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Electrifying the Last Mile Delivery by Eco-Efficiency Analysis: Case Study of Latvia

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Abstract **– The demand for e-commerce platforms has rapidly increased over the last years leading to increase demand on last mile delivery (LMD) services. Not to fall short of 2030 greenhouse gas (GHG) emission targets in the transport sector transitioning to sustainable LMD solutions is the key. Adopting electric vehicles (EVs) in delivery services can significantly reduce direct and indirect emissions, which can be of interest for many supply chain actors willing to report their sustainability practices within Scope 3 as per IPCC guidelines for the upcoming Corporate Sustainability Reporting Directive. This study undertakes the eco-efficiency analysis of a local LMD company in Latvia to understand the financial viability and the external environmental cost related to fleet electrification. As a result, the eco-efficiency analysis confirms the financial and environmental advantages of EVs. The study acknowledges limitations in the current eco-efficiency framework related to the GHG emissions monetisation and recommends leveraging the voluntary carbon credit markets for a more market-based assessment of carbon pricing. The findings support the transition towards sustainable LMD options, aligning with broader sustainability goals.**

Keywords **– Eco-efficiency; electric vehicle; environmental cost; last mile delivery.**

1. INTRODUCTION

There is rising demand for platforms e-commerce platforms, which require product delivery to consumer after a product is bought online. COVID has added an even a higher rise in demand for such platform, also increasing pressure on LMD services, known to be as most expensive, least sustainable, and inefficient delivery with longer delivery times [1]–[3]. Consequently, this tendency has also increased LMD services environmental impacts, due to the use of diesel trucks to deliver products from warehouses to end customers. It is expected that the LMD transportation market size will double its value by 2030, up to 297 billion USD [4], therefore it is important to stimulate the integration of more environmentally sustainable technologies in LMD services.

According to a study of [5], the city of Riga, the capital of Latvia is already missing the GHG emission target for 2030, and showing the highest contribution share to the GHG emissions for transportation. The study concluded that the modern transportation pathway with sustainable LMD solutions is a very promising scenario for achieving the GHG emission reduction. According to [6], the EU regulations on emissions related to the transport sector in EU will be met by the introduction of EVs.

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Under the upcoming Corporate Sustainability Reporting Directive (CSRD) set by the European Union and sustainability reporting standards, companies will be required to provide a more comprehensive report on their sustainability practices, including reporting of their greenhouse gas emissions (GHG) within Scope 1, Scope 2 and Scope 3 defined according to IPCC guidelines [7], and the actions they are taking to mitigate these effects. By shifting from internal combustion engine (ICE) vehicles to EVs, companies can significantly reduce their direct emissions (Scope 1), and, depending on their energy sources, potentially their indirect emissions from purchased electricity (Scope 2) [8]. In Context of Scope 3 emissions, EVs application in the transport sector, managing Scope 3 emissions is particularly important because EVs significantly reduce emissions during the transportation phase in all supply chains compared to internal combustion vehicles. Considering emphasizing of the need in CSRD for robust cost management strategies, traditional Life Cycle Costing (LCC) [9] in this context provides a comprehensive assessment of the total costs associated with the lifecycle of a product or service. In the context of LMD, the LCC can help companies evaluate the economic efficiency of different transport option when planning GHG emissions reduction by the use of EVs.

Looking at the introduction of EVs from the demand side point, the research evidence shows that presenting consumers with environmentally sustainable delivery options would of their interest [10]. The study of [1] revealed that customers who give importance and are willing to pay for environmentally friendly delivery prioritize sustainable delivery vehicles, meaning companies should be offering alternatives of delivery transport for customers who prioritize environmental impact. Other studies related to willingness to pay for emission offset in the transport sector also showed that part of society is willing to pay a relatively small price [11]. Study of [12] suggests that the social aspect is important in "shaping pro-environmental behaviour" and additional information on sustainability can motivate moral obligations and increase the willingness to pay for more sustainable solutions.

According to the study, customers in EU are going to accept new technologies such as electrical vehicles, choosing the most economical vehicle that meets their expectations, but the current supply of commercial EVs is limited and therefore vehicles have high purchase prices and low economic efficiency of the investment. The study found that there is currently a lack of research on societal impacts on the link between energy emissions from road transport and suggested that analysing emission offset societal impacts will create more awareness on the contribution of road transport to environmental pollution and climate change, thus potentially increasing willingness to pay for more sustainable LMD options.

The societal benefits accounted for the deployment of EVs can have a broad interpretation. The study of [13] used direct impacts as monetary payoff as a function of EVs discharge when switching load from the grid to EVs, and indirect impact on the environment to determine social benefits. Study on EVs deployments in the Philippines [14] used a life cycle-based approach for the definition of societal benefits such as Tax Generation, Value of Jobs, Balance of Payments, Energy Security Cost, Health Cost, and GHG mitigation cost. Also in other cases, such information related to external benefits in these cases includes the aspects related to the GHG emissions [13], [15]. A comparison of the cost of ownership and environmental cost of three types of transport in the case of Paris City according to the methodological guidelines of French Handbook on the external costs of transport allowed the study to highlight that more than half of the cost related to the use of conventional ICE delivery vehicles is associated with environmental cost in form of GHG emissions [16].

The importance of adopting policies that include the social cost of carbon is becoming more evident among different research topics (resource production, energy [17], waste management [18]. Such an approach towards evaluation of environmental life cycle cost (E-

LCC) estimation allows to present in research the external cost of different alternative systems created to the environment, allowing properly evaluate the benefits of policies that affect air emission reduction and stimulating decision-making towards more sustainable technologies [19]. According to the study [20], implementing such an approach that accounts environmental externalities related to the cost of GHG emissions could lead to efficiency gains and manageable costs for transitioning to cleaner energy.

Estimates of the E-LCC can be used by policy makers to evaluate climate change policies and GHG reduction projects by means of cost–benefit analyses (CBAs), but can have a wide range of definitions [21]–[23], including eco-efficiency analysis. Analysis including eco-efficiency are complicated by the wide range of values, and the large uncertainties involved in estimating the potential economic impacts and related costs of climate change depending on assumptions about temperature rise and damage and ranging 11–90 USD or even more per one tonne of CO_2eq, and still is underestimated as losses of biodiversity because of climate change are difficult to estimate and express in monetary values [24].

The study on the costs and benefits of establishing a low emission zone in Lyon's urban area, focusing on the external costs related to transport emissions used pollutant emissions converted into monetary values using the latest European guidelines on external costs of transport [25] and found the methodology to be flexible to deal with certain limitations for simulations of changes and reorganization in the structure of vehicle fleets [26].

The applications of eco-efficiency analysis have shown useful insights for creating strategies towards emission reduction, while calculating the monetary benefits and at the same time enhancing stakeholder trust and attracting environmentally conscious investors, customers, and partners. Therefore, the aim of this study is the application of conventional eco-efficiency analysis for fleet electrification in LMD in Latvia. This approach ensures that LMD businesses can make informed, cost-effective decisions that align with sustainability objectives, enhance operational transparency, and even eventually create a basis towards accounting of the credit for additional benefits created to the market participants and community due to reduction of emissions.

2. METHODOLOGY

This chapter outlines the methodology employed to explore the costs and benefits of fleet electrification in LMD company in Latvia based on conventional LCC and E-LCC. The utilization of these methodologies provides crucial insights for the company in terms of monetary benefits, and at the same time gives information to stakeholders, investors and customers on environmental benefits in comparison to conventional ICE vehicles, increasing their trust in business sustainability, environmentally conscious investments and willingness to pay for the more sustainable LMD options.

2.1. Case Study of LMD Company Fleet Electrification in Latvia

The company selected for the case study is DPD Latvia, which specializes in LMD services. The "last mile" in the logistics industry means the last stage of a product's delivery - the journey from the warehouse shelf and the back of the truck to the customer's door. The company DPD Latvia employs more than 200 employees and in 4 years (2016–2020) its turnover has almost doubled. The company also has a positive net profit/loss calculation (see Table 1).

TABLE 1. PERFORMANCE INDICATORS OF DPD LATVIA [27]

Year	2020	2019	2018	2017	2016
Number of employees	215	211	189	163	130
Turnover, EUR	23 376 517	19 864 312	18 540 566	15 606 271	12 702 528
Net profit or loss, EUR	1 659 977	1 060 359	1 552 834	1 341 047	984 704
Total payments in the general state budget, EUR	2 653 450	2 506 960	2 523 270	2 124 970	1 476 230
Personal income tax, EUR	656 240	594 200	494 320	422 090	325 790
State social insurance contributions, EUR	1 326 230	1 218 040	1 004 170	772 430	594 930

The company specializes in the delivery of shipments and parcels in Latvia and within the city limits and has a widespread number of Pickup points or parcels. Packages were being ordered or picked up in Riga at 74 locations and 12 more locations in the sub-urban region around Riga city.

The daily life of one unit of transport consists of the following activities:

– Route length about 100 km;
– Quantity of packages approx. 90 pieces;
– After the end of the working day, the vehicle is parked on the company's territory for the night;
– Car transport is loaded with packages at night;
– In the morning, the courier starts the fully prepared vehicles;

The DPD unites more than 200 parcel locker points in Latvia. Parcels are sorted in 12 sorting terminals throughout Latvia.

2.2. Electrification Scenario

The company's choice of delivery EV is the e-Crafter van of the famous German car manufacturer Volkswagen (VW) as the only electric model. According to available real-world data for the VW Crafter, the diesel version consumes about 19 % more fuel in the city (~10 L versus 8.4 L per 100 km) than when driving smoothly on the highway [28]. The performance indicators of EV and ICE used in the study are shown in Table 2.

TABLE 2. PERFORMANCE INDICATORS OF ELECTRICAL AND ICE VAN [29], [30]

Parameter	Value	Value
Driving distance, km	173	720
Battery capacity, kWh / Fuel Tank size, L	35.8	75
Charging time (AC/CCS up to 80 %), hours/NA	5.20/0.45	–
Electricity consumption (NEDC), combined, kWh/100 km Fuel Consumption, combined, L/100 km	21.5 kWh/100 km	10 L/100 km
CO_2 emissions, kg/km	0 g/km	203 g/km

The electric version of the VW Crafter, like any electric car, has the best performance in the city cycle. Recuperation is constantly used to charge the battery and at speeds of up to 90 km/h, the lithium-ion battery gives maximum efficiency. According to available data, the VW e-Golf, from which the entire electrical circuit and the same battery of the VW e-Crafter are taken and used, consumes 39 % less electricity in the city than on the highway – 11.4 kWh against 18.8 kWh per 100 km [31]. Thus, the difference in monetary equivalent per 100 km between diesel and electric cars is usually three times in favour of the latter. This means that the greater the daily mileage, the greater the possibility of compensating the price of electric transport with the difference in fuel costs when driving an electric car. The electrification scenario for DPD Latvia foresees 5 years of leasing to cover the new fleet cost.

The purchase of charging equipment and infrastructure construction costs are not considered. The authors believe that the remaining capacity of the batteries of the vehicles selected by the DPD company when driving in after the end of the working day around 18:00, will not be lower than 10 % of 35.8 kWh or 3.58 kWh. This means that considering the start time of the working day around 8:00 AM and the time period available for charging ~14 hours, the company can charge its transport units daily from a normal outlet (1 f, 10 A, 2.3 kW = 14 × 2.3 = 32.2 kWh or 90 % of the battery capacity of the VW e-Crafter).

2.3. Financial Analysis

The Total cost of ownership (TCO) calculation method is necessary for the company to make the right decision on the choice of the type of transport. The data for estimation of TCO is presented in Table 3.

TABLE 3. COMPARISON OF TCO FOR EV AND ICE VEHICLE

Cost Type Over 5 Years	EV	ICE vehicle
Initial Payment	0 %	0 %
Leasing Interest and Capital Costs	38 700.90 €	21 966.70 €
Registration Fee	844.49 €	493.44 €
Additional Registration Fee	123.97 €	123.97 €
Energy Consumption Costs for 156 000 km in Combined Cycle	5990.40 €	23 509.20 €
Insurance	1908.57 €	1085.70 €
Maintenance	760.00 €	1160.00 €
Operation Tax	0 €	660.00 €
Registration at CSDD and License Plates	0 €	36.30 €
Parking Lot Usage	0 €	0 €
Subsidies	0 €	0 €
Total, EUR excl. VAT	48 328.33	49 035.31

During the 5 years of leasing, the company will fulfil the condition of not exceeding the mileage limit of 160 t, km. Considering the average daily mileage of one DPD Latvia transport unit in the range of 90–100 km, the annual mileage ranges from 23.5 t, km to 36.5 t, km. The data for the financial calculation is taken for the 2nd–3rd quarter of 2022. The price of 1 kWh, according to the calculator of the Energy24 portal, the offer of the Enefit company for unlimited consumption on in this period amounted to EUR 0.1786 on average [32].

This includes calculating the Net Present Value (NPV) and the Internal Rate of Return (IRR) for the EVs scenario. These additional calculations provide a more nuanced financial perspective by considering the time value of money and the profitability of investing in EVs. Bank rates for commercial vehicle leasing are considered to be 1.45 % with a 6-month Euribor for EVs and 2.29 % with 6-month Euribor for ICE cars. As for inflation, it is forecasted in Latvia 2–3 % in the future with an arithmetic average of 2.364 %. The financial data of the DPD Latvia company for the last 5 years, the average net profit was 7.14 %.

Together with TCO, NPV and IRR calculations form a comprehensive financial analysis that provides the company with essential insights into the long-term economic viability of transitioning to an electric fleet, particularly under the conditions specified for the leasing agreement and operational parameters of DPD Latvia.

2.4. Environmental Cost-Benefit Analysis

External costs of EV and ICE vehicle are costs not included in the market price of the goods and services produced and can be associated with environmental damage created due to the market activities. Including all external costs of the transport sector is difficult as the ways how transportation affects different aspects of life is not so straightforward. The external costs of the transport sector can be divided in several ways, for example, into related and unrelated sectors [33], or categorized separately [34]. These include costs from accidents, air pollution, climate change, noise, congestion, energy production and supply, loss of habitats, and other costs. One of the most extensively discussed external costs is the impact on air quality, focusing only on direct emissions [35]. This work divides transport external costs into categories used in the European Handbook on External Transport Costs [36].

Three types of external environmental costs are considered for environmental cost-benefit analysis are related to vehicle emissions. These aspects are evaluated from the side of GHG (CO_2, CH_4, N_2O) and air pollutants (PM2.5, PM10, NO_x, SO_2, NMVOC) which are also used in this study for estimates of:

- Air pollution costs;
- The costs of climate change;
- Emissions costs of energy production and supply.

Air pollution can lead to various costs, but one of the most studied aspects of the costs of air pollution is the impact on human health. Apart from the health effects, the costs of air pollution include the degradation of buildings and materials, reduced yields, and reduced natural diversity. Although there are few studies that directly reflect the external costs of transport air pollution [37], there is a growing body of research demonstrating the negative health effects of air pollution [38].

Internal combustion transport emits CO_2, N_2O, and CH_4, which are all GHG emissions. Despite the conclusion of several international agreements, such as the Paris Agreement, existing policy goals and plans will not prevent global warming, which is projected to increase by more than 2 °C this century [39]. Global warming is one of the climate changes that will lead to radical changes in human health, ecosystems, agriculture and societies. The costs of climate change are associated with sea level rise, loss of natural diversity, water system management problems, weather extremes, crop losses.

The previous sections covered the direct effects of vehicle use. Energy production and delivery known as well-to-tank (WTT) emissions also are related to external environmental costs and must be the analysis. WTT includes: the extraction of an energy source, energy source processing, energy source transportation and transmission, construction of power plants and other infrastructure.

Equations (1), (2) and (3) were used to calculate the external costs of emissions from air pollution, climate change and energy production and supply according to the values suggested by [36] for specific vehicles and country.

$$Pkm_{\text{engine size}} = \frac{\sum \frac{\sum Pkm_{\text{road type}}}{n_{\text{road type}}}}{n_{\text{environment}}}\ , \tag{1}$$

where

Pkm	amount of indirect costs per kilometre travelled by each passenger, EUR;
road type	asphalted roads with a permitted speed above 50 km/h, asphalted or paved roads with a permitted speed of up to and including 50 km/h, other roads, engine size;

$n_{\text{road type}}$ number of road types;
$n_{\text{environment}}$ the number of centres in which vehicles move (intercity, suburban, city).

$$Pkm_{\text{energy}} = Pr_{\text{energy}} \cdot \sum \left(Pkm_{\text{engine size}} \cdot Pr_{\text{engine size}} \right) , \tag{2}$$

where
Pr proportion, % in the fleet;
energy energy type (petrol, diesel, electricity).

$$EC_{\text{total}} = \frac{\dfrac{\sum Pkm_{\text{energy}}}{\Delta GDP} \cdot N_{\text{km}}}{N_{\text{passenger}}} \cdot N_{\text{Tr}} , \tag{3}$$

where
EC_{total} vehicle external costs per year;
ΔGDP state GDP ratio to average ratio in ES-28;
N_{km} travelled distance per year;
$N_{\text{passenger}}$ number of passengers in vehicle;
N_{Tr} number of vehicles in the fleet.

The final values obtained for external costs of EV and ICE vehicle fleets in DPD Latvia are compared within eco-efficiency perspective, adopting the Eco-Care Matrix [40], shown in Fig. 1, which has been applied also in other technology context and can promote willingness to pay for more sustainable technologies [41], [42].

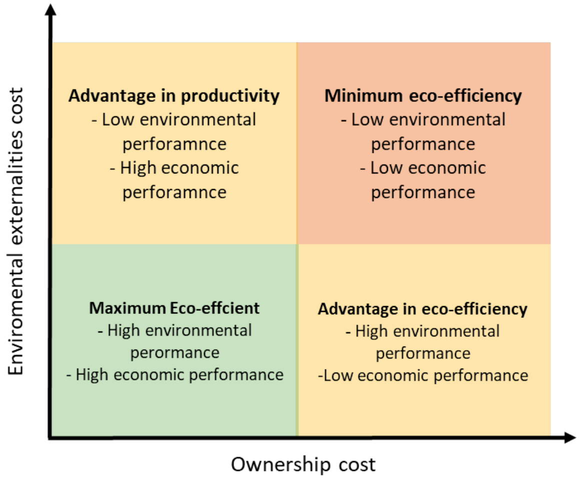

Fig. 1. Adopted Eco-Care Matrix for comparison of DPD Latvia fleet scenario.

By comparing the final values obtained for the external costs of both EV and ICE vehicle fleets in DPD transport Latvia, the matrix helps to visualize where each option stands in terms of environmental impact and cost-effectiveness.

3. Results and Discussion

The estimation of NPV and IRR indicators with a comparison rate of 10.6 % in the case of EVs, shows that the company DPD transports brings a sufficiently good financial return and is economically feasible. The NPV of the EV solution is EUR 89 271.92 and the IRR is 48.05 %.

In the process of electrification, the company will reduce its expenses by 1.45 %, which increases the net annual profit by 0.13 %. By switching to an environmentally friendly car, the company will not incur losses, the capital investment will pay off already from the 2nd year, as shown in Fig. 2. The growth intensity of the cash flow curve changes due to lowering insurance costs and according to maintenance activities schedule.

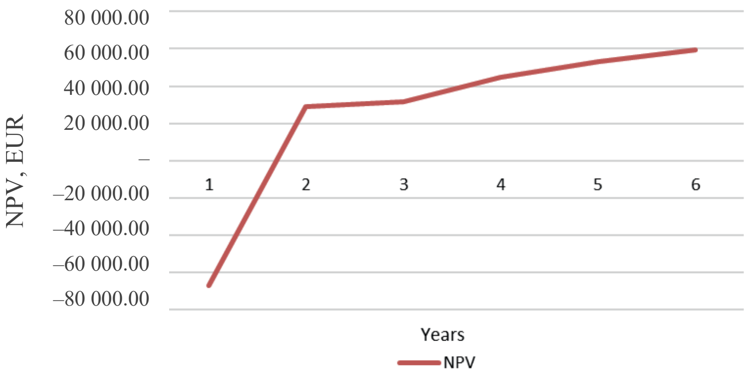

Fig. 2. Cash flow of DPD Latvia EV scenario.

Building upon the comprehensive financial analysis perspective from financial metrics to environmental considerations allows ensuring a more holistic assessment of the fleet's eco-efficiency. Figure 3 shows the results of environmental externalities cost for ICE vehicle and EV scenario in DPD Latvia, considering Air pollution and climate change impacts from the operation of vehicles, and WTT emissions created within the upstream supply chain.

The ICE vehicle shows significant costs in all three categories, with total environmental cost above EUR 140 000 and the costs of climate change impact being the highest. On the other hand, the EV bar only shows cost equal to approx. EUR 100 000 and only one category of cost stands out, the 'Well-to-tank' emissions, which are related to the upstream supply chain in electricity generation for EVs. There are no costs attributed to climate change impact or air pollution from the operation of the vehicle for the EV, indicating that these are either negligible in comparison to ICE vehicles.

By considering the financial analysis alongside the environmental externalities cost within the Eco-Care Matrix in Fig. 4, the viability of EV adoption is considered not just in terms of cost and profit, but also by the capacity to a more sustainable business model. The EV scenario in Fig. 4 is in the "Maximum Eco-efficiency" quadrant, indicating that it has lower costs in both financial terms and environmental externalities, thus is considered more eco-efficient. The ICE vehicle scenario is placed in the "Minimum eco-efficiency" quadrant, denoting that it has higher financial and environmental costs, hence lower eco-efficiency compared to the EV.

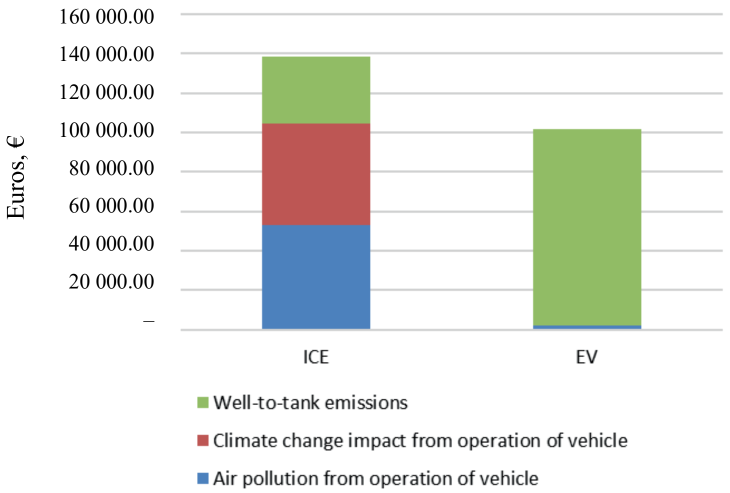

Fig. 3. Environmental externalities cost for ICE vehicle and EV scenario in DPD Latvia.

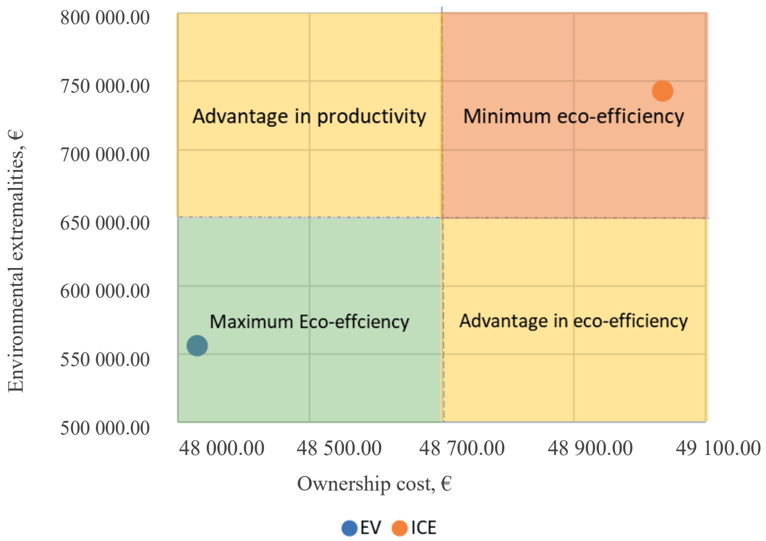

Fig. 4. Eco-efficiency analysis of EV and ICE vehicle scenario in DPD Latvia.

This type of Eco-efficiency analysis can be an effective communication tool advocating the fleet electrification scenarios for stakeholders, including investors and customers. By clearly demonstrating that EVs offer lower external costs compared to ICE vehicles, the matrix can help to shift customer preferences towards more environmentally friendly technologies.

The findings highlighted the relative advantages of EVs in terms of environmental and ownership costs. However, there are limitations concerning the eco-efficiency analysis, which are connected to the difficulty of setting boundaries for external cost accounting. Moreover, the extension of the method to encompass not just environmental but also social costs is yet much covered in the literature.

The presented model for accounting external environmental cost does not account for the extreme risks associated with climate change. This climate catastrophe can fundamentally alter the external cost, but is not covered within the frame of the methodology suggested by [36]. The existing methodology applies an approximation of external environmental cost in the form of the average cost of climate change mitigating actions. The some of the current literature suggests that existing values of carbon pricing are unrealistic, biased and can lead to significant errors in assessing the benefits of reducing emissions [24], [43], however, the voluntary carbon credit markets where carbon credits are sold in between companies similarly like stocks in the stock market, are active and growing rapidly [44]. Though the price is based on negotiations depending on the project the number of credits issues is increasing, showing that the cost assigned to climate impact-related gases is already applied in the markets [45].

In light of these considerations, the future analysis related to eco-efficiency should consider potential external monetary benefits in a frame of existing voluntary carbon credit markets that can offer a more robust and accepted basis of carbon pricing determined by market values. This would facilitate better-informed decision-making of the company and its customers for assessing the external environmental impacts cost of transitioning to sustainable technologies.

4. Conclusions

The findings reveal that integrating EVs into LMD operations presents a viable pathway toward both cost-effective and environmentally preferable alternative to ICE vehicles. Financial analyses, including NPV and Internal Rate of Return IRR calculations, have shown a clear investment feasibility of EVs over a five-year lease period. The environmental cost-benefit analysis has highlighted the significant reductions in GHG emissions and air pollution by adoption of EVs, emphasizing the customer and supply chain actor benefits of transitioning from ICE vehicles, leading to win-win scenario.

To address the limitations identified, the paper recommends that future research should be aimed at expanding the eco-efficiency framework to integrate the social costs associated with climate risks. Additionally, engaging in the framework the voluntary carbon credit market may offer a more nuanced and realistic valuation of carbon for fleet electrification projects.

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