Professional paper

ENABLING SUSTAINABLE LAST MILE DELIVERY BY USING ELECTRIC VEHICLES

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ABSTRACT: *Transport in the last mile delivery (LMD) takes place towards the end customer in the supply chain, is concentrated in urban areas and is responsible for the emission of about 25% of greenhouse gases. Much attention has been paid to clean vehicle technology, biofuels and modes of transport, such as the use of bicycles and electric vehicles in the LMD to mitigate the negative impact of logistics systems towards environmental sustainability. This paper outlines operative features of electric vehicles which make them suitable for LMD in terms of sustainability*

Keywords: *LMD, electric vehicles, sustainable transport*

1. INTRODUCTION

The last-mile delivery (LMD) is performed in the final stage of the supply chain, via dedicated distribution centres or cross dock terminals, mostly within the urban area, affecting lead times and customer satisfaction in a direct way. Although it covers relatively short transport distances, studies (Jacobsen, 2022) have shown that this part of the supply chain is accounted for 53% of total shipping costs and this percentage is expected to increase in the future. The LMD is also the least energy efficient part of transport in the supply chain (Afshari et al., 2022).

The necessity for improvement and advancement in LMD to reduce the overall cost of distribution and also to reduce the emissions causing the pollution in LMD, has enforced the vendors or companies to experiment and evaluate various alternatives. In the pursuit of this, electric vehicles (EVs) have emerged as an innovative technology that reduces local emissions which helps in reducing the emissions of fumes and noises in the distribution process in the e-commerce industry (Kishore et al., 2022).

Electric Vehicles will become more economical than conventional internal combustion engine (ICE) vehicles over the life cycle. The overall cost of ownership of the vehicle will be further reduced with a reduction in battery prices. One of the downsides for EVs today is that their procurement costs are higher than same version ICE vehicles (Kishore et al. 2022).

Organizations engaged in supply chain last-mile delivery solutions are welcoming the move for greener logistics practices to reduce the carbon footprint and to minimize the impact of their business on the environment (Sharma, 2021).

The maintenance costs depend on the vehicle type and annual mileage. The maintenance **costs** depend on the vehicle type and annual mileage. Maintenance costs include the costs for all the small and large maintenances throughout the vehicle's lifespan. These costs are necessary to keep the vehicle operational. They include oil replacements, brake replacements, etc. In general, the maintenance costs for EVs are lower compared to ICE vehicles. Since EVs have fewer moving components, they face less temperature stress and do not need oil and filter replacements. Also, due to the possibility to recuperate energy whilst braking, the braking pads will last longer (Lebeau et al. 2013).

Solar energy can play a significant role in Electric Vehicle Charging Stations (EVCS) or carports by incorporating solar panels into the charging infrastructure (Bernal et al. 2020). Besides, it is possible to generate renewable energy onsite to power the charging process (Bastida-Molina et al. 2020). This reduces reliance on the grid and decreases the carbon footprint of electric vehicles. Solar energy has the ability of reducing the carbon emission in transportation sector by switching into EV rather than Internal Combustion Engine Vehicle (ICEV) and exploit the Renewable Energy Sources (RESs) could combat the climate changes (Maestre et al. 2021). Additionally, EVs produce zero tailpipe emissions, meaning they don't release any Carbon Dioxide (CO2) or other harmful pollutants while driving. Several studies have been conducted in the state-of-the-art for the utilization of solar energy and its impacts on the environment, economic, and technological advancement (Mwasilu et al, 2014).

The goal of this paper is to show main differences between EVs and ICEVs and to outline operative features of EVs which makes them suitable for LMD in terms of sustainability . Furthermore, it is important to show economical and ecological benefits of EVs and trends of introducing them in modern logistics. With reference to that, the investments in EVs and supporting infrastructure, including investments in solar panels, is considered in terms of sustainability and profitability of business operations..

2. TRANSPORT REQUIREMENTS IN THE LAST MILE DELIVERY

Energy efficiency of freight transportation has high priority in achieving environmentally sustainable development in logistics operations. In logistics it helps decrease the total energy consumption and can contribute to the EU target set for 2050. Energy efficiency of LMD is understood in regard to three interacting components in the logistics system: (A) distribution structure; (B) transportation execution; and (C) household logistics capability. Figure 1. summarizes this logic, and the three components are considered with respect to their implications for energy efficiency of the last-mile fulfilment options (Halldórsson and Wehner, 2020).

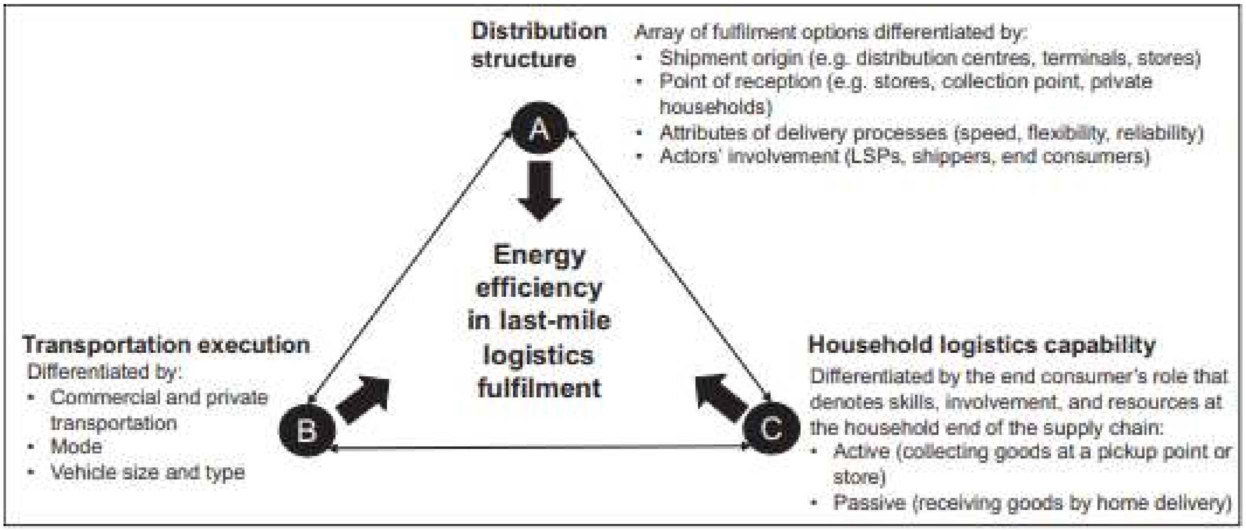

Figure 1. The three components that shape energy efficiency in LMD
Source: Halldórsson and Wehner, 2020

3. OPERATIVE FEATURES OF ELECTRIC DELIVERY VEHICLES

The operative features of road EVs are considered with reference to several factors, such as the purpose of the vehicle itself, related to the type of transport substrate and transport suprastructure, as well as the conditions of exploitation. Some of the most important and most common operative features of such vehicles are: engine power, battery capacity, range, maximum speed, type of charging (AC or DC), dimensions, payload and power consupmtion, which are presented in Table 1. for some of the most comonly used EVs.

Table 1. Operative features of EVs

	Cenntro metro	Opel Combo-e	Renault Kangoo E-tech	Opel Vivaro	Volkswagen ID.Buzz
Engine power (kW)	24	45	51	56	70
Battery capacity (kWh)	26	50	45	75	77
Range (km)	216	275	245	270	350
AC Charging (V)	230	230	230	230	230
Dimensions (cm)	370x140x190	440x130x140	448x192x184	495x164x193	471x200x190
Payload (kg)	580	800	800	1100	650
Consumption (kWh/100 km)	11,9-13,4	19,3-21,5	25-27	26,5-29,5	19-22

Source: Data provided by the manufacturer

As shown in Table 1., operative features of EVs vary, except for AC charging and dimensions of vehicles which are more or less similar. It is evident that Volkswagen ID.Buzz is the best, while Cenntro metro is the worst in the selected group of vehicles, by most of the features, however Cenntro metro consumes the least amount of energy in exploitation.

Main advantages and disadvantages of EVs over ICEVs, in terms of operative features are given in Table 2.

Table 2. Advantages and disadvantages of EVs

Advantages	**Disadvantages**
Favorable impact on the environment	Shorter range
Operating costs	Longer charging time
Use of incentives	Convenience of charging
Quiet operation	Purchasing costs
Driving performance	Weight
Benefits when charging	Loss of battery efficiency
Image	Decline in value

4. ECOLOGICAL AND ECONOMIC ASPECTS OF USING ELECTRIC VEHICLES IN THE LAST MILE DELIVERY

Both ICE vehicles and EVs are environmentally intensive forms of propulsion. In a direct comparison, as given in Table 3., the EVs are less harmful to the environment, however the battery recycling issues are not taken into consideration here.

Table 3. Comparison between ICEVs and EVs from ecological aspect

	Internal combustion engine	**Battery powered propulsion**
Drive	Internal combustion engine with exhaust gas purification unit (catalyst)	Electric motor with battery
Fuel	Fossil gasoline/diesel, biogenic gasoline/diesel, e-fuels	Electric current
Raw materials for production	Iron, aluminum, plastic, magnesium, copper, plastic, glass, rubber and others	
Pollution of raw materials	16 tons	42 tons
Direct emissions during exploitation	Carbon dioxide (CO2), nitrogen oxides (NOx), sulfur oxides (SOx), particles (PM), microplastics	Fine dust and microplastics (from tire and brake abrasion)
CO_2 emissions during the life cycle	200 - 250 g/km	75 - 150 g/km

The economic benefits of the adoption of EVs, on the long run, will compensate for the high initial cost of acquisition. Savings on fuel and operating costs will lead to passing the benefits like reduction in the retail prices of products as the logistics cost contribute a lot to the cost structure. With the record rise in demand for home deliveries, EVs will be the choice for last-mile deliveries. Though the acquisition cost is higher at this point, it is supposed to come down with advancements in technology and a reduction in the battery cost. The shift towards electric mobility looks unavoidable. The creation of a robust affordable, accessible, and reliable ecosystem will drive the stakeholders towards a smooth transition towards EVs (Kishore et al. 2022).

The number of electric and hybrid vehicles in 2020 in Croatia has increased. In just one year (from 2019 to 2020), the number of EVs increased by 45.6%, and 31.3% for hybrids. The increase in the number of EVs in 2022 increased by 36.36% compared to 2021, while hybrid vehicles recorded an increase of 39.86% in the same period, as presented in Figure 2. This was shown in the association's report of the car manufacturer ACEA (the European Association of Car Manufacturers which is the main group for industry standardization and lobbying in the EU).

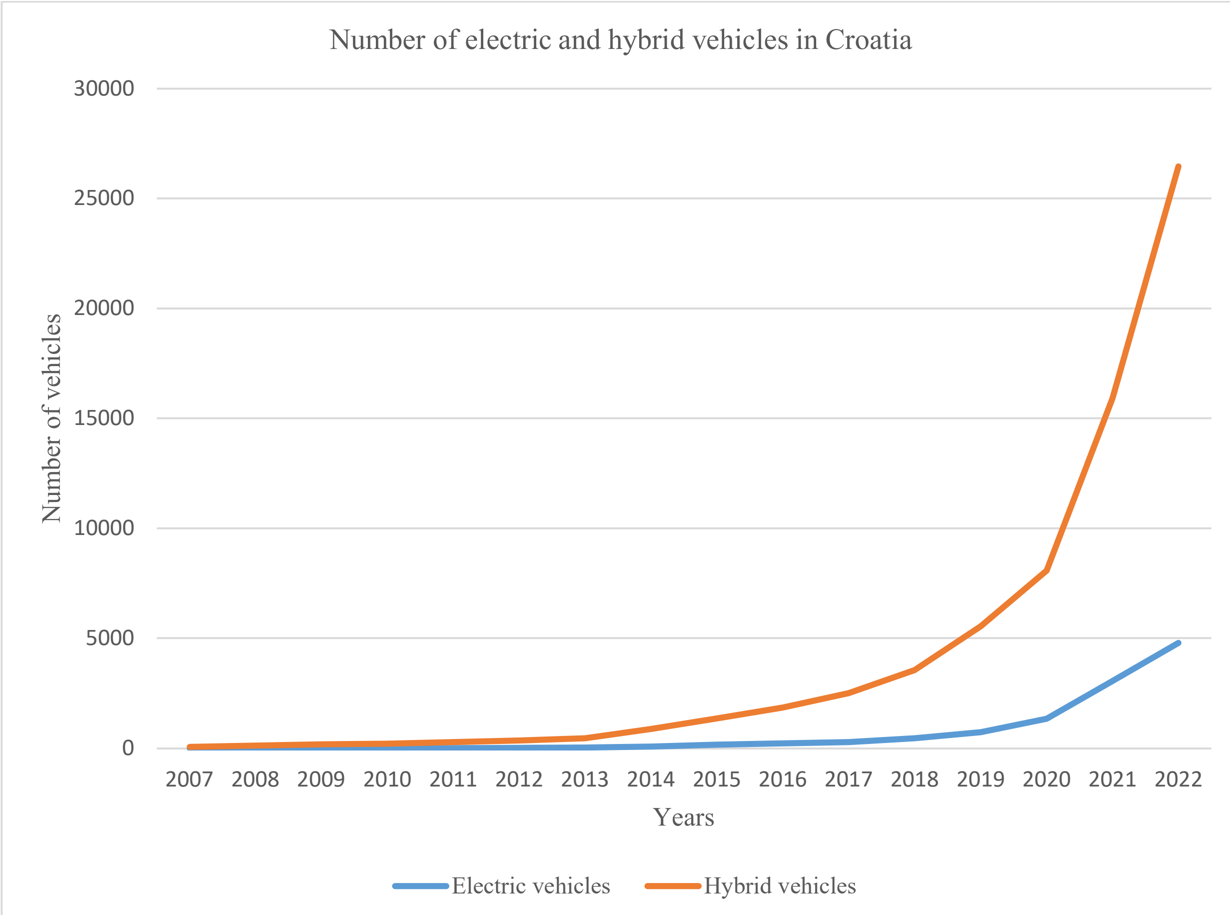

Figure 2. Trends of using electric and hybrid vehicles in Croatia 2007. – 2022.

5. CASE STUDY: USING ELECTRIC VEHICLES IN PARCEL DELIVERY

In this chapter, the advantages and disadvantages of the application of EVs are presented, with an emphasis on the profitability of their introduction into the fleet of a company whose name has not been specified due to data confidentiality and is referred to in the following text as the Company. The Company deals exclusively with the transportation of packages in cardboard boxes in domestic and international traffic. The company's fleet in Sesvete consists of 19 ICEVs and nine EVs.
Annual refueling/recharging costs of the Company's ICEVs and EVs are calculated based on the data given in the Table 4. It is important to note that calculation is based on 250 working days in a year.

Table 4. Annual refueling/recharging costs for Company's ICEVs and EVs

	Renault Master	Renault Kangoo	Mercedes Vito	Renault Master E-tech	Renault Kangoo Z.E.	Mercedes eVito
Average distance	110 km/day			60 km/day		
Average consumption	8,0 l/100 km	5,2 l/100 km	7,3 l/100 km	21,0 kWh/100 km	15,2 kWh/100 km	20,0 kWh/100 km
Tank/battery capacity	80,0 l	60,0 l	70,0 l	50,0 kWh	31,2 kWh	41,0 kWh
Fuel/power price	1,40 €/l			0,082 €/kWh		
Refueling / recharging	28/year	25/year	32/year	83/year	83/year	83/year
Annual costs	**3.136,00 €**	**2.100,00 €**	**3.136,00 €**	**341,67 €**	**213,20 €**	**272,24 €**

Source: Calculated by the authors against the data provided by the Company

The structure of the annual operative costs of ICEVs and EVs is presented in Table 5. It consists of inspection, registration, insurance, maintenance, tires and amortization (over four years period) as fixed costs, and refueling/recharging as main variable costs. Also, the Company has been granted the government incentives, that subsidise 40% of the EVs purchasing price, which has been taken into account of the amortization costs.

The Power cost of EVs (Table 4. and Table 5.) would be 83,33% higher if the average daily distance was the same as of ICEVs (110 km), however it wouldn't make a significant difference.

Table 5. Comparison of the annual cost structure across the Company's vehicles

Costs	Renault Master	Renault Kangoo	Mercedes Vito	Renault Master E-tech	Renault Kangoo Z.E.	Mercedes eVito
Inspection [€]	26,86	26,86	26,86	26,86	26,86	26,86
Eco test [€]	17,01	17,01	17,01	0	0	0
Road fee [€]	114,6	70,66	114,6	45,84	38,97	43,18
Environment fee [€]	45,87	25,47	37,05	4,41	4,41	4,41
Other fees [€]	21,02	21,02	21,02	21,02	21,02	21,02
Insurance [€]	315,00	267,00	310,00	356,00	307,00	353,00
Maintenance [€]	270,00	231,00	270,00	158,00	146,00	158,00
Tires [€]	246,00	176,00	246,00	283,00	220,00	283,00
Amortization [€]	13.728,00	5.688,00	13.728,00	8.740,80	5.241,60	9.964,80
Fuel/Power [€]	3.136,00	2.100,00	3.136,00	341,67	213,20	272,24
Number of vehicles	3	4	2	3	4	2
Total annual costs per vehicle [€]	53.761,08	34.492,08	35.813,08	29.932,8	24.876,24	22.193,02
Total annual cost [€]	**124.066,24**			**77.002,06**		

Source: Data provided by the Company

6. DISCUSSION OF THE RESULTS

The operative costs of EVs are significantly lower, but beside the operative costs given in Table 5. the costs of infrastructure for charging EVs must also be considered. The costs structure of the infrastructure for charging EVs is given in Table 6.

Table 6. The costs structure of the infrastucture for charging EVs

Fast charging installation [€]	130.000
Normal plugs (slower charging) [€]	8.000
Electric network upgrade [€]	25.000
Charging cable installation [€]	3.600
Charging rack installation [€]	2.250
Total costs of the infrastructure [€]	**168.850**

Source: Data provided by the Company

Based on the data on the total annual operating costs of ICEVs and EVs (Table 5) and the total costs of the charging infrastructure (Table 6), the introduction of EVs will pay off in the fourth year, as shown in Figure 3.

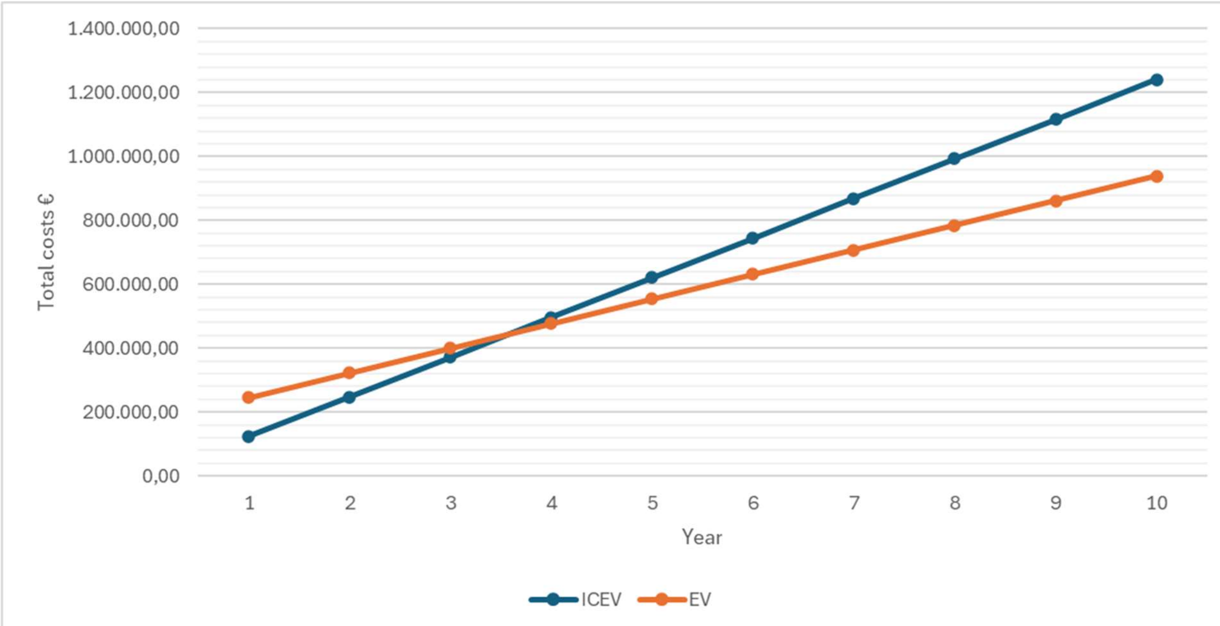

Figure 3. Costs of ICEVs and EVs

Also, the Company invested into installation of solar panels, to produce power for charging the EVs from renewable source of energy. The cost structure for installation of solar panels is given in Table 7.

Table 7. Costs structure for installation of solar panels

Solar panels	10.000 €
Assembly and small equipment	7.500 €
Examination of installation – preparation of reports	495 €
Cables, connectors and protective cabinet	3.880 €
LiFePO4 battery system	2.450 €
Total costs	**24.325 €**

Source: Data provided by the Company

According to the data in Table 5, annual cost of charging EVs amounts 2.422,29 €. With reference to that, instalation of the solar panels (Table 7) will pay off within the period of 10 years, as shown in Figure 4.

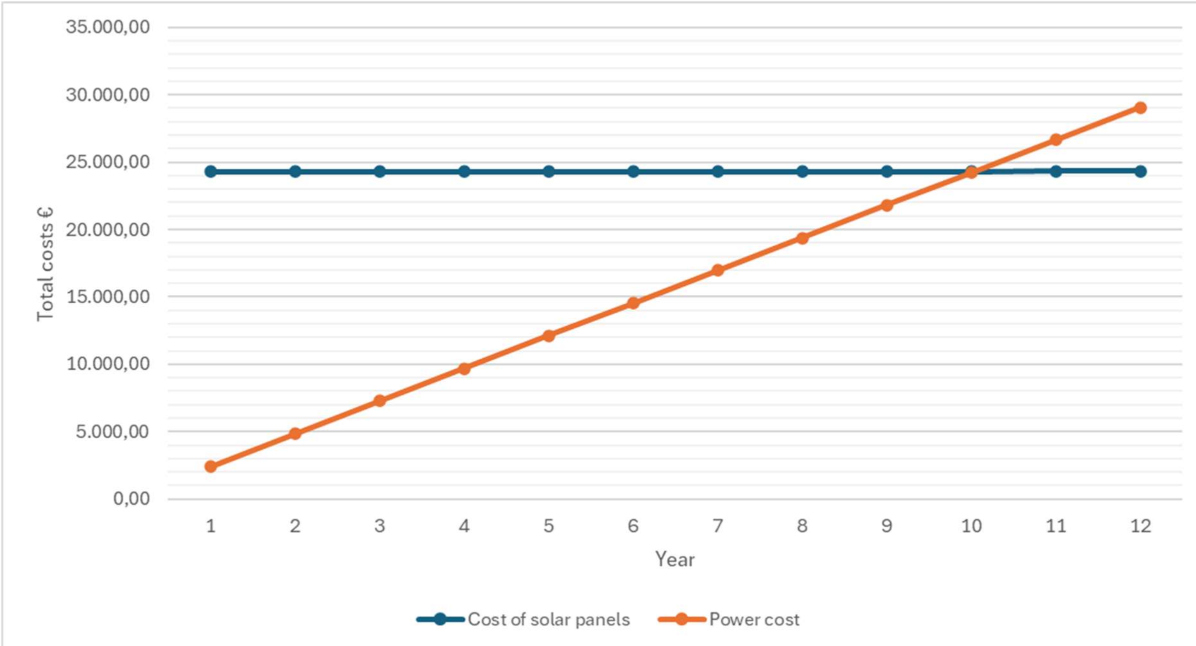

Figure 4. Investment in solar panels

Although the CO_2 footprint in production of EVs is greater than of ICEVs, they do not emit CO_2 during exploitation. Compared to the CO_2 emission of ICEVs (Table 8), EVs are more environmentally friendly, which is especially important in LMD, where transport operations take place in urban areas.

Table 8. CO_2 emissions of the Company's ICEVs

	Renault Master	Renault Kangoo	Mercedes Vito
Emissions of CO_2 [g/km]	280	150	240
Working days in a year	250		
Average daily mileage [km]	110		
Number of vehicles in the fleet	11	5	3
Annual emissions of CO_2 [kg]	84700	20625	19800

Source: Calculated by the authors against the data provided by the Company

The discussion of the results mainly refers to the economic parameters, as they directly effect the profitability of the Company operatons, which is the major concern of the management in terms of strategic decisions and sustainability of the business, although the environmental issues are constantly gaining more importance.

7. CONCLUSIONS

The results of the case study show that the use of EVs in performing LMD enables sustainability in terms of economy, as well as in terms of environmental impact. Although EVs do not emit CO_2 during exploitation, i.e. performing transport operations, greenhouse gases are emitted during the production process of such vehicles, also various toxins are released at recycling the batteries. Despite this, they are still considered the most energy efficient and environmentally friendly means of transport.

High purchase prices of EVs are compensated by the government incentives, while their limited operative range and longer charging times are not a problem in performing LMD, while the companies can benefit from lower operative costs and environmental neutrality, which improve their business in terms of sustainability.

In addition, solar energy plays important role in charging EVs, providing for environmental benefits, cost savings, energy independence and sustainable transportation. Also, ongoing advancements in solar panel efficiency make solar energy more economical and feasible option for charging EVs.

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