Ecological Indicators 72 (2017) 597–604

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

# Environmental assessment of urban mobility: Combining life cycle assessment with land-use and transport interaction modelling—Application to Lyon (France)

Cyrille François[a], Natacha Gondran[b,*], Jean-Pierre Nicolas[a], David Parsons[c]

[a] Laboratoire Aménagement Economie Transports (UMR CNRS 5593), Ecole Nationale des Travaux Publics de l'Etat, Rue Maurice Audin, F-69518, Vaulx-en-Velin Cedex, France
[b] Univ Lyon, Ecole Nationale Supérieure des Mines de Saint Etienne, CNRS, UMR 5600 EVS, F-42023, France
[c] School of Water, Energy and Environment, Cranfield University, Cranfield, Bedford MK43 9PB, UK

ARTICLE INFO

*Article history:*
Received 12 May 2015
Received in revised form 30 June 2016
Accepted 13 July 2016

*Keywords:*
Urban mobility
Land Use and Transport Interactions model
Environmental assessment
Life cycle analysis

ABSTRACT

In France, greenhouse gas (GHG) emissions from transport have grown steadily since 1950 and transport is now the main source of emissions. Despite technological improvements, urban sprawl increases the environmental stress due to car use. This study evaluates urban mobility through assessments of the transport system and travel habits, by applying life cycle assessment methods to the results of mobility simulations that were produced by a Land Use and Transport Interactions (LUTI) model. The environmental impacts of four life cycle phases of urban mobility in the Lyon area (exhausts, fuel processing, infrastructure and vehicle life cycle) were estimated through nine indicators (global warming potential, particulate matter emissions, photochemical oxidant emissions, terrestrial acidification, fossil resource depletion, metal depletion, non-renewable energy use, renewable energy use and land occupancy). GHG emissions were estimated to be 3.02 kg $CO_2$-eq inhabitant$^{-1}$ day$^{-1}$, strongly linked to car use, and indirect impacts represented 21% of GHG emissions, which is consistent with previous studies. Combining life cycle assessment (LCA) with a LUTI model allows changes in the vehicle mix and fuel sources combined with demographic shifts to be assessed, and provides environmental perspectives for transport policy makers and urban planners. It can also provide detailed analysis, by allowing levels of emissions that are generated by different categories of households to be differentiated, according to their revenue and location. Public policies can then focus more accurately on the emitters and be assessed from both an environmental and social point of view.



## 1. Introduction

The transport sector has become the main source of GHG emissions in France, producing 136.4 Mt $CO_2$-eq (carbon-dioxide equivalent), 27.8% of the total GHG, in 2012. Personal vehicles represent 57% of these emissions, and individual mobility accounts for approximately two-thirds of total transport emissions—the other third being generated by freight transport (MEDDE, 2014). Individual mobility comprises local and long-distance mobility (above 80 km from home). In 2008, local mobility represented 99% of individual journeys, 59% of total distance and 69% of greenhouse gas emissions. The total GHG emissions from internal travel by French residents increased by 14% between 1994 and 2008, due to a significant increase in local travel emissions (+17%) compared to long-distance travel emissions (+8%), mainly linked with population growth (+6%) (Nicolas et al., 2013). The challenge for local authorities is to take decisions to reverse this trend and implement urban transport systems with lower environmental impacts without increasing social disparities.

This paper focuses on the concept and development of new environmental assessment tools to help urban planning decision making. It is based on three assumptions: (1) the environmental assessment should be large enough to avoid excessive blind spots for public decisions; (2) it is important to link emission and emitters, which is not easy in the case of transport; (3) urban modelling now furnishes operational tools which are efficient enough to guide an assessment at a conurbation scale.

Firstly, in the field of environmental assessment for public policies, although some scientific reviews now provide a good survey of the environmental impacts of transport (Joumard and

* Corresponding author.
*E-mail address:* Natacha.Gondran@mines-stetienne.fr (N. Gondran).

http://dx.doi.org/10.1016/j.ecolind.2016.07.014
1470-160X/

Gudmundsson, 2010), most applied studies still focus on direct emissions from vehicle operation and their spatial distribution inside the defined perimeter. However, research on life cycle analysis shows the importance of including indirect impacts resulting from other stages, such as infrastructure, fuel production, car manufacturing, maintenance and disposal (Le Féon, 2014). It is also important to enlarge the scope by considering different kinds of emissions and impacts, which can be cumulative or can compensate each other. Indeed, public policies may have both environmental advantages and disadvantages if various environmental impacts and the whole lifecycle of transport are taken into account. For example, promoting electric vehicles may reduce urban atmospheric pollution, but it also generates additional environmental impacts during the fabrication of batteries and electricity production. This study contributes to identifying some of these combined factors in order to simulate cascading effects of transport policy in a more realistic manner.

Secondly, it is necessary to link emissions with emitters to be able both to evaluate policies more accurately and to take social inequality into account. Many studies give good estimates of transport emissions and their impacts at various territorial scales (for example, EEA, 2012 at the European level, or, for France, CITEPA, 2014 at a national level and Aurenche, 2010 at a local scale), allowing estimation of the importance of the issue and the economic activity at stake. However, in the case of transport, as these emissions are due to a multitude of individuals who move for many reasons and have different constraints, that link is more difficult to establish. Assessments often simply link emissions to traffic levels, with no precise knowledge of who emits, which is not helpful in defining fairer and more efficient public policies. To overcome this limitation, some research has employed household travel surveys enhanced with emission estimates, allowing a better understanding of who emits what, how much and why (Brand and Preston, 2010; Dupont-Kieffer et al., 2010; Nicolas and David, 2009). This may help local authorities to better target their actions and avoid penalizing those who do not emit.

Lastly, evaluating environmental impacts of urban mobility is made possible by using land use and transport interaction models (LUTI models), which allow long-term scenarios to be tested and give outputs for large scale urban transport systems. Of course, such a choice encounters some limitations: the simplifications and hypotheses intrinsic to modelling allow a limited range of prospective scenarios, as well as introducing some biases and uncertainties. On the other hand, once the initial investment to develop such a tool is made, its use simplifies data acquisition from a complex system, and it then facilitates simulations to test the effect of developments in the overall context (public policies, economic trends, demographic evolutions, behaviour changes, etc.) on emission levels. Several models now exist at a sufficiently disaggregated level to give a good picture of the emitters (see Antoni (2010) for France and Hunt et al. (2005) or Wegener (2004) at an international level). The model selected for this study is SIMBAD (SImuler les MoBilités pour une Agglomération Durable, ie Simulate Mobility for a Sustainable City), which has been developed for the Lyon urban area (Nicolas et al., 2009).

The aim of this paper is to demonstrate the relevance and the feasibility of combining these three assumptions by providing a clear and structured environmental assessment of urban mobility in Lyon. In order to achieve this goal, several objectives were set:

- To undertake a life cycle assessment of the environmental impacts of Lyon's urban transport system using a multi-indicator evaluation
- To integrate the LCA with data resulting from a LUTI model
- To link emissions with emitters.

## 2. Methods

To assess the environmental impacts of urban mobility, estimates were made using a method based on standard LCA methods (ISO, 2006). Urban mobility was considered as a system whose function is to enable people living or working within an urban area to travel during a working day. Using this functional definition, urban mobility is defined not only by the transport system, but also includes journey habits and locations of both activities and households (Geurs and Van Wee, 2004). In order to assess the whole system, the functional unit was expressed as per inhabitant day to take into account the transport system, the distance and the number of trips. To provide comparison points with other studies and to discuss functional unit choices, some results were expressed in different units, such as per person kilometre (pkm) and per trip.

SIMBAD is a Land Use and Transport Interactions model developed by the Laboratoire Aménagement Économie Transports (LAET) (Nicolas et al., 2009). It is designed on a city commuting scale, in order to estimate economic, environmental and social impacts of alternative public policies in urban and transport planning. It simulates the location changes for households and companies over a 25 year timeframe, in interaction with a complete urban transport system (public transport, car and non-motorized modes for individuals, and goods movements due to economic activities).

It has been applied to the case of Lyon, the second most populous area in France, covering 3300 km$^2$ distributed in 296 municipalities and 777 IRIS, which are used as the spatial unit basis[1] and are represented in Fig. 1. The location modelling has been calibrated and estimated using 1999 census data for households and 1999 SIRENE[2] data for companies. Public transport and road networks have been built and validated in the model for the same year and are regularly updated to take changes into account. Goods movements are generated with the FRETURB model developed by the Laboratoire Aménagement Économie Transports (LAET) to simulate the transport of goods in urban areas (Routhier and Toilier, 2007), and the individual trip model has been calibrated using the 2006 Lyon household travel survey (SYTRAL, 2006).

For the case study presented here, which tests the feasibility and relevance of combining LUTI output with a life cycle assessment to assess an urban transport system, a 2006 simulation was conducted and used. This study focused on individual daily mobility; goods movements were not considered. Currently the area has a population of 1,710,000 people, and the model calculates 6,900,000 journeys per day distributed among individual car, public transport and non-motorized modes. All motorized trips were allocated to the road network and public transport network in one representative peak hour or one representative off-peak hour of an average working day. The flows of vehicles simulated on each network section for 2006 were used as input data for environmental impact assessment, based on the LCA methodology (ISO, 2006).

In order to estimate the environmental impacts of the transport system, nine indicators were selected (Table 1). Global warming potential and both renewable and non-renewable energy use measure the achievement of global environmental targets to reduce GHG emissions and improve energy efficiency (MEDDE, 2011). However, the transport sector is a large user of fossil resources

[1] The French National Institute for Statistics, INSEE, developed a system for dividing the country into units of equal population size (about 2000 inhabitants). IRIS (acronym for 'aggregated units for statistical information') represent the fundamental unit for dissemination of infra-municipal data. Towns with more than 10,000 inhabitants, and a large proportion of towns with 5000–10,000 inhabitants, are divided into several IRIS units. France is composed of around 16,100 IRIS (see http://www.insee.fr/en/methodes/default.asp?page=definitions/iris.htm)

[2] SIRENE is the French national system of identification and directory of companies and of their establishments.