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Linking energy and transport models to support policy making

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ABSTRACT

Energy is an essential input to the transport system and transport energy use is a major component of the overall energy demand. Transport currently accounts for nearly half of global oil consumption and is the only field to be almost exclusively based upon a sole primary energy source. A possible evolution might be based on more oil-independent vehicles, on a higher use of energy efficient transport modes, on the integration of them through Intelligent Transport Systems (ITS). The answer to this partially global problem can be found both in transport and energy planning as well as in the adoption of new industrial and ICT technologies.

Both energy strategy makers and transport planners need supporting tools for a better assessment of the impact of possible alternative policies and to set realistic targets for the transport sector.

The present paper presents a conceptual link between two families of models - energy and transport - and provides some preliminary results of integrated modelling exercises for the Italian case, which show the importance of accurate ICT based data exchange between the models and the relevance of the comparison of present and future policy implementations.

1. Introduction

Demand of mobility and transport of goods has been increasing for all the XX Century and the beginning of the XXI around the world due to the globalisation of production and to the rise of wealth in consolidating economies. The consequence of this is obviously the rocketing of global fuel consumption, the vast majority of which is still based on crude oil. In 2013, transport accounted for more than 60% of global oil consumption and more than 27% of world total final energy consumption (OECD, 2015). In OECD countries, this latter value rises up to more than 30%; emerging economies have been entering or reinforcing the private transportation sector and may not want to bear in the short term the costs and impact of alternative fuels on such a steep rising of demand.

Furthermore, focusing on the EU-28, about one quarter of the GHG emissions is due to the transport sector: in particular, in 2014 95.1% of GHG emissions related to the fuel combustion in the sector has been generated by road transport, 1.8% by inland navigation, 1.7% by inland aviation and 0.1% by railways (Eurostat, 2016). In addition to this direct impact, the production of fuels used in the transport sector also causes indirect emissions. The action plan approved by the 2015 Conference of the Parties (COP21) and the single national and international regulatory frameworks (like the European and the U.S. ones) set measures to obtain an effective transport emissions reduction in the mid-term: among these measures, the increase in efficiency for heavy-duty vehicles, the improvement in the traffic management and the definition of more severe emission standards for cars and vans by 2020 can be mentioned (European Economic and Social Committee, 2016). According to this context, from the policy point of view it could be useful to promote the penetration of alternative fuels and energy carriers – including electricity – in the transport sector, thus enhancing the need for new fuelling and recharging infrastructures.

The transport borne carbon dioxide emissions rate do not follow exactly the same slope of the fuel consumption in the sector (OECD, 2016), as, although impacting, it is slightly slackened thanks to the penetration of electrified means such as trains, metros, automated people movers (by rope or rail) and by the improvements in the powertrains efficiency. Some world areas, such as the OECD countries, are struggling to enforce policies that tend to reduce dependency on fossil fuels, operating on both motorisation and ITS, with consequent (positive) environmental impacts.

The dense urban environment is, then, particularly sensitive to the

Abbreviations: BEV, Battery electric vehicles; EV, Electric vehicles; FE, Full electric; FSM, Four step model; GDP, Gross domestic product; GHG, Green house gases; GIS, Geographical information system; HFC, Hydrogen fuel cell vehicles; ICE, Internal combustion engine; ICT, Information and communication technologies; ITS, Intelligent transport systems; O/D, Origin/destination; PHEV, Plug-in hybrid electric vehicles; TTW, Tank-to-wheel; V2G, Vehicle-to-grid; V2X, Vehicle-to-everything

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transport pattern which transforms itself continuously by integrating electric solutions (based on stationary generation), low emission powertrains, modal split options, shared mobility and ICT technologies. These all contribute to enhance energy efficiency of motorised transport, which supports the mobility of people and logistics of freight: yet, how far?

An optimal solution may appear to be the fulfilment of the whole transport demand in the next future with non-fossil fuels as through, e.g., only electric vehicles recharged with energy obtained from renewables: a too simple and unrealistic solution. It has to be noticed that currently the average EU energy mix for power generation is strongly dependent on fossils: in particular, in 2014, 42.3% of the overall power generation has been obtained from fossil sources (OECD/IEA, 2016). As such, electrification, even by using energy carriers or storage solutions (such as batteries and hydrogen), cannot be labelled as the non-fossil optimal choice, yet. A change in the fuel mix of electricity production is requested (and expected) in order to fulfil the International environmental commitments and agreements, like the Paris Agreement, according to the so-called "energy transition" towards a decarbonisation of the energy systems. Some forecasting scenario analyses, mostly devoted to the implementation of environmental policies, like the 450 Scenario of the IEA, estimate a reduction in the percentage contribution of fossil fuels to the power mix, which is expected to lower to 10.1% in the EU in 2040 (OECD/IEA, 2016). As one of the most relevant issues of such a power system mainly relying on renewables is represented by the possible instabilities of the electrical grid caused by the intermittency of renewable sources, an electrification of the transport sector based on a vehicle-to-grid (V2G) approach could be beneficial. In fact, it would support decarbonisation pathways based on the increase in renewable penetration in the power generation and consequently on the increase in electricity consumption in the end-use sectors (European Commission, 2017).

Even though it is an evidently shared opinion that diversification - modal split also through ITS and technological innovation in powertrains - optimisation and rationalisation (efficient use of energy and public soil) in the field of transport are mandatory, these issues need to be addressed as far as possible with scientifically sound or acceptable tools. At the state of knowledge, there is no univocally defined optimal solution (Dalla Chiara and Pellicelli, 2016): the preferred distribution of solutions is set between the present nearly full-oil and the radical full-electric pattern and it can be shaped by means of suitable modelling tools strictly connected to the set of constraints chosen by the decision maker.

The objective of this paper is to illustrate the need for a link between energy models and transport models in order to guarantee that the best of each family of tools is integrated and used to support the forecast and the comparison of the effects of technologically based policies imposed by governments at each level of territorial scale.

The structure of the paper is the following: Section 2 presents the background and a literature review about both kinds of sectorial modelling (energy and transport); Section 3 introduces the methodology adopted for testing the link among models, providing details about the energy model equations and about where the link can be effective; Section 4, presents the commented results of a series of scenario obtained running the energy model under some hypotheses derived from transportation policy constraints and focusing on the Italian case. The conclusion section provides some policy implications that may arise testing the proposed kind of tools.

2. Background and literature review

2.1. Energy modelling

When dealing with future perspectives, energy analysts often make use of energy modelling tools that describe the energy system of a region and depict the courses of fuels and technologies deployment necessary to fulfil defined services demands.

Energy modelling simulations can propose a possible evolution in time of energy consumption, identifying the different fuel mixes and the technologies that can be used to satisfy the required service demands. These are usually exogenously provided and are calculated by making use of additional econometric models which keep in due account a set of drivers, such as the development of economic activities, demographic trends, energy prices on international markets. The main aims of energy models are to:

- forecast the future energy demand and supply, referred to a Country or a Region;
- evaluate the effects of different policies and measures (scenario analysis) on the energy system;
- quantify the impact of different targets (f.i. GHG emissions reduction, supply risk reduction) on the system;
- compare the economic costs of alternative configurations;
- represent supporting tools for decision-makers.

With these methodologies and tools it is possible to analyse costs and benefits of the energy options as well as, progressively, to build analytical and computational models for exploring - along different time horizons - the effects of particular actions or to choose trajectories able to minimise the system costs or to achieve particular objectives, namely from the technological, energy supply and environmental points of view.

As illustrated hereafter, many energy modelling tools also embed the capability of describing the technological evolution of devices and infrastructures. In this sense, energy and technology models are mutually coupled. Many energy models include GIS tools and specific modules that deal with global warming issues (providing the possibility to calculate GHG emissions and concentrations) but also, increasingly, with the socio-political aspects and the human choices.

As the technological description is so important for a great family of energy models, the availability, reliability, homogeneity of technological data bases are crucial and, possibly, a weak point. Additionally, the transport sector description poses a particular difficulty, as it is not trivial to integrate spatial variables into the RES (reference energy system) and to describe the origin/destination characteristics of mobility and logistics.

2.1.1. The type of modelling tools

Referring to energy models, two main approaches can be identified:

- top-down, mainly related to the General Equilibrium econometric models; as examples of this approach, the General Equilibrium Model for Economy-Energy-Environment (GEM-E3), a multi-regional and multi-sectorial model focusing on the interactions between the macroeconomic and the energy system (E^3M Lab, 2010), and the Global Trade Analysis Program (GTAP) model (Hertel, 1997) can be mentioned.
- bottom-up, characterised by high detail in technological description and widely used to estimate possible future configurations of an energy system, taking into account both demand and supply of energy commodities; bottom-up models can be further classified into two main categories, that are:

  - simulation models, which allow to compare two or more different scenarios; among these, the Model for Analysis of Energy Demand (MAED) (IAEA, 2006) can be cited;
  - optimisation models, which try to find the optimal set of technologies and fuel mix that minimise or maximise a certain objective function under a set of constraints (f.i., a target on CO_2 emissions). They are usually mathematically implemented in the form of linear equation systems; together with the TIMES model generator, described in the methodological section, the Open Source energy