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Research Article

Which one is greener for the consumer? Product emission comparison between diesel and battery electric vehicles

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ABSTRACT

This study delves into a comparative analysis of electric vehicles (EVs) and diesel vehicles (DVs) across emissions, design, technology, and fuel consumption. One of the aims is to reveal the relationship between changes in form-based mass of the designed part, material selection influenced by production technologies, and the resulting production emissions and mass-based fuel consumption. The research aims to elucidate the environmental impact of EVs and DVs, particularly focusing on emissions stemming from raw materials of the production. Methodologically, the study employs theoretical analysis alongside practical assessments using Autodesk Fusion 360 and CCaLC2 software for mass determination and emissions calculation, respectively. Through an examination of key parameters such as vehicle design, material usage, and powertrain systems, the study sheds light on the nuances of emissions generated by each vehicle type's parts. The research contextualizes the growing importance of sustainable transportation solutions in the face of escalating environmental concerns, emphasizing the need for rigorous evaluation of alternative fuel vehicles. By comprehensively analyzing data on emissions, design, and fuel consumption, the study provides insights into the complexities of sustainability in the automotive industry. The findings underscore the critical role of industrial design in emissions reduction and offer recommendations for stakeholders to prioritize sustainability in vehicle production and consumption practices. Also, mentioning important notes for green consumers who are buying products according to environmental effects. The study contributes to advancing understanding in the field of sustainable transportation and underscores the importance of methodological rigor in evaluating environmental impacts.

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INTRODUCTION

In today's world, the transition to alternative fuel vehicles has accelerated due to the emissions created by fossil fuels. As it is known, production accelerated after the industrial revolution, and this acceleration increased the supply and demand [1]. The increase in supply also impacted population growth momentum. This growth in both supply and demand in production has also triggered resource use and emission problems. Today, the transportation and automotive sectors exemplify this supply and demand relationship. In parallel with the increasing population, vehicle demands are also increasing [2]. Consequently, emissions from vehicle fuels have become a significant issue. Alter-

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native fuel vehicle technologies were developed through research and development (R&D) to reduce emissions from fossil fuel vehicles. The most effective solutions today include hybrid, fully electric, and hydrogen-powered engines. Alternative fuel vehicles, called hybrids, contain electric propulsion systems along with fossil fuel. Thanks to this mixed resource use of the vehicle, fossil fuel usage is reduced. In fully electric vehicles, there are differences depending on the battery solutions [3]. As the name suggests, electric vehicles provide movement using electrical power. However, the battery technologies used in this technology have serious effects on the range and usage of the vehicle. Another technology is engines powered by hydrogen. These engines are still being developed to be more efficient [4]. Hydrogen engine vehicles use the energy produced by the combustion of hydrogen gas [5]. Extensive studies are being carried out on the release of oxygen to nature as a result of burning hydrogen due to its structure. R&D studies continue in this field within the scope of engine cost and commercial profit margin.

Apart from hybrid, electric vehicles that run entirely on alternative fuel sources are divided into battery electric vehicles and plug-in electric vehicles. Battery electric vehicles are considered to be very efficient in reducing emissions [6]. It is explained that environmentally friendly transportation can be achieved if the energy stored in the battery is used to reduce greenhouse gas emissions and the energy drawn from the lines to the battery is produced from renewable energy systems such as solar panels and wind turbines. In addition, the two biggest problems of battery electric vehicles are the product life cycle (lifespan of the vehicle) and the limited range of the batteries [7]. There are differences in terms of energy density between the technology used in the batteries of battery electric vehicles and the products made of different minerals. According to these differences; Lithium-ion battery is most suitable for use in vehicles, but rapid aging and decreased durability occur in fast charging situations. The use of LTO ($Li_4Ti_5O_{12}$) and LFP ($LiFePO_4$) cells within the scope of fast charging for high battery volumes is also common. In lithium-ion battery technologies, the battery type with the highest energy density compared to other lithium batteries is lithium nickel manganese cobalt oxide (NMC) [8]. Plug-in hybrid vehicles use a plug-in mechanism to charge their batteries, distinguishing them from conventional plug-in electric vehicles, which do not have a fossil fuel engine. It contains low-capacity batteries and uses electricity and fossil fuel effectively during long-term journeys, thanks to its systems that use fossil fuels [7]. Due to the reduction in fossil fuel consumption on long journeys and the efficiency of electricity in short-distance working situations, it is ensured that it operates with an optimum combined consumption.

In addition to optimum greenhouse gas emission and consumption studies provided commercially, one of the most important issues of today is sustainability, and achieving sustainability targets in both production and consumption have become a common goal for all stakeholders in society. The United Nations recognized that the world's resources are not unlimited and brought up the issues of sustainable production and consumption in 1972. In the meetings held in Rio de Janeiro in 1992, unsustainable production and consumption models were shown as the most important reason for the constant deterioration of the global environment. The definition of sustainable production and consumption was made at the meeting held in Oslo in 1994, and in 2015, a common decision was reached by the countries on the "2030 Agenda for Sustainable Development and 17 Sustainable Development Goals" in order to transform the world for the better [9–11]. According to Zuo et al. [12] in their study, likens sustainability to a structure consisting of three pillars: the environment, economy and society, and states that these three pillars must be balanced in order for sustainability to be built more solidly. However, it appears that these three dimensions are not treated equally in ensuring sustainable development. It seems that most of the sustainable efforts, especially in transformation processes, are directed towards issues related to environmental sustainability, such as energy efficiency, carbon emissions, resource consumption, ecology and waste management [12].

Günaslan et al. [13], in their study evaluating the life cycle of electric vehicles, state that the main factors causing greenhouse gas emissions emerge during the production process of these vehicles. They suggest that different technological developments are needed to improve the current situation. In another study investigating the relationship between circular economy and company performance, it was found that the circular economy has a significant and positive relationship with company performance. When the circular economy components are examined separately on a business basis, it is stated that businesses are turning to the production of sustainable products by taking measures such as reducing consumption or saving resources [14]. With the acceleration of studies in this direction after the sustainability criteria published by the European Union, green purchasing behavior has developed and attracted the attention of both academic and business circles. In order to encourage the adoption of green products, it has become important to identify moderators that can increase the consistency between attitude and behavior in the consumption of green products [15].

Setting aside any inherent contradictions in the concept, green consumerism is described as an accessible way for a significant portion of the Western industrial population to engage in pro-environmental and sustainable behavior. This includes purchasing energy star-labeled appliances, buying organic produce, conserving energy by turning off electrical appliances when not in use, and shortening shower times [16]. Green consumerism, defined as an accessible way to engage in pro-environmental and sustainable behavior for a significant part of the Western industrial population [16], and green products, defined as products produced in accordance with environmentally friendly and environmental sustainability [17], are now awareness

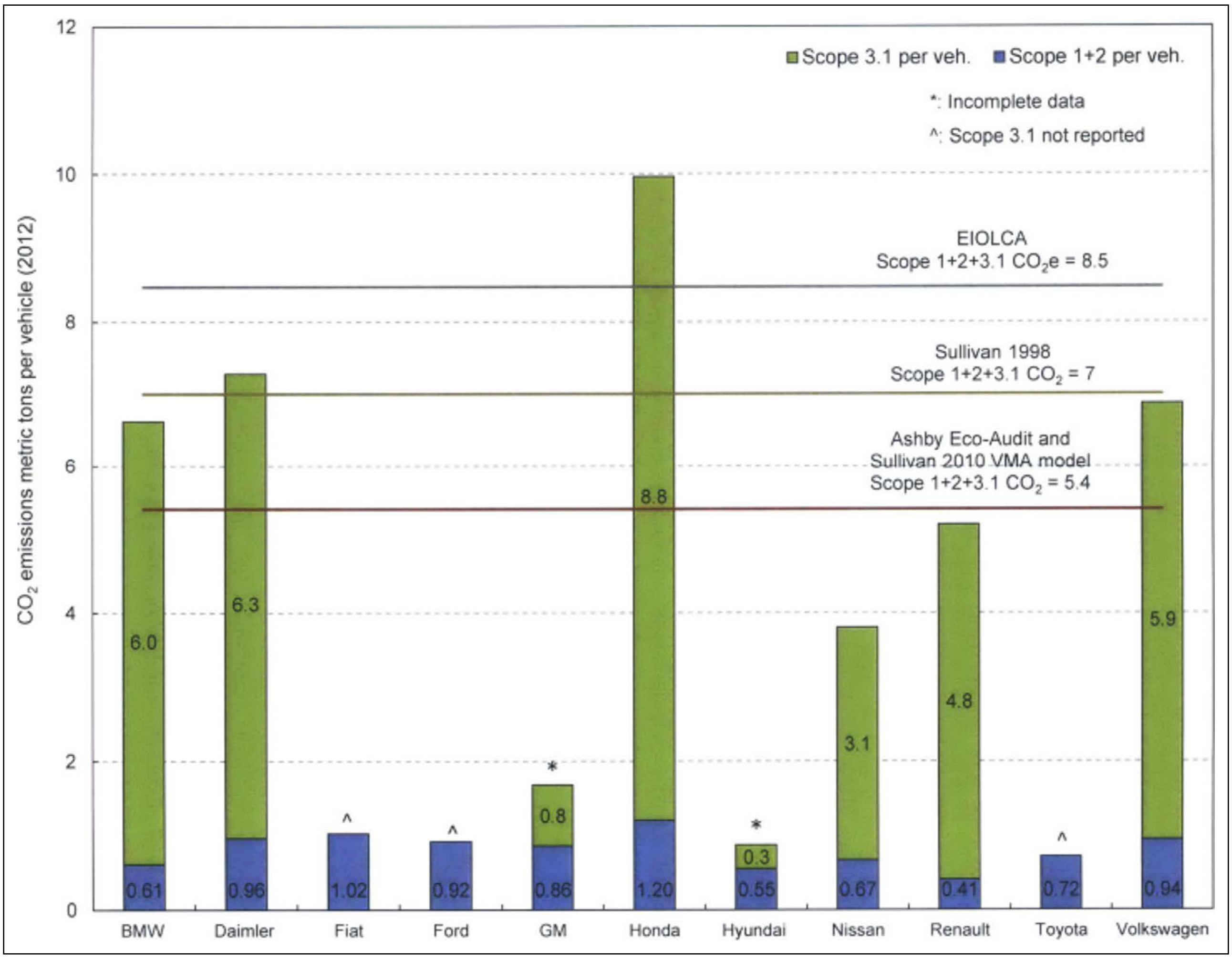

Figure 1. Scope 1, 2 and 3 emissions of vehicle manufacturers given in Raykar's thesis [19].

of consumers. Products that claim to be green or environmentally friendly are being researched more carefully by consumers before purchasing. Questions such as whether battery electric vehicles, which have become widespread because they are said to be economical and environmentally friendly, are really environmentally friendly or just reduce emissions caused by fuel consumption, are becoming more important day by day.

Regarding the reporting of emissions implemented by the European Union and how the reporting in vehicle production is done, the European Union examines emissions in three categories: scope 1, 2 and 3. In order to determine the positions of the parameters under the scopes in the calculations made; It refers to the direct emissions caused by the organization or its parts under scope -1 [18]. Scope -2 refers to indirect emissions such as purchased electricity and heat, which the organization does not produce directly but causes to be produced by purchasing what is produced. Scope -3 refers to the indirect emissions resulting from the activities of all the remaining organizations and their products. These emissions include emissions made by the company's stakeholders, transportation and distribution, purchased, rented parts, etc. They are called indirect emissions caused by the organization.

According to the research, the emissions shared by vehicle manufacturers globally are scope 1 and scope 2 emissions, and these are data related to emissions such as the processes used to shape the material in the factory, welding, and the energy used by the factory [19]. It has been understood that vehicle manufacturers also supply the metals and other parts they purchase for shaping under scope 3 because they do not produce them themselves but procure them from outside.

As seen in Figure 1, it is understood that the emissions caused by vehicle production are not only scope 1+2 emissions shared by the factories, but are the emissions caused by the vehicle manufacturers' own factories. Based on the values given in Figure 1, it has been seen that in order to understand how much emissions a vehicle causes, scope 3 data should also be looked at. According to the specified emissions, these values show radical changes to various parameters, such as the segment of the vehicles, the technologies used [20], the countries where the production and suppliers are located [21].

In the study, it was investigated which of these vehicles, Renault Clio as a diesel vehicle and Renault Zoe as a battery-electric vehicle, is more suitable for green consumer, considering the production and usage processes of these vehicles. Whether this green consumption depends only on the raw material of the vehicle will be examined in terms of other factors like fuel usage within the scope of the study. In the following sections, vehicle specifications including powertrain are provided. Each component is delineated in the methodology by a percentage, calculated in kilograms. Weight values for each material are multiplied by emissions to determine raw material emissions in this study. Furthermore, energy sources and their usage, along with emissions from various sources, are compared with the total raw material emissions of the vehicle.

In the following chapters, there are comprehensive analysis comparing diesel and electric vehicles, focusing on their environmental impact, design considerations, and technological aspects. The study employs advanced software tools to examine vehicle components, material composition, and associated emissions. There are detailed comparisons of emissions from raw materials, production processes, and fuel consumption for both vehicle types in Materials and Methods section. The research challenges common perceptions about electric vehicle sustainability, revealing how factors such as energy sources and geographical locations significantly influence their environmental impact, which is mentioned in the Results and Discussion section. The study also highlights the crucial role of designers in reducing emissions through thoughtful design choices in Conclusion section. Additionally, the analysis provides valuable insights into the relationship between vehicle design, material usage, and emissions which are also mentioned in the Recommendations section.

MATERIALS AND METHODS

This study aims to reveal the accuracy or inaccuracy of the hypothesis through theoretical analysis of the results. Autodesk Fusion 360, one of the computer-aided design software, is used to determine vehicle part masses. Then, the emission values of the parts will be calculated according to raw material usage rates using CCaLC 2 software [22]. Analysis will be carried out to compare the basic hypothesis of the study, examining how sustainable electric vehicles and diesel vehicles are in terms of parts and fuel consumption calculations. CCaLC 2 is an essential tool that uses one of the most important material database for sustainability, Ecoinvent. Consider revising for clarity: "The aim is to contribute to relevant scientific fields by detailing raw material usage emissions through vehicle parts and, consequently, Scope 3 emissions. The methodology of this article is explained in Figure 2 as flow chart diagram.

As mentioned in Figure 2, two types of vehicles were considered as constraints. Renault Clio as a diesel vehicle and Renault Zoe as a battery electric vehicle constitute these vehicles. [23]. While the features of the diesel vehicle are given in Table 1, the basic features of the battery electric vehicle are given in Table 2. The model of the Renault Clio vehicle with a diesel engine is 2012, and the model of Zoe is 2016 [24].

Table 1. Key specifications for Renault Clio [23]

Parameters	Specifications
Engine	Diesel 1.5 dci 51 kW
Total weight (kg)	1185 kg

Table 2. Key specifications for Renault Zoe [24]

Parameters	Specifications
Battery	Li-Ion NMC-41 kWh
Electric motor	AC 65 kW
Total weight (kg)	1480 kg

Table 3. Mass distribution of parts excluding powertrain systems for diesel vehicle [25]

Section name	Percent by mass (%)
Body in white	30
Closures/fenders	11
Suspension/chassis	28
Glazing	3
Lighting	1
Interior	19
Electrical	4
Thermal	2
Bumpers	2

In selecting the specified vehicle models, the parameter of accessibility to research data conducted in the global literature came to the fore. Such an approach was taken because companies will not share such detailed data. Therefore, the calculations do not reflect Renault data, but will show approximate data of any vehicle with similar design features. Vehicle segments are taken as economy segments due to material usage data. A reference source will be used that equates part weights as percentages based on the total mass of the vehicles. This reference will allow us to determine the amount of material used in various vehicle parts by mass.

As seen in Table 3, the percentage distribution by mass of the vehicle, excluding powertrain parts, is given. Using these percentages, it will be seen how much plastic or metal an economy segment vehicle uses, and the emissions within the scope of raw materials will be revealed.

Calculations for a diesel vehicle are based on the constraints of a 121.7 kg engine and 54.2 kg of transmission parts (including differentials, axles, and bearings) [26],

$$\Sigma W\ (kg) - 175.9\ (kg) = \Sigma NetW\ (kg) \quad (1)$$

By using the equation (1), the total net weight, excluding powertrain, in kg will be calculated using the mentioned symbol, $\Sigma NetW$. ΣW symbol refers to total weight in kg, including powertrain. Data on the percentage mass distribution among vehicle parts will be obtained. When calculating the total mass of each part,

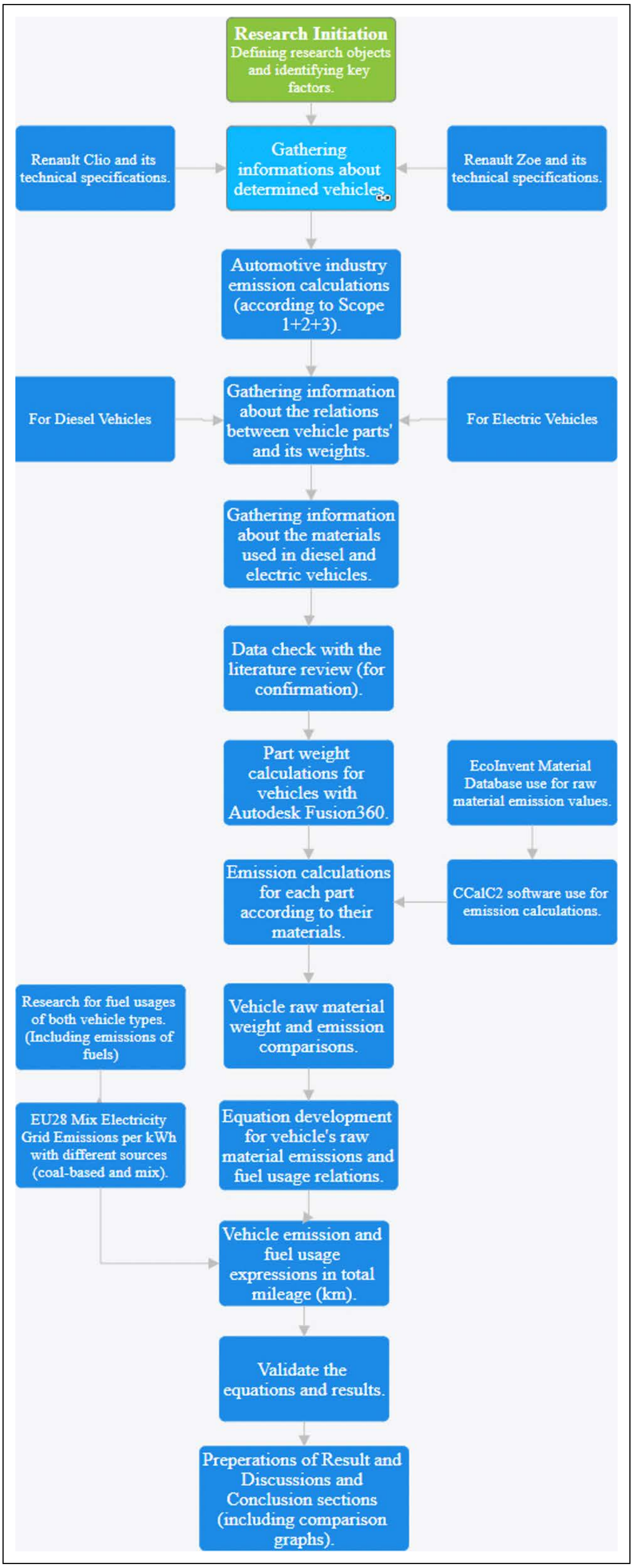

Figure 2. Flow chart diagram for the detailed explanation of methodology.

Table 4. Powertrain parts and masses for battery electric vehicle

Part name	Specifications	Net weight (kg)
Battery Pack 41 kWh Li-Ion	192 cells, 940 grams	305 kg [28]
Electric motor	65 kW	65 kg [29]
Transmission (shafts, differential, casings, bearings etc.)	–	18.1 kg [30]

Table 5. Percentage of materials excluding powertrain in general mass [25]

Section name	Material name	Percent by section's mass (%)	Percent by overall mass (%)
Body in white	Mild steel	88	26.4
Body in white	Low carbon steel	9	2.7
Body in white	Paint and isolation materials	3	0.9
Closures/fenders	Mild steel	97	10.67
Closures/fenders	Low carbon steel	3	0.33
Interior	Plastics	39% Plastics (90% Polypropylene, 6% Acrylonitrile Butadiene Styrene, 4% Polyurethane)	7.41
Interior	Low carbon steel	36	6.84
Interior	Wood fiber	1	0.19
Interior	Fabric	5	0.95
Interior	Carpets	14	2.66
Interior	Glass	5	0.95
Suspension/chassis	Mild Steel	46	13.08
Suspension/chassis	Low Carbon Steel	15	4
Suspension/chassis	Aluminium	18	5.04
Suspension/chassis	Others	21	5.88
Glazing	Glass	100	3
Lighting	Polycarbonate	100	1
Electrical	Others	100	4
Thermal	Plastics	100	2
Bumpers	Mild steel	100	2

$$\sum SW\ (kg) = \frac{Percent\ by\ Mass\ (\%)\ x\ \sum NetW\ (kg)}{100} \quad (2)$$

equation will be used. Section weights ($\sum SW$) will be calculated as mentioned (2). According to the research, the use of iron and steel in the powertrain systems of diesel vehicles averaged 57% for vehicles between 2011 and 2014. In cases where data is inaccessible while performing calculations, this ratio will be used to continue the calculations. [26].

Given the absence of a transmission in the powertrain systems of battery electric vehicles, it is crucial to know the masses of the battery pack and electric motor. According to this, the data given in Table 4 was accepted as a limitation in the research data obtained [27].

Based on the values given in Table 4, it can be seen that the powertrain for an electric vehicle has an average mass of 388.1 kg. Based on this, the equation applied to the diesel vehicle should be repeated, and the calculation should be made as,

$$\sum W\ (kg) - 388.1\ (kg) = \sum NetW\ (kg) \quad (3)$$

After separate calculations are made for each vehicle (3), detailed data in terms of material usage will emerge, so it is necessary to go into the material details of the sections under the section name.

It was aimed to obtain the net masses of the parts and materials used for both vehicles based on their ratio to the general mass, using constant coefficients taken from international automotive industry publications. The values are given in Table 5. CCaLC2 software is used to calculate raw material emissions. In these calculations, the term 'At plant' refers to emissions associated with the production of ready-to-use materials from raw materials.

(F.u. stands for Functional Unit) As seen in Table 6, the main cause of emissions is non-natural materials. The first highest emission value comes from industrial paints, followed by aluminum at 12.0 kg, and the lowest emission value is found in tempered glass at 0.235. Since there is no

Table 6. Emission values provided via CCaLC2 software

Raw material	Amount (kg/f.u.)	CO_2 eq. (kg/kg raw material)	CO_2 eq. (kg/f.u.)	Database section
1 hour painting and ısolation	1.00	268	268	
2 square meter – polyester (27.8 kg)	1.00	6.40	6.40	
Acrylonitrile butadiene styrene at plant	1000	4.40	4403	Ecoinvent / materials
Aluminium at plant	1000	12.0	1.20E+4	Ecoinvent / materials
Copper production, primary, EU	1000	1.91	1911	Ecoinvent / materials
Nylon 6 at plant	1000	9.29	9285	Ecoinvent / materials
Polycarbonate at plant	1000	7.79	7788	Ecoinvent / materials
Polypropylene granules at plant	1000	1.98	1983	Ecoinvent / materials
Polyurethane flexible foam at plant	1000	4.85	4845	Ecoinvent / materials
Polyvinylidenchloride granules at plant	1000	4.92	4916	Ecoinvent / materials
Synthetic rubber at plant	1000	2.66	2656	Ecoinvent / materials
Tempering, flat glass	1000	0.235	235	Ecoinvent / materials
Turning, steel, conventional, average	1000	3.34	3343	Ecoinvent / materials
Turning, steel, conventional, primary	1000	3.22	3219	Ecoinvent / materials
Total	**1.20E+4**	**Total:**	**5.69E+4**	

Table 7. Net weights of parts for diesel vehicle

Section name	Percent by mass (%)	Net weight (kg)
Body in white	30	302.73
Closures/fenders	11	111
Suspension/chassis	28	282.55
Glazing	3	30.27
Lighting	1	10.09
Interior	19	191.74
Electrical	4	40.36
Thermal	2	20.18
Bumpers	2	20.18

Table 8. Net weights of parts for battery electric vehicle

Section name	Percent by mass (%)	Net weight (kg)
Body in white	30	327.57
Closures/fenders	11	120.11
Suspension/chassis	28	305.74
Glazing	3	32.75
Lighting	1	10.92
Interior	19	207.47
Electrical	4	43.68
Thermal	2	21.83
Bumpers	2	21.83

recycling in the evaluations, pure values, which include the use of raw materials, were used. Studies can also be conducted that include factors such as production, transportation, wastewater resources, and other emissions. However, since it is not the focus of this study, this includes a comparison of electric vehicles and diesel vehicles and basic material usage emissions.

Data on fuel consumption per 100 km [23] for both vehicle types were found in the literature. When looking at the real-time fuel consumption of the vehicles, it was found that the electric vehicle consumed 16.6 kWh of electricity at a distance of 100 km, and the diesel vehicle consumed 4.9 L of fuel at a distance of 100 km. The greenhouse gas emission directly caused by 1 liter of diesel fuel is 2.64 kg CO_2. For the European Union EU28 mix (2016), 1 MWh of electrical energy corresponds to 295.8 kg of CO_2 emissions. If 1 MWh of electrical energy is produced from a coal-consuming power plant (according to EU28 mix source), it results in 850 kg of CO_2 emissions [31], which means 0.85 kg of CO_2 emissions per kWh.

It has been observed that the mass of the economic segment, diesel vehicle's mass is 1185 kg; it is 1009.1 kg, excluding the powertrain. When the percentage application was performed to determine the masses of the other parts, the results in Table 7 emerged.

It is seen that the powertrain systems in the battery electric vehicle with a mass of 1480 kg correspond to a value of 388.1 kg. It can be said that the mass excluding the powertrain is calculated as 1091.9 kg.

The values given in Table 8 also take into account the design-related emissions in the production of electric vehicles. The biggest reason why there are different values in both tables is that the design of both vehicles is different. The difference in powertrain systems accounts for the variation in overall vehicle mass.

Table 9. Materials massively used in diesel and battery electric vehicles

Section name	Material name	Percent by overall mass (%)	For diesel vehicle (kg)	For battery electric vehicle (kg)
Body in white	Mild steel	26.4	266.40	288.26
Body in white	Low carbon steel	2.7	27.24	29.48
Body in white	Paint and ısolation materials	0.9	9.08	9.83
Closures/fenders	Mild steel	10.67	107.67	116.51
Closures/fenders	Low carbon steel	0.33	3.33	3.60
Interior	Plastics (polypropylene) [32]	6.67	67.31	72.83
Interior	Plastics (ABS)	0.44	4.44	4.80
Interior	Plastics (polyurethane)	0.30	3.02	3.28
Interior	Low carbon steel	6.84	69.02	74.69
Interior	Wood fiber*	0.19	1.92	2.07
Interior	Fabric (polyester)	0.95	9.59	10.37
Interior	Carpets (nylon) [33]	2.66	26.85	29.04
Interior	Glass	0.95	9.59	10.37
Suspension/chassis	Mild steel	13.08	131.99	142.82
Suspension/chassis	Low carbon steel	4	40.36	43.68
Suspension/chassis	Aluminium	5.04	50.86	55.03
Suspension/chassis	Others (wheels - Rubber)	5.88	59.34	64.21
Glazing	Glass	3	30.28	32.75
Lighting	Polycarbonate	1	10.09	10.92
Electrical	Others (battery, wires, electronics etc.)*	4	40.36	43.68
Thermal	Plastics (polyvinyl chloride) [34]	2	20.18	21.84
Bumpers	Mild steel	2	20.18	21.84
Total	–	**100%**	**1009.1**	**1091.9**

Table 10. Emissions from powertrain parts of diesel and battery electric vehicles

Diesel vehicle powertrain parts	Emissions (CO_2 Eq. (kg/f.u.)	Battery electric vehicle powertrain parts	Emissions (CO_2 Eq. (kg/f.u.)
Engine	**406.47**	Electric Motor [35] (%42.37 mild steel, %12.89 low carbon steel, %17.32 aluminium, %8.88 copper, %18.54 others)	91.98 + 26.97 + 135.09 + 11.02 = **265.06**
Transmission (including shafts, differential, axles etc.)	**174.52**	Battery	**2160** [36]
		Power Inverter, Converter (**), Transmission (shafts, differential, casings, bearings etc.)	100 (**)+58.28 =
Sum of emissions (CO_2 Eq. (kg/f.u.)			**158.28**
580.99			**2583.34**

Table 9 shows the usage of diesel and battery electric vehicle materials in kilograms. Accordingly, the amount of usage on a material basis is shown. The amount of materials used by the vehicles and the changes in kilograms due to the design factor are also expressed in this table. Parameters marked * are not included in the emission calculations of both vehicles. Wood Fiber is not included in the emission calculations due to its low usage rate and the natural nature of the material.

In Table 10, emission values are calculated based on the raw materials used, based on the masses of the parts in the powertrain systems of battery electric vehicles and diesel vehicles. 18.54% of the electric motor could not be included in this cal-

Table 11. Material emission data for electric vehicles

Raw material	Amount (kg/f.u.)	CO_2 eq. (kg/kg raw material)	CO2 eq. (kg/f.u.)	Database section
*Others (including powertrain)	2583	1.00	2583	
1 hour painting and isolation	1.00	268	268	
2 square meter – polyester (27.8 kg)	0.373	6.40	2.39	
Acrylonitrile butadiene styrene at plant	4.80	4.40	21.1	Ecoinvent / materials
Aluminium at plant	55.0	12.0	663	Ecoinvent / materials
Nylon 6 at plant	29.0	9.29	270	Ecoinvent / materials
Polycarbonate at plant	10.9	7.79	85.0	Ecoinvent / materials
Polypropylene granules at plant	78.2	1.98	144	Ecoinvent / materials
Polyurethane flexible foam at plant	3.28	4.85	15.9	Ecoinvent / materials
Polyvinylidenchloride granules at plant	21.8	4.92	107	Ecoinvent / materials
Synthetic rubber at plant	64.2	2.66	171	Ecoinvent / materials
Tempering, flat glass	43.1	0.235	10.1	Ecoinvent / materials
Turning, steel, conventional, average	569	3.34	1904	Ecoinvent / materials
Turning, steel, conventional, primary	151	3.22	488	Ecoinvent / materials
Total	**3611**	**Total:**	**6732**	

Table 12. Material emission data for diesel vehicles

Raw material	Amount (kg/f.u.)	CO_2 eq. (kg/kg raw material)	CO_2 eq. (kg/f.u.)	Database section
*Others (including powertrain)	581	1.00	581	
1 hour painting and isolation	1.00	268	268	
2 square meter – polyester (27.8 kg)	0.345	6.40	2.21	
Acrylonitrile butadiene styrene at plant	4.44	4.40	19.5	Ecoinvent / materials
Aluminium at plant	50.9	12.0	612	Ecoinvent / materials
Nylon 6 at plant	26.9	9.29	249	Ecoinvent / materials
Polycarbonate at plant	10.1	7.79	78.6	Ecoinvent / materials
Polypropylene granules at plant	67.3	1.98	133	Ecoinvent / materials
Polyurethane flexible foam at plant	3.02	4.85	14.6	Ecoinvent / materials
Polyvinylidenchloride granules at plant	20.2	4.92	99.2	Ecoinvent / materials
Synthetic rubber at plant	59.3	2.66	158	Ecoinvent / materials
Tempering, flat glass	39.9	0.235	9.35	Ecoinvent / materials
Turning, steel, conventional, average	526	3.34	1759	Ecoinvent / materials
Turning, steel, conventional, primary	140	3.22	450	Ecoinvent / materials
Total	**1530**	**Total:**	**4435**	

culation due to the variety of sub-materials, and the constant coefficient in power inverters and converters was considered as 100 kg CO_2. The calculated CO_2 emissions were 2583.34 kg for battery electric vehicles and 580.99 kg for diesel vehicles.

The main focus of the study was the supply of materials from manufacturers' scope 3 emissions. The values given in Table 11 are the emission amounts caused by the specific raw materials used during the production of the vehicle. The machines used in the processes evaluated within the framework of scope 1 and 2 and their energy consumption are not included in the mentioned values. Additionally, calculations were conducted based on the total emissions of resulting parts, without distinguishing between scopes for parameters such as dyeing, powertrain, and polyester.

The parameters given in Table 12 are the emission values resulting from raw material consumption according to the raw material used during the production of a diesel vehicle. Within the scope of the study, the emissions resulting from the parts and materials required for the operation of the vehicles were found to be 6732 kg for electric vehicles and 4435 kg for diesel vehicles. Those values are results from Table 11 and Table 12.

$$\sum_{[Diesel]} R = \frac{4435\ kg\ CO2}{2.64\ kg\ CO2\ per\ Liter} \quad (4)$$

$$EM\ (km) = \frac{100\ km}{4.9\ Liter}\ x\ \sum_{[Diesel]} R \quad (5)$$

Total reps ($\sum_{[Diesel]}R$) values shows the total raw material emission's divided by energy emission per source (4,6). In the Expressed Mileage (EM) calculations (equivalent to km), the results are compared to the vehicle's raw material emissions and mileage emissions by energy source (5,7). When these values are compared with the fuel consumption of vehicles, diesel one will travel an average of 34270.63 km and will be equivalent to the emissions caused by the materials used. According to equations (4) and (5), higher fuel usage reduces mileage, while higher fuel emissions from the source also reduce mileage. Conversely, higher raw material emissions tend to increase mileage. However, it's important to note that higher raw material emissions typically lead to increased fuel usage. Therefore, the overall result is lower mileage for vehicles with higher raw material emissions. These calculations pertain specifically to automobiles. In electric vehicles, there is no stable value since the emissions resulting from the production of electricity are different in each country and each grid.

$$\sum_{[Electric]} R = \frac{6732\ kg\ CO2}{0.2958\ kg\ CO2\ per\ KWh} \quad (6)$$

$$EM\ (km) = \frac{100\ km}{16.6\ KWh}\ x \sum_{[Electric]} R \quad (7)$$

Accordingly, based on the EU28 mix (2016) value, it corresponds to the fuel consumption at an average distance of 137006.89 km. When you change the electrical energy source with its emissions (8), it will show the differences between energy sources in perspective of sustainable world (9).

$$\sum_{[CoalBasedElectric]} \boldsymbol{R} = \frac{\boldsymbol{6732\ kg\ CO2}}{\boldsymbol{0.85\ kg\ CO2\ per\ KWh}} \quad (8)$$

$$\boldsymbol{EM\ (km)} = \frac{\boldsymbol{100\ km}}{\boldsymbol{16.6\ KWh}}\ \boldsymbol{x} \sum_{[CoalBasedElectric]} \boldsymbol{R} \quad (9)$$

When electrical energy is provided from coal, the average distance reaches 47678.4 km. These findings indicate that before making claims about emission reductions from electric vehicles, the relevant parameters should be considered on a country, region, and power grid basis.

RESULTS AND DISCUSSION

This research study reveals the differences between electric vehicles and diesel vehicles in terms of emissions, design, technology, and fuel consumption. Even in design differences alone, changes in materials used and, consequently, emission increases have been highlighted. The aim was to understand whether electric vehicles or fossil fuel vehicles are less harmful to the environment in terms of emissions generated by design and product. Additionally, the effects of industrial design discipline on emissions were intended to be clearly demonstrated. As seen in the resulting tables, the segments of vehicles significantly affect emissions due to differences in design and material usage. Within this framework, an important example study has been presented for industrial designers and transportation vehicle designers to understand the sustainability and effectiveness of design on emissions. It has been understood that design activities conducted at the industrial level are not merely designs but can also lead to significant emissions, and designers can play a crucial role in reducing emissions. Given that green consumption and green production themes are deepening in today's conditions, it has been observed that the industry and consumers need to engage in production and consumption consciously.

As a result of the examination conducted on battery electric vehicles and diesel vehicles, it has emerged from the data that contrary to what is indicated in advertising campaigns, electric vehicle production results in more emissions, primarily due to battery-related factors. Diesel vehicles, on the other hand, do not cause additional emissions due to their use of more standardized technologies, while it has been understood that battery technologies are not part of a circular economy, both in their production and the minerals they use. Nowadays, the degree of "greenness" of the transition to electric vehicles under the banner of green transformation should be much more thoroughly debated. In today's context where electric vehicle emissions are produced with even more emissions compared to conventional vehicles, it can be observed that productions made under the concept of sustainability continue to harm the environment. Instead of converting as many vehicles as exist in the world to electric, a transformation journey has begun where vehicles are re-manufactured electrically in the same quantity as existing vehicles. This way, manufacturers continue their production with the potential for sales equivalent to the existing number of vehicles, rather than aiming to maintain or decrease the number of vehicles in the market.

In the research, not only material-based emission comparisons between electric vehicles and diesel vehicles were conducted, but also an attempt was made to calculate the distance equivalent of material emissions of vehicles through fuel consumption. As a result of the calculations, it was observed that while diesel vehicles provide a more consistent value, electric vehicles can have emissions from various fuel consumption sources through the grid they are connected to. For example, energy may be produced by wind turbines or solar panels on the grid where it is charged, while in another country or region, energy may come from power plants that consume coal. This diversity implies that electric vehicles can lead to significantly different fuel emissions regardless of the model or brand. While emissions per kilometer could be the same with diesel fuel on one hand, on the other hand, emissions per kilometer in electric vehicles could be 8 times, 9 times, or even higher differences with significantly lower emissions. In this context, whether electric vehicles are sustainable or not varies depending on the country, region, and grid they will be used in, and it would be more accurate to make an inference about their sustainability accordingly.

CONCLUSION

It is a fact that humanity faces various challenges in the face of changing and evolving technologies, with one of the foremost current issues being environmental disasters caused by the ease of mass production. In light of this reality, the desire of companies worldwide to implement sustainable economic growth with less environmental damage has become a prominent issue in today's industry. This study examines the transition to alternative fuel vehicles in the automotive industry in response to this situation, addressing how electric vehicles compare to fossil fuel vehicles in terms of their environmental impact, considering design and technological integration.

While factors such as the economic segment of the vehicle, materials used, and production capabilities concern the technological aspect, it has been determined how effective the design is in terms of emissions in the formation of the product, with parameters such as body in white, bumpers, trunk, windows, interior design, which are the parts where the design will be realized according to these capabilities. Especially in the automotive industry, it has been concluded that design should be done while considering technology, design, and carbon emissions.

The raw material emission section in Figure 3 is a significant aspect involving both technology and design considerations. It has been observed that even factors such as whether the vehicle is a hatchback or sedan greatly influence these emissions, and the adoption of alternative fuel technologies in vehicles leads to varying outcomes. While calculating emissions from usage and production is more feasible for diesel vehicles, electric vehicles yield different results depending on grid emissions. This challenges the notion that electric vehicles are inherently sustainable.

Figure 3 shows the overall raw material emissions of diesel and electric vehicles. From this, it can be understood that sustainability is holistic, requiring collaborative progress across all sectors and stakeholders to achieve sustainable outcomes. To determine whether electric vehicle users are making a sustainable choice, it is crucial to first investigate how far they can travel based on grid emissions in their country. Figure 4 shows the difference between EU28 Mix grid-based and coal-based electric grid emissions for an electric vehicle. According to this comparison, electric vehicle's raw material emissions are similar to Option 1 if the grid uses green/sustainable energy. Option 2 applies if the grid uses higher emission per kWh, which is shown in Figure 4 as a sharp decrease in expressed mileage (km).

According to Figure 4, in this study, equality is achieved if an electric vehicle travels on average 1.52 times farther per kilometer compared to a diesel vehicle, due to the raw material emissions ratio indicating this value. This average factor of 1.52 leads to a result of 52090 km, requiring grid emissions to be at least 0.7781 kg CO_2 per kWh. Under the conditions depicted in Figure 4, electric vehicles surpassing this emission value will create a less efficient environment compared to diesel vehicles in all scenarios. These conclusions are derived by reversing Equations (6) and (7).

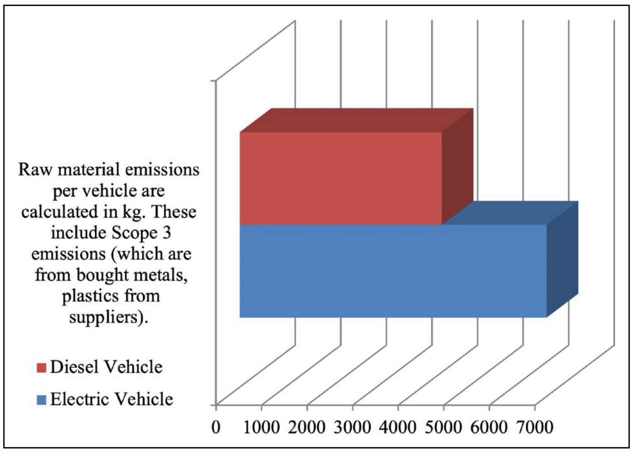

Figure 3. Comparison of raw material emissions for diesel and electric vehicles.

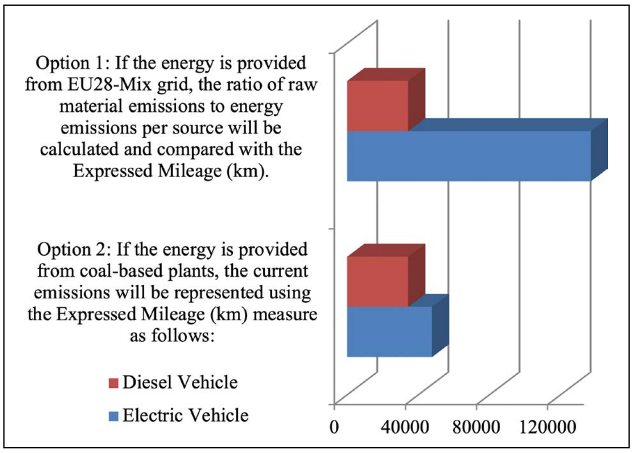

Figure 4. Expressed mileage comparisons for diesel and electric vehicles.

The study has uncovered important information for the global literature and consumers. From a literature perspective, data has been generated that can benefit individuals and institutions in the technical and social disciplines working in this field. It is of great importance for various scientific disciplines such as engineering, industrial design, and transportation vehicle design, which are involved in the design of vehicles in the industry, to understand to what extent their own contributions affect emissions. Specific data within the scope of the study includes which part designs can reduce emissions, the density of plastic or metals used in various parts, and how much emissions these parts cause. This information is crucial for understanding the primary impacts of different scientific disciplines such as engineering and design, on emissions.

RECOMMENDATIONS

The study highlights important perspectives for consumers, especially green consumers, to consider sustainability values when making purchases. It is emphasized that in every sector, Scope 1-2 emissions do not represent all emissions caused by a product, and it is important not to forget that material emissions caused under broad parameters such as

Scope 3 also exist. Therefore, it is recommended that consumption should continue with awareness of the material emissions caused under broad parameters like Scope 3, rather than solely relying on Scope 1-2 emissions.

For industries and manufacturers, the importance of emission calculations and reducing emission values is evident today. However, to understand the effectiveness of converting any item or vehicle to electric under the guise of sustainability, it is crucial to consider the amount of emissions per kWh in the connected grid. Otherwise, it should not be forgotten that conversions made may not reduce emissions but could even lead to an increase in emissions. If the emissions value in the connected grid is high, the optimum values of devices or items running on diesel or gasoline should be examined, and the conversion should be made accordingly. Otherwise, there could be an increase in emissions and a loss of resources as a result of the conversion. Since all the results are relevant and crucial for the respective scientific disciplines, consumers, and industries, an approach has been suggested that can be followed in studies related to these scientific disciplines.

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DATA AVAILABILITY STATEMENT

The author confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

USE OF AI FOR WRITING ASSISTANCE

Not declared.

ETHICS

There are no ethical issues with the publication of this manuscript.

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