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COST-BENEFIT ANALYSIS OF TRANSITION TO ELECTRIC VEHICLES IN A LOGISTICS COMPANY

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Abstract: *This research investigates the economic feasibility of transitioning a logistics company's fleet to electric vehicles (EVs). The study evaluates the economic viability of this transition by comparing the total cost of ownership (TCO) of EVs to that of traditional internal combustion engine (ICE) vehicles. Key factors considered in the analysis include vehicle purchase costs, operational expenses, energy consumption and costs, maintenance expenses, and government incentives. The study aims to quantify the potential financial benefits and drawbacks associated with EV adoption and to assess the overall economic viability of such a transition. The findings of this CBA provide valuable insights for logistics companies seeking to make informed decisions about their fleet electrification strategies*.

1. INTRODUCTION

The transition to electric vehicles (EVs) is one of the most important transformations in the transportation sector globally. In recent years, this trend has extended beyond the passenger car segment, including the road freight transport sector. This process is being accelerated by a number of factors, including environmental concerns, diminishing fossil fuel reserves and their price volatility, evolving technologies, and governmental and international policies.

Vehicles with internal combustion engines are a major source of air pollutants affecting public health, especially in urban areas. Since emissions from road transport are a major cause of air pollution and climate change, along with industry and energy, replacing vehicles with internal combustion engines with vehicles powered by electricity can significantly contribute to reducing these emissions. At the present time the electrification of road transport is considered a key solution for reducing these emissions and achieving international climate goals.

The transition to electric vehicles reduces dependence on fossil fuels, contributing to price stability and energy security. Fluctuations in oil and natural gas prices make the operating costs of internal combustion engine (ICE) vehicles less predictable.

Electric motors provide more torque at low revolutions, which can improve vehicle performance, especially when starting and climbing.

Lower electricity costs compared to fossil fuels and lower maintenance costs can lead to significant savings in the long run.

Recent technological advances which have led to battery improvements, increased autonomy and the development of charging infrastructure make EVs increasingly attractive to users.

Many countries and regions around the globe have implemented policies, regulations and financial incentives to promote the adoption of EVs, such as subsidies, tax and duty reductions, including in the freight sector.

By electrifying their fleets, organizations not only demonstrate environmental leadership and dedication to sustainability, but also encourage wider adoption of EVs by other fleets and consumers, thus fostering significant societal change.

A significant barrier to widespread fleet electrification is the absence of sufficient electric vehicle options in the pick-up truck, medium-duty, and heavy-duty classes, thereby constraining fleet managers' ability to fulfill operational needs.

Concerns about the operational range and a lack of familiarity with the new technology are causing initial employee resistance to the electrification of the fleets. To address this initial employee resistance, awareness and education programs are required. For both fleet managers and employees, increasing their understanding of EV benefits can be achieved by emphasizing cost savings and environmental advantages via advertisements and workshops.

Electrifying vehicles is challenging due to charging times and range limitations. Furthermore, public disapproval of EVs as potentially wasteful government expenditures can deter their integration into fleets.

2. COST-BENEFIT ANALYSIS MODELS APPLICABLE IN THE TRANSPORT SECTOR

Cost-benefit analysis (CBA) is an essential tool in the decision-making process, especially when significant investments are involved. This allows for systematic assessment of all aspects of a project, from a financial, social and environmental point of view, with the aim of determining whether the anticipated benefits outweigh the associated costs (*fig. 1*). CBA helps to clearly define a project's objectives and determine whether they are economically feasible. A sound cost-benefit analysis provides an objective justification for investment decisions, both for those involved in the decision-making process and for external stakeholders.

CBA helps to identify projects that offer the best cost-benefit ratio, thus ensuring an optimal use of financial resources. This allows the comparison of different project alternatives, thus facilitating the choice of the best option. Through the detailed assessment of all relevant factors, CBA enables the identification of potential risks and mitigation measures, thus reducing the chances of project failure. Through its transparency, CBA contributes to a better understanding of the impact of projects on the environment, society and economy.

Cost-benefit analysis has multiple uses in the transport sector, from evaluating infrastructure projects, analyzing the operating costs of different modes of transport, comparing different propulsion technologies to assessing the impact of transport policies.

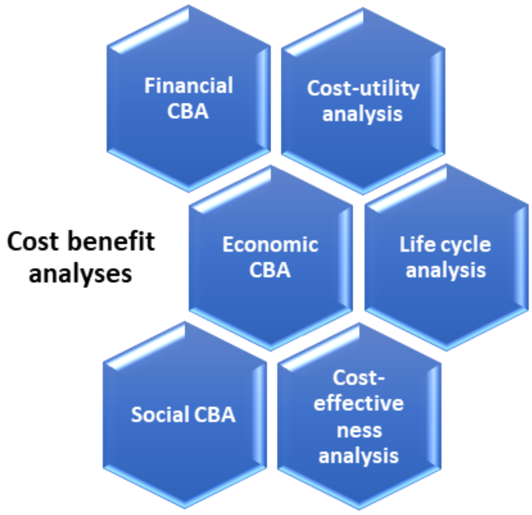

Figure 1. Types of analyses for the transportation sector

In their paper de Rus et al. [1] discussed the theoretical framework and practical rules for conducting CBA of transportation projects, focusing on economic evaluation methods and their implications for social welfare.

Eremina and Sohn [2] realized a CBA evaluating four major alternative routes based on selected cost and benefit factors. The cost considered factors are transportation time, gauge difference, custom procedures and cross-border factors, costs being expressed in terms of days and hours and benefits in monetary units. They take into consideration as benefit factors the volume of cargo, industrial production of adjacent regions, access to natural resources, market size and investment climate. A transformation coefficient is used to translate physical time into monetary value, based on empirical findings that a 10% increase in transportation time reduces bilateral trade volume by 5%.

Noel and McCormark [3] present a cost-benefit analysis comparing V2G-capable electric school buses to traditional diesel school buses, highlighting economic and environmental advantages. Although battery costs are often considered a barrier, sensitivity analysis shows that varying battery replacement costs have a relatively minor effect on the overall cost-benefit analysis. The analysis shows that the electric bus becomes cost-effective primarily due to the V2G revenues.

On the other hand, in their comparative cost-benefit analysis, Shirazi et al. [4] of alternatively fueled buses, compressed natural gas (CNG) and vehicle-to-grid (V2G) electric buses, concluded that diesel buses are the most cost-effective option, while CNG and eBuses have potential under specific conditions, such as infrastructure availability or future cost reductions. They considered the economic viability of eBuses to be affected by high upfront costs, infrastructure requirements, battery-related challenges, temperature impacts, V2G revenue limitations, and regulatory hurdles.

Park et al. [5] present a cost-benefit analysis of public service electric vehicles (EVs) with V2G capability, focusing on their operational savings and environmental impacts in sectors like school buses, waste collection trucks, and city buses. The analysis highlights that EVs are more cost-effective due to lower operational costs, environmental benefits, and additional revenue from V2G services.

Pagliara et al. [6] propose a methodology to estimate the benefits and costs of stakeholder engagement (SE) in the transport decision-making process, including CBA for efficient resource allocation and Multi-Criterion Analysis (MCA) to evaluate the social utility of public projects. The methodology involves a detailed breakdown of all potential costs associated with SE activities, both direct and indirect. They highlight the significant positive impact of SE on the project's success and the importance of incorporating SE into the decision-making process for transport projects.

CBA can be used both before (ex-ante) and after (ex-post) the implementation of a project to assess its feasibility and effectiveness. Ex ante analysis helps in planning and decision-making, while ex post analysis evaluates the actual outcomes and lessons learned.

Kelly et al. [7] studied the ex-ante and ex-post cost-benefit analyses of ten EU-funded transport projects across eight countries, revealing the deficiencies in ex-ante methodologies, while also highlighting the benefits and challenges of ex-post cost-benefit analysis.

Filippi et al. [8] in their ex-ante assessment focuses on estimating the environmental, social, and economic impacts, such as pollutant emissions, traffic congestion, and costs, to ensure that the measures will effectively reduce negative externalities and improve urban mobility sustainability.

In a study focused on the accuracy of ex-ante benefit-cost analyses (BCAs) in transportation realized by Odecka and Kjerkreitc [9], they concluded that ex-ante BCAs tend to underestimate benefits and overestimate costs and ex-post evaluations are essential for assessing whether projects deliver promised benefits and for identifying areas to improve ex-ante BCAs. They enhance the credibility of BCAs as a decision-making tool and ensure informed investment decisions.

Hajinasab et al. [10] studies various types of policy instruments aimed at changing the behavior of travelers categorized into three main types: economic, administrative, and informative.

In their paper de Bok et al. [11] analyze the potential transport impacts of a proposed distance-based heavy goods vehicle charge, using strategic transport models to assess various implementation scenarios and their effects on freight transport demand and logistics.

Financial cost-benefit analysis evaluates the profitability of a project from the perspective of a private economic agent, considering only direct financial costs and benefits. Initial investments, operation and maintenance costs, generated income, and residual value of assets are considered.

Economic cost-benefit analysis assesses the impact of a project on the entire economy, including both direct and indirect and external costs and benefits, considering effects on production, consumption, employment, tax revenues, as well as positive externalities (reduction of pollution, improvement road safety) and negative (noise, congestion). It is a method suitable for major infrastructure projects, such as building highways or high-speed railways.

Cost-effectiveness analysis compares different alternatives to achieve a predetermined objective, identifying the most cost-effective option, based on the costs associated with each alternative and the level of achievement of the objective. It focuses on minimizing transportation costs to achieve a certain level of benefit and is useful when the budget is limited. This is a model that can be used for projects with well-defined objectives, such as reducing congestion or improving road safety.

Whitmore et al. [12] treated the integration of shared autonomous vehicles into public transportation systems to enhance transit equity and cost-efficiency, particularly for transit-dependent populations.

Social cost-benefit analysis involves evaluating the impact of a project on social welfare, being suitable for projects with a significant impact on the quality of life, such as the development of public transport.

Cost-utility analysis evaluates costs against benefits measured in units of utility (e.g., life years gained, travel time reduced). It is frequently used in infrastructure projects that affect public health or quality of life.

Target costing analysis is a strategic cost management approach used to ensure that services meet customer expectations while maintaining profitability. It involves setting a target cost, which is the maximum allowable cost for a service, and then designing the service to meet this cost while delivering desired functionalities and customer value.

But CBA needs to evaluate the welfare impacts of a transport project by considering both the positive and negative effects on society. This includes environmental impacts, social inclusion, and economic development.

Life-cycle assessment (LCA), which assesses the environmental impact of a product or service throughout its life cycle, from raw material extraction to waste disposal, is based on data such as energy consumption, greenhouse gas emissions greenhouse, waste production, water use. Based on this, the carbon footprint, respectively the ecological footprint, can be highlighted. The model finds its applicability in the case of the evaluation of vehicle procurement projects or the development of intelligent transport systems.

Manzo and Bang Selling [13] demonstrated the importance of the integration of LCA into traditional transport cost-benefit analysis (CBA) to better evaluate the environmental impacts of transport infrastructure projects, to better assess long-term sustainability and provide more comprehensive information for decision-making

In the LCA realized by Rial and Pérez [14], climate change impacts are central to evaluating the environmental performance of heavy-duty propulsion technologies, as reducing greenhouse gas emissions is a key goal for sustainable transportation. The study highlights the importance of addressing emissions not only during the use phase but also in fuel production and vehicle manufacturing.

CBA has diverse applications within the transport sector, ranging from evaluating infrastructure projects and operating costs to comparing technologies and assessing the impact of transport policies. Different cost-benefit analysis methods are tailored to specific perspectives and objectives.

The accuracy and effectiveness of CBA can vary depending on the stage of analysis. Ex-ante analyses are prone to underestimating benefits and overestimating costs, highlighting the importance of ex-post evaluations for learning and improving future analyses.

The transport sector presents unique challenges and opportunities for CBA. Factors such as network effects, externalities (like pollution and congestion), and the long-term nature of infrastructure investments require careful consideration in CBA. For this reason, integrating other analytical tools with CBA enhances its comprehensiveness, like LCA to provide a more thorough evaluation of environmental impacts, leading to more sustainable decision-making. Multi-Criterion Analysis (MCA) can complement CBA by evaluating also the social utility of projects.

The selection of the most appropriate evaluation method is project-specific and depends on the goals of the analysis. A thorough and well-executed analysis is essential for making optimal investment decisions in the transport sector, contributing to sustainable and efficient development.

3. LIMITATIONS OF COST-BENEFIT ANALYSIS

Cost-benefit analysis has several important limitations. First of all, assessing benefits such as improved quality of life can be difficult and subjective. The future is unpredictable and estimates of costs and benefits may be affected by external factors that are difficult to anticipate or estimate. Many times, CBA models involve simplifications of reality.

Park et al. [5] highlight as limitations of CBA the sensitivity to assumptions such as diesel costs, electricity prices, battery lifespan, and maintenance costs. environmental cost estimation, uncertainty in V2G revenue, dependent on time-varying frequency regulation prices and the ability to optimize charging and discharging schedules, the upfront cost of EVs, battery replacement costs, the limited scope, external factors and simplified models, which may not capture real-world complexities.

Even though their paper only refers to the evaluation of transport infrastructure projects, Jones et al. [15] capture very precisely the weaknesses of the Cost-Benefit Analysis, which can be extended to other transport investments. They highlight inaccuracy in traffic forecasts, cost estimation errors, environmental impact assessment, regional and local impact, and sensitivity to assumptions. Underlining the significant impact of discount rates on CBA, affecting the Net Present Value (NPV) of a project, they highlight that higher discount rates reduce the present value of long-term benefits, favoring projects with immediate returns over those with long-term impacts and this can lead to the neglect of projects with substantial future benefits, such as environmental sustainability initiatives.

Multi-criteria analysis evaluates projects, as the name suggests, based on several criteria, both quantitative and qualitative, namely economic, social, environmental, political criteria, which can be difficult to quantify in monetary terms.

Annema et al. [16] discuss the perspectives of Dutch transport politicians on the use of CBA and multi-criteria decision-making (MCDM) as appraisal tools in transport policymaking. While CBA provides a clear efficiency criterion through monetary valuation, MCDM offers flexibility in incorporating qualitative criteria and stakeholder opinions. Both methods have their strengths and limitations, and a combination or new approach focusing on clear trade-offs and transparency might better support transport policy decision-making.

Used for evaluating projects under conflicting criteria, MCA is particularly useful when non-monetary factors need to be considered alongside economic impacts [1].

Fekpe et al. [17] describes the development of a multi-criteria systems-based benefits assessment framework for evaluating transport research projects, based on systems theory, which views benefits assessment as an open system composed of interacting and interdependent subsystems. This approach allows for the assessment of benefits across multiple dimensions, including economic, social, environmental, and user satisfaction.

Mann and Levinson [18] present an alternative approach to cost-benefit analysis for transport investments, focusing on access-based valuation through hedonic pricing models to better quantify project benefits compared to traditional travel time savings methods. This approach aims to provide a more accurate and comprehensive evaluation of transport projects by considering land use and economic impacts, avoiding the common issue of forecast inaccuracy associated with traditional travel-time savings methods.

Computable General Equilibrium Models (CGE) are recommended for mega-projects where some requirements for CBA are not satisfied. CGE models analyze the broader economic impacts, such as changes in gross value added or employment, and adapt these to produce monetary measures of welfare changes.

The choice of a suitable CBA model depends on the specifics of each project and the objectives pursued. A rigorous and comprehensive analysis can contribute to an optimal investment decision in the transport sector, ensuring a sustainable and efficient development of transport infrastructure and services.

CBA models often simplify complex realities, and this can lead to an incomplete picture and may not capture all relevant real-world dynamics.

The outcomes of cost-benefit analyses are heavily dependent on the initial assumptions made. Variables such as discount rates, fuel expenses, maintenance costs can substantially alter the results of a CBA, in real conditions, in a very dynamic business environment.

4. COST-BENEFIT ANALYSIS IN THE ELECTRIFICATION OF THE FLEET OF DELIVERY VEHICLES

A large amount of data is needed to assess the feasibility and profitability of switching to a fleet of electric delivery vehicles.

First, data on the current fleet of vehicles, the existing infrastructure, as well as data on electric vehicles and the infrastructure required for them are needed. In connection with these, financial and operational data are required, as well as environmental and social impact data. And finally, data on uncertainties and risks are needed.

Rodríguez-Molina et al. [19] based on their model for the cost-benefit analysis of privately owned Vehicle-to-Grid (V2G) relieved that V2G technology is more economically efficient in the long term compared to Internal Combustion Engine (ICE) vehicles, due to lower operational costs, including maintenance and fuel (electricity) costs. For professional drivers, V2G solutions become economically advantageous almost immediately, while for frequent drivers, V2G solutions become more cost-effective after the first year and for occasional drivers, after 3 to 4 years. They considered in their analysis the impact of battery degradation, energy trading, battery leasing vs. ownership and externalities, such as health impact costs, carbon emissions, and the social cost of carbon.

Christensen and Christensen [20] compare electric and diesel vehicles across several key cost components, including investment, operation, maintenance, environmental impact, noise, refueling/switching time, and marginal excess tax burden (METB). The methodology used in the analysis involves conducting a CBA to evaluate the socio-economic impacts of purchasing and operating an EV compared to a diesel vehicle. They considered as indirect benefits the improved air quality and reduced greenhouse gas emissions. The Social Discount Rate (SDR) is determined through a combination of empirical data and theoretical models. Empirically derived discount rates are based on market data and include Marginal Rate of Return on Private-Sector Investments (r), Social Marginal Rate of Time Preference (p) and

Government’s Real Borrowing Rate (i). The theoretically derived discount rates are based on Optimal Growth Rate Model (Ramsey Model).

Lavee and Parsha [21] evaluate three levels of government support: basic, medium, and high, considering the costs and benefits associated with purchase subsidies, investment in public charging infrastructure, and taxation of private use of company cars. The analysis shows that only the basic level of government support passes the cost-benefit test, yielding a positive net benefit, while medium and high support levels result in net negative benefits, indicating that the costs exceed the benefits.

The methodology used in a study realized in 2018 [22] involved evaluating the costs and benefits of two different levels of plug-in electric vehicle (PEV) penetration in Arizona between 2030 and 2050. The study compared a "Moderate PEV" scenario, which aligns with the transportation electrification goals in Arizona Corporation Commissioner Andy Tobin’s 2018 Draft Energy Modernization Plan, and a "High PEV" scenario, which includes more aggressive PEV penetration levels. Cost calculations include costs for electricity generation, transmission, incremental peak generation capacity, and infrastructure upgrades. They also calculated the NPV of total societal benefits, including cost savings to drivers, utility customer savings, public charger owner benefits, and the monetized value of reduced emissions.

In a similar study realized in Florida [23], PEV adoption in Florida offers substantial economic, environmental, and societal benefits. But achieving high penetration levels requires coordinated policy efforts and infrastructure investments. Managed charging strategies can maximize benefits for both drivers and utility customers.

In a TNO report, Tol et al. [24] provides a cost-benefit analysis of adopting zero-emission vehicles, ZEVs, for medium trucks (7.5-16 tons) and tractor-trailer trucks (>32 tons) across various EU+UK countries, focusing on road tolls, energy consumption, vehicle prices, and maintenance costs.

A wide range of scenarios can be considered for a cost-benefit analysis in electrification of the fleet for a logistics company.

First, the results may differ substantially depending on the type of vehicle and the type of electric drive. This includes hybrid electric vehicles (HEV), plug-in hybrid electric vehicles (PHEV), battery electric vehicles (BEV) and vehicles equipped with vehicle-to-grid technology (V2G).

By feeding energy back into the grid during peak demand and high electricity prices, V2G could generate revenue. This capability could significantly enhance their cost-benefit profile, counteracting charging costs and potentially yielding profits. At the same time, V2G-enabled charging strategies offer a pathway to higher NPV by generating additional cash flows from grid electricity sales.

In their paper Bagheri Tookanlou et al. [25] based on a cost-benefit analysis, propose a strategy reduces the cost of electric vehicles (EVs) by 18% and increases the revenues of EV charging stations (EVCSs) and electricity suppliers (ESs) by 21% and 23%, respectively, compared to the scenario where EVs do not use the strategy for vehicle-to-grid (V2G) and grid-to-vehicle (G2V) operations.

But it is very important, however, to incorporate battery degradation costs into the financial model, as these could offset long-term profitability. Therefore, it's necessary to analyze how the frequency of discharging power to the grid affects battery lifespan and the total number of batteries required throughout the truck's operational life.

In order to prepare a cost-benefit analysis it has to identify the types of costs associated with the introduction or replacement of the existent fleet with a fleet of electric vehicles (*fig. 2*). The costs could be classified as regards investment costs, maintenance and operational costs.

Investment costs referred to prices of vehicles and the additional related to purchase, costs of battery replacement and the costs related to charging infrastructure.

So, the total investment expenditure (I_{EV}) to support of the transition to electric vehicles is the sum of several distinct capital outlays: the purchase price of the vehicles ($P_{vehicle}$), additional taxes, registration fees, and initial insurance premiums ($F_{regulatory}$), the present value of future battery replacement costs ($PV_{battery\_replacement}$), and the costs associated with the acquisition and installation of charging infrastructure ($C_{charging\_infrastructure}$).

$$I_{EV} = P_{vehicle} + F_{regulatory} + PV_{battery\_replacement} + C_{charging\_infrastructure} \quad (1)$$

Purchase price of fleet ($P_{vehicle}$) represents the initial capital outlay for acquiring the electric vehicles. For a fleet of n vehicles, each with a price p_i, the total purchase price is:

$$P_{vehicle} = \sum_{i=1}^{n} p_i \quad (2)$$

The additional taxes, registration fees, and initial insurance premiums ($F_{regulatory}$) encompass all mandatory initial costs associated with registering and insuring the vehicles of the fleet for operation, including sales taxes, registration fees, and the first insurance premium.

$$F_{regulatory} = \sum_{i=1}^{n} \left(T_{tax,i} + F_{registration,i} + P_{insurance,i}^{initial} \right) \quad (3)$$

Present value of future battery replacement costs ($PV_{battery\_replacement}$) represent the future expense of replacing the vehicle batteries over their operational lifespan, discounted to its present value. This requires estimating the battery replacement cost ($C_{battery\_replace}$), the time until replacement ($t_{replace}$), and the discount rate (r), taking into considerations that batteries may need replacement at different times for different vehicles based on usage and degradation.

$$PV_{battery\_replacement} = \sum_{i=1}^{n} \frac{C_{battery\_replace,i}}{(1+r)^{t_{replace,i}}} \quad (4)$$

Costs associated with the purchase and installation of charging infrastructure ($C_{charging\_infrastructure}$) include all expenses related to acquiring and setting up the necessary charging infrastructure: the cost of the charging units ($C_{charger}$), installation costs ($C_{installation}$), any required electrical upgrades ($C_{electrical\_upgrade}$), and potential land or permitting costs ($C_{permitting}$).

$$C_{charging\_infrastructure} = \sum_{j=1}^{m} C_{charger,i} + \sum_{j=1}^{m} C_{installation,j} + C_{electrical\_upgrade} + C_{permitting} \quad (5)$$

The general repair and maintenance expenditure (M_{EV}) for a fleet of n electric trucks over a specific operational period (Δt) can be determined as the sum of costs associated with scheduled maintenance ($C_{scheduled}$), unscheduled repairs ($C_{unscheduled}$), tire replacements (C_{tires}), and other miscellaneous maintenance activities (C_{misc}).

$$M_{EV}(\Delta t) = \sum_{i=1}^{n} \sum_{\Delta t} (C_{scheduled,i} + C_{unscheduled,i} + C_{tires,i} + C_{misc,i}) \quad (6)$$

Scheduled maintenance costs ($C_{scheduled,i}$) are the costs associated with routine maintenance tasks performed at predetermined intervals (based on time or mileage) as recommended by the manufacturer. These tasks typically include inspections, lubrication of specific components (if any), brake system checks, cooling system maintenance for the battery and electronics, and software updates. The cost can be modeled as a function of the frequency of these services ($f_{scheduled,i}$) and the average cost per service event ($\bar{c}_{scheduled,i}$)

$$C_{scheduled,i} = f_{scheduled,i} \cdot \bar{c}_{scheduled,i} \quad (7)$$

Unscheduled repair costs ($C_{unscheduled,i}$) are the costs incurred due to unexpected breakdowns or failures of vehicle components requiring repair or replacement outside the regular maintenance schedule. These can include issues with the electric powertrain (motor, inverter, power electronics), battery system faults (excluding full replacement, which is typically treated as a separate investment cost), braking system malfunctions, suspension issues, and other electrical or mechanical failures. The occurrence of these repairs is often stochastic and can be modeled using failure rates ($\lambda_{component}$) for various components and their respective repair costs ($c_{repair,component}$). Over a period Δt, the expected cost can be complex to model precisely, but can be estimated based on historical data or reliability predictions

$$E[C_{unscheduled,i}] = \sum_{components} (\lambda_{component,i} \cdot \Delta t) \cdot c_{repair,component,i} \quad (8)$$

Tire replacement costs ($C_{tires,i}$) represent the costs of replacing tires due to wear and tear or damage. The frequency of replacement depends on factors such as mileage, load, driving conditions, and tire quality. The cost can be modeled based on the number of tire sets replaced ($n_{tires,i}$) during the period and the cost per set ($\bar{c}_{tires,i}$). The number of replacements can be estimated based on the average tire lifespan and the total mileage of the truck.

$$C_{tires,i} = n_{tires,i} \cdot \bar{c}_{tires,i} \quad (9)$$

Miscellaneous maintenance costs ($C_{misc,i}$) includes other periodic or occasional maintenance expenses not covered in the above categories, such as wiper blade replacements, fluid top-ups (e.g., coolant, brake fluid), light bulb replacements, and minor bodywork repairs. These costs are often relatively small but contribute to the overall maintenance expenditure, being tracked as a total sum over the period.

$$C_{misc,i} = \sum_{events} c_{misc\_event,i} \tag{10}$$

Regarding the maintenance electric vehicles generally have fewer moving parts than diesel trucks, resulting in less wear and tear and reduced maintenance requirements. While generally lower, maintenance of the electric motor, power electronics, and battery management system requires specialized knowledge and tools.

The operational expenditure (O_{EV}) of electric vehicles comprises distinct cost components incurred over a defined operational period (Δt): electricity consumption ($C_{electricity}$), insurance premiums and related taxes ($C_{insurance\_taxes}$), charging infrastructure use (Ccharging), drivers costs ($C_{salaries}$), and fleet management expenses ($C_{fleet\_management}$).

$$O_{EV}(\Delta t) = \sum_{\Delta t}(C_{electricity} + C_{insurance_{taxes}} + C_{charging} + C_{salaries} + C_{fleet_{management}} \tag{11}$$

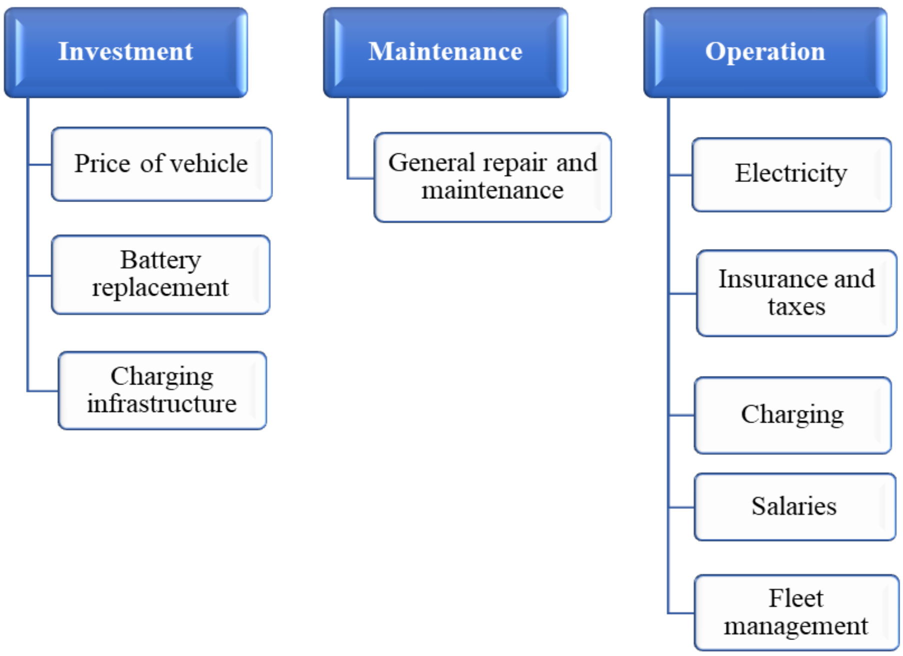

Figure 2. Cosst associated with the fleet electrification in a logistics company

Electricity consumption cost ($C_{electricity}$) is determined by the total energy consumed (E) by the vehicle during operation and the unit cost of electricity ($p_{electricity}$)

$$C_{electricity} = E \cdot p_{electricity} \tag{12}$$

The energy consumption (E) is a function of factors such as distance traveled (d), vehicle energy efficiency ($\eta_{vehicle}$ in kWh/km), and auxiliary power demands.

Insurance and related taxes ($C_{insurance\_taxes}$) encompasses the periodic insurance premiums ($P_{insurance}$) and any applicable taxes or fees directly associated with vehicle ownership and operation ($T_{vehicle}$). These costs are typically assessed over a specific time interval (e.g., annually) and must be prorated for the operational period Δt.

$$C_{insurance\_taxes} = P_{insurance} + T_{vehicle} \tag{13}$$

Charging infrastructure utilization cost ($C_{charging}$) is associated with the energy sourced for recharging the vehicle. For private charging, it is typically included within $C_{electricity}$. For public charging infrastructure, it includes the energy consumed during charging (E_{charge}), the unit cost of electricity at the charging point ($p_{charging}$), and any additional fees associated with the charging service (e.g., per-session fees, subscription costs, $F_{charging}$):

$$C_{charging} = E_{charge} \cdot p_{charging} + F_{charging} \tag{14}$$

Charging strategies and infrastructure are critical factors influencing the economics of EV fleets. If it is necessary to charge the vehicle during working hours, reducing the duration of vehicle travel corresponding to the periods for charging results in an increase in payroll expenses in relation to the distance traveled. The need for multiple charging stops in long-haul e-truck delivery routes diminishes productivity and drives up driver costs.

Opportunity charging can help integrate renewable energy into the grid by charging during periods of excess solar or wind energy availability. By charging trucks during idle periods between trips, opportunity charging avoids creating high peaks in electricity demand. The avoidance of high electricity demand peaks, achieved through charging trucks during inter-trip idle periods, serves to mitigate network costs. Thus, operators can optimize costs and maintain uninterrupted service.

Low-capacity charging offers the flexibility to charge trucks at lower power levels (e.g., 22 kW), which can translate to better cost efficiency than relying solely on faster, high-capacity charging.

Smaller fleets can more easily manage charging to align with their depot's general electricity consumption. However, for larger fleets, charging needs become the primary concern, overshadowing the impact of other depot consumption on overall costs. They need load management solutions to optimize electricity consumption by avoiding peak demand and aligning with lower electricity prices.

Strategically placing depots in areas with well-developed power infrastructure is another way to mitigate network connection costs and fees.

Human resource cost ($C_{salaries}$) represents the wages and benefits paid to drivers, the personnel directly involved in the operation of the vehicle. It is a function of the labor hours (h) dedicated to vehicle operation and the applicable wage rate (w).

$$C_{salaries} = h \text{ x } w \quad (15)$$

For commercial operations, this may also needs to include considerations for charging time that impacts driver availability and efficiency.

Fleet management expenses ($C_{fleet\_management}$) include costs associated with the overall management and administration of a fleet of electric vehicles, encompassing software subscriptions for tracking and optimization ($C_{software}$), maintenance of charging infrastructure ($C_{infrastructure\_maintenance}$), personnel costs for fleet management ($C_{management\_personnel}$), and other administrative overheads ($O_{administrative}$).

$$C_{fleet\_management} = C_{software} + C_{infrastructure\_maintenance} + C_{management\_personnel} + O_{administrative} \quad (16)$$

In what it concerns the benefits, they are mainly generated by the fuel cost savings, maintenance cost reduction and avoided emission costs comparing with ICE vehicles. Comparing to diesel trucks, they generate lower maintenance costs per kilometer, due to a reduced frequency of repairs and significantly lower costs with consumables. Electric trucks will have zero for pollutants like NOx, particulate matter, CO and greenhouse gas emissions.

These savings can make EVs more economically efficient in the long term compared to internal combustion engine vehicles.

In this study there had been analyzed the comparative cost-benefit of integrating different truck technologies—ICE, HEV, PHEV, and BEV—into the fleet of a logistics company. The analysis considers the acquisition of 200 trucks over an 8-year operational lifespan, employing a discount rate of 7%. The simulation of various scenarios was conducted using MATLAB.

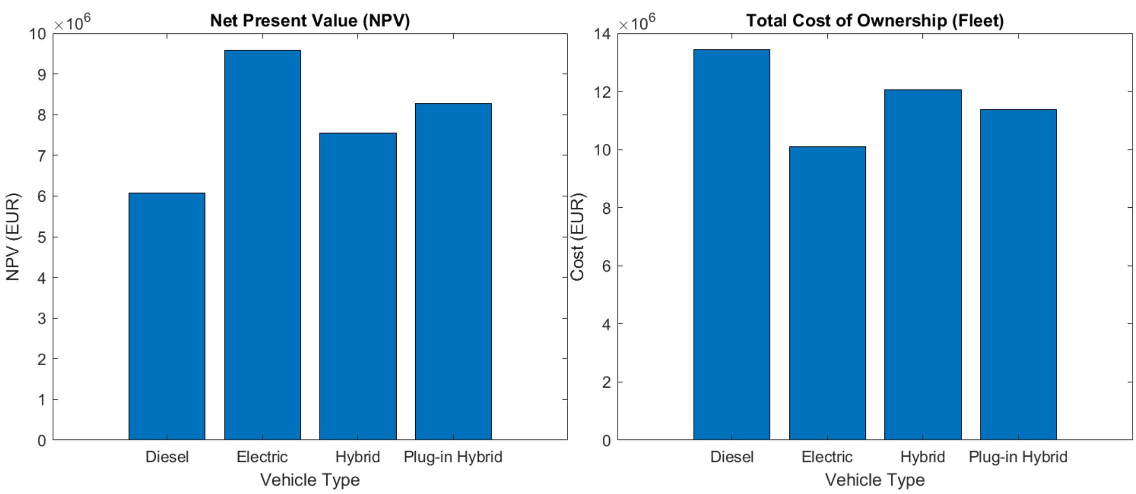

Figure 3. NPV and TCO for different types of freight vehicles

Key findings from the financial analysis, encompassing NPV, TCO and Cost-Benefit Ratio (CBR), reveal as the most economically advantageous being BEV (*fig. 3*, table 1). The input data is specific to the Romanian freight vehicle market and electricity prices in Romania.

Table 1. Financial results of the simulation

Type of vehicle	Total Cost of Ownership (TCO)	Net Present Value (NPV)	Cost-Benefit Ratio (CBR)
ICE	13,428,385.62 EUR	6,069,731.95 EUR	0,69
BEV	10,107,219.62 EUR	9,585,879.13 EUR	0,51
HEV	12,051,173.93 EUR	7,544,434.23 EUR	0,62
PHEV	11,362,568.08 EUR	8,281,785.38 EUR	0,58

The study also summarizes the impact of sensitivity analyses conducted on electricity prices and various charging scenarios for BEV and PHEV trucks, highlighting the factors that significantly influence their profitability.

In the case of the sensitivity analysis of NPV depending on the price of electricity, its increase influences BEVs the most, which was expected, given that electricity is the only source of energy for them (*fig. 4*).

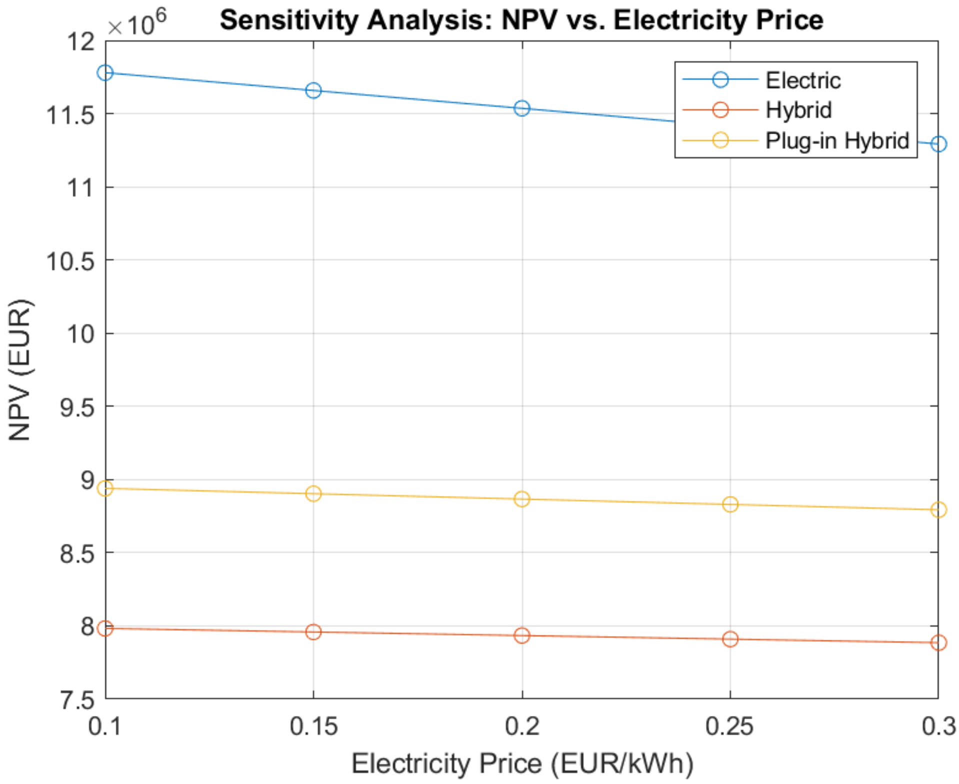

Figure 4. Sensitivity analysis NPV vs. electricity price

The sensitivity analysis of NPV considering annual revenue reveals an increasing with about 40% with an increase of only 20% in transport revenues (*fig. 5*).

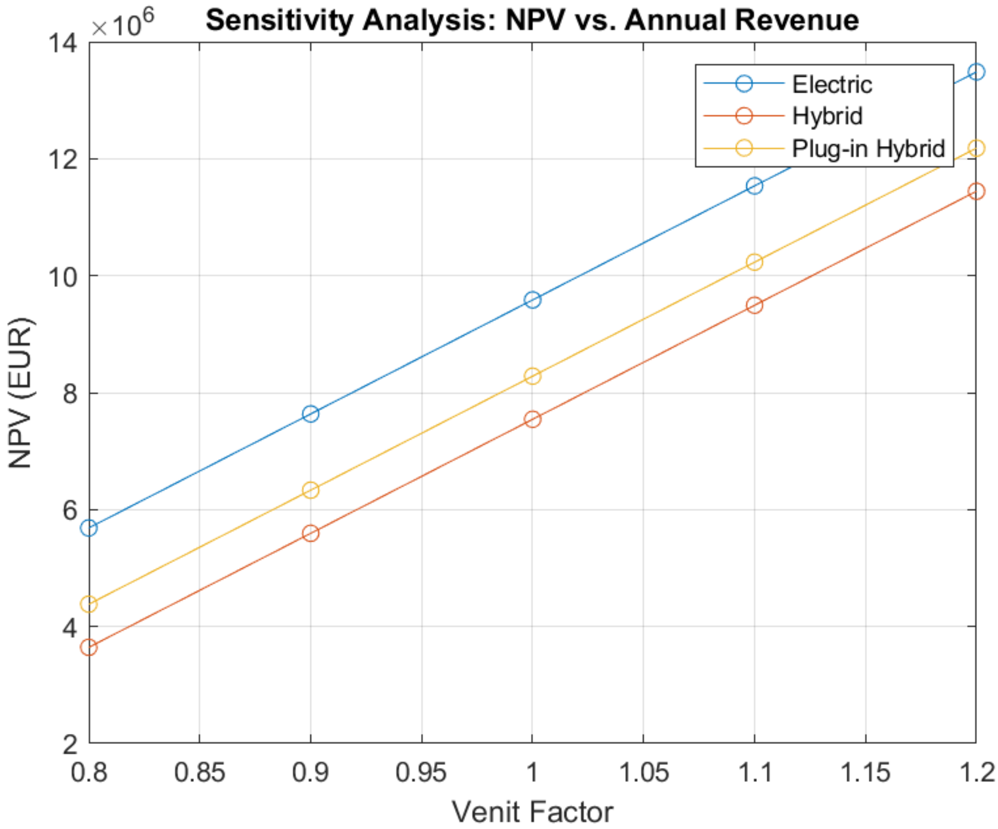

Figure 5. Sensitivity analysis NPV vs. annual revenue

Taking into account the economic context, it is also important to conduct a sensitivity analysis of the discount rate to see how it influences the level of discounted net income. This reveals for all types of vehicles a halving of the NPV at an increase in the discount rate from 0.05 to 0.15 (table 2).

Table 2. Sensitivity analysis NPV vs. discount rate

Discount Rate	Diesel NPV (EUR)	Electric NPV (EUR)	Hybrid NPV (EUR)	Plug-in Hybrid NPV (EUR)
0.05	6,973,247.93	10,947,176.53	8,636,684.66	9,468,403.02
0.07	6,069,731.95	9,585,879.13	7,544,434.23	8,281,785.38
0.1	4,900,884.85	7,824,816.17	6,131,427.96	6,746,699.52
0.12	4,226,277.12	6,808,407.19	5,315,902.18	5,860,714.70
0.15	3,344,059.91	5,479,199.93	4,249,399.59	4,702,069.43

Several charging scenarios were considered: fast charging at a public charging station, slow and fast charging at the depot, and charging using electricity supplied by photovoltaic panels during the day. The optimal option is the latter, followed by slow overnight charging at the depot.

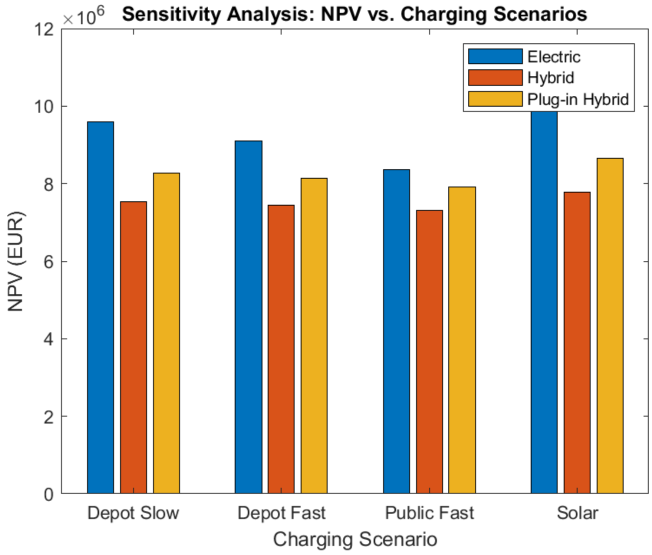

Figure 6. Sensitivity analysis NPV vs. charging scenarios

The consideration of various charging scenarios reveals that strategically optimized charging practices can significantly influence the economic benefits of electric vehicle fleets. Utilizing on-site photovoltaic power during the day and implementing slow overnight charging at the depot appear to be economically advantageous strategies. Furthermore, concepts like opportunity charging and load management for large fleets are crucial for minimizing electricity costs and network connection fees.

5. CONCLUSIONS

The process of preparing a cost-benefit analysis for fleet electrification requires a systematic identification and classification of associated costs. These costs can be broadly categorized into investment costs (vehicle purchase, regulatory fees, battery replacement, charging infrastructure) and maintenance and operational costs (general repair, scheduled maintenance, unscheduled repairs, tires, electricity consumption, insurance, charging infrastructure utilization, driver salaries, fleet management). For a thorough economic evaluation, a detailed comprehension of these individual cost elements and the variables that affect them is indispensable.

Cost-benefit analyses for fleet electrification need to consider various factors. These include the type of electric vehicle (HEV, PHEV, BEV, V2G), the specific costs associated with investment, maintenance, and operation (including charging infrastructure and battery replacement), and the potential for additional revenue generation through V2G. The V2G technology offers an opportunity to enhance the cost-benefit profile of electric vehicle fleets. By enabling vehicles to feed energy back into the grid during periods of high demand and elevated electricity prices, V2G can generate revenue streams that offset charging costs and potentially yield profits. This capability could contribute to higher NPV) by creating additional cash flows from grid electricity sales. This study did not incorporate this technology into the simulation model because it is not yet common in Romanian companies of this type.

The need for en-route charging can increase labor costs and reduce productivity, especially for long-haul deliveries. However, opportunity charging during idle periods can offer benefits by integrating renewable energy, mitigating peak demand, and reducing costs. Also, low-capacity charging can be more cost-effective than relying solely on high-capacity fast charging. Smaller fleets can more easily align charging with existing depot electricity consumption, while larger fleets require sophisticated load management solutions to optimize electricity use and avoid peak demand charges. Strategic depot placement can also help reduce network connection costs.

The sensitivity analyses conducted on electricity prices, annual revenue, and the discount rate demonstrate the significant impact of these economic parameters on the NPV of an electric vehicle fleet adoption. Notably, BEVs are most sensitive to electricity price fluctuations, while NPV across all vehicle types is inversely related to the discount rate. Furthermore, a positive correlation between annual revenue and NPV highlights the importance of operational efficiency and revenue generation in the financial viability of fleet electrification.

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