Renewing bus fleet into diesel plug-in hybrid electric vehicles: environmental implications in a medium-size city in Italy

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Abstract: In urban and metropolitan area, the transport sector significantly contributes in terms of both fuel consumption and pollutant emissions. In this context the ex-ante evaluation (through quantitative methods) and the implementation of sustainable policies must be a central aim for urban mobility.

Many papers deal with the importance to take rational decisions to improve the transportation system (.eg. Cascetta et al., 2015). The idea of this paper is to propose an ECO-rational transportation planning, that means acting in the best possible way considering the men's health and the environment's benefits (ECO-logocal) and are sustainable for an economic point of view (ECO-nomical). Starting from this definition, the question proposed is: are the so called "common" sustainable transport policies always eco-rational? For example the renewal of vehicle fleet; the use of light goods vehicles for urban distribution, the introduction of a restricted area in the city center, are always rational interventions? In this research I have tried to partially answered to this question, estimating the environmental impacts of using electric and/or plug-in hybrid electric vehicles for renewing the bus fleet for public transport services in an Italian medium size city. Results of the estimation show that updating (renewing) the 30% of the Salerno public transport bus fleet into electric vehicles the fuel consumption and the equivalent CO2 emissions will reduced to -7.2%, while the PM10 will reduced up to -10.0%. By contrast, from an economical point of view, the high acquisition cost for electric buses and the inefficiencies deriving from the low autonomy of the batteries suggest that this scenario is not "eco-rational".

The simulation results deriving from the renewing a percentage of the bus fleet into a diesel plug-in hybrid electric vehicles show comparable environmental impacts (scenario with bus equipped with two batteries for a double autonomy) and is economically sustainable with an investment cost of 4.8 millions of Euro and a payback period of about 10 years.

Key-Words: Environmental models; transportation planning; sustainable mobility; greenhouse gas and particulate matter emissions; fuel consumption; ex-ante analysis.

1 Introduction

In urban and metropolitan area, the transport sector significantly contributes in terms of both fuel consumption and pollutant emissions. In this context, policies aimed at reducing these effects are very important. Many urban areas are trying to adopt planning strategies aimed to a sustainable use of resources often referred to as sustainable mobility (e.g. [1], [2], [3]). These policies, as reported in [4], are very different in terms of costs and expected benefits, and the effects of these policies and their combinations are difficult to anticipate on a purely intuitive basis and sometimes the end effect could be contrary to intuitive expectations (e.g. policies aimed to reduce pollution, ending up in increasing it).

Many papers deal with the importance to take rational decisions to improve the transportation system (.eg. Cascetta et al., 2015). This means acting in the best possible way considering the aims and constraints. Cascetta ae at. (2015) define some minimal requirements of rationality: the decisions must be comparative (considering more than one alternatives); aware of the effects derived from the options (features) considering the context (physical and decisional; internal, horizontal and vertical coherence) and the impacts (costs, benefits, risks and opportunities); consistent, comparing options with aims and constraints; flexible because the future is unknown and the context (unpredictable) could change.

The idea is to prefixing the acronym "ECO" to the term rationality (e.g. [4], [5]). ECO-rationality in transportation planning means acting in the best possible way considering the men's health (pollution/welfare) and the environment's benefits (pollution - ECO-logocal) and are sustainable for an economic point of view (ECO-nomical). Starting from this definition, the question proposed in this paper is: are the so called "common" sustainable transport policies always eco-rational ? For example the renewal of vehicle fleet; the use of light goods vehicles for urban distribution, the introduction of a restricted area in the city center, are always rational interventions as defined before? In this research I have tried to partially answered to this question, estimating the environmental impacts of using electric and/or plug-in hybrid electric vehicles for renewing the bus fleet for public transport services in an Italian medium size city.

In this context, transit service quality is one of the main drivers of eco-rational planning as it increasingly steers user choices toward energy and space-efficient transport modes (e.g. [6], [7]). Public transport quality depends on several factors (attributes) of the service [7]; some are quantitative (e.g. average travel time and its reliability; transit waiting time; monetary costs) while others are qualitative, whose effects on user behaviour are more difficult to assess (e.g. riding comfort, information, personal security).

Assessment of service quality in public passenger transport requires methods for defining standard quality indicators and related measurement techniques.

In this context the ex-ante evaluations (through quantitative methods) must be a central aim for sustainable urban mobility (eco-rational planning). With respect to energy consumption and vehicle emissions models, in literature (for a complete state of the art see [8] and [9]), different mathematical models are proposed, that allow estimations of average concentrations by means of variables representing the characteristics of the travel demand (e.g. origin-destination matrix, the composition of the vehicle fleet, the average length of trips/paths) as well as variables representing the traffic flow conditions (e.g. average speed, vehicle density). The most pursued approaches are often aggregated and use input variables estimated through surveys. Those approaches that implement disaggregated models are based on simulation models, but refer only to small portions of the transport system (e.g. single individual intersections or roads) and do not allow evaluation of the impacts on the entire system. As regards traffic fuel consumption and greenhouse gas emission estimations, the proposed approaches can be further classified according to the geographical area [8] where they were calibrated (estimation of model parameters). This is because some conditions such as the traffic flow (average speed, accelerations and all mobility behaviours in general), geometric infrastructure (width, radii of curvature, slopes, lateral disturbance index) and environment (average temperature, altitude, rainfall index, characteristics of the wind etc..) influence, in a non-negligible way, traffic-derived emission and consumption factors. According to such a classification, most of the models developed in the literature were estimated in the United States of America and in Europe. The most used models implemented in the USA are (e.g. [8]): *MICRO2, CALINE*, *UMTA*, *MOBILE* and *EMFAC*

With regard to the models estimated in Europe, one of the first models, developed in UK, was *TRLL*, which allows the estimation of hourly average concentrations of carbon monoxide at specific points of the road network. Although in Europe several experiments have been carried out, the European Community long ago decided to develop a reference model. Such model, known as COPERT, has now been taken as reference by all Member States. This method was financed by the European Environment Agency (EEA) and developed by CORINAIR (COoRdination INformation AIR) team.

In addition to these environmental models, several other applications have been developed at different scale (e.g. [9], [9] and [11]). Although the proposed modelling formulations are interesting and give interesting insights, it can be noted they are not easily transferable to different case studies, they cannot support cross-comparisons with other case studies and, above all, conclusions obtained from models implementation cannot be easily extended to different geographical contexts.

Together with contributions oriented to the specification/estimation of emission and consumption models, an extensive literature concerning operational results exists and can be classified in ex-ante and ex-post evaluations. Even if the quantitative methods for the ex-ante environmental policies evaluation cover a central role in rational decision making process for transportation planning (e.g. [1], [2]), several applications are only proposed for ex-post evaluations (e.g. [12], [13]). As regards ex-ante analyses the reader may refer to [14], [15], [16], [17], [18].

Starting from the results of two previous works ([8], [9]), the paper proposes the estimation of the environmental and energy implications of renewing

a percentage of Salerno bus fleet to both electric and plug-in hybrid vehicles.
The paper is divided into three sections; in the first the applied methodology is presented; in the second application to a real case is described, while the last section reports main conclusions and research perspectives.

2 Methodology

The applied methodology is based to the results obtained in [8]. Cartenì and Luca [8] proposed an integrated modelling framework which combines a transportation simulation model (demand, supply and supply-demand interaction) with a traffic fuel consumption and vehicle emission models. Transportation model simulates the relevant interactions among the various elements of a transportation system, supply and demand sub-systems, and allows to estimate the performance of the system by estimating some indicators (average speed and km/year travelled by vehicle category) both related to the base scenario and referring to design scenarios. Traffic fuel consumption and emission model allows to estimate the impacts of simulated scenarios.

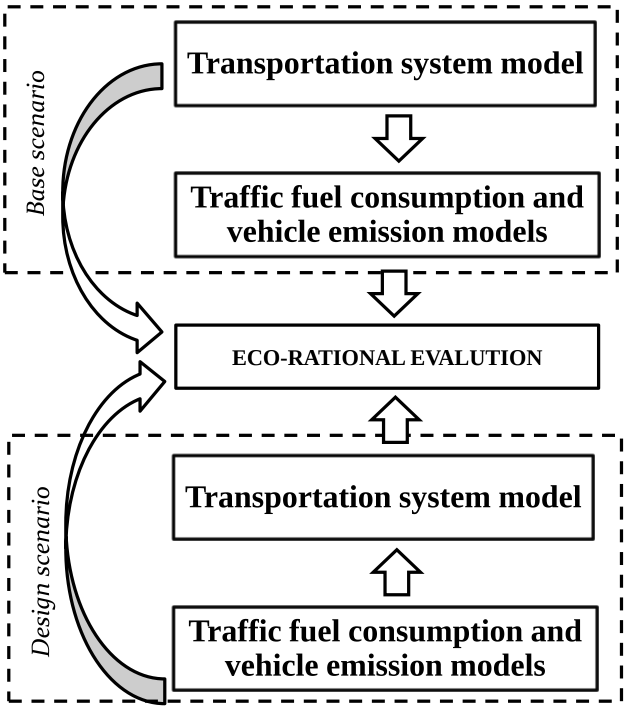

Fig.1 – Estimation methodology

The transportation model is constituted of three sub-models: supply model [8], demand model and supply-demand interaction model (see [19], [20], [21]). All the three sub-models are based on consolidated approaches of transportation system analysis (e.g. [22]).

The methodology for estimating traffic fuel consumption and vehicle emissions proposed in this paper belongs to the bottom-up approach (e.g. [1]). From a series of more or less disaggregated input data (the number of trips, average distance and average speed per vehicle type) the bottom-up approach allows estimation of fuel consumption and emissions. As stated above, the European approach, based on the *COPERT*, model was pursued. *COPERT* model allows three different emission types to be estimated: hot emissions, cold emissions and evaporative emissions. The sum of these emission types gives the total emissions due to road traffic. Hot emissions are those emissions that occur when the engine and the emission abatement systems (catalysts) reach temperatures of full capacity; they depend on the average trip distance, the average vehicle speed and the vehicle type, as well as the age, weight and cubic volume of the engine. Cold emissions are emitted during start-up of the engine and emission abatement systems; estimation of these emissions depends on the quantity of kilometres that the vehicle does at "cold", which in turn depends on the type of vehicle, environmental conditions, the type of route and guidance. Evaporative emissions, instead, are those resulting from the evaporation of the fuel from the tank which occurs both while the vehicle is moving and when it is stationary.

The overall the emissions model estimates:

$$E_{ijk} = EF_{ijk}\,(AV_{jk}) * VFC_j * KM_{jk} \qquad (1)$$

where:

E_{ijk} = is the annual emission of the pollutant *i* for vehicle category *j*, on the path *k* (tons / year);
EF_{ijk} = is the emission unit factor of pollutant *i* for vehicle category *j* on the path *k* (grams / km);
VFC_j = is the number of vehicles belonging to the category *j* (Vehicle Fleet Composition);
KM_{jk} = average annual driving related to the vehicle category *j* on the path *k* (km / year);
AV_{jk} = is the average speed of the vehicle category *j* on the path *k* (Km / h).

The COPERT model cover different emissions (e.g. CO, NOx, VOC, SO2, CO2, PM10) and different vehicles categories. In particular, unit factors EF_{ijk} are currently available relating to gasoline cars; diesel cars; Liquefied Petroleum Gas (LPG) cars; light goods vehicles (gasoline and diesel); diesel heavy goods vehicles; buses and motorcycles.

With regard to gasoline and diesel cars, the relations are expressed by continuous functions according to the average speed (between 10 and 130 km/h), while relations related to other vehicle categories are expressed with reference to three driving conditions (urban, suburban, highway).

This methodology can be used with different levels of spatial and temporal aggregation. For example, it can be used to estimate the annual national emissions level or for urban estimations.

The model output allows to estimate concentrations of a wide range of pollutants resulting from combustion and evaporation of the fuel used by vehicles and the corresponding total vehicle energy consumption. Obviously, the more accurate the input data, the more reliable are the estimations.

3 Application case study

The case study is Salerno municipality (Fig.2). Salerno is located in the south of Italy with a population of more than 138,000 and a GDP of 3.4 million of euro. The study area was divided into 82 zones. The topological supply model consists of a graph with 538 nodes and 1,172 links ([23]); the generalized transport cost associated to each link was estimated as the result of a sum of two terms: the running time (estimated using the function proposed in [24]), considering different free flow speeds for the various categories of vehicles *j* considered, and waiting times at intersections.

Fig.2 – Salerno municipality, Italy (case study)

Origin-destination demand flows were estimated through a system of trip frequency, distribution and mode choice models. The interdependencies were taken into account assuming a hierarchical decision structure and explicitly computing the inclusive variable (satisfaction or log-sum) in order to take into account the influence of “lower” choice dimensions on “upper” levels (e.g. path choices/availability influence the mode choice).

Furthermore, aggregate data (traffic counts some aggregate origin-destination flows) were also used in order to update origin-destination demand flow estimations (see [25]).

For more details on the implemented models see [26] and [23] for passenger vehicles demand (car, motorcycle and bus), while see [27] and [28] for freight vehicles demand (heavy and light goods vehicles).

The proposed methodology was applied for different vehicle categories *j* (type of vehicle, power, fuel type, ECE regulation reference).

Using the implemented model system the traffic fuel consumption was estimated (see Tab1, Tab. 2 and Fig.3). Every year in Salerno gasoline consumption is about 12,000 tons while diesel consumption amounts to about 27,000 tons. These values were converted into petrol equivalent tons (pet) through the Global Warming Potential (GWP) coefficients. With respect to these coefficients, in Salerno every year about 43,000 pet are consumed, amounting to about 0.3 per inhabitant. Results related to the different vehicle categories show that cars consume 46% of the total pet per year, goods vehicles consume about 30% of the pet, buses consume more than 20% of the pet, while motorcycles consume about 3% of the pet per year.

Tab.1 – Vehicle fleets composition and consumptions

Vehicle category	**Number of vehicles**	**Diesel consumption (tons/year)**	**Gasoline consumption (tons/year)**	**Total consumption (pet/year)**
cars	79,367	6,759	10,239	19,587
motorcycles	18,788	0	1,034	1,241
buses	563	9,511	0	10,272
HGVs	1,641	7,751	34	8,411
LGVs	8,489	2.663	336	3,279
Total	**108,848**	**26,684**	**11,643**	**42,790**

Tab.2 – Percentage distribution of vehicle composition and consumption

Vehicle category	Number of vehicles	Diesel consumption (tons/year)	Gasoline consumption (tons/year)	Total consumption (pet/year)
cars	73%	25%	88%	46%
motorcycles	17%	0%	9%	3%
buses	1%	36%	0%	24%
HGVs	1%	29%	0%	20%
LGVs	8%	10%	3%	8%
Total	**100**	**100%**	**100%**	**100%**

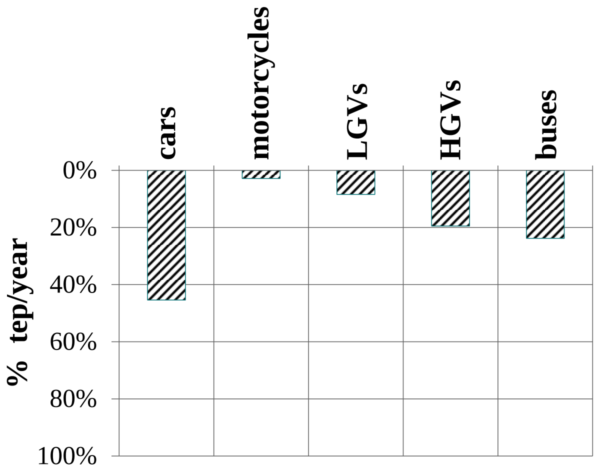

Fig.3 – Distribution of pet/year among vehicles categories (%)

With respect to the vehicle emissions, both the greenhouse gases and fine particles were estimated. In Fig.4 and Fig.5 estimation results in term of percentage distribution among the vehicles categories considered. The total emission are more than 127,000 tons of equivalent CO2, equal to 120,000 tons/year of CO2, plus about 2,000 tons/year of CO, plus more than 4 tons/year of NO2, plus more than 21 tons/year of methane and plus about 300 tons/year of VOC. Looking at each vehicle category, it can be easily seen that cars emit the highest percentage of CO2 equivalent (about 45%), followed by goods vehicles (about 27%), bus (about 24%) and motorcycles (about 4%). As regards fine particle emissions 53 tons of PM10 fine particles are emitted in a year.

The cars, as expected, are the vehicle category which produces the highest percentage of pollutants. It shows a percentage incidence always greater than 40% for each greenhouse gas. As regards fine particles, car flows emit about 12 tons/year of PM10 (about 23%).

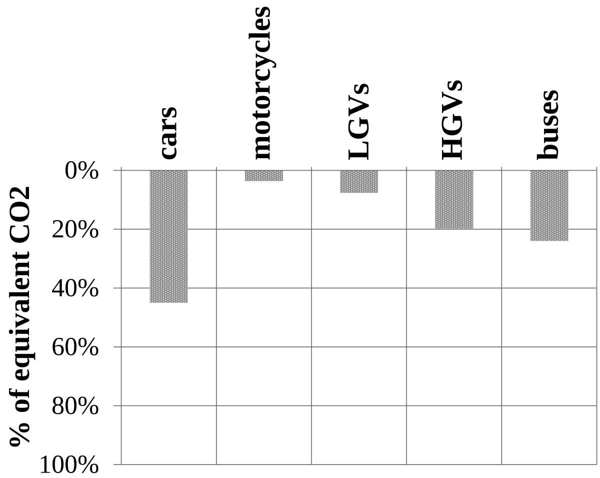

Fig.4 – Distribution of equivalent CO2/year among vehicles categories (%)

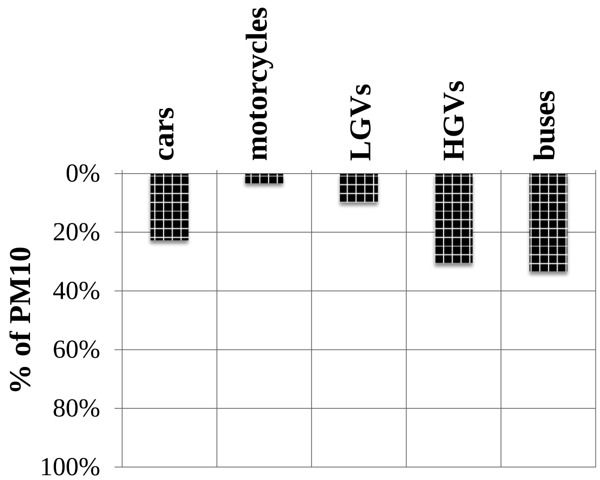

Fig.5 –Distribution of PM10/year among vehicles categories (%)

Summing up emissions values for all the other transport modes (bus, heavy goods vehicles - HGVs, and light goods vehicles - LGVs), it should be pointed out that they emit more than 55% of CO2 and more than 50% of equivalent CO2. Buses and heavy goods vehicles show similar emission percentages for all the considered greenhouse gases, light goods vehicles, due to their smaller modal share, show in some cases negligible emissions.

From estimation results for fine particles buses and heavy goods vehicles emit more than 60% of PM10 (34 tons/year).

2.1 Environmental and energy implications of renewing bus fleet into electric vehicles

The environmental and energy implications deriving from updating (renewing) a percentage of the Salerno public transport bus fleet into electric vehicles was estimated. For this scenario, 10%, 20% and 30% percentage of updating bus fleet was tested, applying the simulation model described before.

In the following table, estimation results are reported in terms of fuel consumption, equivalent CO2 emissions and PM10 emissions.

Tab.3 – Environmental and energy implications of updating in electric vehicles a percentage of the bus fleet

	% bus fleet updated	0%	10%	20%	30%
total consumption	(pet/year)	42,790	41,763	40,736	39,709
	Δ%	0%	-2.4%	-4.8%	-7.2%
Equivalent CO2	(tons/year)	127,130	124,079	121,028	117,977
	Δ%	0%	-2.4%	-4.8%	-7.2%
PM 10	(tons/year)	53.1	51.3	49.6	47.8
	Δ%	0%	-3.3%	-6.7%	-10.0%

As regards fuel consumption, benefits vary from -2.4% with a conversion rate of 10% to -7.2% with a conversion rate of 30%. A similar trend can be observed for CO2 equivalent emissions, whereas significant reductions can be obtained for PM10 emissions: -3.3% with a conversion rate of 10%, -10.0% with a conversion rate of 30%. From an economical point of view, for this scenario, the high acquisition cost for electric buses and the inefficiencies deriving from the low autonomy of the batteries suggest that this policy is not “eco-rational” for this case study.

2.2 Environmental and energy implications of renewing bus fleet into diesel plug-in hybrid electric vehicles

The proposed methodology was also applied to the simulation of eco-rationality of a project scenario aimed at upgrading the Salerno public transport bus fleet into a diesel plug-in hybrid electric vehicles. To increase the environmental benefit of this scenario, it was simulated considering also to design and install, in each bus parking-area a grid-connected photovoltaic system that yields energy to the grid during the day and recharge the bus through a plug-in system during the night. The proper design of the photovoltaic system ensures a perfect balance between energy sold during the day and that absorbed during the night. This could significant reduce fuel consumption and emissions compared to the scheme with a simple diesel-hybrid upgrading of the bus fleet.

The costs and the economic returns (benefits) resulting from the combination of a plug-in bus fleet with a photovoltaic system for charging the batteries was estimated through the unit values proposed in [9] (Tab.4).

Tab.4 – Economic feasibility parameters

Number of bus updated	19
km/year per bus	69,500
Acquisition cost for one diesel standard bus (€)	214,000
Acquisition cost for one diesel Hybrid-plug bus (€)	373,000
diesel price (€/liter)	1.416
photovoltaic system (€/kW)	5.229
Average annual energy produced by photovoltaic (kWh/kW)	1,300
Average bus diesel consumption (km/liter)	2.5
Average hybrid plug-in bus Consumption (km/liter)	3.86
Battery capacity (kWh)	32
Average number of daily battery recharges	1
Energy for recharge batteries (kWh/year)	221,964
Energy produced by the photovoltaic (kWh/year)	221,964

The total economic investment (Tab.5) was estimated considering the cost of a standard diesel plug-in bus, the cost of standard photovoltaic panels and assuming: i) that the buses operate for 8 hours/day and ii) at the end of each day the batteries are fully charged. As regards the storable energy in the battery pack, reference was made to a bus plug-in hybrid whose technical specifications, in terms of maximum power and flow rate (e.g. number of passengers) are comparable to those used in Salerno. Three different scenarios were simulated: 1) 10% of the buses operating within the municipality of Salerno was renewed into plug-in hybrid vehicles; 2) a second scenario similar to the first one, in which each hybrid bus was equipped with two batteries (double autonomy); 3) a third scenario, similar to the second, where it is expected a 25% reduction of the bus acquisition cost (scenario for medium to long term).

Tab.5 – Economic feasibility results

Scenario	**1 batteries /bus (Scen. A)**	**2 batteries /bus (Scen. B)**	**2 batteries/bus and -25% purchase costs for hybrid bus (Scen. C)**
Total investment cost (millions of Euro)	3.910	4.802	2.801
Pay-back period (years)	12.41	9.94	5.80
net present value in 12 years (millions of Euro)	-0.774	0.007	2.008
net present value in 18 years (millions of Euro)	0.423	1.843	3.844

With respect to the proposed scenario and taking into account the current costs of solar panels and of a traditional diesel bus, an economic feasibility was performed and described in Tab.3.

The simulation results show comparable environmental impacts (e.g. scenario with bus equipped with two batteries for a double autonomy) to those estimated in the previous section (for full electric buses), but in this case (for hybrid electric buses) was observed also an economical sustainability for a public/private operator. With respect to the Scenario 1 was estimated an investment cost of 3.9 millions of Euro, a pay-back period of 12.4 years and a reduction in energy consumption and total emissions (of all vehicle categories) of about 4%. Regarding the second scenario (two batteries/bus), was estimated an increase in costs (two batteries and the need of a more powerful photovoltaic system) against an increase in environmental benefits. In this scenario, the cost of the investment amounts to 4.8 millions of Euro, the payback period is 9.9 years and was estimated a reduction in consumption and emissions of about 8%. Finally, if we assume that in the next years the purchase and maintenance costs of bus hybrid vehicles will decrease up to the 25% (Scenario 3), we estimated a total investment cost equal to 2.8 millions of Euro with a pay-back period of 5.8 years (high investment cost-effectiveness).

Tab.6 – Environmental and energy implications of updating in diesel plug-in hybrid electric vehicles

10% bus fleet updated		**Scen. A**	**Scen. B**	**Scen. C**
total consumption	Δ%	-1.8%	-2.6%	-2.6%
Equivalent CO2	Δ%	-1.8%	-2.6%	-2.6%
PM 10	Δ%	-2.4%	-4.8%	-4.8%

4 Conclusions and research perspectives

In recent years the concept of eco-rational planning has assumed a central role in the identification of the right mix of policies to be implemented on the transport system that is financially effective, rational and effective for the transport system, sustainable for the people's health and for the environmental and acceptable by the collectivity and the stakeholders. Starting from the consideration that the development of new technology will allow the development of electric/hybrid bus fleets (e.g. [29]; [30]; [31]; [32]), in this paper were estimated the environmental and energy implications of renewing a percentage of Salerno bus fleet into both electric and plug-in hybrid vehicles.

Results of the estimation show that updating (renewing) the 30% of the Salerno public transport bus fleet into electric vehicles the fuel consumption and the equivalent CO2 emissions will reduced to -7.2%, while the PM10 will reduced up to -10.0%.

By contrast, from an economical point of view, the high acquisition cost for electric buses and the inefficiencies deriving from the low autonomy of the batteries suggest that this scenario is not "eco-rational" (not economically convenient).

In a second project scenario were estimated the simulation of environmental impacts and investment costs deriving from the upgrade of a percentage of the bus fleet into a diesel plug-in hybrid electric vehicles. Results of the estimation show comparable environmental impacts (e.g. scenario B: bus equipped with two batteries for a double autonomy)
to those estimated using fully-electric buses, but in this case (for hybrid electric buses) was observed also an economical sustainability with an investment cost of 4.8 millions of Euro and a payback period of about 10 years.

One of the research perspectives will be to apply the proposed methodology to estimate the environmental impacts and the investment costs deriving from the installation of an automotive after-market mild-solar-hybridization kit [33].

Other research perspectives will be to integrate in the urban multi-modal network optimization methods (e.g. [34], [35], [36], [37], [38], [39]) also environmental impacts reduction as an explicit design variable of the multi objective function.

Finally another possible future research in this field will be to extend the application case study to the estimation of the environmental impacts deriving from ITS applications (e.g. environmental impacts deriving from the application of the models able to estimate the effects of information on travelers' behavior [40], [41], [42], [43])

References:

[1] Cascetta, E., Cartenì, A., Pagliara F., Montanino, M., A new look at planning and designing transportation systems as decision-making processes, *Transport Policy* 38, 2015, pp. 27–39.

[2] de Luca S., Public engagement in strategic transportation planning: An analytic hierarchy process based approach, *Transport Policy*, Vol. 33, 2014, pp. 110-124.

[3] de Luca S., Papola A., Evaluation of travel demand management policies in the urban area of Naples, *Advances in Transport*, Vol. 8, 2001, pp. 185-194.

[4] Cartenì, A., Urban sustainable mobility. Part 1: Rationality in transport planning, *Transport Problems*, 9 (4), 2014, pp. 39 - 48.

[5] Cartenì, A., Urban sustainable mobility. Part 2: Simulation models and impacts estimation, *Transport Problems*, 10 (1), 2015, pp. 5-16.

[6] Cascetta, E., Cartenì, A., The hedonic value of railways terminals. A quantitative analysis of the impact of stations quality on travellers behavior, *Transportation Research Part A*, vol. 61, 2014, pp. 41-52.

[7] Cascetta, E., Cartenì, A., A quality-based approach to public transportation planning: theory and a case study, *International Journal of Sustainable Transportation*, Taylor & Francis, Vol. 8, Issue 1, 2014, pp. 84-106.

[8] Cartenì, A., de Luca S., Greening the transportation sector: a methodology for assessing sustainable mobility policies within a sustainable energy action plan, *International Journal of Powertrains*, Vol. 3, No. 4, 2014, pp. 354-374.

[9] Ardekani S., Hauer E. and J. Bahram, Traffic Impact Models, in N. H. Gartner, C. J. Messer, and A. K. Rathi (Eds), *Traffic Flow Theory - A State-of-the-Art Report: Revised Monograph on Traffic Flow Theory*. Turner Fairbank Highway Research Center U.S. Department of Transportation, 2002.

[10] Greenwood, I.D., Dunn, R.C.M. and Raine, R.R., Estimating the effects of traffic congestion on fuel consumption and vehicle emissions based on acceleration noise, *Journal of Transportation Engineering*, Vol.133, No.2, 2007, pp. 96-104.

[11] Wilmink, I., Viti, F., Van Baalen, J. and Li, M., Emission modelling at signalised intersections using microscopic models, *Proceedings of the 16th ITS World Congress, ITS World Conference*, Stockholm, 2009.

[12] Poudenx, P., The effect of transportation policies on energy consumption and greenhouse gas emission from urban passenger transportation, *Transportation Research A*, Vol. 42 No. 6, 2008, pp. 901-909.

[13] Harford, J.D., Congestion, pollution, and benefit-to-cost ratios of US public transit systems, *Transportation Research D*, Vol. 11 No. 1, 2006, pp. 45-58.

[14] Cartenì A., Sorrentino M., Una mobilità sostenibile nelle aree urbane: stima degli effetti di una riqualificazione del parco veicolare bus a veicoli ibrido-diesel plug-in, *in Sostenibilità, qualità e sicurezza nei sistemi di trasporto e logistica*, edited by E. Marcucci and E. Musso, Franco Angeli, 2011.

[15] Potoglou, D. and Kanaroglou, P.S., Carbon monoxide emissions from passenger vehicles: Predictive mapping with an application to Hamilton, Canada, *Transportation Research Part D*, Vol. 10 No. 2, 2005, pp. 97-109.

[16] Lam, T. and Niemeier, D., An exploratory study of the impact of common land-use policies on air quality, *Transportation Research Part D*, Vol. 10 No. 5, 2005, pp. 365-383.

[17] Cortés, C.E., Vargas, L.S. and Corvalán, R.M., A simulation platform for computing energy consumption and emissions in transportation networks, *Transportation Research Part D*, Vol.13 No.7, 2008, pp. 413-427.

[18] Wang, G., Bai, S. and Ogden, J.M., Identifying contributions of on-road motor vehicles to urban air pollution using travel demand model data, *Transportation Research Part D*, Vol. 14 No. 3, 2009, pp. 168-179.

[19] Cantarella G.E., de Luca S., Cartenì A., Stochastic equilibrium assignment with variable demand: theoretical and implementation issues, *European Journal of Operational Research*, Vol. 241, Issue 2, 2015, pp. 330–347.

[20] Cantarella G.E., de Luca S., Gangi M.D., Di Pace R., Stochastic equilibrium assignment with variable demand: Literature review, comparisons and research needs, *WIT Transactions on the Built Environment*, Vol.130, 2014, pp. 349-364.

[21] Cantarella G.E., de Luca S., Di Gangi M., Di Pace R., Approaches for solving the stochastic equilibrium assignment with variable demand*:* Internal vs. external solution algorithms, *Optimization Methods & Software* Vol. 30, No 2, 2015, pp. 338-364.

[22] Cartenì, A., Galante G., Henke I., An assessment of models accuracy in predicting railways traffic flows: a before and after study in Naples. *WIT Transactions on Ecology and the Environment*, 191, 2014, pp. 783 – 794.

[23] de Luca, S., Cartenì, A., A multi-scale modelling architecture for estimating of transport mode choice induced by a new railway connection: The Salerno-University of Salerno-Mercato San Severino Route [Un'architettura modellistica multi-scala per la stima delle ripartizioni modali indotte da un nuovo collegamento ferroviario: il caso studio della tratta Salerno-Università di Salerno-Mercato San Severino], *Ingegneria Ferroviaria*, 68 (5), 2013, pp. 447-473.

[24] Cartenì, A., Punzo, V., Travel time cost functions for urban roads: A case study in Italy, *WIT Transactions on the Built Environment* 96, 2007, pp. 233-243.

[25] Cartenì, A., Updating demand vectors using traffic counts on congested networks: A real case application, *WIT Transactions on the Built Environment* 96, 2007, pp. 211-221.

[26] Bifulco, G.N., Cartenì, A. and Papola, A., An activity-based approach for complex travel behaviour modelling, *European Transport Research Review*, 2(4), 2010, pp. 209-221.

[27] Cartenì, A., Accessibility indicators for freight transport terminals, *Arabian Journal for Science and Engineering*, Vol 39, No. 11, 2014, pp. 7647-7660.

[28] Cartenì, A. and Russo, F., A distribution regional freight demand model, *Advances in Transport*, 16, 2004, pp. 275-285.

[29] Faranda R. and Leva S. (2008); Energy comparison of MPPT techniques for PV Systems; *WSEAS Transactions on Power Systems*; Issue 6, Volume 3, pp. 446-455.

[30] Wu Z., Zhang J., Jiang L., Wu H., Yin C. (2012); The energy efficiency evaluation of hybrid energy storage system based on ultra-capacitor and LiFePO4 battery; *WSEAS Transactions on Systems*; Issue 3, Volume 11; pp. 95-105.

[31] Xiong W., Yin C. (2009); Design of Series-parallel Hybrid Electric Propulsion Systems and Application in City Transit Bus; *WSEAS Transactions on Systems*; Issue 5, Volume 8, pp. 578-590.

[32] Huang Y., Yin C. and Zhang J. (2008); Optimal Torque Distribution Control Strategy for Parallel Hybrid Electric Urban Buses; *WSEAS Transactions on Systems*; Issue 6, Volume 7, pp. 758-773

[33] de Luca S., Di Pace R., Modelling the adoption intention and installation choice of an automotive after-market mild-solar-hybridization kit, *Transportation Research Part C: Emerging Technologies*, Vol. 56, 2015, pp. 426-445.

[34] Cantarella G.E., de Luca S., Di Pace R., Memoli S., Network Signal Setting Design: Meta-heuristic optimisation methods, *Transportation Research Part C: Emerging Technologies*, Vol. 55, 2015, pp. 24-45.

[35] Cantarella G.E., de Luca S., Di Pace R., Memoli S., Signal setting design at a single junction through the application of genetic algorithms, *Advances in Intelligent Systems and Computing*, Vol. 262, 2014, pp. 321-331.

[36] Gallo M., D'Acierno L. and Montella B., Global Optimisation of Signal Settings: Meta-heuristic algorithms for solving real-scale problems, *Advances in Intelligent Systems and Computing* 262, 2014, pp. 177-193.

[37] D'Acierno L., Montella B. and Gallo M., A fixed-point model and solution algorithms for simulating urban freight distribution in a multimodal context, *Journal of Applied Sciences* 11(4), 2011, pp. 647-654.

[38] D'Acierno L., Gallo M., Montella B. and Placido A., The definition of a model framework for managing rail systems in the case of breakdowns, *Proceedings of IEEE ITSC 2013 – 16th International IEEE*, art. no. 6728372, 2013, pp. 1059-1064.

[39] D'Acierno L., Gallo M. and Montella B., Application of metaheuristics to large-scale transportation problems, *Lecture Notes in Computer Science* 8353, 2014, pp. 215-222.

[40] Bifulco G.N., Cantarella G.E., de Luca S., Di Pace R., Analysis and modelling the effects of information accuracy on travellers' behaviour, *IEEE Conference on Intelligent Transportation Systems, Proceedings, ITSC*, art. no. 6082961, 2011, pp. 2098-2105.

[41] Bifulco G.N., Cantarella G.E. and Simonelli F., Design of Signal Setting and Advanced Traveler Information Systems, *Journal of Intelligent Transportation Systems: Technology, Planning and Operations* 18(1), 2014, pp. 30-40.

[42] Bifulco G.N., Pariota L., Brackstone M. and McDonald M., Driving behaviour models enabling the simulation of Advanced Driving Assistance Systems: Revisiting the Action Point paradigm, *Transportation Research Part C: Emerging Technologies* 36, 2013, pp. 352-366

[43] Pariota L., Bifulco G.N. and Brackstone M. A linear dynamic model for driving behaviour in car-following, *Transportation Science* (In press).