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Research article

The air quality benefits of electric vehicles' adoption in the short food supply chain

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Abstract. Concerns continue to rise about environmental sustainability and the impacts of traditional transportation systems. Exploring alternative solutions therefore becomes imperative. This paper aims to investigate the potential advantages of integrating battery electric vehicles into the agricultural short food supply chain with a specific focus on air quality improvements. In order to reach the research goal, this study gives a thorough and comparative environmental analysis based on a real-world test conducted under the EnerNETMob project financed by the InterregMed programme, in contrast to other studies that primarily relied on general parameters and simulations. This study illustrated that using an electric vehicle (EV), like the Nissan e-NV200, for short-distance transportation of agri-food products is not an environmentally sustainable solution instead of using a petrol-powered vehicle. However, as the distance travelled increases, the environmental impact of electric vehicles diminishes, surpassing that of internal combustion vehicles. This study holds significant theoretical, practical and policy implications that are worth considering.

Keywords: Bactery electric vehicle (BEV), Environmental cost, food delivery, logystics, sustainable food supply chain, carbon footprint.
JEL codes: Q01, Q52, L94.

HIGHLIGHTS

- Transitioning towards sustainable distribution models is crucial to reduce environmental pressures caused by transportation.
- Sustainable measures in goods distribution, like optimized routes and zero-emission technologies, reduce transport-generated greenhouse gas emissions.
- Environmental costs of electric vehicles decrease compared to petrol-powered vehicles as the distance travelled increases.
- There is a need to address challenges in the production of batteries with better performance, considering also the significant emissions generated.

1. INTRODUCTION

1.1. Research background

The distribution of products is among the primary factors contributing to environmental concerns linked to the emissions of GHGs in the various phases and in particular that of transport (Validi *et al.*, 2014). According to the latest data from the International Energy Agency (IEA, 2022), transport generates almost a quarter of global CO_2 emissions, and after a sharp drop recorded in 2020 due to the COVID-19 pandemic, emissions have started to increase again, reaching 7.7 Gt CO2 in 2021 (+8% compared to the previous year). The significant contribution of the transport sector to overall emissions and its negative impact on the sustainability of the global supply chain has placed the issue of transport at the centre of the international and European political debate. In the 2030 Agenda for Sustainable Development of the United Nations (UN, n.d.), transport is, in fact, integrated into various objectives, particularly those relating to energy efficiency (7.3), sustainable infrastructures (9.1) and the need to guarantee access for all to a safe, convenient, accessible and sustainable transport system. In line with these objectives, EU policy, through the Green Deal and Paris Agreement, has also introduced measures to reduce the carbon footprint of the transport sector, which, compared to other sectors, has seen a rise in emissions of CO_2 since the 1990s (EC, 2022; Schulthoff *et al.*, 2022).

Agri-food products, in the broader context of freight transport, represent one of the most significant items. The carbon footprint generated by the distribution of agri-food products through the main options to move freight from one area to another (road, shipping and air) presents a wide variability in relation to the characteristics of the agri-food chain, the phases of the chain under study and the geography of the distribution. Indeed, on the one hand, Aikins and Ramanathan (2020), in their study on the key factors affecting the carbon footprint of the agri-food supply chain, show that transport and sales/distribution are the main determinants of CO_2 emissions in the UK. On the other, Vitali *et al.* (2018), looking at a local organic beef supply chain, find that the distribution activity accounts for only 1.1% of GHG emissions for the whole supply chain. In light of these considerations, it is clear that local supply chains can play a key role in reducing GHG and CO_2 emissions through a change in the supply networks and in reducing the kilometres/miles travelled, producing social and environmental benefits (Hendry *et al.*, 2018). From this point of view, the short food supply chain (SFSC), recognized by EU Regulation 1305/2013, plays an important role not only because it puts producer and consumer in contact but also because it helps to reduce transport costs and consequently emissions of CO_2 with a positive impact on public goods and the environment (Canfora, 2016).

1.2. Extant gaps

Much of the economic literature on the SFSC has focused on consumer perception by analysing the main factors affecting their choice to pay a price premium for foods delivered in the SFSC (Galati *et al.,* 2022; Lombardi *et al.,* 2015) These studies highlight that consumer participation in SFSC initiatives is guided, on the one hand, by benevolence and universalism values and in particular by the desire to preserve, protect and support the environment, and improve people's well-being and, on the other, by the belief that products delivered in the SFSC are healthier, as they are obtained through sustainable and responsible production methods (Lombardi *et al.,* 2015; Morris and Kirwan, 2011). There are also numerous studies on the contribution of this specific way of distributing agri-food products to the sustainable development of rural areas (Galati *et al.*, 2020; Deller *et al.*, 2017; Fiore, 2016). The results demonstrate that the SFSC is the most appropriate channel to increase the sustainability of agricultural production and to generate positive environmental, economic and social effects for the area (De Fazio, 2016). Indeed, SFSCs not only reduce prices but also have a beneficial impact on the environment, and they notably help to strengthen regional and local identity because there are fewer intermediaries between producer and customer (Paciarotti and Torregiani, 2021). However, some authors find that the SFSC has some weaknesses linked, in particular, to logistics which create negative externalities that make it in some ways less sustainable than the global distribution system (Malak-Rawlikowska *et al.,* 2019; Nsamzinshuti *et al.,* 2018; Coley *et al.,* 2011).

Despite the importance of distribution logistics for the environmental sustainability of the SFSC, few studies to date have focused their attention on the impact that the mode of transport can have on the carbon footprint of this supply chain and on the strategic solutions that can be taken to reduce CO_2 emissions. The study of Pirog *et al.* (2001) compares the CO_2 emissions of local and conventional supply chains, demonstrating that distribution over short distances, particularly in farmers' markets, contributes to reducing fuel consumption and in particular CO_2 emissions by about eight times compared to the conventional supply chain. Consistent with this, Torquati *et al.* (2015) find that the distribution of fresh milk at a regional level, compared to the national supply chain, represents an advantageous solution from both an economic, thanks to the higher profit margins for farmers, and an environmental point of view, thanks to the reduction of CO_2 emissions, which drop from 0.1255 to 0.0516 kg CO_2 per litre of milk. However, other studies analysing the transport phase of the SFSC find conflicting results. If, on the one hand, the reduction in kilometres travelled, compared to the global supply chain, helps to reduce greenhouse gas emissions, on the other, the frequency with which farmers participate in farmers' markets can generate a greater carbon footprint (Galati *et al*., 2021; Giacomarra *et al*., 2019; Schmit *et al*., 2017). Indeed, as pointed out by Malak-Rawlikowska *et al*. (2019), conventional agri-food supply chains, even if developed over a long distance, have, per product unit, a lower impact in terms of food miles and carbon footprint than short supply chains. To this, some scholars add that goods may generate a bigger carbon footprint than non-local commodities if they are preserved and bought out of season (Edwards-Jones, 2010; Cowell *et al*., 2003). It is clear that the results obtained are contradictory and that further analyses are necessary to better understand the effective contribution of the SFSC to environmental sustainability and the possible strategic solutions to be adopted to reduce the carbon footprint. From this point of view, as Kneafsey *et al.* (2013), underline, identifying appropriate logistics arrangements can help improve the sustainability of the agri-food short chain. With reference to this matter, a recent literature review on the short food supply chain (Paciarotti and Torregiani, 2021) identifies a series of actions at the logistical level aimed at improving the efficiency of the SFSC, including the careful choice of vehicle for transport. In this scenario, the adoption of electric vehicles (EVs) also for the distribution of foods can be an opportunity to achieve the strategic objectives set at an international and European level and make the SFSC increasingly sustainable.

1.3. Research aim and value

This work proposes a logistics solution based on the choice of adopting an electric vehicle for the transport of food products along the SFSC in Italy. The study's specific objective is to evaluate the environmental costs associated with using electric vehicles to distribute agri-food commodities compared to an internal combustion engine vehicle (ICEV) with similar features. Compared to previous studies based on national or international databases, or on technical information provided by car manufacturers (Fevang *et al*., 2021; Hoekstra, 2019), this research is based on empirical data and in a real-world setting during the testing stage of a research project that took place in Sicily and that was financed by the European Interreg Med Programme.

The results of the study provide an important theoretical contribution on the logistics of agricultural products' distribution within SFSC and on the carbon footprint of the transport phase in relation to the type of vehicle used. From a managerial point of view, the results can be an important decision support tool by providing useful information for a comparison between electric and conventional vehicles on the basis of the contribution to emissions generated. Finally, this study may be of interest for policymakers, constituting an empirical basis of information, useful for defining reasoned actions and directing future measures in support of greater sustainability of the supply chain.

The article is organized as follows. In the second section the methodological approach used to achieve the aim of the study is described. Results are presented and discussed in the section below. Final considerations close the article.

2. METHODOLOGICAL APPROACH

The empirical analysis conducted compared the environmental costs caused by the adoption of a commercial BEV (Nissan e-NV200) and that produced by an ICEV, with comparable features (Fiat Doblò 1.4 T-jet Pc-Tn cargo Easy) in the SFSC. The BEV has a cargo capacity of 4.2 m^3, which is equivalent to 2 pallets of 705 kg, which, according to previous findings (Giacomarra *et al.,* 2019), satisfies the needs of farmers participating in SFSC initiatives (Giacomarra *et al.,* 2019). Specifically, we estimated the environmental cost associated with the distribution of foods from farms to local retail stores and farmers' markets. This analysis was conducted using the approach recommended by Costa *et al.* (2021), which takes into consideration only the emissions produced by the EV battery and assumes that the end-of-life impact on emissions for both vehicles is small (<3%) and similar between them (Hawkins *et al*., 2013). The formula may oversimplify the complexity of real-world EV dynamics and may not capture all the relevant variables and factors that affect the environmental impact, potentially resulting in incomplete or biased conclusions. Nevertheless, the formula takes into account a variety of variables, offering a comprehensive assessment of the environmental aspects of EVs. This enables a more complex assessment of their sustainability.

In terms of battery emissions, a study of the Swedish Institute for Environmental Research (Emilsson and

Dahllöf, 2019) states that the production of a lithium-ion battery for an BEV could lead to a total emission of 66-106 kg CO_2-eq per kWh of battery capacity. With a 40 kWh battery for the BEV studied, this means a total emission of about 3.44 tons of CO_2-eq in total. To assess the environmental cost of the BEV the following formula was used:

$$E_{EV}(gCO_2eq) = E_{mix}\left(\frac{gCO_2eq}{kWh}\right) * EC\left(\frac{kWh}{km}\right) * \Delta x(km) + BPE(gCO_2eq).$$

E_{mix} stands for the emission cost of the Italian energy mix; *EC* for the BEV energy usage; Δx for the number of kilometres covered; *BPE* for the emissions value throughout the battery manufacturing. *Emix* was obtained on the basis of data provided by Nowtricity, a private company that provides EV charging solutions and services, in their 2022 report (Nowtricity, 2022). Besides, Nowtricity, being a company whose solutions are based on the high amount of electricity usage, is actively involved in the research of the impact of different sources of energy on the CO_2 emissions generated by electricity usage.

The data used for this empirical analysis are the result of the pilot action of the EnerNETMob project "Mediterranean Interregional Electromobility Networks for intermodal and interurban low carbon transport systems", funded under the European Interreg Med Programme, which tested "last mile" delivery of agricultural goods across short distances between rural areas, metropolitan and urban areas. More specifically, the testing phase of the project took place in Sicily by connecting the municipalities of Acireale, on the eastern coast of the region, and Troina, in the Sicilian hinterland, using the Nissan e-NV200 vehicle for the transport of local agricultural commodities. The vehicle, exclusively powered by electricity, was used by Rete Fattorie Sociali Sicilia, a social farm, and its associated partners, to transport agricultural goods in the study area for a four-month timeframe. For the investigation's needs, vehicle movement tracking records were used to collect pertinent data. In particular, the drivers of the vehicle recorded the following data: date, departure time, mileage at departure (on the odometer), place of departure, arrival time, mileage on arrival (on the odometer), destination, active electrical devices (AC, heating), vehicle load (% of total volume), and type of products transported, charging start and end date and time; total mileage (on the odometer); place of charging; type of charging (domestic, normal, fast); battery level at the start and end of charging (percentage). The energy used to recharge the battery was obtained through a digital infrastructure of an energy distributor, which provided, in addition to the kWh of energy used for recharging, other information related to the recharging times in relation to the plug used.

3. RESULTS AND DISCUSSION

3.1. Environmental costs in numbers

The Nissan e-NV200 testing phase of the EnerNETMob project lasted for four months (from November 2021 to February 2022). During this period, the vehicle completed 59 journeys of freight transport and was used by Rete Fattorie Sociali Sicilia to deliver local foods covering from 5 to 123 km for each journey and more than 1500 km in total. The vehicle was charged 21 times during this period with energy from 0.05 to 25.35 kWh and with 279.32 kWh in total. Thus, the energy consumption of the vehicle per km has been calculated and the value is given in Table 1.

Besides, the examined vehicle (Nissan e-NV200) has a battery capacity of 40 kWh. As suggested by Emilsson and Dahllöf (2019), the GHGs generated during the production of the vehicle battery is calculated by multiplying the battery capacity with the average emission for each kWh of the capacity. The value is given in Table 1.

Additionally, emission cost of the Italian energy mix was obtained from the 2022 report by Nowtricity (2022), and was calculated by multiplying the contribution of each energy source in Italy with the average emission of GHGs per kWh of electricity used, making it possible to determine the CO_2-eq emissions for each kWh (ISPRA, 2021).

Last but not least, the table does not include the emissions generated by the vehicle production, since it is considered that, except for the battery, the end-of-life impacts of other parts are similar for corresponding BEV and ICEV. Therefore, this component can be excluded from the analysis, according to the formula proposed by Costa *et al.* (Costa *et al.*, 2021; Hawkins *et al.*, 2013).

After collecting all these data, it was possible to calculate the environmental cost of using the Nissan e-NV200 of Rete Fattorie Sociali Sicilia with the formula provided by Costa *et al.* (2021). The total emissions of this vehicle for 1505 km covered is 3 548 655.03 g, thus about 3.55 tons of CO_2-eq. It worth noting that this result is different from the previous study (Galati *et al.*, 2023) since the Emix value has been updated and some corrections have been made to the empirical collected data. Thus, changes in the variables' values result in different outputs of the research.

A similar analysis has been conducted for the corresponding ICEV (Fiat Doblò 1.4 T-jet Pc-Tn cargo Easy).

Table 1. Components of the formula of BEV's environmental cost.

Variable	Abbreviation	Calculation	Value
Emission cost of the Italian energy mix	Emix	gCO_2eq/kWh	389
Energy consumption	EC	Total kWh / total km	≈ 0.1856…
Consumed energy	kWh	*sum*	279.32
Travelled distance	Δx (km)	*sum*	1 505
Emissions generated by battery production (g)	BPE	Average of 66 000-106 000 gCO_2eq per kWh of battery capacity	3 440 000
Nissan e-NV200 battery capacity	-	-	40
Total emissions (g)			3 548 655.03

Table 2. Components of the formula of ICEV's environmental cost.

Variable	Abbreviation	Value
Emission cost of the Italian energy mix	Emix	-
Emissions	EC	165
Travelled distance	Δx (km)	1 505
Emission generated by battery production	BPE	0
Total emissions (g)		248 325

In this case, the data have been obtained from secondary sources. Precisely, the median emission value per vehicle is 165 g/km according to car-emissions.com (Car Emissions, n.d.). In order to compare that with the corresponding BEV, the same distance has been taken for the analysis: 1505 km. As for the E_{mix}, it does not make sense for ICEV, since the vehicle uses fuel instead of electricity. Besides, it does not contain any battery, so the BPE is equal to 0. Finally, the end-of-life impact on emissions of the entire vehicle has not been taken into consideration, since it is similar for both vehicles (Costa *et al.*, 2021; Hawkins *et al.*, 2013).

Consequently, the same table for ICEV has the values shown in Table 2.

Applying the values listed above in the formula proposed by Costa *et al.* (2021), we obtained 248 325 g of total emissions of this vehicle for the covered distance of 1 505 km, or 0.25 tons of CO_2-eq.

3.2. Environmental impact analysis

The environmental costs of utilizing an BEV and a corresponding ICEV have been calculated for the 1 505 km travelled. The results show that for this short distance, the ICEV has significantly lower (about 14 times less) environmental impact compared to the BEV. However, it should be highlighted that at the end of their life, commercial vans have passed much greater mileage than 1 505 km. According to the Department of Transport (DfT) of the UK (DfT, n.d.), the average annual mileage of vans is 13 200 miles, or 21 243 km. Moreover, for the vans used for "delivery/collection of goods", this number is 21 200 miles, or 34 118.1 km. On the other hand, according to the S&P Global (S&P Global, 2022), the average age of the vehicles is increasing, and in 2022 this represented 11.6 years for light trucks. This means that during the life-cycle of commercial vans, they cover approximately 395 759.96 km of distance. Therefore, it is interesting to compare the environmental cost of the BEV and ICEV for this distance.

Furthermore, it has to be noted that the 40kWh battery life of Nissan e-NV200 guaranteed by the manufacturer is 160 000 km (Nissan News, n.d.). Thus, for covering 395 759.96 kms, the Nissan e-NV200 will need two additional batteries, which will generate 6.88 more tons of CO_2-eq (Emilsson and Dahllöf, 2019).

By recalling the formula of Costa *et al.* (2021) and inserting new data into it, we obtained absolutely different results. Specifically, the total emissions of the examined BEV are 38 892 298.17 g of CO_2-eq, while the same value for the corresponding ICEV is 65 300 393.40 g of CO_2-eq, thus about 38.89 and 65.3 tons of CO_2-eq for the BEV and ICEV, respectively. It means that, at the end-of-life cycle, the ICEV has made 40.44% more harmful impact on the environment than the corresponding BEV (Figure 1).

As Figure 1 illustrates, for the short distance run by the vehicles, the environmental cost of the BEV is higher due to the battery production. Consistent with this, Bieker *et al.* (2021) noted that emissions generated during the manufacturing of BEV and ICEV is similar and that the most relevant influence is related to the battery manufacturing, due also to the energy required to acquire raw materials, which has a more significant environmental impact than petrol-powered cars. However, the situation is reversed when the distance covered is longer and nearer to the average of the entire life cycle mileage of commercial vans used for "delivery/collection of goods". The study outcome is in line with a number of

Figure 1. Comparison of environmental costs of BEV and ICEV.

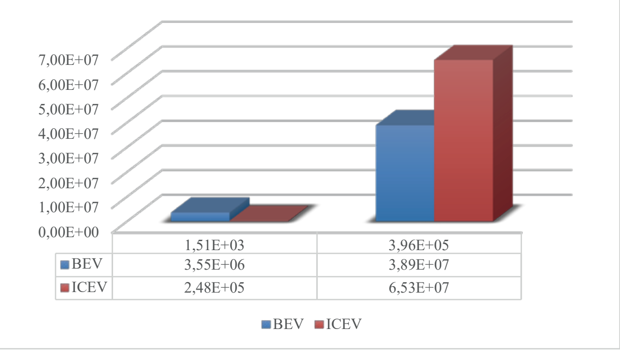
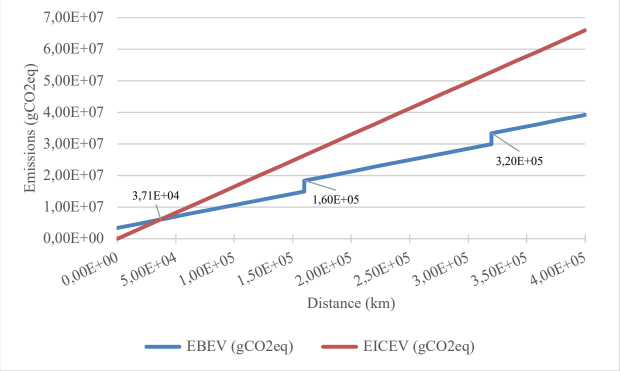


Figure 2. BEP of CO_2 emissions of BEV and ICEV.



previous studies, which argue that, potentially, the adoption of EVs reduces the harmful environmental impact through minimizing the CO_2 emissions. Indeed, De Santis *et al.* (2022) prove that BEVs can be considered less impactful vehicles for the environment than ICEVs in terms of CO_2 emissions. Consistent with our work, Canter (2022) studied the case in the US in more detail, and observed that at the production level, BEV generates significantly more CO_2, but after 1.2-1.6 years ICEV reaches the same amount of CO_2 emitted by BEV and, at the end of its life cycle, it is substantially lower. Similarly, Kawamoto *et al.* (2019) investigated more regions, including the US, EU, Japan, China, and Australia, and they confirmed that the harmful environmental impact of an BEV is higher than an ICEV, since more electronic components are needed to be produced, generating higher CO_2 emissions. But the authors also declare that the more distance the vehicles cover, BEV has less and the ICEV has greater impact per km.

The break-even point (BEP) – i.e., the lowest distance travelled in kilometres after which the BEV is considered more environmentally friendly than the corresponding ICEV – has been calculated. In our case, BEP is equal to 37 068.97 km (Figure 2). In Figure 2, the function of environmental cost of an ICEV is represented by the red line and the following equation: Y=165x. While, another equation stands for the environmental cost of an BEV: Y=72.20x+3440000. Where x is number of kilometres travelled; 72.20 is obtained by multiplying E_{mix} and EC; and 3 440 000 is BPE. Besides, after covering every 160 000 km, the maximum range capacity of a 40kWh battery of a Nissan e-NV200 (Nissan News, n.d.), additional emissions generated by battery production are taken into consideration. These findings are consistent with previous studies which showed that the environmental advantage related to the CO_2 reduction increases when the distance travelled rises, additionally providing the possibility to lower the emissions of NOx, CO, VOCs and PM2.5, compared to the ICEV (Kawamoto *et al.*, 2019; Pipitone *et al.*, 2021).

In accordance to our results, Joshi *et al.* (2022) argue that production of BEVs, due to the necessity of having a battery, generates considerably higher amounts of CO_2. The authors also conclude that the CO_2 emissions over the life of an BEV can be significantly lower than an ICEV if renewable energy sources are used. Indeed, if the emission cost of the energy mix is equal to 0, it will make the usage of BEV more environmentally friendly, since, for any distance travelled by the vehicle, the environmental cost of the vehicle will remain constant and equal to the BPE, or 3 440 000 g of CO_2-eq for every 160 000 km, while the same value for an ICEV will continue to increase, with 165 g of CO_2-eq per km (Figure 3). Similarly, Puricelli *et al.* (2022) prove that an BEV generates 41% less life cycle emissions compared to the corresponding ICEV, which is almost the same number as our result – 40.44%. Still, this difference can be increased if renewable energy sources are used for charging. Haase *et al.* (2022) studied the adoption of BEV or ICEV in Germany, and they found that the BEV powered by wind energy is the best option for the country in 2020 as well as in 2050. Similarly, Winkler *et al.* (2022) studied the food retailing industry in Berlin and revealed that in the circumstances of a given energy mix in Germany, an BEV reduces CO_2 emissions by 25% compared to an ICEV, while they can be reduced by 92% if the energy sources are fully renewable. The result of our simulation, in agreement with what has been found by other authors, shows that the sustainability of the adoption of EVs cannot be separated from investments in renewable energies.

Using renewable energy sources slightly changes the breakeven point, as it will shift from 37 068.97 km to 20 848.48 km (Figure 4). In Figure 4, the function of the environmental cost of an ICEV is represented by the red line and the following equation: Y=165x. The blue line

Figure 3. Comparison of environmental costs of BEV and ICEV (renewable energy sources).

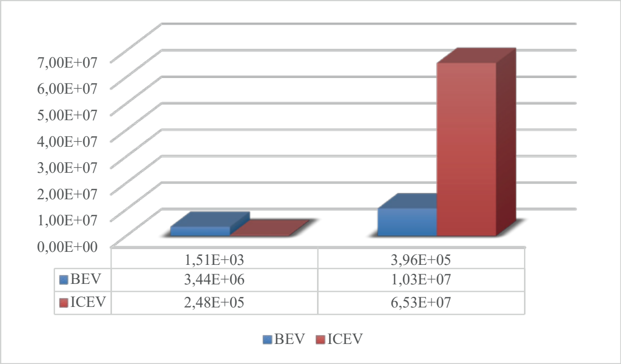
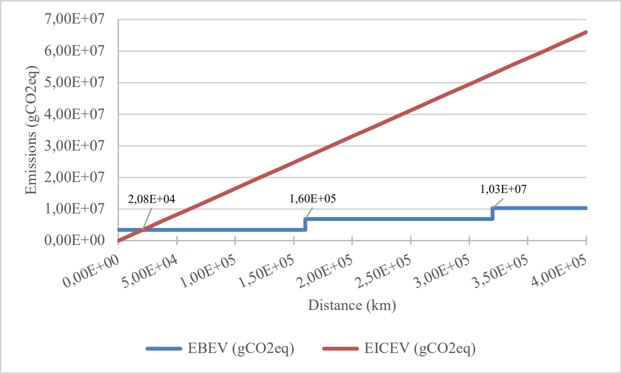


Figure 4. BEP of CO_2 emissions of BEV and ICEV (renewable).



stands for the environmental cost of an BEV and represents 3 440 000 g of CO_2-eq for every 160 000 km. In other words, the larger is the proportion of energy generated from renewable sources in the energy mix, the less distance is needed to be covered in order to make up for the significant environmental impact associated with the battery production phase (Cao *et al*., 2021; Alp *et al*., 2022). A virtuous example in this context is that of Norway which bases its energy mix on renewable sources with a considerable reduction in the environmental costs of EVs (Costa *et al*., 2021).

Table 3 summarizes the CO_2 emissions generated by the investigated BEV and ICEV for 1505 km (experiment data) and for 395759.96 km (average end-of-life milage for commercial vehicles) in the case of the actual Italian energy mix and when the energy is obtained fully from renewable sources.

Studying the environmental impact of the "last mile" delivery distribution with EV or ICEV in the case of different distances covered and different circumstances in terms of energy sources, illustrated how the output of the study, thus the environmental impact may differ if the conditions are different and the input variables of the formula given by Costa *et al.* (2021) change.

4. CONCLUSIONS

The transition towards increasingly sustainable distribution models in order to reduce the environmental pressures generated by transport is today one of the cornerstones of the 2030 Agenda for Sustainable Development, reiterated at the Sustainable Innovation Forum held during COP26. The need to reduce greenhouse gas (GHG) emissions generated by transport has led to the definition of measures and strategies focused on sustainability also in the goods distribution sector, whose contribution to the ecological footprint is increasingly significant. The solutions being adopted range from the optimization of routes to the adoption of transport management systems in all phases of the value chain, and up to the adoption of zero-emission technologies such as electric batteries. In particular, the adoption of BEV provides an occasion for companies to achieve sustainable development objectives by offering advantages that include environmental concerns, such as lowering CO_2 emissions. Our study, aimed at comparing the environmental costs, in terms of GHG emissions, of an electric commercial vehicle and a petrol-powered vehicle in the distribution of agricultural commodities in the SFSC, fits into this scenario. In particular, this study gives a thorough and comparative environmental analysis grounded in an actual real-world experiment conducted as part of the EnerNETMob project financed by the InterregMed

Table 3. Emissions by distance and energy sources.

	Vehicle	Actual energy mix		Renewable energy	
		1505 km	395759.96 km[1]	1505 km	395759.96 km[1]
CO_2	BEV	3 548 655.03 g	38 892 298.17 g	3 440 000 g	10 320 000 g
	ICEV	248 325 g	65 300 393.4 g	248 325 g	65 300 393.4 g

[1] End-of-life of the vehicle.

initiative, in contrast to earlier studies that were mostly focused on general parameters and simulations.

The study's findings, which are supported by actual evidence, show that deploying an electric commercial vehicle, Nissan e-NV200, for the transportation of agricultural commodities is not an environmentally sustainable option for short distances compared to the petrol-powered vehicle. However, as the kilometres travelled increase, the environmental costs of the EV decrease, to the disadvantage of the ICEV. This finding supports prior research which showed that the benefits of driving an BEV over an ICEV rise with the number of kilometres travelled, also contributing to reducing NOx, CO, VOCs, and PM2.5 emissions. The study highlights some relevant aspects that deserve particular attention. On the one hand, the significant weight of the emissions generated in the battery production phase, which is still too significant today, reduces the environmental convenience of using EVs. In this area, considerable effort has been made and is continuing to produce batteries with better performance, also from an environmental point of view. For example, numerous researches are trying to identify solutions for the recovery of precious battery materials to generate greater sustainability over the entire life cycle. On the other hand, there is the influence of a country's energy mix on the environmental cost. From this point of view, our study, starting from empirical data, simulated the effect of an energy mix composed of entirely renewable energy sources. The data corroborate preceding research which found that the higher the proportion of energy from renewable sources is in the energy mix, the shorter distance is needed to be covered by EVs in order to make up for the significant impact of emissions generated by their batteries' production.

The study's findings must be understood and interpreted in the light of the scenario being looked at, especially in the light of the features of the transportation methods used during the project testing phase, the nation's energy mix, features of the road infrastructure, etc.. However, the proposed methodological approach can also be replicated in other geographical contexts, making it possible to evaluate its effectiveness for environmental convenience analyses and increasing real-life research on the adoption of battery-powered vehicles compared to petrol-powered vehicles.

Several theoretical, practical and policy implications can be envisaged. The study enriches the literature in this research field by presenting a comparative environmental analysis between battery-powered and internal combustion vehicles based on a real-life test. On a managerial level, the results of the study provide insights and suggestions to various stakeholders. For farms participating in the short supply chain, the study demonstrates that the adoption of EVs can contribute to the SFSC philosophy as a highly sustainable agri-food product distribution model, albeit still hampered by high vehicle costs. For manufacturing companies, these results are useful because they trigger a reflection on the importance of identifying more sustainable solutions, improving the environmental performance of current batteries on the market. This obviously also requires investments in R&D aimed at identifying solutions for battery recycling. Finally, the results can represent a guideline for policymakers in order to concentrate their efforts on measures capable of supporting the sector and transitioning towards increasingly sustainable distribution models. In particular, as emerged from the study, it is essential to move towards an increasingly greener energy mix, increasing the share of energy from renewable sources and supporting the diffusion of charging stations powered by renewable energies and not by fossil sources in order to reduce environmental costs.

5. LIMITATIONS AND FUTURE RESEARCH DIRECTIONS

Despite considerable theoretical and practical implications of this research, the study has several limitations that indicate the need of future researches in the field. First of all, the formula used may require further clarification regarding its applicability and limitations. For instance, it does not include the error rate that would compensate for uncertainties. Furthermore, the end of life of the batteries should be taken into account when assessing the environmental impact of the use of EVs. Future research could focus on refining the formula and conducting the analyses to determine its range of applicability.

Besides, the study does not include monitoring data related to the use of diesel vehicles, which are common in Italy and Europe. To address this limitation, future research could incorporate data and analysis specifically focused on the environmental implications of diesel vehicles. This would provide a more comprehensive assessment of the entire vehicle landscape and enable a comparative analysis between diesel, ICEVs, and BEVs. Furthermore, additional experiments with different vehicles and in different regions will provide a wider picture of the feasibility of EV adoption in SFSCs.

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