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Strong Sustainability in Public Transport Policies: An e-Mobility Bus Fleet Application in Sorrento Peninsula (Italy)

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Abstract: Sustainability can be defined as the capacity to satisfy current needs without compromising future generations. Sustainable development clashes with the transport sector because of the latter's high fossil fuels usage, consumption of natural resources and emission of pollutant and greenhouse gases. Electric mobility seems to be one of the best options to achieve both the sustainability goals and the mobility needs. This paper critically analysed weaknesses, strengths and application fields of electric mobility, proposing a real case application of an e-mobility bus fleet in Sorrento peninsula (Italy). The aim and the originality of this research was to propose a public transport design methodology based on a "strong sustainability" policy and applied to a real case study. To be precise, the renewing of the "old" bus fleet with a diesel plug-in hybrid one charged by a photovoltaic system was proposed, aiming to both improve environmental sustainability and perform an investment return for a private operator in managing the transport service. The proposed case study is particularly suitable because the peculiar morphology of the Sorrento peninsula in Italy does not allow other types of public transport services (e.g., rail, metro). Furthermore, this area, rich in UNESCO sites, has always been an international tourist destination because of the environment and landscape. Estimation results show that the new e-mobility bus service will be able to reduce the greenhouse gases emissions up to the 23%, with a financial payback period of 10 years for a private investor.

Keywords: e-mobility; electric vehicle; plug-in hybrid; strong sustainability; weak sustainability; MaaS; sustainable mobility; new technologies; local emissions; environmental impacts; revenue-cost analysis

1. Introduction and Motivations

Sustainable development is defined by the United Nations Environment Programme (UNEP) as the capacity to satisfy current needs without compromising future generations [1], managing the earth's resources and minimizing climate change's negative impacts [2]. This concept is so important that, in 2015, the United Nations endorsed the 2030 Agenda for Sustainable Development and 17 Sustainable Development Goals (SDGs), reaffirming the World Community commitment to Sustainable Development [3]. Through this Agenda, 193 member states in a big action plan with 169 targets seek to achieve the Millennium Development Goals. Among the 17 goals, two of them are related to the transport sector: one points out the need to build resilient infrastructure, promote sustainable industrialization and foster innovation; the second one concerns the need to make cities inclusive, safe, resilient and sustainable. Furthermore, the transport sector can contribute significantly to two other aims: to reduce CO_2 emissions and increase energy efficiency.

In transport planning, the concept of sustainable transport infrastructure is very hinged on different fields. As highlighted by Henke et al. [4] a transport infrastructure to ensure sustainable development should be: (i) environmentally sustainable (e.g., produce benefits on greenhouse gas emission, pollutant emission and noise emission [5]); (ii) socially sustainable, improving quality of life [6] and social equity [7] and (iii) economically viable [8].

Regarding the fact that environmentally sustainable development generally clashes with the transport sector because of its high fossil fuels usage, consumption of natural resources and emission of pollutant and greenhouse gases. Electric mobility (sometimes named e-mobility) seems to be one of the best options to achieve both the sustainability goals [9] and the mobility needs [10]. The European Commission has set some limits in the transport sector to significantly reduce emission, including emission-free urban mobility by 2050 [11] and emission-free urban freight by 2030 [12]. In 2017, the Commission submitted a package of directives and other mobility measures, known as "Europe on the Move", to make Europe one of the leaders in clean mobility. This has the aim of limiting CO_2 emissions and to stimulating the market of "clean" vehicles. One of these measures was to set, by 2025 and 2030, clean and energy-efficient vehicle targets for light-duty vehicles [13].

Among the useful actions to achieve this goal seems to be the development and usage of e-mobility vehicles and services [14]. This technology refers to those vehicles that use electricity as their primary energy source [9], supported by the production of sustainable energy for recharge (e.g., wind energy, solar energy). E-mobility vehicles have old origins, being designed, tested and marketed before those with the internal combustion engine. In the 1830s, the Scottish entrepreneur Robert Anderson designed the first electric carriage model [15], powered by the non-rechargeable primary cells [16], while in 1835, the first electric vehicle, designed by Professor Sibrandus Stratingh of Groningen, was built [17]. These prototypes were difficult to practically use due to the non-rechargeable battery and the electric motor inefficiency. In 1908, Henry Ford managed to reduce production costs which, together to a low cost of gasoline (due to the discovery of new oil fields) and better vehicle performance, led to a wide diffusion of internal combustion vehicles [18], which became a product intended for a mass market [19].

In the 1990s, the growing interest in global environmental problems brought sustainable mobility to the centre of transport policies worldwide (e.g., in 1997, the Kyoto Protocol [20] defined the goals to reach an emissions reduction [21]) and of the scientific debate. For this reason, one of the most highlighted valid solutions studied in these years was electric mobility. Many countries performed pro-electric mobility policies, proposing incentives for the purchase of electric cars aiming in pushing car manufacturers (e.g., Renault, General Motors, Nissan, Volkswagen) to develop and produce electric vehicles with higher performance standards [22].

In the last decade, battery-powered electric vehicles (BEV) and plug-in hybrid electric vehicles (PHEV), such as Leaf, Mitsubishi i-miev, Chevrolet Volt and Tesla Model S started to enter the market [16].

Since the 2000s, opportunities and limitations of electric mobility are also widely discussed among scientists and politicians [23] through the application of quantitative methods [24] and procedures (e.g., cost benefit analysis [25–29], multi-criteria analysis [30–33] and cost-effectiveness analysis [34]).

The current main weaknesses of e-mobility concern the following: (i) the high purchasing price (70–100% higher than a traditional vehicle) [35]; (ii) the autonomy of the battery, which limits the maximum distance travelled without recharging (despite the kms of a fully charged electric vehicle being comparable to a traditional one, the limitation is due to the recharging time not being immediate, which is different to the other vehicles) [36]; (iii) the limited re-charging infrastructure network (not enough to satisfy the demands of future potential users) [37]; (iv) the "no zero" carbon footprint emission (for production, consumption and disposal) [38]. The electric vehicle emits on average about

15–20% less than a traditional one and about 11% than a hybrid vehicle (source: elaboration of DEFRA, EPA and IPCC data, 2016).

Moreover, beyond the technological problems that limit the massive diffusion of electric vehicles [39], there are also psychological factors in term of a priori reluctance in using a new technology [40]. There is a copious literature (e.g., [41–45]) about users' reluctance toward new technologies. In particular, referring to electric vehicles, Kim et al. indicated that respondents were rather reluctant to exchange their car for an electric one [46].

However, there are several strengths in using Electric Vehicles (EVs), placing this technology as promising for sustainable mobility. First, these vehicles have "zero local emissions", and this is a not negligible advantage, especially referring to their usage in cities with high population density, where the reduction of the local emissions could significantly reduce pollution and enlarge the quality of life. Furthermore, the consumers' willingness to pay for sustainable products/services [47] could also justify a higher price than environmentally unfriendly vehicles. In addition, the electric vehicles' introduction into a significative percentage in the market (e.g., EU) might diversify energy supplies from the oil monopolists (e.g., United States, Saudi Arabia and Russia) to those essential for the production of electric vehicles (knowing that the main holder of the so-called rare earth elements is China (unique monopolist)).

Starting from these considerations, the new forms of mobility (e.g., Mobility as a Service—MaaS [48–50]) could emphasizes the strengths of EVs (i.e., zero local emissions), reducing their weaknesses (i.e., high purchase price and the limited autonomy). Among the main sustainable urban e-mobility applications there are: (i) the micro mobility (for the last mile trips); (ii) the sharing mobility; (iii) the electric public transport fleets.

The micro mobility could mainly refer to the trips related to the last mile, that is the distance from a transport hub (e.g., station) to the destination (and vice versa). In fact, with trips shorter than 10 km, there is no need of a high battery autonomy. At the same time, the micro electric mobility also reduces local pollutant emissions in the city.

Regarding the sharing mobility, the use of the electric vehicle combined with the sharing mobility service [51], on one hand, will produce benefits for the human being and the environment, and on the other, it will also push vehicle manufacturers, rental companies and those who deal with charging infrastructure management to start new projects in favour of increasingly sustainable mobility. With a sharing mobility service, users may give up using their own cars to rent it out for the needed time through a company that owns a fleet of vehicles (e.g., cars or bicycles) [52]. In this way, the economic spread of the electric vehicle (high costs and low autonomy) can be absorbed by the greater willingness to pay, knowing that it is good for the human being and the planet.

An urban electric public transport fleet plays an important role in e-mobility being a solution to reduce Particulate Matter (PM) pollution [26]. Indeed, most of the buses circulating in European cities are powered by diesel [53] and significantly contribute to increasing polluting substances in the air such as particulate matter and nitrogen oxides [54]. Many studies [26,55,56] suggested that one of the causes of the pollution problem was principally linked to obsolete vehicles still in circulation, which were highly polluting and less efficient. So, electric bus systems are defined as environmentally friendly, powerful energy-saving systems that are easily integrated into high-quality sustainable urban transport [57]. Several studies investigate the most efficient and effective way to achieve zero-emission in public transport services [58–60] and identify electric buses as potential solutions [61].

The Finnish government created a test platform used by several electric bus manufacturers worldwide and this test platform became a centre for the assessment of manufactured prototypes [61]. Germany is working on silent and low emission transport systems, which are also able to regenerate braking energy and store this energy with ultra-capacitors with electric buses.

Starting from these considerations, the topic addressed in this research concerns the circumstance that sustainable solutions/policies regarding the transport sector are often expensive, difficult to implement and almost never of "strong sustainability", where for a strong sustainability policy we refer to an intervention for which the natural capital stays at least the same as the artificial one [62–65], aiming in an increase of the overall social and economic welfare. With this paper, we have tried to contribute to covering this gap, proposing a design methodology that combines consolidated practices and technologies that, jointly with the application of quantitative methods and guidelines, allow us to propose sustainable and profitable (for a private operator) solutions/policies. Precisely, a specific design methodology for a plug-in hybrid diesel bus fleet was assessed, aiming at reducing both global and local negative transportation impacts [66]. The thesis investigated in this paper has been that using both hybrid buses and a photovoltaic system for recharging it could be considered a policy that meets the "strong sustainability" mark for public transport in the operational phase because of fewer fossil fuels consumed (global impact) and absence of local pollutants emissions. So, the natural capital remained constant and the artificial one is improved (strong sustainability) since there were new and high-quality buses that consume fewer primary resources, pollute less and therefore improved the quality of life (welfare).

Furthermore, the proposed theoretical methodology has been also applied to a case study in order to verify its applicability in real contexts: the substitution of a bus fleet in Sorrento peninsula (Campania region—Italy). Precisely, a renewing of an "old" bus fleet with diesel plug-in hybrid vehicles charged by a photovoltaic system was proposed. After this, the environmental effect and investment return (for a private transport service operator) of replacing an "old" bus fleet with new with diesel plug-in hybrid vehicles respect the case of the renew with new generation diesel buses was estimated. This case study is particularly suitable because the peculiar morphology of the peninsula does not allow other types of public transport services (e.g., rail, metro, tram) other than bus lines. Furthermore, this area, rich in UNESCO sites, has always been an international tourist destination, which, in the summer period, produces a high level of road congestion.

The paper is divided into three sections. In the first one, the proposed methodology is reported. The application case study is described in the second section, while the last part reports the main conclusions of the research.

2. A "Strong Sustainability" Public Transport Design Methodology

As said, one of the aims of the paper was to propose a public transport design methodology based on a "strong sustainability" policy in transport planning [67]. The concept of strong sustainability was born from debate on the importance of economic development versus the importance of environmental quality. Could a high economic growth lead to low environmental quality? Two different interpretations of sustainability were developed in the literature [62] to answer this question and clarify this point. According to the "strong sustainability" interpretation, the natural capital must stay at least the same as the artificial one, which generally aims to increase both the social and economic welfare. By contrast, within the "weak sustainability" interpretation, the artificial capital is more important than the natural one [63], or at least can replace it with a view to increasing overall welfare [64]. The strong sustainability principles can be synthetized in (i) complementarity between natural resources and physical resources; (ii) safeguarding and conservation of irreversible natural resources and (iii) qualitative development (with the definition of biophysical limits within which economic activity must be carried out) [65].

As said, electric mobility seems to be one of the best options to achieve both the sustainability goals and mobility needs [10]. In the transport sector, it is very hard to reach a strong sustainability policy, because every change to improve human welfare leads to a consumption of natural resources. Even if, in lifecycle, a full-electric vehicle recharging with green energy cannot reach this goal, as the natural resources consumption in production and waste disposal is not negligible [9], this goal could perhaps be reached considering only the operational phase with zero local emissions. Within this topic, e-mobility could be an example of policy closer to strong sustainability, if it were supported by the production of "green energy" for recharging the battery (e.g., wind energy, solar energy). In fact, the local emissions of this technology are null (e.g., electric vehicles) or very low (e.g., plug-in hybrid vehicles) if the recharging energy comes from sustainable suppliers (e.g., photovoltaic/wind system).

In light of what has been said, the proposed methodology follows the strong sustainability principle for a transport service in the operational phase. The proposed design methodology is described in Figure 1, and it is composed of three main activities:

(a) transport demand analysis (estimation);
(b) bus fleet design;
(c) photovoltaic system design.

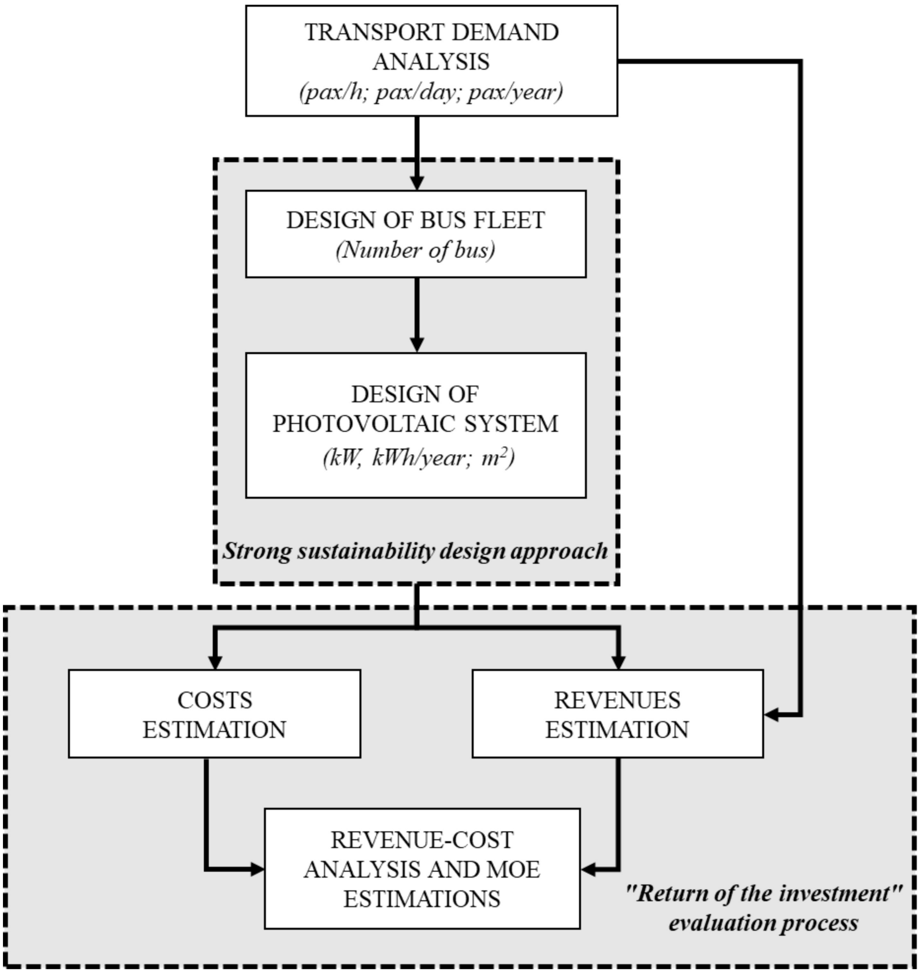

Figure 1. The proposed strong sustainability methodology for a public transport policy.

The first step was the definition of the transport demand. Common methods to estimate the demand are the following (for details see [25,28,68–70]): (i) direct estimations and (ii) estimation through mathematical models. The direct estimation has limited forecasting capacity and only allows the current demand estimation but is easily to implement. The model estimation has a high forecasting ability and allows the mobility demand estimation including hypothetical scenarios but is more complex and requires high technical skills [71].

The transport demand required to design the bus fleet provides the required service. The number of vehicles N required to be able to operate the line can be estimated through the equation:

$$N = INT(\mathrm{TL} \times f) + 1 \quad (1)$$

where:
f is bus frequency [min] of the line, that is, the number of vehicles (buses) that pass through a stop in an hour;

TL is the round-trip travel time [min], that is, the time of a vehicle to complete a round trip.

It includes the times of inversion at the bus terminal in the case of a circular line and can be estimated by the equation:

$$TL = Lc/(S_{ac} + TT) \tag{2}$$

where:
Lc is the total length of the line [km];
S_{ac} is the average bus commercial speed [km/h], that is, the ratio of the total length of the path (Lc) and the travel time (T_{tr}) that include time spent stationary for stops;
TT is the inversion time at the terminal [min.]; it is the time that elapses between the arrival of a bus at the terminal and the departure for the next run (service), taking into account the time required to reverse the vehicle, the rest times of the traveling staff and the recovery times set to recover any delays in the line.

The frequency measurement unit considered is bus/hour, which is a function of the rush hour demand on the line and of its hourly capacity [pass/hour]; moreover, it is a design feature of the service.

The lap time (I) of the bus line is the time between two successive bus passages; its measurement unit is in minutes and could be estimated through the equation:

$$I = 60/f \tag{3}$$

Considering the rush hour demand on the line, it is possible to evaluate the bus number needed.

The third activity is the design of the photovoltaic system [72]. The photovoltaic system was designed taking into account the requirements, the climatic conditions, the photovoltaic technology, the type and quantity of surface available and the location [73].

The first design parameter to size is the Power (P) that the photovoltaic system can deliver. The Power (P) that a photovoltaic module can supply depends on the intensity of the solar radiation proportionally to the radiation incident on the module. The measurement unit considered is called "peak kiloWatt" (kWp) or, more commonly, "peak power". It is the power generated by a module subjected to a standardized equivalent radiation to 1000 Watts per square meter in nominal conditions, i.e., with a pressure of 1 atmosphere and a temperature of 25 degrees centigrade.

The power of the installed photovoltaic modules (P) could be estimated as a ratio between the recharge energy and the annual energy produced by 1 kWp $\left(E_p\right)$:

$$P = E_r/E_p \tag{4}$$

where:
E_r is the recharge energy [kWh] that is function of the days of bus operation N_d, the energy of the bus battery (E_b) and the number of buses needed to operate the service following the equation:

$$E_r = N_d \times E_b \times N_{bus} \tag{5}$$

$E\ _p$ is the annual energy produced by 1 kWp [kWh/kWp].

In order to estimate the Energy produced in one year by the photovoltaic system (E_{p_y}) [kWh/year], the following formula was considered:

$$E_{p_y} = P \times E_p \tag{6}$$

Another design parameter is the area occupied by panels. It expresses the percentage of space that the panels of a PV system can occupy considering the shadows, and it is estimated considering the "filling factor" (F_s).

The ideal multiple-row system requires that the rows of fixed panels (facing south and inclined with respect to the ground at a latitude angle of approximately 30°) are spaced apart so that there is no mutual shading, which beyond lowering the performance by 95% could damage the panels. The equation used to estimate the occupied area by the photovoltaic panels is:

$$S = F_s \times P \times S_o \tag{7}$$

where:
F_s is the "filling factor";
S_o is the area occupied by 1 kWp [m^2/kWp].

After designing the plug-in bus system, a revenue-cost analysis needs to be implemented. Revenue-cost analysis is usually used to determine the performance and suitability of a project/investment. This is considered as a process of evaluating businesses, projects, budgets and other finance-related transactions [74]. In the Revenue-Cost analysis, the economical convenience is estimated as the variation between the design and the reference scenario or as the variation between two design scenarios. One of the first activities is the identification of the analysis time period. This represents the number of years for which the impacts were taken into account in the analysis. The choice of the time period influences significantly the results of the evaluation process. We defined the project scenario to compare the time period, and the activities to implement are shown in Figure 1 and described below:

- *Cost Estimations* is a variation between the design and the current scenario or the variation between two design scenarios. All costs supported during the overall time period have to be considered: investment costs, operative costs, ordinary and extraordinary maintenance costs. In plug-in hybrid buses implementation, the investment costs take into account the costs connected to the power system. This has some costs due to the Electrical Energy Storage (EES) used to store the surplus of energy due to Photovoltaic Panels [72]. As proposed by Lai et al. [72], these kinds of costs could be summarized into direct and indirect. The first one can be economically traced (e.g., investment costs due to battery, casing and electrolyte and replacement costs), the second one is represented by the "not visible" costs (e.g., operation and maintenance cost and the degradation of the battery). Furthermore, in a long-term analysis, the replacement cost due to battery packs degradation must be also considered in the estimation [75], leading to reductions in range and power output.
- *Revenues Estimations* are two kind of revenues: those deriving from possible incentives (those deriving from possible incentives for the purchase and installation of a photovoltaic system, those based on power, energy or reliability [72] and those deriving from fuel savings) and those deriving from selling more tickets within the bus service;
- *MOE Indicators Estimations*: Once all the impacts (revenues and costs) were quantified, the economic convenience of the project was evaluated through the estimation of some measure of effectiveness:

The Net Present Value (*NPV)* reports the various effects relating to the project in an analysed period:

$$NPV(r) = \sum_{t=0}^{Tm} \left(\frac{\sum_j R_j^t - \sum_j C_j^t}{(1+r)^t} \right), \tag{8}$$

where:
r is the rate of return;
T_m is the analysis time period;
R_J is all the revenues that can be produced;
C_J are all supporting costs
IRR (r_o) is the value of the rate of return that null the *NPV*:

$$IRR = r_o; \tag{9}$$

$$NPV(r_o) = 0 \tag{10}$$

The Payback Period (*PBPi*) discounted is the minimum number of years beyond which a positive *NPV* occurs (that is the return on the investment):

$$PBP_i = T_{min}; \quad (11)$$

$$NPV_i(r) > 0 \quad (12)$$

3. Application Discussion and Results Estimation

The proposed "strong sustainability" methodology described above was applied to the proposed case study. As said, the introduction of a policy close to "strong sustainability" was one of the aims of the paper. This were supported by the production of "green energy" (solar energy) for recharging the battery of the bus fleet.

The analysed case study was placed in the Sorrento Peninsula (Figure 2), which is an Italian peninsula extending into the Tyrrhenian Sea, considered one of the main tourist destinations in Campania region (Italy). This Peninsula covers an area of about 200 km^2 with 21 total municipalities, 9 in Naples and 12 in Salerno, for a total of over 200,000 inhabitants [76]. This area has high congestions problem, especially in summer. Therefore, in 2017, a protocol of understanding was signed in Naples for sustainable mobility in this area. In fact, the area has always been an international tourist destination as it is an environment rich in UNESCO sites. This, connected to its morphology, produces heavy traffic on difficult roads. Due to these factors (i.e., the geographical context, the morphology of the territory, the current mobility system and the critical issues in terms of traffic and transit difficulties), it was needed to plan and design sustainable urban and suburban transport systems capable of decreasing the negative externalities caused by the movement of goods and people on the environmental, economic and social levels. The morphology of the area is very peculiar, with both mountain and sea landscapes connected each other by narrow roads and blind turns (Figure 2); that is why the proposed intervention, in this area, does not relate to rapid mass transport system such as underground bus lines. For this reason, in this context, the intervention on the public transport system aimed at improving environmental sustainability proposed the use of electric bus fleet.

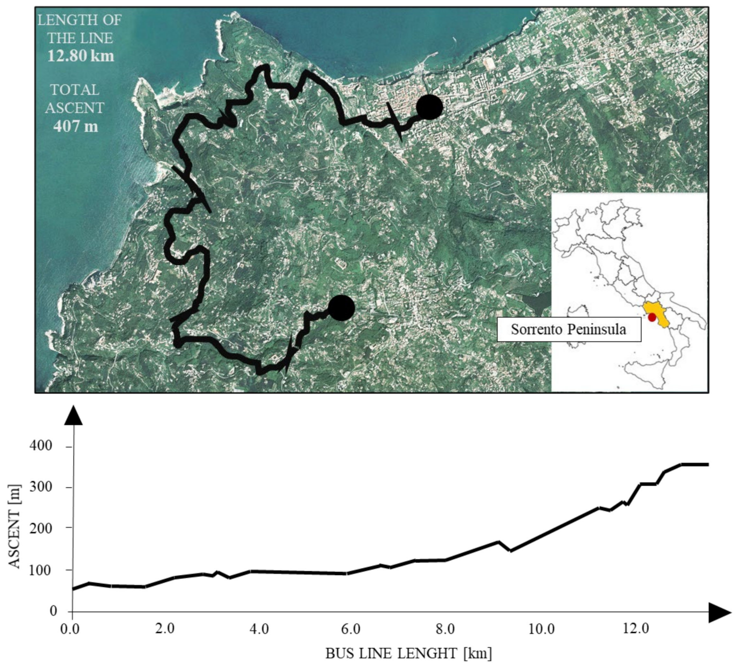

Figure 2. The morphology of the studied bus line in Sorrento Peninsula (Italy).

Another important element connected to the suitability of the case study is the average age of the buses. In Campania region, this is over 14 years [77]. Since the technical limit of a bus's first useful life is 12 years (except for a total overhaul) [78], it was necessary to modernize the bus fleet in the Sorrento peninsula. The age of the old bus fleet is reflected in the emission classes, which produce significant emissions especially concerning the local pollutants PM_{10}, NOx, CO and NMVOC. In this context, the development and modernization of the local public transport network can make a decisive contribution through an increasingly green and eco-sustainable service offer. This is thanks to the replacement of the bus fleet with new, less polluting vehicles. In this paper it was suggested to upgrade the bus fleet to a plug-in hybrid diesel technology recharged by a photovoltaic system, and it was compared with a traditional diesel new bus fleet (in terms of both environmental sustainability and revenue sustainability).

Plug-in Hybrid electric vehicles (PHEV) are vehicles with an electric battery combined with an internal combustion engine (ICE) [79]. Plug-in hybrid configuration, despite the hybrid configuration, has an additional feature that allows recharging with an external electric source [80]. This allows buses to drive without using the ice/generator for a limited range [81].

This makes the application closer to a "strong sustainability" policy because it will not only lead to an improvement in the public transport, but it will also improve the health of the planet and the quality of life. This, however, must be referred only to the operational phase since by using both hybrid buses and a photovoltaic system for recharging, fewer fossil fuels were consumed and fewer local pollutants were emitted.

In particular, the case study refers to one of the main bus lines in Sorrento peninsula (Italy): S. Agata-Massa Lubrense-Sorrento, about 13 km long with 5 stops and about 40 departures/day. A diesel plug-in hybrid system was analysed and designed to evaluate its environmental sustainability later rather than using a new diesel bus fleet.

According to the proposed methodology, the first activity implemented was the demand estimation. For the analysed case study, there is no service provided variation (in term of frequency, route, ticket price), so the current demand was considered as a constant (conservative hypothesis; it is expected to generate demand for a high quality and closer to the environment new transport service). The bus fleet size for the bus service in Sorrento line consists of 3 buses, estimated considering the Equation (1) and considering a frequency of 2 routes/hour, 300 days/year of operation and a fully recharge of the battery at the end of each day. In Table 1, the bus fleet design parameters were reported. Every day a bus on that line travels about 171 km in service with a commercial speed of 22 km/h (estimated considering the characteristics of the route, the number of stops and the travel time). Considering this and the tortuous roads, a full electric bus service in this case was excluded; in fact, the energy consumption for the limited battery autonomy, such as the investment costs, are too high. The analysis results with hybrid plug-in diesel buses scenario are given below.

Table 1. The estimated bus fleet design parameters.

S_{ac}	Commercial Speed [km/h]	22.0
LC	Length of the line [km]	12.8
$Stop$	Number of stops	5.0
I	Waiting time between two successive departures [min]	30.0
f	Frequency [routes/h]	2.0
TL	Lap time [h]	1.2
km	Km/day per bus	171.0

With respect to the sizing of the photovoltaic system, the design scenario included a grid-connected photovoltaic system in the bus parking areas to recharge the buses during the night stop. The Power (P) that the photovoltaic system can deliver represents the main design parameter considered. This may be estimated through the Equations (4)–(6) considering the input data of Table 1 and considering for the current area an energy produced equal to about 1500 kWh/year. Estimation results suggested that the Power necessary to satisfy the needs of the analysed scenario was equal to 11 kWp.

Another design parameter is the size of the area (S) exposed to the sunlight. It expresses the percentage of space that the panels of a PV system can occupy considering the shadows, and it is estimated considering the "filling factor" (F_s). The input data to estimate the occupied area by the photovoltaic panels (7) are shown in Table 2 considering s/h ratio (where s is the distance between two adjacent rows of panels and h is the height of the panel) at least 1.6 to have shading losses lower than 5%. So, the surface (S) is equal to 164 m^2.

Table 2. Photovoltaic panels design parameters.

$\boldsymbol{N_{bus}}$	Number of bus [num]	3
N_d	Average operation days per year [num]	300
E_b	Energy of the bus battery [kWh]	19
E_r	Recharge energy [kWh]	17,100
E_p	Average annual energy produced by photovoltaic [kWh/kW]	1500
E_{p_y}	Energy produced in one year by the photovoltaic system [kWh/year]	17,100
F_s	Filling factor	2
S_o	Surface occupied by 1 kWp [m2/kWp]	7.2

The sustainable strategy implemented was to design the photovoltaic system by correctly balancing the energy transferred during the day with that absorbed at night, with the aim being to reduce consumption and emissions impacts produced by the new bus line. Specifically, during the day, the energy is sold to the national energy provider, while in the non-operating hours (night hours), the buses restore (purchase) the energy to fully recharge the battery pack. Figure 3 shows the proposed EV charging system stages: (i) Photovoltaic panels generate direct current (DC) thanks to sunlight exposure; (ii) electricity is transformed into alternate current (AC) using an inverter; (iii) the main part of the generated electricity is used to recharge the bus batteries (according to the scheme "sale to the supplier during the day and purchase during night", with an overall zero costs balance), while the excess is sold to the national energy provider (Electric grid). The photovoltaic system was overdesigned regarding energy production so all the energy losses can be solved though EES. They were designed considering that the photovoltaic plant will be placed on the existing bus shelter, which is loaned to the service manager, who has the authorization to install this system.

The project scenario consisting in a hybrid-diesel bus fleet and a photovoltaic system, designed through the methodology describe above, was compared with renewing the bus fleet with new traditional EURO 6 diesel vehicles.

The two scenarios were compared from both a local and a global point of view. Estimation results showed that during the operational phase, the plug-in hybrid bus would generate about 41 ton of CO_2 eq./year (greenhouse gases emissions) against the 52 ton of CO_2 eq./year emitted by the traditional bus fleet (values estimated starting from the unit reference values proposed by [82]), allowing us to conclude that the proposed sustainable design scenario would be able to reduce the local impacts up to 23% in term of greenhouse gases emissions (Table 3).

Furthermore, the global impacts saved during the operational phases were estimated. Overall, the plug-in hybrid bus fleet scenario would consume 24 tons/year of Tons Oil Equivalent (TOE) per bus, against the 57 of TOE/year consumed by the traditional bus fleet, allowing us to conclude that the proposed sustainable design scenario would be able also to reduce the global impacts up to 58% (Table 3).

Table 3. Example of Global and Local impacts produced by the hybrid-diesel bus fleet scenario against the traditional ones.

Hybrid-Diesel Bus Fleet Scenario vs. Traditional Scenario	TOE/year	Ton of CO_2 eq./year
Δ variation	−36	−33
% variation	−58%	−23%

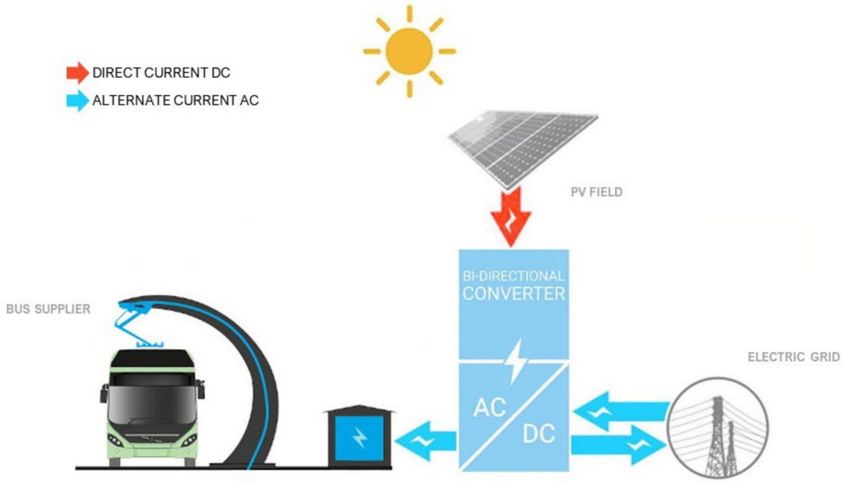

Figure 3. The proposed EV charging system.

In addition, the revenue-cost analysis performed has allowed us to verify the return of the investment for a transport operator (private or public) who aims to invest in this sustainable technology. Specifically, two scenarios were analysed with their financial viability, a first one renewing the actual (old) bus fleet with a plug-in hybrid bus feel, a second one considering a traditional diesel new bus fleet.

Overall, the delta investment cost (ΔC) between the two scenarios (plug-in hybrid diesel against new generation diesel buses) is:

$$\Delta C = (C_{hb} - C_{db}) \times n_{bus} + C_p \times P, \quad (13)$$

where:

C_{hb} is the acquisition cost of one diesel Hybrid-plug bus, set at 448,905 €/bus according to current market prices [83];

C_{db} is the acquisition cost for one diesel standard bus, set at 265,000 €/bus according to current market prices and to an analysis of the Environmental and Energy Study Institute (EESI) in 2012 [83];

n_{bus} is the bus fleet size, equal to 3 vehicles as estimated above;

Cp is the cost of the photovoltaic system, set at 1850 (€/kW) as suggested by [84] and according to current market prices;

P is the installed power required to provide the bus service (kW), equal to 11 kW as estimated above.

In addition, the maintenance and management costs of the two scenarios were also estimated and considered. Regarding the maintenance costs, it was estimated that the hybrid buses are more expensive than the traditional diesel ones by about 7000 euros (lifetime costs).

Regarding management cost, it was considered that a hybrid bus consumes on average 58% less fuel than a new generation diesel bus. By contrast, the cost of electricity is null since the photovoltaic system was designed, as said, with this aim. Finally, with the plug-in hybrid diesel renewal, about 67,000 euros in operating costs per year will be saved.

Revenues, as said in the methodology above, may be generated by selling tickets (traffic revenues) or by taking incentives, tax breaks and State funding. In this case study, the mobility demands of the two project scenarios were the same, so the variation for traffic revenues is null. In estimating the revenue variation, it was only considered the incentives due to the purchase and installation of a photovoltaic system and the production of this green energy.

Finally, the discount rate was considered equal to 4% according to the provisions of Regulation no. 480/2014 of the European Commission for a period ranging from 2014 to 2020 [85].

Estimations results were computed with respect to the main financial Measures Of Effectiveness (MOE) indicators. As shown in the second paragraph of the methodology, the main MOE indicators used to evaluate the financial viability of an investment are as follows: Revenue/Cost, used to estimate if, in the useful life of the project, revenues are higher than costs; Internal Rate of Return (IRR), used to estimate the profitability of potential investments (Equation (9)); Net Present Value (NPV), used to analyse the profitability of the project (Equation (8)); Pay-Back Period (PBP), which measures the time to recover the cost of an investment (Equation (11)).

The results for this case study are reported in Table 4. The Revenues/Costs ratio is equal to 1.33 indicating that the project revenues are higher than costs during the service life period. The NPV reports the cash flow relating to the project that, in the specific case with a time period of 12 years (average bus life in Italy), is about 86,450 euros. Figure 4 reports the cash flow (difference between discount benefits and costs) during the time period. The Payback Period (PBPi) result is equal to about 10 years (Figure 3); after 10 years, the benefits outweigh the costs. In addition, IRR (ro) is equal to 6.9%, so higher than the discount rate currently used of 4%. So, it is possible to conclude that the project is financially viable.

Table 4. Revenue-cost analysis results.

The MOE Indicators Estimated	
Revenue/Cost (€)	1.33
discount rate	4.0%
NPV (€) (12 years)	86,450
IRR	6.9%
Pay-back period (years)	10

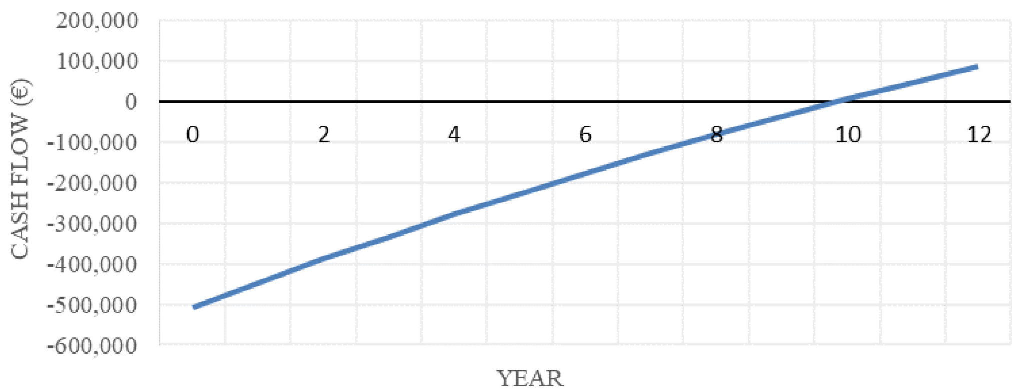

Figure 4. Cash flow (difference between discount benefits and costs) during the time period.

In accordance with this result, some studies showed the financial viability of e-mobility in public transport [86–90]. For instance, the study of Topal and Nakir [86] proposed the electric bus concept to achieve sustainable and zero-emission goals in Turkey. Agaton et al. [87] identified that investing in EVs rather than diesel-fuelled vehicles in the current business environment is the best decision;

in accordance with this, Moon and Lee [88] founds EVs more cost-effective than internal combustion engine vehicles, also without incentives. Dealing with the studies mentioned above, Agaton et al. [90] said that the electric option represents the best investment opportunity in Philippines due to the higher energy efficiency of EVs and cost savings from using electricity.

In conclusion, the strength of the results obtained was validated with a sensitivity analysis which allowed us to evaluate the reliability of hypotheses performed in the analysis. This is crucial for all the "weaker" hypothesis, which are the ones with major discretion and minor reliance of the evaluations. It consists in applying positive and negative variations (e.g., +10%, +30%, +50%) to the hypothesized parameters/indicators/discount rate and evaluating if and how the estimated MOE changed (e.g., NPV and IRR). To perform the sensitivity analysis, the first activity is to define the critical variables with an elasticity higher than 1 for which every "X" variation has a "greater than X" percentage variation (in an absolute value) for the NPV observed. The critical variables individuated with the highest elasticity with respect to the NPV are the discount rate (r) (Figure 5), the incentives (Table 5) and the investment costs (Table 5). As shown in Table 5, even when applying large (negative) variations in the incentives (unrealistic variations), the NPV is always positive, confirming the robustness of the analysed project scenario. On the contrary, the sensitivity analysis shows that the investment cost is a particularly critical variable. In fact, an increase in the investment cost of 15% produces a negative NPV. This result shows that e-mobility is not financially viable with higher investment costs. In fact, according to an analysis of cost difference between diesel bus and electric bus in Latvia, Laizāns et al. [91] highlights that initial investments of changing a public transportation fleet to electric buses and the costs of battery replacement were still too high to be financially viable, despite advantages gained from lower operational costs and additional environmental benefits.

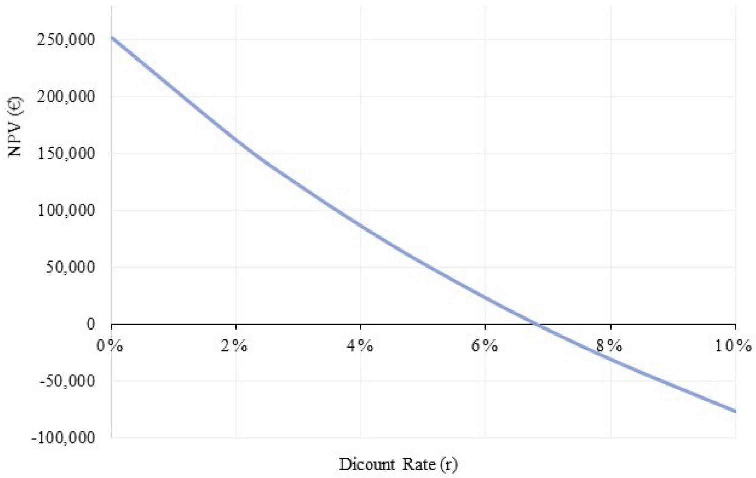

Figure 5. Sensitivity analysis: elasticity of the Net Present Value (NPV) with respect to the discount rate (r).

Table 5. Sensitivity analysis by changing incentives and investment costs.

		NPV	Payback Period	IRR
Incentives Variation [%]	−50%	76,683	11	6.9%
	−30%	80,590	10	6.6%
	−10%	84,496	10	6.7%
Costs Variation [%]	15%	−8394	13	3.8%
	10%	23,221	11	4.7%
	5%	54,835	11	5.7%

4. Conclusions

Sustainability is one of the main policies to minimize the climate change consequences of investment in the transport sector. Within this aim, "strong sustainability" policy means developing an intervention for which the natural capital must stay at least the same as the artificial one, which generally aims to increase both the social and economic welfare. By contrast, sustainable development clashes with the transport sector because of high fossil fuels usage, consumption of natural resources and emission of pollutant and greenhouse gases. Electric mobility seems to be one of the best (useful) options to achieve both the (strong) sustainability goals and the mobility needs.

Within this topic, this paper critically analysed weaknesses, strengths and application fields of electric mobility, proposing a closer "strong sustainability" methodology for public transport services. Furthermore, a real case application placed in Sorrento peninsula (Italy) was proposed, which consists in the application of a plug-in hybrid diesel bus fleet together with a photovoltaic system for recharging the batteries. Indeed, using both hybrid buses and a photovoltaic system for recharging, fewer fossil fuels were consumed (global impact), and no pollutants (local impact) were emitted in the operational phase. So, the natural capital remained constant, and the artificial one improved (strong sustainability), since there were new buses that pollute less and therefore improved the quality of life.

A full-electric scenario was also tested (which would have been even closer to strong sustainability) but rejected because of the length of the bus line (170 km/day) and the morphological characteristics of the area, which include winding roads and high altitude exclusions (altimetry of thousands of meters per day).

Furthermore, a revenue-cost analysis was also assessed to verify the financial convenience for a private operator in investing in this technology.

Estimation results show that the new e-mobility bus service will be able to reduce both the greenhouse gases emissions and fuel consumption (primary resources) with a positive net present value in 12 years and a payback period of 10 years. Specifically, the joint use of plug-in buses and a recharged station with a photovoltaic system limits the fossil fuels consumption by about 58% (global impact) compared to a traditional bus fleet and, at the same time, allows to significantly reduce greenhouse gases emissions by about 23% (local impact).

The results obtained in this research could be considered a first step towards a new vision of transport planning (public decision-making processes) based on the culture of sustainable and profitable design where, in addition to sustainability aims, a central role is covered by the investments profitability, especially during economic crisis periods where investment funds in the transport sector are limited. Precisely, research results show that a closer "strong sustainability" policy is also possible for the transport sector, and this could be also sustainable and profitable for a public/private transport operator and easily developed when the (old) life of buses requires that they be replaced with new vehicles. The main findings suggest that the proposed application could be considered as a first example of best practice for a strong sustainability policy, whose methodology could be exported and applied in different transport sectors but also for sustainable development in a multidisciplinary perspective.

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