are the output of three interacting models composing a planning scenario, as shown in Fig. 1:

- the land use model contains socioeconomic data about the number of residents and land use destinations in each traffic zone composing the urban area. It is assumed that each traffic zone generates a demand flow to all other zones as a function of the number of residents and a fixed trip frequency for each type of destination (such as a workplace, school, retail, or services);
- the transport model provides a mathematical description of the road, transit, pedestrian and cycling networks to calculate the shortest distance between each origin destination (OD) pair for each transport mode;
- the energy model assigns an intensity energy to each category of vehicles composing the public and private fleets.

The mode choice model assigns a transport mode to each OD pair following a set of simple fixed rules based on the length of the trip, the transit accessibility and the set of mode choices available to the users. Then, the optimal distribution of demand flows among ODs is calculated by solving a standard transportation problem (Hillier & Lieberman, 2001) to minimise the total transport energy in the urban area, while respecting the capacity constraint of the land use destinations. More details about the procedure can be found in Inturri et al. (2014). The value obtained from optimisation is not the actual energy consumed, but the amount of energy each person would consume in an optimal condition of trip distribution (going to the nearest available destination satisfying the travel purpose) and transport mode choice (the most "suitable" mode of transport is used, according with its availability and the length of the trip). In this sense, the final output of this procedure can be used to verify that the adopted policies satisfy a fixed standard (TED* in Fig. 1) for the approval of a plan, for example a SEAP or a Sustainable Urban Mobility Plan.

For each planning scenario s and travel purpose p, Transport Energy Dependence (TED) in kWh is calculated by the following expression:

$$TED_s^p = \sum_o \sum_d t_{od}^p \cdot l_{od} \cdot \frac{e_v}{c_v \cdot LF_v} \quad (1)$$

being

t_{od} the number of trips assigned from zone o to zone d for the travel purpose p that minimise the total transport energy (passengers)
l_{od} the shortest distance between zone o and zone d (km), by the chosen transport mode
e_v the energy intensity of the chosen transport mode (kWh/veh-km)
c_v the capacity of the vehicle (spaces/veh)
LF_v the load factor (passengers/spaces).

For a given scenario and a given trip purpose, TED is the minimum energy that would have been consumed if, given a fixed distribution of population, urban functions and transport mode options, every person could select the nearest destination and would choose the best available transport mode for each distance range to be travelled.

TED calculated at the zone level can be used to compare different scenarios within the same area, but it can also be used to compare transport energy needs in different cities or in the same city over time, according to its forecasted evolution. It also allows correlations to be performed among characteristics of the traffic zones (such as mixed land use, compactness, centrality, jobs-housing balance), spatial mobility patterns and transport energy dependence.

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