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Energy management in metro-transit systems: An innovative proposal toward an integrated and sustainable urban mobility system including plug-in electric vehicles

Maria Carmen Falvo [a], Regina Lamedica [a,*], Richard Bartoni [b], Gennaro Maranzano [c]

[a] DIAEE – Electrical Engineering, University of Rome Sapienza, via delle Sette Sale 12b, 00199 Rome, Italy
[b] Maire Tecnimont, Italy
[c] Atac Roma S.p.A. (Rome Urban Mobility Company), Italy

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ABSTRACT

The energy consumptions growth, the upward interest for environmental sustainability and the technological evolution carry to the necessity to review the planning criteria of urban mobility systems in large cities and metropolitan areas. With this aim, new studies and projects are in progress, especially dealing with the power systems for metro-transit lines and surface electric vehicles. In this framework, the authors perform a study that, from an overview about the main energy management issues connected to the city transport, provides an innovative proposal for the design of sustainable urban mobility system: the integration of the metro-lines with surface plug-in electric vehicles. The present paper includes the energy analysis results, obtained by an application on a real case study of an home-made simulation software, describes the proposal in terms of power systems architecture and business models, pointing out the potential advantages that its implementation could give in terms of energy saving, environmental sustainability and reduced economic impact, as a result of the maximum exploitation of existing electric power plant.

1. Introduction

Nowadays the energy and environmental sustainability in the mobility systems design is one of the most important objectives. The achievement of this requirement is a nearly necessary condition for guaranteeing also the economic efficiency of the proposed solutions [1–4]. In fact it is demonstrated that an energy-efficient and environmental sustainable transport system is essential to the high-quality performance of modern economic systems: the gross domestic product (GDP) and the transport activity of a Country are closely coupled. As example Fig. 1 shows such coupling in the case of the European Union (EU) and its future trend under a *business-as-usual* scenario. In other words, transport demand will increase as a result of economic growth, but the latter is only possible if transport activity is able to develop consequently. On the other hand, it is well known that the transport sector in EU is responsible for: approximately 30% of total energy consumptions, 27% of total greenhouse gas (GHG) emissions, 72% of which are attributable to road transport alone. Figs. 2 and 3 respectively show up these two aspects.

Recent reports by Intergovernmental Panel on Climate Change point at the need to reduce global GHG emissions by 60% at least by 2050. In this context developed countries will have to cut emissions even further (around 80%), considering that developing countries would find harder to combine strong emission reductions with fast economic growth. Nowadays a reduction of GHG emissions only from transport around 80% is not compatible with the use of oil-derived fuels and internal combustion engines, on which transport is almost entirely dependent. Moreover, oil price volatility and its potentially insecure supplies have serious effects on global economies and the picture is likely to get worse in the future: global oil production expected to peak and start declining in the near future, while demand continues to grow steadily at the same time. In this worldwide context, the introduction of more energy-efficient and environmental sustainable alternative transport solutions becomes essential. For these reasons the automotive sector alone is spending 20 billion € per year on research and technological development in Europe. At the same time the EU

Abbreviations: AC, alternative current; BEV, battery electric vehicle; DC, direct current; DSO, distribution system operator; ESS, electric sub station; EU, European Union; EV, electric vehicle; GDP, gross domestic product; GHG, green house gas; G2V, grid to vehicle; IEMS, Intelligent Energy Management System; LV, low voltage; MV, medium voltage; PHEV, plug-in hybrid electric vehicle; TS, traffic scenario; V2G, vehicle to grid.

* Corresponding author. Tel.: +39 06 44 585 808; fax: +39 06 48 83 235.
E-mail addresses: mariacarmen.falvo@uniroma1.it (M.C. Falvo), regina.lamedica@uniroma1.it (R. Lamedica).

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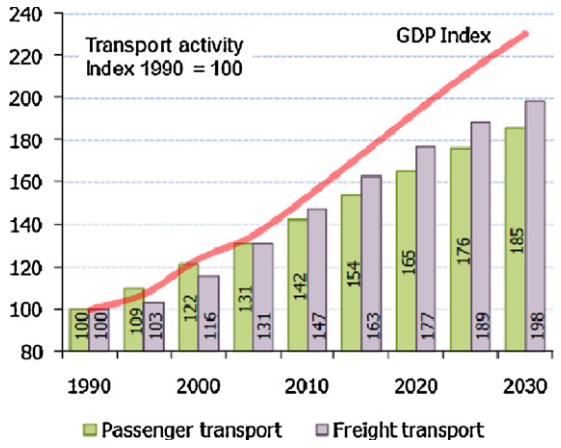

Fig. 1. Trend of the transport activity in EU in function of the GDP growth.

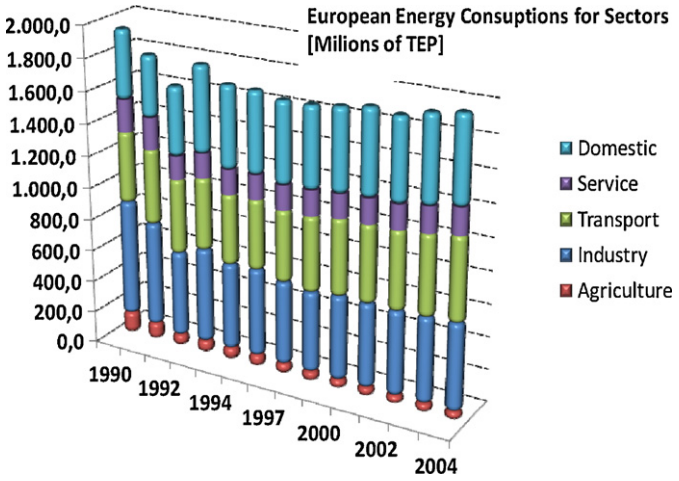

Fig. 2. European energy consumptions for sectors [MTEP].

is supporting under the 7th Framework Program all the research ideas proposing "*greener, safer and smarter*" transport systems with a research budget of over 4 billion € in 7 years.

Focusing on the urban mobility problems in large cities and metropolitan areas, this general soaring interest for energy saving and environmental sustainability, with the increasing of the consumptions and the technological evolution, have renewed in the last years more than ever, the attention of the researchers at issues about:

- the metro-transit transport system, that is the most energy-impacting, considering the large quantity of power in use;
- the on-road public and private vehicles park for the surface transport, that is the most environmental-impacting, considering the large number of units in use.

About the metro-transit systems, the result of this renewed interest entailed studies and projects, dealing with proposals on upgrading actions including new technologies, and on management techniques, derived from new simulation models and software [5–13]. In this framework, in the last years, the authors implemented a multi-stage program for performing high-quality energy studies on metro-transit systems [14–23]. Recently a reviewed and updated version of the software has been realized in order to achieve other evaluations, principally regarding the assessment of the impact of the braking energy recovering on the power consumptions. This analysis has also allowed revaluating the choices on the power system design for the management of the braking energy, according to the actual available technologic solutions [24,25].

About the surface urban transport, the strong request of reducing the environmental impact made necessary the introduction of zero-emission vehicles and in particular of electric vehicles (EV) of different types. The authors performed an analysis on the penetration of this type of transport in urban context and on the barriers for its spread, mainly linked to the electric infrastructure for their recharge. Different technological solutions and business models have been got in literature [26–33].

At the end of the analysis on the two transport systems, matching the results obtained by the simulation studies and the actual state of the art on the involved technologies, the authors suggest an innovative proposal for clearing the energy problems connected to them, that would allow energy saving with a reduced economic impact, as a result of the maximum exploitation of the already existing electric power systems. The present paper is organized in 7 sections. In particular:

- Section 2 reports the overview on metro-transit energy management techniques for saving, proposed in literature and real implemented in worldwide metro-lines, in particular dealing with the braking energy recovering;
- Section 3 shows the main features of a simulation software, made by the authors, with the specific task of evaluating energy questions about metro-transit systems;
- Section 4 reports the software application on a real metro-line, giving the details of the case study and the main simulation results, in order to get a real assessment of the energy saving associable to the braking energy recovering;

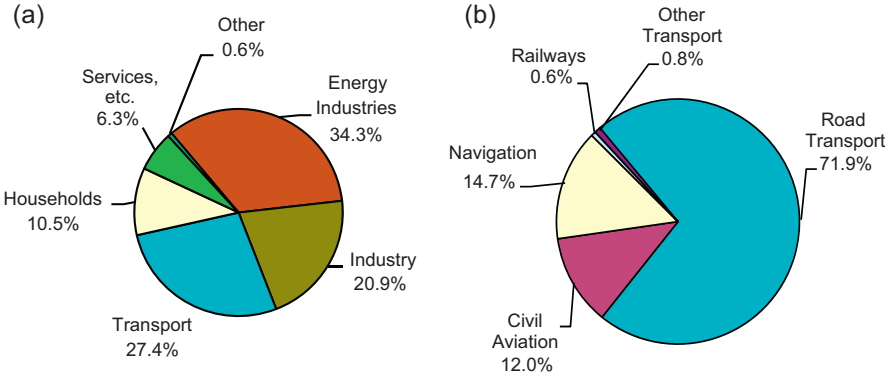

Fig. 3. (a) Total GHG emissions by sector in the EU in 2005. (b) Transport-related GHG emissions in the EU in 2005.