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Key Evaluation Criteria for Assessing the Introduction of Electric Vehicles into the Logistics Operator's Fleet

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Abstract

Increasing demands for logistics services cause several challenges related to total costs and meeting global environmental requirements. Logistic operators make efforts to improve all logistic processes and the distribution chain system by optimizing distribution networks and transport routes. Also, using clean or renewable energy help to meet the above-mentioned requirements by using environmentally friendly means of transportation such as electric and hybrid vehicles. The replacement of conventional with electric vehicles provides numerous benefits for improving the efficiency of the distribution chain system. This process is part of the concept known as Green Logistics, which strives to minimize the environmental impact of the logistics network and delivery. This paper focuses on identification of indicators for evaluating the acceptability of replacing conventional vehicles with electric vehicles in the fleet of logistics operators. We propose an evaluation matrix based on key indicators such as total costs, eco score fleet rating, and range and energy supply of vehicles. We use these indicators to determine the advantages, challenges, and possibilities of introducing electric vehicles in the logistics operator's fleet. Also, we conducted a multi-criteria analysis of replacing conventional with electric vehicles in the fleet of one logistics operator.

Keywords*: Electric vehicles, Logistics Operator's fleet, Evaluation criteria, Multi-criteria analysis*

1. Introduction

Due to the inhabitant's increase in cities and the process of digitalization, the logistics sector is becoming extremely attractive. On the other hand, environmental protection restrictions are also increasing. These two parallel processes impose main managerial and organizational changes for logistics operators. Meeting the growing needs of users and the needs of the environment is a particular challenge for logistics operators which must comply with the principles of sustainable development. These principles of sustainable development, which link user requirements and sustainability in the example of urban transport, are shown in Table 1 [1].

To satisfy the principles of sustainable urban transport, there was a need to introduce the concept of Green Logistics which enables the realization of growing customer requirements, through the protection of the environment and the needs of future generations [2]. To fulfill the concept of Green Logistics and the set goals, all elements of Green Logistics need to analyze at a satisfactory level. That means meeting the basic principles of logistics grouped into aspects of sustainability [3]:

- System-wide sustainability (principles: consistency, adaptability, development, self-organization, and competence);
- Economic viability (principles: polluter pays, equity, efficiency and security, optimality and savings/resource reuse);
- Environmental sustainability (principles: minimal impact, innovation, rationality, and hierarchy);
- Socio-cultural development (principles: accountability, transparency, and rational spending).

To satisfy sustainability, it is necessary to adhere to these four principles. One of these principles is minimal impact, which is in a relationship with the distribution chain in the logistics process. This principle implies the reduction of negative impact on the environment through the processes of production, transport, use, and recycling. Since the transport process is one of the main parameters for fulfilling the set principles, there is a need to change the elements of the system in this domain. One of these elements is the driving units. The main goal of this paper is to define the key criteria for evaluating the introduction of electric vehicles in the fleet of logistics operators.

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Table 1. Principles of sustainable urban transport.

Principles of sustainable development (meeting the requirements of users)	Principles of sustainable urban transport (conditions for logistics operators)
-Social equality (intergenerational equality, stable social system) -Economic growth -Environmental protection (retention or reduction of existing pollution from all elections)	-Preservation of human health -Maintenance and capital growth -Efficient economy -Environmental protection (emission limitation, waste management, land use restrictions)

2. Defining Important Criteria for Fleet Evaluation Sustainability

In this paper, the focus of research will be on one segment of the potential solution to the problem, the justification of electric vehicle's introduction in logistics processes. Due to the insufficient response from companies for changing the fleet structure, there is a need to determine the justification of electric vehicle introduction in this sector.

To compare selected features of different types of vehicles, it is necessary to define evaluation criteria. Selected criteria for comparing electric and conventional vehicles are:

- The total cost of ownership (TCO);
- Eco score fleet rating;
- Range and supply of vehicles.

Other indicators are important and they must be included to obtain overall results. Since these indicators are not in the function of propulsion energy, they will not be considered. Details for all fleets analysis indicators can be found in the professional literature [4].

2.1. The total cost of ownership (TCO)

Observing costs through the procurement of vehicles is quite rough and incomplete. The reason is that the vehicle, together with fixed purchase costs, requires additional spending during operation. Therefore, the Total Cost of Ownership (TCO) methodology obtains actual images of vehicle ownership costs. One of the definitions of TCO is that it is a purchasing methodology and philosophy, which aims to understand the actual total price of a particular good or service [5]. TCO is a calculation that is extremely useful for estimating the direct and indirect costs associated with purchase over the entire life cycle of a vehicle or product in general [6].

Vehicle ownership costs include the costs of buying and owning a vehicle, and the variable costs of using and operating the vehicle [7]. In summary, total vehicle ownership costs include (Figure 1): depreciation costs (which make up the cost of purchasing vehicles), fuel, insurance, maintenance, repairs, and government fees.

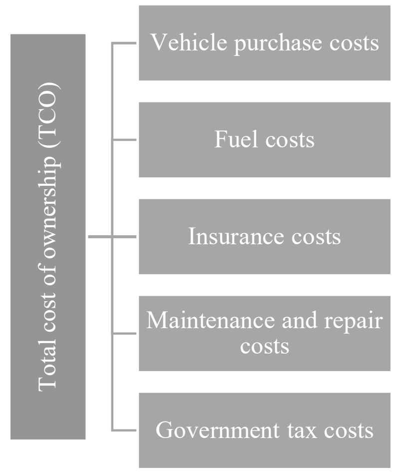

Figure 1. The total cost of ownership (TCO).

The distribution of ownership costs varies from vehicle to vehicle and from state to state. Figure 2 shows the share of individual vehicle ownership costs for the US market, for 5 years of vehicle ownership. The diagram clearly shows the importance of the analysis of total costs when deciding on the purchase of a vehicle.

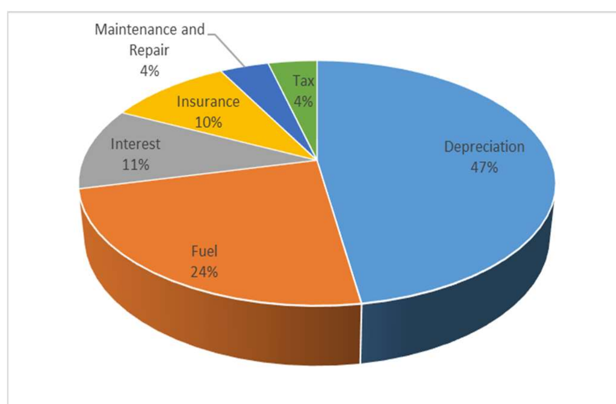

Figure 2. The total cost of ownership for a new vehicle for a period of 5 years (US market) [6].

Total cost of ownership can be determined using the following equation (1):

$$TCO = (PR - RP) + FC + TIC + IC + MR + T - S \quad (1)$$

where: TCO is the total cost to owner; PR purchase price; RP sales price of the vehicle after use; FC fuel costs; TIC total interest expenses; IC insurance costs; MR maintenance and repair costs; T government fees and S government subsidies. All parameters in equation (1) are in the monetary units [6]. It is important to note that the difference between the purchase and sale price actually forms the total depreciation cost. So in equation (1) instead of (PR-RP) can be included the total depreciation cost DR.

The total interest costs (TIC) are optional, and can be included in the case of the purchase of vehicles in installments. TIC can be determined via equation (2).

$$TIC = \frac{r * P}{1 - (1 + r)^N} * N - P \qquad (2)$$

where: *r* is monthly interest rate; *P* amount of loan for which interest is calculated; *N* number of months during which the refund is made.

2.2. Eco score fleet rating

The Eco Score is a methodological procedure developed in Brussels, which the Belgian government uses as an official tool for forming a policy of subsidizing transport companies. This procedure is based on the environmental assessment of the vehicle, taking into account the most important pollutants. The eco score includes emissions during driving (exhaust emissions) and emissions during the production and distribution phases of fuel. This approach is known as the well-to-wheel approach [8].

The Eco score rating range is from 0 to 100. The Eco score rating has been transformed from the total environmental impact (TI), with a rating of 100 representing a total clean and silent vehicle. The benchmark for a clean vehicle corresponds to an Eco score rating of 70 [9]. The transformation is based on an exponential function (Figure **3**3) to avoid negative results.

It is important to note that this methodology does not include pollution during the vehicle production and recycling phases. There are two key reasons, it is complicated to obtain input data, and the impact in these phases is lower (about 10% of total pollution). However, the Eco score methodology includes the difference between new and used vehicles [11].

Eco score methodology in vehicle assessment includes three types of emissions:

1. Emissions with an impact on global warming (Carbon dioxide CO_2, Methane CH_4, and Nitrogen dioxide N_2O);
2. Emissions with an impact on air pollution (Carbon monoxide CO, Carbohydrates HC, Nitrogen oxides NOx, Particles PM, and Sulfur dioxide SO_2) and
3. Emissions with noise impact (Engine noise dB (A))

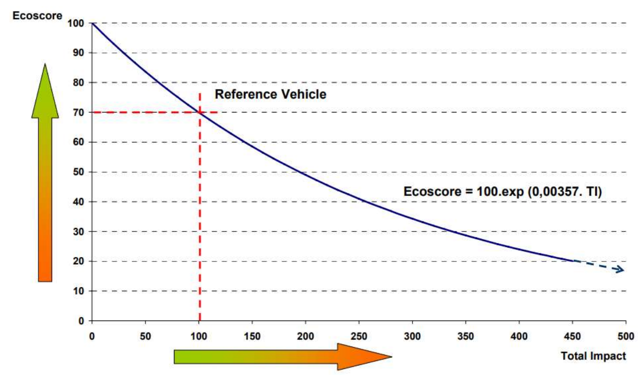

Figure 3. Transformation Total Impact to Eco score and referent value [10].

The values of the first set of emissions are most influential on the Eco score rating (50% of the impact), followed by the values of air pollutants (40% of the impact), while the remaining 10% of the impact is formed based on vehicle noise.

Eco score is determined for passenger cars and light goods vehicles using equation (3).

$$ES = 100 * [-0{,}00357 * (A * CO_2 + B * HC + C * NO_X + D * CO + E * PM + F * FC + G * dB(A) + H]^2 \qquad (3)$$

where: $CO_2, HC, NOx, CO,$ and PM are standard designations for individual pollutants expressed in (g/km); FC average fuel combined consumption in (l/100km) for petrol, diesel, and LPG engines, in (kg/100km) for CNG engines and in (kWh/100km) for electric engines; A, B, C, D, E, F, H coefficients whose values depend on the fuel type and Emission standards (values of coefficients see in [8]).

The calculation of the Eco score rating for Euro 6 passenger cars and light commercial vehicles, for vehicles with a built-in PHEV engine, and heavy vehicles differs from equation (3) [12], [13]. Since the calculation requires a large number of pollutants, which are often difficult to measure or unknown, their values defined by Euro standards are taken [14]. If values can be measured, the obtained results will be entered into the equation.

Figure 4 shows the Eco score rating for the assessment of the total rolling stock in Belgium. The diagram shows the Eco score grade as a function of the type of fuel and the usability of the vehicle (new or second-hand vehicle). Also, the diagram shows the average overall condition of the vehicle fleet. The Eco score rating of new vehicles is higher than the rating of used vehicles. Also, electric vehicles do not change their Eco score grade as they age, which is not the case with diesel and petrol engines. Comparing the values from Figure 4 with the benchmark value of the Eco score (Figure 3), it is concluded that vehicles powered by petrol, diesel, hybrid diesel, or LPG do not meet the overall environmental impact threshold.

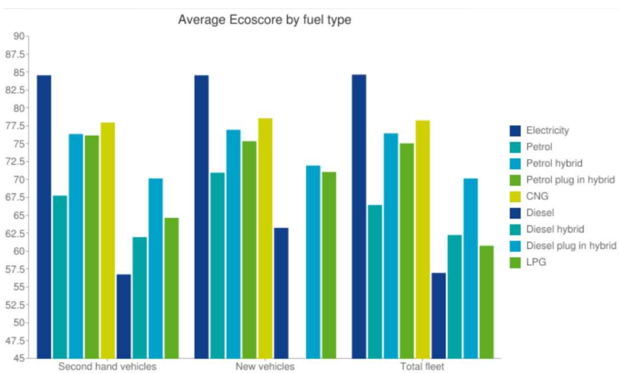

Figure 4. Eco score fleets grade [15].

2.3. Range and supply of vehicles

Important parameters in the execution of logistics operations are the range of the vehicle and the time required to supply the vehicle with fuel [16]. Vehicle range refers to the distance traveled by a vehicle with one full tank/battery. The time required to supply vehicles with fuels refers to the time of charging the tank/battery.

These two parameters are the key disadvantages of electric vehicles [17], and they are a challenge for all logistics operators. The range of a conventional vehicle is practically unlimited with the minimum time required to fill the tank. The range of electric vehicles is limited, with significant vehicle battery charging times [18]. The key trends in the development of electric vehicles are based on increasing the distance traveled and reducing the charging time. Currently, due to these limits, the use of electric vehicles is not possible to meet all transport needs.

Vehicle range will be considered as the total distance traveled by the vehicle during the observed time with one full tank/battery. The range of the vehicle differs for each type of vehicle and is in function from:

- average consumption per 100 kilometers;
- the total capacity of the tank/battery;
- correction factors that depend on operating conditions and environmental conditions.

For the calculation of the range of a conventional vehicle, the standardized fuel consumption model can be used [19], which after conversion looks like equation (4).

$$K = \frac{FC * 100}{P_g * f_i}\ (km) \qquad (4)$$

where: *FC* is tank capacity (l); *Pg* average combined fuel consumption (l/100km); *fi* correction factors consumption depending on the operating conditions (-).

Analogous to the calculation of the range of a conventional vehicle, the range of electric vehicles can be calculated with equation (5), or with another method [20].

$$K = \frac{EC * 100}{P_E * f_i}\ (km) \qquad (5)$$

where: *EC* is battery capacity (kWh); *PE* average combined electricity consumption (kWh/100km); *fi* corrective factors consumption that depends on the conditions of exploitation and environmental conditions.

3. Overview of the Fleet and Infrastructure of Electric Vehicles

Growing trends in the registration of electric vehicles and the construction of the accompanying infrastructure are evident in European countries. However, despite all the efforts, the current situation is not satisfactory. The countries of the Western Balkans lag far behind developed European countries. Table 2 shows the share of electric vehicles in the fleet of selected countries and the number of charging stations for electric vehicles per 100 square kilometers.

Table 2. Display of the number of electric vehicles in the fleet of selected countries and coverage parameters [21], [22].

Country	Participation of electric vehicles in the fleet (%)	Coverage parameter (charging station /100km^2)
Germany	1,4	16,6
France	1,3	6,8
Austria	1,5	15,6
Netherland	2,6	215,7
Norway	13,2	4,4
Croatia	1,3	3,1
Bosnia and Herzegovina	0,006	0,28

We can see that Norway is far ahead of other countries in terms of the percentage of electric vehicles in the fleet (13.2%). The coverage of charging stations is currently by far the most pronounced in the Netherlands (215.7 charging stations/100 km^2).

4. Case study: Calculation of Defined Key Indicators

The previously explained theory is the basis for analysis justification of electric vehicle introduction in the logistics operators fleet. A multi-criteria approach, in this case, is inevitable, due to the different values of the criteria. The case analysis was performed for a logistics company with 98 vehicles. The vehicles are powered by a diesel engine with an average Eco score of 43 (-) which is determined by applying the Eco score model (Eq. 3). The fleet includes 34 Euro 3 vehicles, 38 Euro 4 vehicles, 24 Euro 5 vehicles, and 2 Euro 6 vehicles.

Based on the data of the company fleet, a representative vehicle was determined that meets the requirements of the company, and it is a vehicle with a mass of 1900 (kg). The characteristics of this vehicle were used for comparison evaluation criteria. It is important to note that the new, Euro 6 diesel vehicle with a power of 100 (kW) is compared with an electric vehicle with the same characteristics according to previously defined criteria.

For the application of the multi-criteria evaluation method TOPSIS [23], a basic evaluation matrix was formed (Table 3). Eco score and tank/battery filling time are obtained directly from the references, while the total cost of ownership and range of the vehicle is obtained indirectly using the equations (1, 4, 5). After adopting the ponders of the criteria ($w_1 = w_2 = w_3 = w_4 = 0.25$ *(-)*), setting the maximization goal for eco-score assessment and vehicle range, the minimization goal for the total cost of ownership and filling time of the tank/battery and multi-criteria evaluation procedures it turns out that the diesel vehicle currently has a greater justification for its application in the logistics sector, as shown by the obtained results of the multi-criteria evaluation (Table 4).

Table 3. Basic evaluation matrix.

Evaluation criterion	Vehicle type		Ref.
	Diesel	Electric	
TCO (€/km)	0,443	0,513	[6], [24]
Eco score rating (-)	45	81	[25]
Range (km)	900	130	[26]
Supply (min)	8	30	[26]

Note: changing the ponders of the criteria the results will change, but in this case for any value w_i diesel vehicle is the best option.

Table 4. Ranking of variants.

Position	Variants	Evaluation
I rank	Diesel vehicle	0,891
II rank	Electric vehicle	0,109

5. Conclusion

Converting conventional vehicles to electric is not an easy process. This paper showed that the analysis of the introduction of electric vehicles in the fleet should be approached thoroughly. All criteria that influence the final selection should be taken into account in the analysis.

The paper focuses on three key evaluation criteria:

- The total cost of ownership (TCO);
- Eco score fleet rating;
- Range and supply of vehicles.

The first criterion includes the financial expenses that the company needs to provide for owning a vehicle. The second criterion shows the impact of the vehicle on the environment, and the third shows the possibility of exploitation in certain conditions.

Based on the analysis, we conclude that the key advantage of electric vehicles is environmental protection. Key challenges are related to the high cost of purchasing vehicles, and relatively short-range and long battery charging. The cost of purchasing an electric vehicle is high, but maintenance is cheaper than conventional vehicles. Nevertheless, it is not profitable to procure these types of vehicles without government subsidies. In addition to subsidizing, the total cost over a longer time is equated with the cost of conventional vehicles.

The challenges of long charging and short range can be resolved if the vehicle operates in one shift, with the average daily vehicle travel being no more than cc 150 (km/day), depending on the vehicle type. Replacement of conventional vehicles with electric ones is possible, in cases of government subsidies, shorter daily routes, and good coverage of charging stations for electric vehicles.

Competing Interest Statement

The authors declare no known competing interests or personal relationships that could have influenced the work reported in this paper.

Data and Materials Accessibility

No additional data or materials were utilized for the research described in the article.

Transparent Statement

Ermin Muharemović as both author and editorial board member, confirm that the article underwent an independent peer review process. The review process adhered according to Peer Review Policy and Publication Ethics.

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