A cost-benefit analysis based on the carbon footprint derived from plug-in hybrid electric buses for urban public transport services

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Abstract: Sustainable mobility and green development are based on the achievement of three goals: environment, society and economy. This means that a sustainable plan/project must be, at the same time, equitable, viable, and bearable. In urban areas, the transport sector significantly impacts with respect to both fuel consumption and environmental emissions. At this aim, planning policies aimed at reducing these negative impacts are very important. Many researches cover the problem of perform rational decisions to improve the transportation sector. One of the most useful quantitative methods to evaluate rational project solution is the cost-benefit analysis. In literature the "traditional" cost-benefit analysis not always take into account the overall carbon footprint of a transport project/policy. The "carbon footprint" is the total (direct and indirect) amount of greenhouse gas emissions caused by a project/policy/service expressed as the overall amount of carbon dioxide equivalent emitted. Moreover, the recent economic crisis has made necessary also to generate a "profit" from transport services/infrastructures, as well as positive impacts for users and for environment.
Starting from these considerations the aims of this paper were: i) to evaluate if the use of hybrid electric buses for a new urban public transport services could produce profit for a private/public transport operator; ii) to develop a cost-benefit analysis explicitly considering the overall carbon footprint (and not only the local impacts) produced by this vehicle technology. The case study was a new urban bus line designed in a medium size city, Salerno, in Italy. The results of the study underline that the use of hybrid electric buses could produce a profit for private/public transport operators and the analysis based on the overall carbon footprint allow to better estimate the (positive) impacts deriving from the use of this vehicle technology. Since the hybrid electric buses have a carbon footprint -12/18% lower than a traditional bus, an urban transportation service based on this type of technology allows to obtain grater benefits up to +82% against a traditional one.

Key-Words: carbon footprint; sustainable mobility; clean transport; transportation planning; greenhouse gas; particulate matter emissions; fuel consumption; ex-ante evaluations; cost-benefit analysis; revenue & cost analysis.

1 Introduction

Urban sustainability, sustainable mobility and green development are based on the achievement of three goals: society, environment and economy. This means that a sustainable policy must be, at the same time, equitable, viable, and bearable. In urban areas, the transport sector significantly impacts with respect to energy consumption and environmental emissions. At this aim, transportation planning aims in reducing these negative impacts. Many cities are adopting urban plans aimed to both a green development and a sustainable mobility (e.g. [1], [2], [3]). These solutions, as discussed in [4], are very different both in terms of benefits produced and in term of costs supported, and the overall effects are often difficult to anticipate and sometimes the overall (final) effects could be the opposite as the expectations (e.g. policies aimed in reducing traffic emissions, ending in increasing them).

Many researches cover the problem of develop rational decisions to improve the transportation system (e.g. [1], [4]). A rational decision means acting in the best possible way considering the aims and constraints. The authors in [1] define some "*minimal requirements of rationality*": the decisions must be:

- *comparative,* considering more than one solution;
- *aware* of the impacts derived from the project implementation in term of costs, benefits, risks and opportunities;
- *consistent*, comparing solutions with the aims and the constraints;

- *flexible* with respect to the unknown and unpredictable future.

As suggested in [4], [5], the idea is to prefix the term "rationality" with the acronym "ECO". ECO-rationality in a transportation planning means acting in the best possible way considering the men's health and the environment's benefits, considering also the economic point of view.

With respect to these aims, the ex-ante evaluations (through quantitative methods) could improve a sustainable mobility through an eco-rational transport planning as defined before.

The European Commission in 2014 has proposed two important guide lines for cost-benefit analysis of investment projects ([6], [7]) that define both the methodology and the marginal external costs to use for these kinds of quantitative studies.

With respect to vehicle emissions and energy consumption, the European Commission suggest implementing accurate estimations. Among the most useful models in the state of art (e.g. [12], [13]), there are mathematical formulations that allow quantifications of average concentrations of pollutants in function of vehicle fleet composition and the average paths length (travel demand) as well as the traffic flow conditions (e.g. vehicle speed and/or density). The most common approaches applied are often aggregated and the input variables were estimated through traffic surveys. The most sophisticated models (disaggregated approaches) area traffic simulation models require a large amount of inputs variables, and for this reason could be applied only to small portions of the transport system (e.g. single individual intersections or roads) and not allow impact estimations of the entire system.

About traffic fuel consumption and greenhouse gas emission estimations, the most common approaches can be further classified according to the geographical area [12] where they were estimated (quantification of model parameters). This is because some context conditions such as the traffic congestion (e.g. average speed, accelerations and all mobility behaviours in general), geometric infrastructure (e.g. width, slopes) and environment (e.g. average temperature, altitude, rainfall index, characteristics of the wind) influence traffic emission and consumption factors. According to such a classification, most of the models developed in the literature were estimated in USA and Europe. The most used models implemented in the USA are (e.g. [12]): *MICRO2*, *CALINE*, *UMTA*, *MOBILE* and *EMFAC*

About 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 applications were carried out, the European Community decided to develop a reference model named COPERT (financed by the European Environment Agency EEA and developed by CORINAIR - COoRdination INformation AIR), now takes as reference by all Member States.

In addition to these environmental models, several other applications have been developed at different scale (e.g. [13], [14] and [15]).

Jointly with papers dealing with the problem of emission and consumption estimation, there is a copious literature regarding the best practices in term of both ex-ante and ex-post evaluations. Even if the quantitative methods for the ex-ante evaluation (e.g. [18], [19], [20], [21]) cover a central role in rational sustainable transportation planning (e.g. [1], [2]), there are also several applications aimed in ex-post analysis (e.g. [16], [17]).

In this context, also the quality (e.g. [8], [9], [10], [11]) of the mobility policies cover an important role in improving urban sustainability in term of energy and space-efficiency.

In literature the "traditional" cost-benefit analysis not always take into account the overall carbon footprint of a transport project/policy. Moreover, the recent economic crisis has made necessary also to generate a "profit" (revenue & cost analysis) from transport services/infrastructures, as well as positive impacts for users and for environment.

The "*carbon footprint*" is defined as the total (direct and indirect) amount of greenhouse gas emissions caused by a project/policy/service expressed as the overall amount of carbon dioxide equivalent (CO_2 equiv.) emitted. For example, the overall carbon footprint of a bus line (service) includes the extraction of raw materials and the production of semi-finished products and components, the bus construction process, the bus maintenance and operation, the contribution of the bus line to traffic condition (bus*km consumed for the overall life period) and to fuel consumption (liters of diesel consumed for the overall life period) and finally the disposal/reuse of buses at the end of the life cycle. Generally, in the so called "traditional" cost-benefit analysis only the (positive) impacts relative to the operation period are considered. This means that, for example, fully electric vehicles for a bus line produce always local positive impacts (zero-emission) during the service operation period, while in an in deep analysis also the impact deriving from the production of the electricity for the motion and from the construction and disposal/reuse of the

vehicles must be considered in term of impacts (not always "positive") produced.
Starting from these considerations the aims of this paper were:

a. to evaluate if the use of hybrid electric buses (against to the "traditional" diesel buses) for a new urban public transport services could produce profit (revenue & cost analysis) for a private/public transport operator;
b. to develop a cost-benefit analysis explicitly considering the overall carbon footprint (and not only the local impacts) of this vehicle technology solution.

The case study was a new urban bus line designed in a medium size city, Salerno, in Italy.
The paper is structured into three sections; first the proposed methodology is discussed; then the application case study main results is detailed, while finally the main conclusions are reported.

2 The proposed methodology

According with the "Guidelines for assessment the Investment Projects" proposed by the Italian government (derived from the European Commission ones), the methodology proposed in [22] was applied for assessing a rational and sustainable cost-benefit analysis. The first activity was the identification of critical issues for the case study (e.g. perceived and offered public transport quality; modes travel time per period of the day/month). The second activity was the individuation of the project scenario function of the vehicle technology proposed (plug-in hybrid electric), as well as the bus line characteristics (e.g. length, number of stops and frequency in term of bus/hours). The design scenario was performed also following the methodology proposed in [23], [24], [25] and [26].

To complete the project scenarios, enlarging the environmental benefits, was designed to 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 best 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 main characteristics of the project scenario were:

- 19 new plug-in hybrid electric (about 10% of the buses operating within the municipality of Salerno, Italy);
- 10 km length for the new bus line;
- 3 bus/hour is the design frequency (function of the demand estimated for this new line);
- 8 hours/day is the operation time for the new bus fleet;
- 300 day/year is the yearly operation time;
- about 69,500 km/bus per year;
- the bus parking-areas were equipped with a standard photovoltaic system for charging the batteries;
- a full batteries re-charge was performed at the end of each day of operation;
- two bus life time periods were tested: 12 and 18 years (medium and maximum observed in literature for the case study considered).

Furthermore, 3 different scenarios were tested:

1) **Scenario 1**: 19 buses were renewed in diesel plug-in hybrid electric vehicles and a photovoltaic system for charging the batteries was also implemented;
2) **Scenario 2**: 19 buses were renewed in diesel plug-in hybrid electric vehicles and each hybrid bus was equipped with two batteries (double autonomy) and a photovoltaic system for charging the batteries was also implemented;
3) **Scenario 3**: similar to the Scenario 2, but a 25% reduction of the bus acquisition cost was supposed according to the market expectation in the medium -long term.

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.

Before estimating costs and benefits, same conservative assumptions were introduced in the analysis to avoid the so-called "*planning fallacy*", that is the syndrome according to which analysts tend to underestimate the costs and overestimate the benefits produced, in order to legitimize the project. In this sense, among the precautionary hypotheses made there were:

- the underestimation of the residual value of the bus after the analysis time period;
- the neglecting of the induced demand by the new technology, considering in demand estimation only the deviated demand from other transport modes (e.g. private car and other bus lines).

2.1 The investment cost estimation

The costs for evaluating the economic returns of the investment was performed starting from the unit values proposed in [13] and summarize in Tab.1.

The economic investment (Tab.2) was estimated as the difference between the acquisition cost of the plug-in hybrid electric buses and the traditional ones. This difference is the extra cost for a private/public operator in renewing the 10% of the bus fleet into plug-in hybrid buses instead of traditional ones.

Tab.1 – The cost unit values

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

Finally, as suggested in the cited guide line for cost-benefit analysis, all the costs used in the cost-benefit analysis were multiplied by the correction coefficients prosed by European Commission (on average equal to 0.85), in order to exclude taxes and subsidies from the analysis.

Tab.2 – The investment costs estimation

Scenario	(millions of Euro)	
	Total cost (for *Revenue & cost analysis*)	Total cost * correction coefficients (for C*ost-benefit analysis*)
1 battery /bus (Scen. 1)	3.950	3.358
2 batteries/bus (Scen. 2)	4.830	4.106
2 batteries/bus and -25% of the purchase costs for the hybrid bus (Scen. 3)	2.820	2.397

2.2 The benefits estimation for the users of the transportation system

The benefits (positive impacts) produced by the new bus line, was estimated as the difference between the Project (P) condition (that is the scenario with the new line) and the Not Project (NP) ones. The estimated impacts were:

- **benefits for the transport users**, that are both the potential users of the new line and all the other transportation system users (e.g. car and bus users that support a congestion reduction);
- **benefits for the non-users**, that are those who will not use the new line and the transportation system, but anyway have some positive impacts (external cost reduction) from the new line (e.g. pollutant reductions, increase in quality of life).

The new bus line will produce both benefits directly perceived by the transport users (e.g. travel time savings) and benefits not directly perceived by the users (e.g. savings costs for the car maintenance).

As said, the application case study is Salerno municipality - Italy (Fig.1). This city is in southern of Italy. It has a population of more than 138 thousand with an average GDP of 3.4 million of euro/year.

For estimate the impacts for the users, a transportation system model was applied and composed in (e.g. [27], [28], [29], [30]):

a) network supply model;
b) demand models;
c) assignment model.

All the applied simulation models are based on consolidated transportation system approaches (e.g. [31]). The supply model consists of a road network with about 540 nodes and about 1.2 thousand links ([32]). The generalized transportation cost (disutility) associated to each road link was estimated as vehicle running time using the function proposed in [33], and considering different free flow speeds for the various categories of vehicles j considered, plus the waiting times at intersections.

Fig.1 – The case study: Salerno municipality (Italy)

Through a discrete choice demand models were estimate the Origin-Destination (OD) demand flows. A hierarchical decision structure was also taken into account through inclusive variable (satisfaction or log-sum variable) in model specification, in order to take into account the influence of “lower” choice dimensions on “upper” ones (e.g. the path choices influence the transport mode choice).

Furthermore, traffic counts and some other aggregate OD demand flows were also considered to update demand estimations as suggested in [34]. For more details on the models specifications see [35] and [32] for passenger transport (car, motorcycle and bus), while [36] and [37] for freight flows (goods vehicles). The proposed methodology was applied for different vehicle categories *j* in term of vehicle, fuel type and ECE regulation characteristics of the vehicular fleet.

2.3 The benefits estimation for the non-users (external cost saved)

A significant part of the cost-benefit evaluation regards the estimation of external impacts (externalities) produced by the project both to the environment (e.g. climate change costs) and to the human health (e.g. air pollution and road safety). The new bus line will produce a reduction in car-usage with consequent external benefits for the non-users. The external impacts (benefits) estimated were the variations in term of: climate change, air pollution, noises, congestion and road accident. For estimating the monetary value of these benefits were multiplied the estimated pollutant emission variations and consumption emission variations for a marginal cost. The marginal costs used were those proposed by the European Commission in [7], weighed according to the vehicle fleet composition relative to the study area.

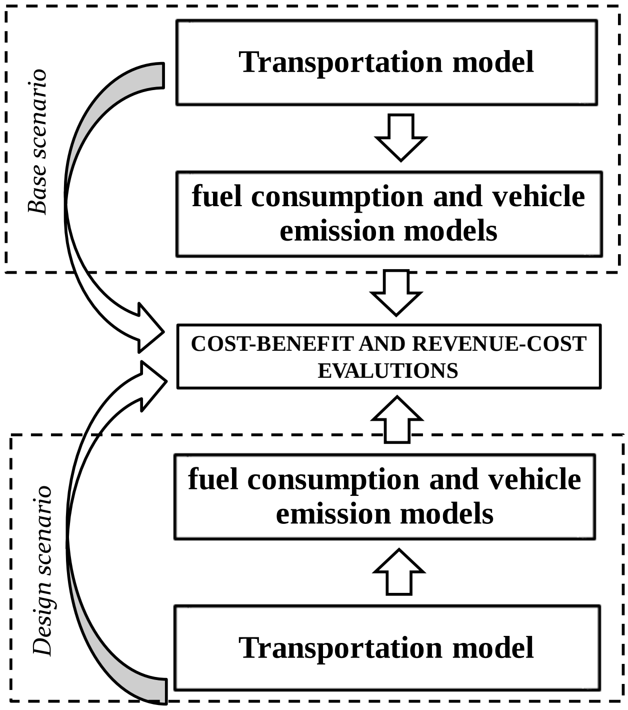

Fig.2 – Pollutant emission and vehicle consumption estimation model

The methodology proposed for the estimation of the pollutant emission variations and consumption emission variations derive from the ones proposed in [12]. Precisely, the authors in [12] proposed an integrated framework which combines an emission and fuel consumption traffic model with a transportation simulation model (demand, supply and assignment models).

Emission and fuel consumption traffic model allows to quantify the effects of design scenarios, while transportation model allows the estimations of performance indicators (e.g. average speed and distance travelled by each vehicle category) regarding both a base scenario and some possible design scenarios.

The methodology applied for estimating traffic fuel consumption and vehicle emissions belongs to a *bottom-up approach*. Starting from disaggregated input data (the number of trips, average distance and average speed per vehicle type) the bottom-up approach allows the estimation of fuel consumption and emissions. The European Commission approach, based on the *COPERT* model was implemented. *COPERT* model allows three different types of emission: 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; 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 emission and consumption model proposed was:

$$TotE_{ijk} = TUF_{ijk}\ (KM/h_{jk}) * Veh_j * KM_{jk} \qquad (1)$$

where:

$TotE_{ijk}$ = is the total annual emission/consumption of the pollutant/fuel *i* for vehicle type *j*, on the path travelled *k* (tons / year and pet / year);

TUF_{ijk} = is the emission/consumption unit factor of pollutant/fuel *i* for vehicle type *j* on the path travelled *k* (grams / km);

Veh_j = is the vehicle fleet composition (the number of vehicles related to the category *j*);

KM_{jk} = is the average annual mileage related to the vehicle type *j* on the path travelled *k* (km / year);

KM/h_{jk} = is the average speed related to the vehicle type *j* on the path travelled *k* (Km / h).

The COPERT is the software used for the estimations. The pollutant considered were: CO, NOx, VOC, SO2, CO2, PM10, while the fuel categories used were: gasoline; diesel; Liquefied Petroleum Gas (LPG), while for the goods vehicles were: light goods vehicles (gasoline and diesel); heavy goods vehicles and buses.

Regarding 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 was applied with different levels of spatial and temporal aggregation. For example, it was applied for estimating both the annual emissions/consumptions level and for daily estimations. The model output are the concentrations /consumptions of a wide range of pollutants/fuels resulting from combustion and evaporation of the fuel used by vehicles. The more accurate are the input data, the more reliable are the estimations results.

3 Estimation results

Through the proposed methodology the overall base scenario urban fuel consumption was quantified (Tab3, Tab.4 and Fig.3). In Salerno the gasoline consumption is about 12,000 tons/year while diesel consumption amounts to about 27,000 tons tons/year. These consumptions are equivalent to 43,000 pet/year (equal to 0.3 pet/year per inhabitant), where "*pet*" is the *petrol equivalent tons*, estimated through the Global Warming Potential (GWP) coefficients.

Analyzing the consumption divided for each vehicle typology emerge that cars consume more than the 46% of the total, the goods vehicles about the 30%, the buses more than 20%, while the motorcycles consume about 3% of the pet/year.

Furthermore, both the greenhouse gases and fine particles PM10 were estimated (pollutant emissions). The main results were reported in Fig.4 and Fig.5 in term of percentage distribution among the vehicles types analysed. The emissions in Salerno were: 120 thousand tons/year of CO2, about 2 thousand tons/year of CO, more than 4 tons/year of NO2, more than 21 tons/year of methane and about 300 tons/year of VOC.

Tab.3 – Estimation results: vehicle composition and consumptions

Vehicle category	cars	motorcycles	buses	HGVs	LGVs	Total
Number of vehicles	79,400	18,800	570	1,650	8,500	108,850
Diesel consumption (tons/year)	6,800	-	9,500	7,800	2700	26,700
Gasoline consumption tons/year)	10,200	1,000	-	34	340	11,650
Total consumption (pet/year)	19,600	1,200	10,300	8,400	3,300	42,80

Tab.4 – Estimation results: percentage distribution of vehicle composition and consumption

Vehicle category	cars	motorcycles	buses	HGVs	LGVs	Total
Number of vehicles	73%	17%	1%	1%	8%	100%
Diesel consumption (tons/year)	25%	0%	36%	29%	10%	100%

Gasoline consumption tons/year)	88%	9%	0%	0%	3%	100%
Total consumption (pet/year)	46%	3%	24%	20%	8%	100%

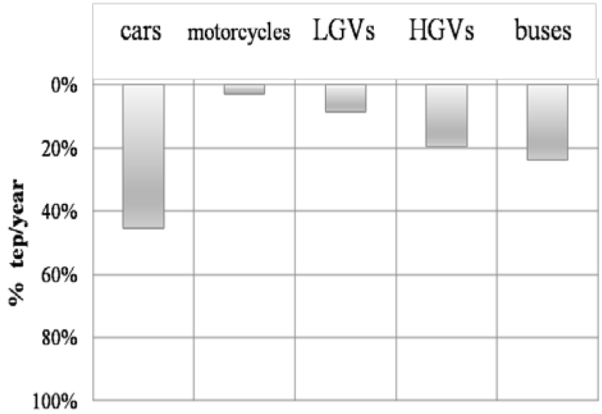

Fig.3 – Percentage distribution of vehicle pet/year consumptions

Overall the environmental impact of transportation system in Salerno is 127 thousand tons/year of equivalent CO2. The impact of each vehicle typology estimated is:

- cars about 45% of the total CO2 equivalent;
- goods vehicles about 27% of the total CO2 equivalent;
- buses about 24% of the total CO2 equivalent;
- motorcycles about 4% of the total CO2 equivalent.

With respect to the PM10 emissions, in Salerno about 53 tons of PM10 are generated every year. The cars, as expected, are the vehicles which produces the highest percentage of this pollutant. Car emits about 12 tons/year of PM10 (about 23% of the total).

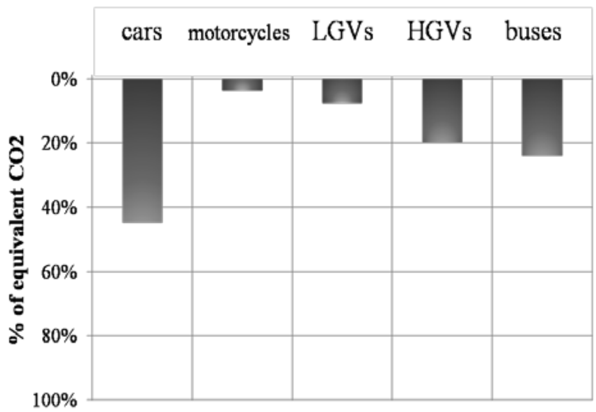

Fig.4 – Percentage distribution of vehicle CO2/year emissions

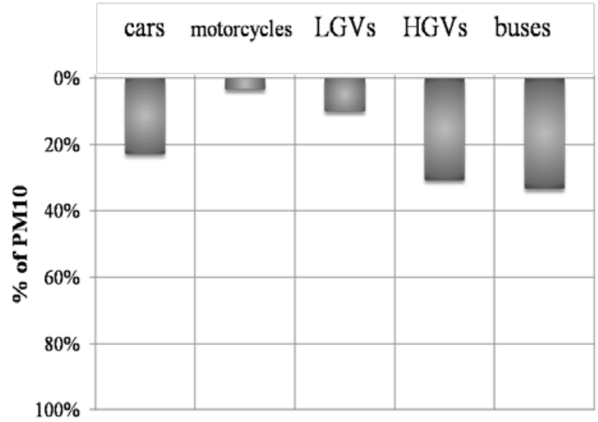

Fig.5 – Percentage distribution of vehicle PM10/year emissions

Finally, summing emissions values for all the other transport modes (bus, heavy goods vehicles - HGVs, and light goods vehicles - LGVs), it should be pointed out that these vehicles 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).

A sensitivity analysis was also performed. Effect (in term of consumption and emission) of 10%, 20% and 30% reduction of the bus fleet composition were estimated applying the estimation model described before. In the following tables, estimation results are reported in terms of: equivalent CO2 emissions, PM10 emissions, total fuel consumption.

Tab.5 – Sensitivity analysis results: total fuel consumption

% bus fleet reduction	**0%**	**10%**	**20%**	**30%**
pet/year	42,79	41,763	40,736	39,709
Δ%	0%	-2.4%	-4.8%	-7.2%

Tab.6 – Sensitivity analysis results: total fuel CO2 emissions

% bus fleet reduction	**0%**	**10%**	**20%**	**30%**
tons/year	127,130	124,079	121,028	117,977
Δ%	0%	-2.4%	-4.8%	-7.2%

Tab.7 – Sensitivity analysis results: total fuel PM10 emissions

% bus fleet reduction	**0%**	**10%**	**20%**	**30%**
tons/year	53.1	51.3	49.6	47.8
Δ%	0%	-3.3%	-6.7%	-10.0%

As reported, the benefits produced in term of fuel consumption range between -2.4% (with a reduction rate of 10%) to -7.2% (with a reduction rate of 30%). A similar trend can be observed for CO2 equivalent emissions, while significant reductions can be obtained for PM10 emissions:

- -3.3% reduction of PM10 emissions, reducing the 10% of the diesel bus fleet into electric buses;
- -10.0% reduction of PM10 emissions, reducing the 30% of the diesel bus fleet into electric buses.

Starting from these results both a revenue & cost analysis and a cost-benefit analysis were performed, verifying the economical convenience of the prosed design scenarios.

The comparison among the project alternatives was performed through the difference between costs and benefits over the years. Defined and quantified (in monetary terms) the impacts related of the new bus line (for each design scenario), some Measure Of Effectiveness (MOE) were estimated.

Net Present Value (NPV) is measure of the profitability of an investment that is calculated by subtracting the present values of cash outflows (including initial cost) from the present values of cash inflows over a period of time:

$$NPV\ (r) = \sum_{t=0}^{T} \left(\frac{\sum_{j} B_j^t - \sum_{j} C_j^t}{(1+r)^t} \right) \quad (2)$$

where:

- r is the rate of return equal to 3% as suggested in the mentioned Italian Guidelines for assessment of Investment Projects;
- T, is the time period equal to 12/18 years;
- B_J are:
  - for the revenue & cost analysis, all the monetary savings obtained (e.g. fuel consumption reduction);
  - for the cost-benefit analysis, all the benefits (both for the users and for the non-users) that the new line will produce;
- C_J is all costs supported (investment, maintenance and management).

Pay Back Period (PBP) is the period of time required to recoup the funds expended in an investment, or to reach the break-even point (return of the investment):

$$PBP = Tmin;\ NPV(r) > 0 \quad (3)$$

The choose of the best project scenario to develop was defined comparing the MOE indicators estimated. In Tab. 8 results of the Revenue & cost analysis are reported.

Tab.8 – Results of Revenue & cost analysis

Scenario	1	2	3
Pay-back period (years)	12	10	6
NPV in 12 years (millions of Euro)	-0.780	0.008	2.020
NPV in 18 years (millions of Euro)	0.430	1.850	3.860

Furthermore, in Tab.9 and 10 are compared results of the Cost-benefit analysis developed both in a “traditional” way and based on the overall carbon footprint (the aim of the paper).

Finally, environmental impacts deriving from the implementation of the proposed design scenarios are reported in the next tables.

Regarding the Revenue & cost analysis, for the Scenario 1, the investment cost is 3.9 million of Euro, the pay-back period is 12 years and a reduction in energy consumption and total emissions (Equivalent CO2 and PM10) was estimated equal to 1.8% and 1.8/2.4% respectively. For the Scenario 2 (two batteries/bus), was estimated an increase in investment costs (two batteries and the need of a more powerful photovoltaic system) against an increase in environmental benefits. In this scenario, the cost amounts in 4.8 million of Euro, the payback period is 10 years and was estimated a reduction in consumption and emissions of about 2.6% and 2.6/4.8% respectively. 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), the investment cost will be equal to 2.8 million of Euro with a pay-back period of 6 years (high investment cost-effectiveness).

Tab.9 – Results of "traditional" Cost-benefit analysis

Scenario	1	2	3
Pay-back period (years)	2	1	1
NPV in 12 years (millions of Euro)	23.0	48.7	50.4
NPV in 18 years (millions of Euro)	33.1	68.9	70.6

Tab.10 – Results of Cost-benefit analysis based on the carbon footprint

Scenario	1	2	3
Pay-back period (years)	1	1	1
NPV in 12 years (millions of Euro)	43.1	88.9	90.6
NPV in 18 years (millions of Euro)	60.9	124.4	126.1

As reported in Tab.9 and 10, the comparison of the MOE indicators show that the analysis based on the overall carbon footprint produced by the design scenarios allow to better estimate the (positive) impacts deriving from the use of this technology. Since the hybrid buses have a carbon footprint -12/18% lower than a traditional (diesel) bus, a transportation service based on this type of technology allows to obtain grater benefits up to +82% against a traditional one.

The sources considered as reference for these estimation analyses were the estimation performed by:

- DEFRA, Department for Environment, Food and Rural Affairs – UK;
- EIA, Energy Information Administration - Official Energy Statistics – USA;
- EPA, Environmental Protection Agency – USA
- GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) Model;
- IPCC, Intergovernmental Panel on Climate Change – ONU.

Tab.11 – Estimation results: total consumptions

Total consumption	**Scenario 1**	**Scenario 2**	**Scenario 3**
Δ%	-1.8%	-2.6%	-2.6%

Tab.12 – Estimation results: equivalent CO2 emissions

Equivalent CO2	**Scenario 1**	**Scenario 2**	**Scenario 3**
Δ%	-1.8%	-2.6%	-2.6%

Tab.13 – Estimation results: PM 10 emissions

PM 10	**Scenario 1**	**Scenario 2**	**Scenario 3**
Δ%	-2.4%	-4.8%	-4.8%

4 Conclusions

Recently the idea of eco-rational planning has assumed a central role in urban sustainable transportation planning, that means financial effective, rational and effective for the transport system, sustainable for the people's health and for the environmental and acceptable by the stakeholders.

In this research were evaluated if the use of hybrid electric buses (against to the "traditional" diesel buses) could produce profit (revenue & cost analysis) for a private/public transport operator and was developed a cost-benefit analysis explicitly considering the overall carbon footprint (and not only the local impacts) of this vehicle technology.

The case study was a new urban bus line designed in a medium size city, Salerno, in Italy.

The main results of the study were:

- the use of hybrid electric buses could produce a profit for private/public transport operators;
- the analysis based on the overall carbon footprint allow to better estimate the (positive) impacts deriving from the use of this technology. Since the hybrid electric buses have a carbon footprint -12/18% lower than a traditional bus, an urban transportation service based on this type of technology allows to obtain grater benefits up to +82% against a traditional one.

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 [38] and/or for a carsharing services [39].

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