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How can technology on the automotive industry save the future?

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Abstract

Transport is Europe is a biggest source of CO_2, being responsible for the emission of over a quarter of all greenhouse gases. Unless transport emissions are brought under control national 2030 climate goals will be missed. To meet the 2050 Paris climate commitments cars and vans must be entirely decarbonized. This requires ending sales of cars with an internal combustion engine by 2035. Big challenges and huge efforts between all stakeholders are needed. Governments are, almost universally, unwilling to constrain demand for mobility and, in particular, car use and ownership. The future demands paradigm changes and better education for sustainable development. The present work aims to present a study on the currently used main vehicle motorization technologies, namely, the vehicles with internal combustion engines (ICE), electric motors (EM), electric-hybrid vehicles (EHV) and vehicles fuel cells (VFC), regardless of the technology diffusion. The main objective of this study is to point out the best model to help reduce the amount of pollutant gas emission as well as contribute to public policy decision making. After a literature review, a Sustainability Index was applied to select a set of sixteen models of different brands and categories. The used management tool is the Hierarchy Process (AHP). After discussion of results, conclusions are presented.

Keywords: Automotive industry, Internal Combustion Engine, Electric Motor, Electric-hybrid, Fuel Cell, Sustainability, Analytic Hierarchy Process (AHP).

1. Introduction

The world's population continues to grow, even though at a slower pace than at any time since 1950, due to reduced levels of fertility. From an estimated 7.7 billion people worldwide in 2019, the medium-variant projection indicates that the global population could grow to around 8.5 billion in 2030, 9.7 billion in 2050, and 10.9 billion in 2100 [1]. Global demand for energy is increasing rapidly, because of population and economic growth, especially in emerging market economies. While accompanied by bigger prosperity, increasing demand generate new challenges. Energy concerns can emerge as more consumers want ever more energy resources. And higher consumption of fossil fuels leads to higher greenhouse gas emissions, particularly carbon dioxide (CO_2), which contributes to global warming [2]. Global cooperation is paramount for stopping the climate disruption [3]. The development of internal combustion engine vehicles (IEC), especially automobiles, is one of the greatest achievements of modern technology [4]. Automotive industry has made great contributions to the growth of modern society by satisfying many of its needs for mobility in everyday life. It constitutes the backbone of the word's economy and employs the greatest share of the working population [5]. However, due the enormous number of cars in use around the world, it caused and continues to cause serious problems for the environment and

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human life. In recent decades, the research and development activities related to transportation have emphasized the development of high efficiency, clean, and safe transportation. Electric vehicles, hybrid electric vehicles, and fuel cell vehicles have been typically proposed to replace conventional vehicles in the near future [6]. Oil resources of the Earth are scarce and depend on the discovery of new oil reserves and cumulative oil production (as well as cumulative oil consumption). If oil discovery and consumption follow current trends, the world oil resource will be used by about 2038 [7,8]. One of the primary ways to crack the link between greenhouse gas emissions and economic activity is to change the energy supply mix, transitioning from fossil fuels to renewable sources of energy. Well-balanced policy strategies should maintain economic stability while broadening access to clean, affordable and reliable energy [9]. However, the world energy balance is dominated by fossil fuels. One major issue raised by this is how to change the future energy matrix towards more sustainable and renewable sources of energy [10]. It is crucial that policy makers closely interact with the academic community in order to realize advances, giving a particular emphasis on educating the socially-conscious engineers and technologists of the future [11].

2. Literature Review

2.1 Decision Making

When solutions must be found and decisions must be taken, selection is one of the most significant involved processes in consciousness and decision-making and is considered as a critical activity all through day-to-day life [12]. Each decision-making process ends in a final choice. The output may be an action or an idea [13, 14]. Decision-making is a problem-solving process which ends when a satisfying solution is achieved. In general, it is a mental process and is done on the bases of values, culture, personality, attitudes, perceptions, belief systems, knowledge, and the insight of the decider(s) [15]. In general, there are two basic factors in any decision-making: one is the expected value and the other is the chance and probability of the desirable results if one acts according to that decision. For that reason, to decide a desired and optimum decision, one shall be able to predict the value of all the probable results of deciding and comparing these values with a kind of quantitative scale and examines the fully success probability. This process would never be easy [12, 16]. In fact, diverse factors are involved in decision-making and many researchers suggest to consider most decisions as unconscious [12], being the influencing factors on decision making result of four categories, namely Rational factors, Psychological factors, Social factors and Cultural factors [17]. Different situations have unlike consequences and influences on decision-making. The decider has to adapt her/his decision domains and decision-making processes with occurred demands and limits in the environment [18]. Typology of decision-making is supported on the blend of dimensions of proximity to danger and levels of authority [12]. Main concerned processes in decision-making consist of situation identification, option generation, evaluation and choice, follow-up and execution. The closer the decision authority is to the origin of the problem, the better decision she/he/it can take. Making decisions is a matter of a huge responsibility for the managers not only against the organization itself, but against all its stakeholders [19]. The literature suggests a lot of references about decisions making models, some exploring the practice of quality management framework as a strategic tool for public management [20], others explaining the quantitative and qualitative methods that can help decision-makers to structure and clarify difficult problems and to explore the implications of pursuing different options [21], among others. Involving teams in decision making improves the quality of decisions most of the times [22] and helps organization to generate and evaluate different alternatives of problems solving [23]. Sometimes decisions are not made because of minority domination or time pressure [24] and the quality and speed of decision making is the key determinant of board success or failure [25].

2.2 Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) was introduced by Thomas Saaty in 1980 and it is an effective tool for dealing with complex decision making, helping decision maker to set priorities and make the best decision. By reducing complex decisions to a series of pair wise comparisons, and then synthesizing the results, the AHP helps to capture both subjective and objective aspects of a decision. Additionally, the AHP incorporates a useful technique for checking the consistency of the decision maker's evaluations, thus reducing the bias in the decision making process [26,27]. The AHP considers a set of evaluation criteria, and a set of alternative options among which the best decision is to be made. It is important to note that, since some of the criteria could be contrasting, it is not true in general that the best option is the one which optimizes each single criterion, rather the one which achieves the most suitable trade-off among the different criteria. The AHP generates a weight for each evaluation criterion according to the decision maker's pair wise comparisons of the criteria. The higher the weight, the more important the corresponding criterion is. Then, for a fixed criterion, the AHP assigns a score to each option according to the decision maker's pair wise comparisons of the options based on that criterion. The higher the score, the better the performance of the option with respect to the considered criterion is. Finally, the AHP combines the criteria weights and the options scores, thus determining a global score for each option, and a consequent ranking. The global score for a given option is a weighted sum of the scores attained with respect to all the criteria [28].

2.2.1. Sustainability Indicators and Indexes

Sustainability indicators are indicators that afford information on the state, dynamics, and underlying drivers of human-environmental systems. In general, indicators become sustainability (or not sustainability) indicators when time dimension, limits, or targets are associated with them [29]. Their values are obtained from environmental and socio-economic data from actual measurements or observations. A cluster of indicators jointly used for a particular purpose or project is often referred to as an indicator set. Sustainability includes environmental, economic, and social dimensions (sometimes institutions are listed as the fourth dimension), each of which has a number of components [30]. Many sustainability indicators only reflect certain aspects of human-environmental systems, some are more integrative than others, and none is adequate to gauge the multiple dimensions of sustainability by itself [30]. However, indicators are a product of a compromise between scientific accuracy and the needs of decision making and urgency of action. They provide decision makers with information on how they are doing with regard to policy goals. However, decision makers need highly condensed information obtained by aggregating data: they need indexes. To develop an index, the different indicators contained in an index need to be weighted according to their relative importance. Information determines the weight of the indicators [31]. When defined the Sustainability Index (SI) decision makers with information about their level of economic, social and environmental sustainability can identify priority areas for action and changes to behavior that can contribute to improve sustainability and competitiveness [32]. It is important to note that the proposal of a sustainability index represents an economic opportunity for organizations/countries to improve their competitive advantage since it contributes for enhancing their image, reputation and revenues [33]. A SI can be an important driver in integrating sustainability into the core business practices and to view the subject as an essential long-term performance factor on radar of investors [34].

3. Methods

3.1 Determination of Indicator Weights

The weights of the indicators, which here will be called coefficients (qi), can be calculated using statistical models or participatory methods and joint analysis [26]. In the present study, the used method was the Analytic Hierarchy Process (AHP). To make a decision in an organized way and generate priorities, it is necessary to decompose the decision, observing the following steps: 1) define the problem and determine the kind of knowledge sought; 2) Structure the decision hierarchy from the top with the goal of the decision, to the lowest level; 3) Construct a set of pair wise comparison matrices where each element in an upper level is used to compare the elements in the level immediately below with respect to it; 4) Use the priorities obtained from the comparisons to weigh the priorities in the level immediately below. Do this for every element. Continue this process of weighing and adding until the final priorities of the alternatives in the bottom most level are obtained [26]. To make the comparisons, a scale of numbers is needed (Table 1) to indicate how much more important or dominant an element is with respect to the criterion or priority that are compared.

Table 1. Fundamental scale of absolute numbers [26].

Scale	Numerical Evaluation
Equally Important	1
Weak or Light	2
Moderate Importance	3
Moderate to Strong	4
Strong Importance	5
Strong to Very Strong	6
Very Strong	7
Very Strong to Extreme	8

The use of odd values is prioritized, for greater differentiation between measurements [35]. AHP involves comparing pairs to a number of different criteria after dividing the criteria into a hierarchy of multiple levels [56]. These factors will be compared to each other in a matrix, as shown in the following Table (Table 2).

Table 2. Pair wise comparisons of AHP [26].

	A	B	C	D
A	1	X_{12}	$1/X_{13}$	X_{14}
B	$1/X_{12}$	1	X_{23}	$1/X_{24}$
C	X_{13}	$1/X_{23}$	1	$1/X_{34}$
D	$1/X_{14}$	X_{24}	X_{34}	1

The reciprocal values are filled in with the inverse values of the original analysis. After making the paired comparisons and defining the due amounts, it is necessary to normalize the comparative matrix. For normalization to be done, just is needed to divide each value of the matrix by the total of its respective column [27, 36]. In order to determine the weights of each criterion, the priority vector, or eigenvector (λ), is calculated. The eigenvector defines the contribution that each criterion will have to the established goal through the arithmetic average of the normalized values of each criterion [27, 36]. With the calculated priority vector, the next step in the process is to check the consistency of the founded data. The purpose of this operation is to make sure that the decision making was consistent and there was no inconsistency in the allocation of amounts in the matrix.

The Consistency Index is based on the eigenvalue (λ_{max}) of the comparison matrix. This value is calculated by summing the product between the defined weights, eigenvector values and the total of their respective columns in the original comparison matrix [26,27]. Thus, the Consistency Index (CI) is determined by:

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (1)$$

being n the size of the comparative matrix. With the Consistency Index, the Consistency Rate (CR) is calculated, determined by:

$$CR = \frac{CI}{RI} < 0.1 \quad (2)$$

The value of RI (Random Consistency Index) is fixed, and it was proposed by Saaty [28] according to the table below (Table 3). If CR<0.1, the matrix comparisons are not inconsistent and evaluations are valid.

Table 3. Random Consistency Index [28].

N	1	2	3	4	5	6	7	8	9	10
R1	0	0	0.58	0.96	1.12	1.24	1.32	1.41	1.45	1.49

3.2. Standardization of Indicators

Normalization is required since the indicators are usually presented in different units. The present research used the Min-Max method, so that all the values of the indicators were contained between zero (0) and one (1). According to this method, when it is necessary to maximize the values, when the indicators generate a positive impact on the sustainability index, the following mathematical formula is used [26]:

$$A'^{+}_{i,j} = \frac{A^{+}_{i,j} - A^{+MIN}_{i,j}}{A^{+MAX}_{i,j} - A^{+MIN}_{i,j}} \quad (3)$$

where:

$A'^{+}_{i,j}$ is the indicator with positive impact i on the sustainability dimension j with normalized values.

$A^{+}_{i,j}$ is the original value of the indicator with a positive impact i on the sustainability dimension j.

$A^{+MIN}_{i,j}$ is the lowest value of the indicator with positive impact i on the sustainability dimension j.

$A^{+MAX}_{i,j}$ is the highest value of the indicator with a positive impact i on the sustainability dimension j.

And when it is necessary to minimize the values, when the indicators have a negative impact on the sustainability index, the following formula is used:

$$A'^{-}_{i,j} = 1 + \frac{A^{-MIN}_{i,j} - A^{-}_{i,j}}{A^{-MAX}_{i,j} - A^{-MIN}_{i,j}} \quad (4)$$

where:

$A'^{-}_{i,j}$ is the indicator with negative impact i on the sustainability dimension j with normalized values.

$A^{-}_{i,j}$ is the original value of the indicator with negative impact i on the sustainability dimension j.

$A^{-MIN}_{i,j}$ is the lowest value of the indicator with negative impact i on the sustainability dimension j.

$A^{-MAX}_{i,j}$ is the highest value of the indicator with negative impact i on the sustainability dimension j.

3.3. Construction of Index

In the present study it was selected the additive weighting method, having in mind the pointed limitations by Nardo et al. [37] saying that in the linear additive aggregation method the indicators must have the same unit of measurement, which implies that poor performance in some indicators can be compensated by high values of other indicators [38]. This additive weighting method is a linear model and is applicable because independence exists between the variables. However, the resulting aggregate indicator may be biased [37]. After calculating the coefficients through the matrices, and normalizing the indicators, it is possible to assemble the mathematical formula to arrive at the final values of the Sustainability Index. The final calculation will be the sum of all selected sustainability indicators.

3.4. Creation of Rating Scale

To classify the calculated values of the indices and identify them as "more sustainable" and "less sustainable", a scale was created with five different categories, being: very good (blue), good (green), reasonable (yellow), bad (orange) and very bad (red), with values varying every two tenths (0.2), on a scale between zero and one.

Table 4. Colour scale for classification of the sustainability index.

Very good	1 ≥ Is ≥ 0.8
Good	0.8 ≥ Is ≥ 0.6
Reasonable	0.6 ≥ Is ≥0.4
Bad	0.4 ≥ Is ≥ 0.2
Very bad	Is ≤ 0.2

3.5. Used methodology

Since the main goal of this research involves the application of a sustainability index, a case study of sixteen models of different brands and categories were selected. The chosen models were according to the available models that the Association of the Automobile Trade of Portugal (ACAP) presented on its monthly magazines during 2018 and 2019. The study was based on a convenience sample. The respective classification was performed based on the classification of ACAP - inferior, superior, luxury, and SUV - Super Utility Vehicle [39] - and different types of motorization – ICE (Internal Combustion Engine), EM (Electric Motor), EHV (Electric-Hybrid Vehicles) and VFC (Vehicles Fuel Cells). The chosen models are: 1) 4 ECI, namely Seat Ibiza Reference 2019 1.0 MPI; Volkswagen Golf Stream 2019 1.0 TSI; Jaguar XF Berlina 2019 25t 2.0 Turbo and Porsche Cayenne 2019; 2) 5 EM, namely Smart EQ Forfour 2019, Renault ZOE R90 2019, BMW i3s 2019, Nissan Leaf Acenta 2019 and Mercedes Benz EQC 400 4MATIC 2019; 3) 4 EHV, namely Volkswagen Golf GTE 2019, BMW 530e iPerformance Berlina 2019, Porsche Cayenne E-Hybrid 2019 and BMW i8 Coupé 2019; 4) 3 VFC, namely Honda Clarity Fuel Cell 2019, Toyota Mirai Fuel Cell EV 2019 and Mercedes-Benz GLC F-Cell. The followed five steps to create the entire model can be seen in the image (Fig. 1) and illustrates the structure of this research [26].

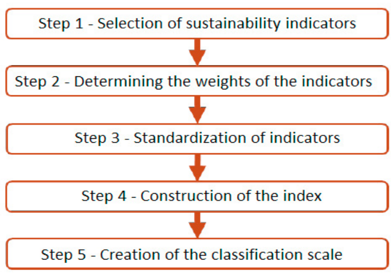

Fig. 1. Steps to create the sustainability indicator.

The Selected Indicators were chosen according to the greatest relevance in relation to the vehicle's performance and are presented on Table 5. Given that there are different drive systems for the models, the characteristic consumptions for each energy matrix used by the different types of drives were taken into account.

Table 5. Selected indicators.

Indicators	Ai	Notes	Unit
Power	P	*	CV
Torque	Bin	*	Nm
CO_2 emissions	ECO_2	*	g/km
Gasoline consumption (urban)	G_{urb}	*	l/100 km
Gasoline consumption (highway)	G_{hih}	*	l/100 km
Electric consumption (urban)	E_{urb}	*	kWh/100 km
Electric consumption (highway)	E_{hih}	*	kWh/100 km
H_2 consumption (urban)	$H2_{urb}$	*	kg/100 km
H_2 consumption (highway)	$H2_{hih}$	*	kg/100 km
Maximum speed	Smax	*	km/h
Own weight	W	*	kg
Battery charge	C	*	kWh
Autonomy	A	**	km

*The much lower, the better, **The much higher, the better

4. Results

The Weights of the Indicators were determined according to the already explained in the Methods on 3.1. Similar procedure was done for the Standardization of the Indicators, explained on 3.2. Regarding the Construction of the Index, after calculating the coefficients through the matrices, and normalizing the indicators, it was possible to assemble the mathematical formula of the Sustainability Index. The final calculation results from the additive weighting method:

$$Is = q_1 P + q_2 Bin + q_3 ECO_2 + q_4 G_{urb} + q_5 G_{hih} + q_6 E_{urb} + q_7 E_{hih} + q_8 H_{2urb} + q_9 H_{2\,hih} + q_{10} V_{max} + q_{11} W + q_{12} Carg + q_{13} Aut \quad (5)$$

The creation of the Classification Scale was determined according to the already explained in the Methods. As already mentioned, sixteen models of different brands and categories were selected. The values of fuel consumption, CO_2 emissions and energy consumption for alternative power trains, with a few exceptions, were removed following the new reference WLTP (Worldwide Harmonized Light Vehicle Test Procedure) that currently applies and claims to bring more real values, compared to the old NEDC (New European Driving Cycle) tests [39]. The following Tables show the values for each characteristic of the models: Table 6 for ICE, Table 7 for EM, Table 8 for EHV and Table 9 for VFC.

4.1. Sustainability Indexes by Model

With all the collected data, structured formula and methods for calculating the defined coefficients, all calculations for assigning values for the Sustainability Index (Is) are presented on next sub-chapters.

4.1.1 Calculation of Coefficients

For the calculation of the coefficients, the first step is to define the hierarchy structure. Fig. 2 shows the followed hierarchy.

Table 6 - Values for ICE. Elaborated with data from [40-43].

Indicators	Seat Ibiza 2019 1.1 MPI	VW Golf Stream 2019 1.0 TSI	Jaguar XF Berlina 2019 2.0 Turbo	Porche Cayenne 2019
Power	80	115	250	340
Torque	95	200	365	450
CO_2 emissions	112	128	186	210
Gasoline consumption	6.1	5.5	11.9	11.4
Gasoline consumption	4.3	4.9	7.0	7.9
Electric consumption (urban)	--	--	--	--
Electric consumption	--	--	--	--
H_2 consumption (urban)	--	--	--	--
H_2 consumption (highway)	--	--	--	--
Maximum speed	169	198	244	245
Own weight	1099	1245	1704	2060
Battery charge	421	515	556	845
Autonomy	800	877	822	815

Table 7 - Values for EM. Elaborated with data from [44-48].

Indicators	Smart EQ ForFour 2019	Renault Zoe R90 2019	BMW i3S 2019	Nissan Leaf Acenta 2019	Mercedes Benz EQC 400 4Matic 2019
Power	82	52	183	149	409
Torque	160	220	270	320	765
CO_2 emissions	0	0	0	0	0
Gasoline consumption (urban)	--	--	--	--	--
Gasoline consumption	--	--	--	--	--
Electric consumption (urban)	13.2	0.168	16.2	0.206	22.2
Electric consumption (highway)	14.0	0.168	16.5	0.206	19.7
H_2 consumption (urban)	--	--	--	--	--
H_2 consumption (highway)	--	--	--	--	--
Maximum speed	130	135	160	144	180
Own weight	1200	1480	1340	1557	2495
Battery charge	360	425	425	435	500
Autonomy	155	300	260	389	471

Table 8 – Values for EHV. Elaborated with data from [49-52].

Indicators	VW Golf GTE 2019	BMW 530e iPerformance Berlina 2019	Porsche Cayenne E-Hybrid 2019	BMW i8 Coupe 2019
Power	204	252	462	374
Torque	350	290	700	320
CO_2 emissions	36	46	78	47
Gasoline consumption	1.8	2.4	3.4	1.8
Gasoline consumption	1.6	2.0	3.2	1.8
Electric consumption	12.0	14.1	20.9	14.0
Electric consumption	11.4	13.1	20.6	14.0
H_2 consumption (urban)	--	--	--	--
H_2 consumption (highway)	--	--	--	--
Maximum speed	222	140	253	250
Own weight	1615	1770	2970	1610
Battery charge	389	410	735	385
Autonomy	883	460	815	440

Table 9 - Values for VFC. Elaborated with data from [53-56].

Indicators	Honda Clarity Fuel Cell 2019	Toyota Mirai Fuel Cell EV 2019	Mercedes Benz GLC F-Cell
Power	176	155	211
Torque	300	335	365
CO_2 emissions	0	0	0
Gasoline consumption (urban)	--	--	--
Gasoline consumption (highway)	--	--	--
Electric consumption (urban)	--	--	13.7
Electric consumption (highway)	--	--	13.7
H_2 consumption (urban)	0.13	0.14	0.34
H_2 consumption (highway)	0.13	0.14	0.34
Maximum speed	165	175	160
Own weight	1875	1948	1735
Battery charge	394	362	550
Autonomy	579	502	430

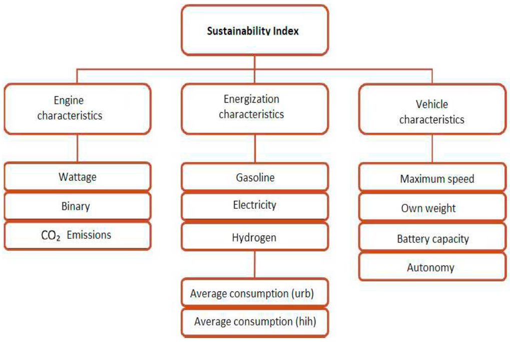

Fig. 2. AHP hierarchy.

4.1.2. Sustainability Indexes by Model

With all the collected data, structured formula and methods for calculating the defined coefficients, all calculations for assigning values for the Sustainability Index (Is) are presented.

For the calculation of the coefficients, the first step is to define the hierarchy structure. Fig. 2 shows the followed hierarchy. With the hierarchy fully defined, it was possible to build the comparison matrices of the main criteria (first level), and the sub-criteria. The calculations were developed in a MS Excel® spreadsheet, together with the values of λ_{max}, IC and RC (Tables 10, 11, 12, 13, 14).

Table 10. Criterion comparison matrix.

	Engine Characteristics	Energization characteristics	Vehicle Characteristics	λ
Engine Characteristics	1.00	2.00	5.00	0.5813
Energization characteristics	0.50	1.00	3.00	0.3092
Vehicle Characteristics	0.20	0.33	1.00	0.1096
RC			0.0042	

Table 11. Engine sub-criteria matrix.

	Power	Torque	CO_2 emissions	λ
Power	1.00	2.00	0.14	0.1374
Torque	0.50	1.00	0.13	0.0828
CO_2 emissions	7.00	8.00	1.00	0.7798
RC			0.0577	

Table 12. Energization sub-criteria matrix.

	Gasoline	Electricity	Hydrogen	λ
Gasoline	1.00	0.13	0.20	0.0683
Electricity	8.00	1.00	3.00	0.6571
Hydrogen	5.00	0.33	1.00	0.2746
RC			0.0580	

Table 13. Vehicle sub-criteria matrix.

	Maximum Speed	Own Weight	Battery Capacity	Autonomy	λ
Maximum Speed	1.00	4.00	6.00	3.00	0.5395
Own Weight	0.25	1.00	2.00	0.33	0.1218
Battery Capacity	0.17	0.50	1.00	0.25	0.0714
Autonomy	0.33	3.00	4.00	1.00	0.2673
RC				0.0490	

Table 14. Consumption sub-criteria matrix.

	Urban Consumptions	Highway Consumptions	λ
Urban Consumptions	1.00	0.50	0.3333
Highway Consumptions	2.00	1.00	0.6667

With all the calculated weights at all levels, it was defined the coefficients by multiplying the weights between the levels, always respecting the hierarchy (Fig. 3).

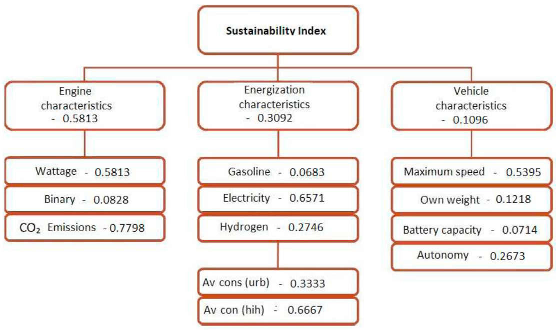

Fig. 3. AHP with respective values.

Then, the coefficient values were defined performing all calculations between levels (Table 15) and with all the coefficients weights within the hierarchy, the indicators values were normalized within the next stage.

Table 15. Coefficient Values by indicator.

Indicators	Coefficients	Values
P	q_1	0.0799
Bin	q_2	0.0481
ECO_2	q_3	0.4533
G_{urb}	q_4	0.0070
G_{hih}	q_5	0.0141
E_{urb}	q_6	0.0677
E_{hih}	q_7	0.1354
$H2_{urb}$	q_8	0.0283
$H2_{hih}$	q_9	0.0566
V_{max}	q_{10}	0.0591
W	q_{11}	0.0133
C	q_{12}	0.0078
A	q_{13}	0.0293

4.1.3. Normalization of Values

To normalize the collected data for each model - since they are given in different units - the calculations followed the formulas previously presented in the Methods, section 3. The calculations for this procedure were also developed in an MS Excel® spreadsheet (Table 16 for ICE, Table 17 for EM, Table 18 for EHV and Table 19 for VFC).

Table 16. Normalized values for ICE.

Indicators	Seat Ibiza Reference 2019 1.0 MPI	Volkswagen Golf Stream 2019 1.0 TSI	Jaguar XF Berlina 2019 25t 2.0 Turbo	Porsche Cayenne 2019
Power	1.0000	0.9084	0.5550	0.3194
Torque	1.0000	0.8433	0.5970	0.4701
CO_2 emissions	0.4667	0.3905	0.1143	0.0000
Gasoline consumption (urban)	0.5743	0.6337	0.0000	0.0495
Gasoline consumption (highway)	0.5741	0.4762	0.1429	0.0000
Electric consumption (urban)	--	--	--	--
Electric consumption (highway)	--	--	--	--
H_2 consumption (urban)	--	--	--	--
H_2 consumption (highway)	--	--	--	--
Maximum speed	0.6829	0.4472	0.0732	0.0650
Own weight	1.0000	0.8954	0.5666	0.3116
Battery charge	0.8297	0.6458	0.5656	0.0000
Autonomy	0.9008	0.9928	0.9271	0.9188

Table 17. Normalized values for EM.

Indicators	Smart EQ Forfour 2019	Renault ZOE R90 2019	BMW i3s 2019	Nissan Leaf Acenta 2019	Mercedes Benz EQC 400 4MATIC 2019
Power	0.9948	0.9686	0.7304	0.8194	0.1387
Torque	0.9030	0.8134	0.7388	0.6642	0.0000
CO_2 emissions	1.0000	1.0000	1.0000	1.0000	1.0000
Gasoline consumption (urban)	-	-	-	-	-
Gasoline consumption (highway)	-	-	-	-	-
Electric consumption (urban)	0.4085	1.0000	0.2723	0.9983	0.0000
Electric consumption (highway)	0.3230	1.0000	0.2007	0.9981	0.0440
H_2 consumption (urban)	-	-	-	-	-
H_2 consumption (highway)	-	-	-	-	-
Maximum speed	1.0000	0.9593	0.7561	0.8862	0.5935
Own weight	0.9277	0.7271	0.8274	0.6719	0.0000
Battery charge	0.9491	0.8219	0.8219	0.8023	0.6571
Autonomy	0.1302	0.3035	0.2557	0.4098	0.5078

Table 18. Normalized values for EHV.

Indicators	Volkswagen Golf GTE 2019	BMW 530e iPerformance Berlina 2019	Porsche Cayenne Hybrid 2019	BMW i8 Coupé 2019
Power	0.6754	0.5497	0.0000	0.2304
Torque	0.6194	0.7090	0.0970	0.6642
CO_2 emissions	0.8286	0.7810	0.6286	0.8000
Gasoline consumption (urban)	1.0000	0.3406	0.8416	1.0000
Gasoline consumption (highway)	1.0000	0.9365	0.7460	0.9683
Electric consumption (urban)	0.4630	0.3676	0.0590	0.3722
Electric consumption (highway)	0.4503	0.3671	0.0000	0.3230
H_2 consumption (urban)	-	-	-	-
H_2 consumption (highway)	-	-	-	-
Maximum speed	0.2520	0.9187	0.0000	0.0244
Own weight	0.6304	0.5193	0.8950	0.6340
Battery charge	0.8728	0.8513	0.2153	0.9002
Autonomy	1.0000	0.0000	0.9188	0.4707

Table 19. Normalized values for VFC.

Indicators	Honda Clarity Fuel Cell 2019	Toyota Mirai Fuel Cell EV 2019	Mercedes-Benz GLC F-Cell
Power	0.7487	0.8037	0.6571
Torque	9.6940	0.6418	0.5970
CO_2 emissions	1.0000	1.0000	1.0000
Gasoline consumption (urban)	-	-	-
Gasoline consumption (highway)	-	-	-
Electric consumption (urban)	-	-	0.3858
Electric consumption (highway)	-	-	0.3377
H_2 consumption (urban)	1.0000	0.9524	0.0000
H_2 consumption (highway)	1.0000	1.0000	0.0000
Maximum speed	0.7154	0.6341	0.7561
Own weight	0.4441	0.4635	0.5444
Battery charge	1.0000	0.9452	0.5773
Autonomy	0.6368	0.5448	0.4588

4.2. Calculation of the Sustainability Index by Model and Classification

After being developed all the coefficient values and normalized the indicator values, it was applied the additive weighting method presented on 3.1 and presented on Table 20.

Table 20. Values and classification of models according to the Sustainability Index.

Energy Matrix	Model	**Sustainability index**	Classification
ICE	Seat Ibiza Reference 2019 10.0 MPI	0.4382	
	Volkswagen Golf Stream 2019 1.0 TSI	0.3738	
	Jaguar XF Berlina 2019 25t 2.0 Turbo	0.1703	
	Porsche Cayenne 2019	0.0834	
EV	Smart EQ Forfour 2019	0.7303	
	Renault ZOE R90 2019	0.8547	
	BMW i3s 2019	0.6624	
	Nissan Leaf Acenta 2019	0.8331	
	Mercedes Benz EQC 400 4MATIC 2019	0.5256	
EVH	Volkswagen Golf GTE 2019	0.6322	
	BMW 530e iPerformance Berlina 2019	0.5943	
	Porsche Cayenne E-Hybrid 2019	0.3398	
	BMW i8 Coupé 2019	0.5333	
VFC	Honda Clarity Fuel Cell 2019	0.7061	
	Toyota Mirai Fuel Cell EV 2019	0.6989	
	Mercedes-Benz GLC F-cell	0.6763	

5. Analysis and Discussion of Results

For the analysis and discussion of the obtained results, two graphs were generated: one with the Sustainability Index Values by models (Fig. 4) and another with the Average Sustainability Indexes by type of motorization (Fig. 5).

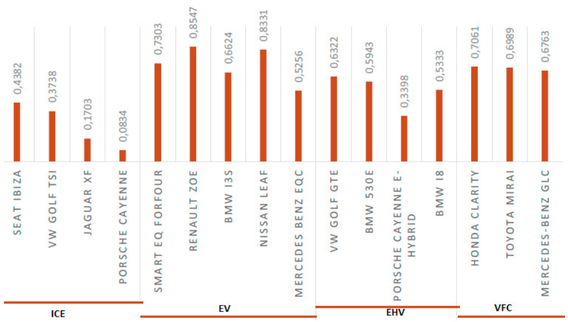

Fig. **4**. Sustainability Index Values by models.

As can be seen in Figure 4, it is possible to identify that the models with internal combustion engines with gasoline engines (ICE) are the ones that obtained the lowest indexes, two of which were the ones that obtained the worst values in general and were on the red scale of the classification. It is also possible to see that among the five worst values, four of them were from ICE models. The model that is among the vehicles equipped with ICE is a model that, despite being hybrid, maintains a high power ICE. Now, considering the models with the best index, it can be seen that the three with the best indexes are electric (EV), with two of them reaching the blue level classification. It is worth mentioning that the fuel cell models (VFC) obtained positive values, since all three selected models were among the six best models, all of which were classified with green. It is worth mentioning that the obtained Sustainability Index by the BMW 530e iPerformance Berlina 2019 was related with the autonomy of exclusive use of the electric mode. With a total autonomy value, the Sustainability Index model would go up one level in the classification, leaving the yellow level to the green one level.

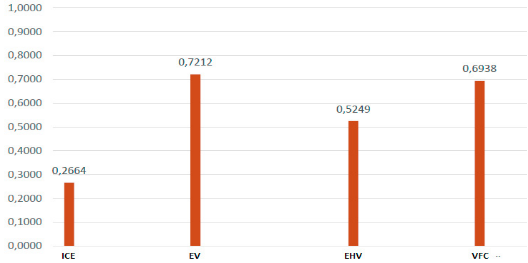

Fig. 5. Average Sustainability Indexes by type of activation.

The graph in Fig. 5 was obtained by averaging the values of the Indexes separated by type of activation, and with these founded values some more significant conclusions can be drawn. The first point to be taken into account is that equipped models with gasoline ICE are the least sustainable, due to their high fuel consumption and extremely high levels of CO_2 emissions. If the obtained average index was analyzed, the classification would be at the orange level, but very close to the values needed to be classified at the red one level. The second point is that hybrid models (EHV) reach good levels in relation to the Sustainability Index, especially when compared to models equipped with ICE, since fuel consumption and pollutant emissions are very low. However, the classification is not so close to the green level, being almost in the middle of the yellow level, that is, almost in the central position of the entire scale, which ends up representing a not so good Index. As a third point, it can be concluded that the purely electric (EV) and fuel cell (VFC) models obtained, in general, the highest rates, for not presenting any values for CO_2 emissions. Another factor to be highlighted in relation to the high Sustainability Index achieved by these models, mainly the electric ones, are the presented higher values of autonomy, referring to the improvement of the energy storage technology by the batteries. Thus, both drives managed at least to achieve a green level classification. The next table (Table 21) presents the classification of the values by type of activation.

Table 21. Values and classification according to the type of drive

Energy	**Sustainability index**	Classification
ICE	0.2664	
EV	0.7212	
EHV	0.5249	
VFC	0.6938	

6. Conclusions

The present research has allowed analysis to be conducted which is the best motorization systems to be used in the present and in the future if there will be no paradigm shifting, if we take into account that the main objective of this work, is to point out the best actual model to help reduce the amount of pollutant gas emissions. Therefore, saying that cars that work exclusively with an internal combustion engine (ICE) will soon be completely replaced, is a probable occurrence. ICE emits more polluting gases than any other form, it is the least efficient and most polluting mode of transport, although it still has the largest number of today's users and it is petroleum-based which is an exhaustible source of energy. Hybrid models (HEV) prove to be a great solution for the present, as they manage to combine the advantages of ICE with EV. They have the high energy density present in fuels, but also the possibility of having a vehicle that works electrically for longer, reducing the amount of the emitted gas by the combustion engines. However, as the goal is to achieve zero emissions, the competitive advantage is only for the short-term. Purely electric models (EV) prove to be the best alternative for the near future, because this drive model does not promote pollutant emissions and its energy source is considerably cheaper than pollutant-emitting fuels. However, although the battery-powered car itself does not produce any emissions, the power plant that generates the electricity used to charge those batteries probably does. Low emissions, much less zero emissions, are only true in certain places where most of the electricity comes from a mix of low-carbon sources such as the sun, wind or nuclear reactors. Nevertheless, residential recharging is now possible even if most of the existent EV still have relatively low autonomy, compared to hybrid models and those powered by ICE. Fuel cells (VFC) prove to be a great alternative for the production of electric energy when consumption is relatively modest as in the automobile. Nevertheless, fuel cells are generally considered as an efficient and eco-friendly source of energy, as they have high cost of production, require appropriate infrastructure for refueling of fuel cell vehicles, as well as, high-pressure hydration systems, in order to increase its durability. One of the most promising types of fuel cell is the polymer exchange membrane fuel cell (PEMFC) and there are researchers who predict that it ultimately will be the type of fuel cell used to power vehicles. However, in order to be a viable alternative to a gasoline-powered engine, the PEMFC has to be able to weather the difficult conditions of the car itself and the weather outside.

There is no doubt that there is still a long way to go before finding the ideal solution. Innovation and technology will be the key factors that will allow companies to find their competitive advantages in a sustainable way. Public policies and partnerships are required from all worldwide sectors and actors. From the point of view of population structure, namely extended life expectancy and fertility decline, among others, changes in the percentage of the labor force will have an effect on the competitiveness of the national manufacturing. Also, in what concerns to ICTs, i.e. the mobile Internet, cloud computing, big data, industrial programmable controllers and innovative applications, manufacturing production and business development models' changes are required. In this sense, sustainable industrial value creation will be closer linked with balance between customers' demand and Industrial Internet of Things (IIoT), which requires an extension of the established Triple Bottom Line, i.e. technical integration, data and information, and public context, always related to economic, ecological, and social implications.

As major limitation of this study, authors identified the lifecycle emissions approached perspective, instead of focusing on the vehicle. For further researchers it would be interesting to deeper study how manufacturing industry is affected by the change to the new models and derive managerial implications. It also will be important to understand how policymakers in Industry 4.0 can enhance the implementation, outcomes and quality of the different initiatives. Finally, as temporal dynamics of such policies and effort to mitigate disadvantages at each stage exist, carmakers should better cooperate and coo create amongst them, in order to optimize the necessary resources and the potential outcomes, having always present in their mind sustainable development.

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