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THE ANALYSIS OF COMMERCIALLY AVAILABLE ELECTRIC CARS

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RESEARCH ARTICLE

ABSTRACT: This paper aims at providing an overview of commercially available electric cars at the global market, with the exception of China. 63 different models of electric cars are currently available, and for all models we have collected the data on price, battery capacity, efficiency, autonomy, acceleration, and maximum speed. We have calculated the charging costs per one charging session to batteries' full capacities and the charging costs per 100km, based on the average electricity price in Serbia. Technical and economic analysis is conducted for the models which are first classified into different categories based on their autonomy in order to ensure better understanding of cars' properties and their relative differences. The results obtained here can help prospective customers to choose the model of an electric car that meets their requirements and satisfies their need.

KEY WORDS: *electric cars, trend, market, characteristics*

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ANALIZA KOMERCIJALNO DOSTUPNIH MODELA ELEKTRIČNIH AUTOMOBILA

REZIME: U radu je izvršen pregled komercijalno dostupnih modela električnih automobila na svetskom tržištu, izuzev Kineskog tržišta. Utvrđeno je da je trenutno dostupno 63 različitih modela elektricnih automobila. Za sve modele prikupljeni su podaci o cenovnom rangu, dostupnim kapacitetima baterija, efikasnosti, autonomiji, ubrzanju i maksimalnoj brzini. Izračunati su troškovi punjenja do maksimalnog kapaciteta kao i troškovi za pređenih 100km, a na osnovu prosečne cene električne energije u Srbiji. Izvršena je tehno-ekonomska analiza svih dostupnih modela koji su radi lakšeg razumevanja njihovih svojstava i razlika prvo klasifikovani u nekoliko kategorija na osnovu autonomije. Rezultati dobijeni ovom analizom mogu da pomognu potencijalnim kupcima električnih automobila pri odabiru modela koji zadovoljava njihove zahteve i potrebe..

KLJUČNE REČI: *električni automobil, trend, tržište, karakteristike*

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INTRODUCTION

According to Eurostat data, transport accounted for 30.5% in the total consumption of final energy in 27 countries of the European Union (EU-27) in 2018 [1]. The same year, the energy consumption in the world reached 2808 megatonnes of oil equivalent (Mtoe), with oil products accounting for 92% of that amount. In addition, 49.2% of the oil was consumed within the road transport sector [2]. According to [3], the transport sector is also a major emitter of air pollutants and greenhouse gas (GHG) emissions because of its dependence on fossil fuel. In 2017, transport accounted for 24% in the global CO_2 emissions. In 8 gigatonnes of CO_2 emitted by transport globally, road transport participated with 74% [2]. Based on the aforementioned data, it is not surprising that The United Nations Framework Convention on Climate Change has highlighted the critical role that transport plays in climate changes.

Owing to the environmental concerns, the reduced consumption of fossil fuels, and the fluctuations in oil prices, electric vehicles (EVs) have gained popularity in developed countries. Several countries, such as China, the UK, the EU countries, and the U.S., have promoted the use of EVs during the last decade by providing supports from the local and national bodies to consumers [4]. The replacement of conventional vehicles, powered by gasoline and diesel, with zero- and low-emission vehicles has been widely accepted as a solution to environmental and energy-waste issues. Battery electric cars reduce air pollutant emissions, such NOx, NO2, and particulate matter [3]. However, their greatest benefit of EVs is the low emission rate of CO2, together with higher acceleration and lower noise emissions [5-7]. One-step closer to cleaner transport was also the declaration of electro-mobility signed by 44 countries, 5 regions/cities and 32 international NGOs [3].

The market diffusion has been facilitated by constant efforts to increase the number and availability of charging stations, to improve government regulations on carbon emissions, and provide subsidies and other incentives (i.e. free charging, free access to car parks or entry into environmental zones) [8]. The factors that should drive the growth of EVs include high decreases in battery prices, improvements in infrastructure and raised awareness about environmental issues in consumers [5]. However, the response by consumers is still below expected levels. The lower acceptability of electric cars (ECs) by end consumers has been attributed to national and local policy frameworks, insufficient infrastructure development, existent vehicle technology, and consumer perceptions [9]. The following factors have also been found to influence the decision to buy ECs: battery size, availability of charging stations, driving range, cost of ownership, and prices of operation and maintenance [10, 11]. Over the years, many reviews on the abundant literature dedicated to EVs have become available [12-15]. They strive to analyze and explain the factors which impact the adoption of "a new technology – electric cars." Among the technical attributes of ECs, the driving ranges and battery degradation have received more attention while acceleration and maximum speeds have been seen as less problematic.

The market of electric cars has been growing exponentially, including the number of manufacturers expanding their supply of models that are fully electricity-driven. With the diversity of models already available, a new challenge for customers is now how to choose the model that they will purchase. These insecurities may hinder faster decisions to buy an electric car so it is crucial to provide more guidance to end customers. The current databases of all-electric cars usually include the following technical properties and economic indicators: minimum prices (for the basic packages of equipment), maximum prices (for the best offered packages of additional equipment), battery sizes (kWh), battery efficiencies (km/kWh), ranges (mileage per one charging session), acceleration from 0 – 100km, and maximum speeds that a model can develop. Such presentations may be confusing for potential customers and result in undesirable procrastination. Obviously, a price is not a guarantee of performance. Cars with similar characteristics can differ in prices significantly. On the other hand, cheaper solutions may not be efficient enough as some more expensive options, so in a long run, customers may eventually end up saving by buying pricier models. In addition, a battery size does not necessarily mean better range (mileage per one charging session). More efficient cars may secure better range even though they have lower battery capacities.

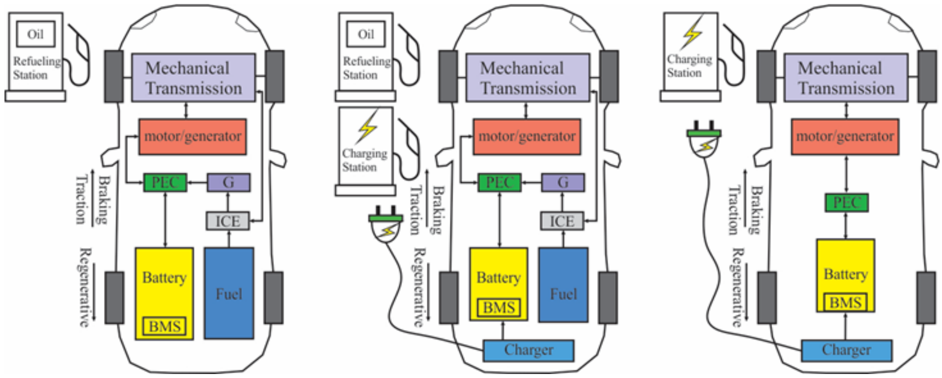
These new challenges that customers are currently facing served as a motivation for this paper. Four categories of all-electric cars are analyzed here: city cars, family cars, long-drive cars and SUVs. This research aims at collecting the data on commercially available models of all-electric cars in order to create a comprehensive systematic review of their most crucial technical and economic properties. The focus is on their minimum price, battery capacities, charging powers, efficiency and range. Efficiency and range are recognized as the most relevant properties in the current literature. We follow this line of thought. However, we are all aware that theory and practice frequently clash. In practice, most commonly the most relevant factor is customers' budget. In other words, no matter how energy-efficient and environment-friendly a car is, we will not see it on our streets as we wish if it is unaffordable. Price is not the only economic indicator that should be taken into account. Since the charging infrastructure is underdeveloped, we shall assume that most customers will rely on their household electricity sources for re-charging a vehicle. Thus, the costs of charging a battery are among the most relevant factors for prospective customers. Based on the collected data on battery capacities, charging powers and model efficiencies, we calculated the charging costs for electricity used to charge a battery to its full capacity and charging costs for used electricity per 100km, based on the adopted average price of electricity in Serbia. These indicators may be also crucial if cheaper models prove to be inefficient and considerably more expensive to re-charge.

1. TRENDS AND DEVELOPMENTS OF ELECTRIC CARS

1.1 Electric cars architecture

Several types of battery-equipped cars have been introduced in the last decade or so, which are mainly classified into four categories: All-electric cars (AECs), Hybrid Electric cars (HECs), Plug-in hybrid electric cars (PHECs), and fuel cell-based EVs. The latter category has lesser emissions and higher efficiency, but high hydrogen production costs, underdeveloped infrastructure and lower commercial availability are a serious obstacle. The paper will focus solely on all-electric cars which use batteries as their sole energy source.

AECs use battery packs and electric motors for traction purposes (Figure 1. (c)). AECs have several benefits over other cars (i.e. conventional ICE cars, HECs, and PHECs), including: smooth operation, higher efficiency, absence of noise pollution, and minimal local GHG emissions. The efficiency of AECs has been evaluated at 60 – 70%, which is substantially higher than 15 – 18%, which is a value range attributed to ICE-based cars [16].



Note: PEC-Power electronic converter, BMS-Battery management system, ICE Internal combustion engine, G-generator

Figure 1 Power train architectures of ECs: (a) Hybrid electric car, (b) Plug-in hybrid electric car, and (c) Full-electric car

1.2 Trends in electric cars

The car market has recorded a huge expansion during the last few years. The growing concerns about the environment, reduction of fossil fuels and fluctuating prices of oils instigated the increases in EC use especially in developed countries. 130,000 electric cars were sold in only one week of 2021. The same amount was sold during the whole year of 2012. The growth has been very intensive during the last three years, despite the fact that the global pandemic has had a negative impact on car sales in general. Namely, the crisis has had no impact on the EC market. In 2020, the total car market reduced, and during the same year over 3 million ECs were sold (accounting for 4.1% in the global car market).

Even though these improvements are considerable, and the EC sales have grown significantly, their ratio in the total car sale is still relatively low. For instance, ECs participated with 2.5% in 2019, and 9% in 2021. Actually, the number of sold ECs doubled in 2021 with respect to 2020 and it finally reached the number of 6.6 million sold cars. The estimated number of electric cars on the road across the world is now approximately 16 million. They consume about 30TWh of electricity. Just for a comparison, it must be noted here that the annual consumption of electricity in Serbia is about 35TWh, in Montenegro 3.8TWh, in Croatia 15TWh, and in Bulgaria 37TWh [17]. The figure 2 shows the sale trends for electric cars since 2010.

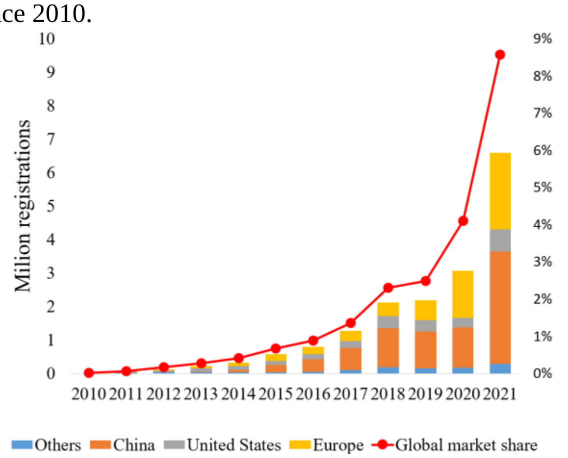


Figure 2 Global sales and sales market share of electric cars, 2010-2021 [18]

As the Figure 2 demonstrates, China was a global leader on the market of electric cars in 2021. The sales in this country increased by more than three times in 2021 (3.4 million cars) in comparison to 2020 (about one million). In China only, more ECs were sold in 2021 than in the entire world in 2020. The ratio of sold ECs on the global market leaped from 7.2% in January to 20% in December. With these trends, China has good chances of reaching the Government's goal – 20% for the whole 2025. The sales are also expected to increase during the following year. The sales of electric cars in Europe are also in expansion. The increase of 70% has been recorded in Europe in a year (2021 versus 2020). In 2021, 2.3 million electric cars entered the roads in Europe. The surge in EC sales in Europe during 2021 was at least partially initiated by new standards on CO2 emissions. In addition, the purchase subsidies were also increased and expanded in most major European markets. Overall, ECs accounted for 17% of the total car sales in Europe in 2021. However, there are tremendous diversities across the different markets. For instance, more than 30% of sold cars in Germany during the last quarter of 2021 were ECs. Still, Norway appears to be a European leader since 72% of all sold cars were ECs. Sweden and the Netherlands recorded 45% and 30% respectively, during 2021.

In the United States, the sales of electric cars doubled in 2021 after a period of stagnation and a decrease in 2019 and 2020. Over one million electric cars were sold in 2021, but they still account for only 4.5% in the total car sales, which is still a relatively low share.

It should be probably noted here that both governments and car industry faced some challenges during 2021. Tight supplies of components and increased prices of bulk materials now place supply concerns as the main priority. Taking into consideration that China, Europe and the U.S. account for only 60% of the global car market and use above 90% of electric cars, we can conclude that the whole concept of electric vehicles is extremely underdeveloped in the remaining parts of the world. For instance, in Brazil and India the share of electric cars in total car sales is below 2%. These values are unacceptably low. The reasons for this lag mainly include: the lack of institutional support and subsidies. These measures should be intensified in the future [19].

The truth is that government policies are the key driving force for global electric car markets. Many countries have introduced several different incentives for buyers and production companies in order to promote the use of ECs over fossil-fuel vehicles. In Europe, the market has been growing rapidly for the last few years. The main contributors are the Netherlands, France, Germany, and the United Kingdom. The benefits for buyers include a tax reduction or a tax exemption. These are generally one-time or annually-based taxes that are mostly paid while purchasing a vehicle. Other benefits for customers include free use or discounts on using parking facilities, free charging at public charging infrastructures, etc. The Netherlands, for instance, offers an exemption to AECs from paying the registration tax and the road taxes are completely waived. AECs can use other benefits here as well, such as: free parking, 100% tax benefits (excluding VAT), and waiver in registration taxes [16, 20, 21].

Still, the supply on the market has grown exponentially. With the growing supply and the surge of new models that are now available at the market, new challenges for customers entered the scene. Namely, after making a decision to replace their old car with an electric solution, they now must make another big decision – which model to choose in this vast variety. While even laymen are informed enough what to look for in a conventional car, electric cars have remained a mystery to ordinary customers who do not fully understand which properties are the most relevant. In order to make an informed decision which electric car to purchase, it is necessary for customers to have a comprehensive summary of what is currently offered on the market and which options are the most appropriate for their own context – budget, operational (i.e. charging) costs based on the electricity price in their country, etc. In the Serbian context, as in many developing countries, the low purchasing power can be a serious obstacle. On the other hand, Serbia is has the highest production of electricity from coal per capita in whole Europe. Thus, it is quite possible that all-electric cars which require greater quantities of energy will fail to fulfill their main purpose – to be eco-friendly.

2. METHODOLOGY OF COLLECTING AND SYSTEMATING DATA ON ELECTRIC CARS

The significance of increasing the participation of ECs on our roads and the failure to see the new technology embraced by consumers motivated us to conduct an analysis of commercially available all-electric cars. Its main contribution will be to facilitate the decision-making process by systematizing the data on commercially available models of electric cars worldwide and providing a comprehensive overview. The data are collected from the relevant webpage which updates the data on commercially available models of electric cars and their technical and economical features daily [22]. We focused on car prices (minimum only), battery capacities, car efficiencies, maximum charging powers and range. We must highlight that the prices presented here may differ from the prices given on other websites. However, we shall adopt the values provided by the same source from which we obtained the data about model properties. Some data about some models are not provided on the selected website. Even though we could obtain them from other sources, we decided not to do so in order to avoid the inclusion of data from multiple different sources and potential confusion. Finally, some models have two options for batteries and with more capacity there comes a higher range. Here we shall focus only on smaller batteries and thus smaller ranges.

Based on the collected data on battery capacities, charging powers and model efficiencies, we calculated the charging costs to maximum capacity for each model (FCC in Equation 1). We have also calculated the specific costs for 100km (SC in Equation 2).

$$FCC = BS_a \cdot EC_a \tag{1}$$

where:

BS_a -[kWh] - Battery size (average)

EC_a -[€/kWh] – Electricity price (average)

$$SC = EEC \cdot EC_a \tag{2}$$

where:

EEC - [kWh/km] – Electric car efficiency

The mean price of electricity in Serbia equals 0.08 €/kWh [23]. Taking into consideration that these cars are mostly charged during night (lower prices for used electricity in Serbia), the prices for charging a car should be lower than this average. We shall neglect this discrepancy because some factors may simultaneously make the real price higher than this mean value. Namely, the average annual mileage in Serbia is about 10,000 kilometers [24]. The average electric car whose battery capacity is about 60kWh could pass 250km with a full battery. This means that an average car should be re-charged about 3 to 4 times a month (about 200kWh of electricity). Taking into consideration that the average consumption of electricity in a Serbian household is 470kWh, the total consumption with an electric car would increase by more than 40%. It is reasonable to expect that this increase would result in exceeding the *zone* limits. Namely, the Serbian tariff-charging system sets the zone limits and a kWh of used electricity in a higher zone is pricier than one kWh which is consumed in a lower one. In addition, due to high investments for purchasing electric cars, it is reasonable to expect that these cars would be primarily attractive to the richer subpopulation. They are also known to generally use more electricity in their households (higher charging zones) so the average value for electricity is significantly higher than the average for the whole Serbian population. For these reasons, we found it even more reasonable to increase the value of average electricity price to 0.09€/kWh.

Just for illustration purposes, the paper will compare the ranges per the same amount of money which associates charging costs and ranges per one re-charge. We find these examples less abstract. They are thus easier to understand, even for laymen. The adopted average price of electricity is the same for all cars, and the costs of re-charging session are calculated based on their battery size and car efficiency. When these costs are related to cars' ranges, all most relevant properties and economic indicators are included in their unique interaction.

3. RESULTS AND DISCUSSION

According to the data base retrieved from the selected source, about 63 models of all-electric cars are currently commercially available. In addition, there are plenty more models that are not available on all continents and, as such, they are excluded from our analysis. For instance, there are a few dozen models produced by Chinese manufacturers that are available only in China and/or in the neighboring countries.

Our analysis focuses on four categories of all-electric cars: city cars (C), family cars (F), long-drive cars (LD) and SUVs. Long-drive cars are a special category in that they include all cars from the previous three groups whose batteries allow a car to pass 300km or more after one charging session. Actually, there are no strict boundaries between these categories so the same car is classified in two or more groups simultaneously:

Table 1 *Overview of models based on their category*

Category	C	F	LD	SUV	C + F	C + LD	C + SUV	
No. of models	28	7	3	4	6	2	2	
Category	F + LD	F+ SUV	LD + SUV	C + F + LD	C + F + SUV	C + LD + SUV	F + LD + SUV	ALL 4
No. of models	12	4	2	6	3	3	14	3

Since it is pointless to use this classification due to numerous overlaps between the classes, the models will be classified here according to their range. Range is generally accepted as one of the most important properties, especially because the charging infrastructure is underdeveloped to the extent that it is highly probable that vast majority of customers will predominantly depend on household electricity sources for charging their vehicles, especially in developing countries, such as Serbia. The models are classified here based on their range into five categories: (1) less than 200km, (2) 200 – 300km, (3) 300 – 400km, (4) 400 – 500km, and (5) more than 500km.

Range: less than 200km

Only four cars have a mean range lesser than 200km which most customers may find unfavorable: Citroen Ami (71km), Renault Twitzy (90km), Smart EQ Fortwo (134km), and Microlino (162km). They are all classified as city cars and their prices range from €5,000 (Citroen Ami) to €19,150 (Smart EQ Fortwo). Renault Twitzy currently costs about €11,000, and Microlino is about €12,000. Despite the attractive price, the top speed that these cars can develop is another setback. Namely, Citroen Ami and Renault Twitzy can reportedly go 48km/h and 80km/h, respectively. The top speed is not reported for Macroline, so Smart EQ Fortwo is the only car from this low-range category whose speed exceeds 100km/h (130km/h). In other words, these cars are literally designed for city driving. Since they may be unattractive even for customers who need car for this sole purpose, we will exclude them from the further analysis, especially because there are options that are not significantly pricier that Smart EQ Fortwo, but offer better performances.

Range: 200 – 300km

The lowest acceptable range (from 200km to 300km) is found in sixteen models. The following table summarizes their technical properties and economic indicators.

As can be seen from the table above, most models from this category are classified as city cars (12 models), and/or as family cars (11 models), while there are only five models labeled as SUVs.

The prices range from €11,407 (Volkswagen e-UP!) to €41,264 (Honda e). By far the cheapest option is Volkswagen e-UP!, and the next cheapest candidate within this range is Dacia Spring (€21,614). Nissan e-NV200, SEAT Mi Electric, Fiat 500e, and Renault Kangoo Ze cost from €24,021 to €29,014, respectively. Fiat appears to be the most lucrative option within this price range in terms of charging costs (€2.6 per one charging session and €1.8 per 100 km). However, if we combine charging costs with ranges, we can conclude that SEAT Mi Electric and Dacia Spring can pass higher distances for the same amount of money.

Renault Kangoo ZE is not much cheaper than the models from the following price range. There are seven models that cost between about €31,000 and 34,000. MG ZS V stands out in terms of its speed (262km/h). With all other models the speed is fairly similar (about 150 – 167km/h). MINI Electric, Hyundai Kona Electric, and Vauxhall Vivaro-e are the most efficient, and the highest ranges are reported for Kia eNiro, Hyundai Kona Electric, and Nissan Leaf. The highest charging costs per charging session are calculated for MG ZS V and Vauxhall Vivaro-e (€9.0 and €6.3). The results indicate that Hyndai Kona Electric and Kia eNiro can pass the longest distances with the same amount of money. MG ZS V and Vauxhall Vivaro-e are significantly lagging behind. For nine euros, MGZS V can be charged once and pass about 290km. Both Hyndai Kona Electric and Kia eNiro can pass about 826km for the same amount of money. These results indicate that efficiency and range are the most important properties and that they can provide a clearer image on cars' performances when combined with charging costs. These should never be observed in isolation. For instance, MINI Electric has the best efficiency (8.8km/kWh), but its range is lower by 233km than those found in Hyndai Kona Electric and Kia eNiro. As a result, it can pass just a half of the distance that the other two cars can reach for the same amount of money.

Citroen ë-Space Tourer, BMW i3 and Honda are significantly pricier (€37,196, €40,592, and €41,264, respectively). The most efficient option is BMW i3 which also has the highest range, top speed, and charging price per session. Even though it can pass larger distances for the same amount of money than other two models, we must note that it cannot surpass Hyndai Kona Electric and Kia eNiro in this aspect because both its range and efficiency are lower.

Table 2 *Technical properties and economic indicators (range: 200 – 300km)*

Model	Category	Min. price [€]	Battery size [kWh]	Efficiency [km/ kWh]	Range [km]	Accelerating 0-100 km/h [s]	Top speed [km/h]	Charging costs per charge [€]	[€/100km]
Volkswagen e-UP!	C	11,407	32.3	8.42	261	12.32	130	2.91	1.07
Dacia Spring	C, SUV	21,614	27	8.40	225	-	-	2.43	1.07
Nissan e-NV200	F	24,021	40	5.39	200	14.5	122	3.60	1.67
SEAT Mii Electric	C, F	25,576	32.3	8.42	272	12.7	130	2.91	1.07
Fiat 500e	C, F	26,411	24	7.63	185	-	150	2.16	1.18
Renault Kangoo ZE	C, F	29,014	33	7.11	230	21.0	130	2.97	1.27
MG ZS V	C, F, SUV	31,411	44.5	5.89	262	7.56	261	9.0	1.48
Nissan Leaf	C, F	32,415	40	6.20	270	7.6	156	3.60	1.45
MINI Electric	C, F	32,421	32.6	8.08	233	7.56	150	2.93	1.11
Mazda MX-30	C, F, SUV	32,475	35.5	6.76	200	10.0	150	3.20	1.33
Kia eNiro	F, SUV	32,845	39	7.10	290	7.77	167	3.51	1.27
Vauxhall Vivaro-e	F	33,179	50	4.84	232	-	-	6.3	1.5
Hyundai Kona Electric	C, F, SUV	34,762	39	7.55	290	10.05	167	3.51	1.19
Citroen ë-SpaceTourer	F	37,196	50	5.12	219	-	-	4.5	1.25
BMW i3	C	40,592	42	6.63	278	7.15	159	3.78	1.36
Honda e	C	41,264	35.5	5.66	220	8.60	145	3.20	1.59

Range: 300 – 400km

For sixteen models the range varies from 300km to 400km. Their technical properties and economic indicators are presented in Table 3.

The models with the desired range vary greatly in price and other characteristics. The cheapest model is Vauxhall Mokka (€30,895), and the most expensive is Mercedes EQV (€80,840), followed by Mercedes EQC (€78,915) and Audi e-tron (€72,767).

Table 3 *Technical properties and economic indicators (range: 300 – 400km)*

Model	Category	Min. price [€]	Battery size [kWh]	Efficiency [km/ kWh]	Range [km]	Accelerating 0-100 km/h [s]	Top speed [km/h]	Charging costs per charge [€]	[€/100km]
Vauxhall Mokka	All four	30,895	50	7.19	336	-	-	4.5	1.3
Vauxhall Corsa-e	C, F, LD	32,565	50	7.47	336	-	-	4.5	1.2
Citroen e-C4	C, F, LD	34,216	50	7.76	349	9.3	150	4.50	1.16
Renault Zoe	C	34,336	52	7.4	383	9.84	-	8.10	1.73
SsangYong Korando e-Motion	F, SUV	36,617	61.5	-	338	-	249	9.0	1.46
Peugeot e2008	All four	41,102	50	6.82	332	9.3	150	4.50	1.32
Volkswagen ID.4	F, LD, SUV	42,021	52	6.49	340	6.4	180	4.7	1.4
DS3 Crossback E-Tense	C, SUV	44,308	50	7.02	315	9.32	150	4.50	1.28
Hyundai IONIQ Electric	C, F	44,933	38	8.22	312	5.4	150	3.51	1.39
Lexus UX3003	F, SUV	50,126	53.3	5.70	315	7.77	259	6.97	1.32
Nissan Ariya	LD, SUV	50,246	63	5.79	359	5.28	-	4.5	1.25
Audi Q4 e-tron	F, SUV	50,222	52	6.6	322	6.4	130	2.91	1.07
Tesla Model Y	F, LD, SUV	66,030	55	6.76	370	3.6	-	4.5	1.25
Audi e-tron	All four	72,767	71	5.13	300	3.75	209	6.4	1.8
Mercedes EQC	C, LD, SUV	78,915	80	4.65	372	5.28	180	7.20	1.94
Mercedes EQV	F, LD	80,840	90	3.77	340	-	259	6.39	2.26

Ssang Yong Korando e-Motion (249km/h) and Lexus UX3003 and Mercedes EQV (259km/h both) stand out in terms of top speed. Tesla and Audi e-tron have the best acceleration. The highest efficiencies are reported for Hyundai IONIQ Electric, Citroen e-C4 and Vauxal Corsa (more than 7km per kWh) while the lowest efficiencies are found in Mercedes EQV, Mercedes EQC, and Audi e-tron. Renault Zoe, Mercedes EQC, and Tesla Model Y have the largest ranges, while the opposite is the case with Audi e-tron, Hyundai IONIQ Electric, Lexus UX3003, and DS3 Crossback E-Tense. When charging costs are taken into consideration, we can see that Audi Q4 e-tron, Hyundai IONIQ Electric, and Tesla Model Y can pass the largest distances for the same amount of money. This once again shows that neither highest efficiencies nor highest ranges are a guarantee that a car has the best performances. These two properties must be observed in their unique interaction. The results also show that speed adds the price, but impacts the total performance quite unfavorably. Two fastest cars, Lexus while Mercedes EQV, have high charging costs and they can pass less than a half of the distance that Audi Q4 can for the same amount of money. Lexus is more efficient than Audi Q4 e-tron and Mercedes EQV has a higher range. Still, the model with a better combination of these two properties appears to be the most acceptable solution if we observe the models from this perspective.

Within the lower price range (€30,895 to €36,617), the most favorable interaction between efficiency and range is found in Citroen e-C4. After Hyundai IONIQ Electric, this is the second most efficient car in this category. This Citroen's solution is cheaper by €10.000 than Hyundai's IONIQ Electric, and as such, it is more affordable and will probably be perceived as more attractive option.

Range: 400 – 500km

According to the selected database, 18 models have a range from 402 to 499km per one full charge. This classifies them all as long-drive cars. Pininfarina Battista and Rimac Nevera are excluded from further analysis because they are not serially produced and their prices surpass 2 million euros. The technical properties and economic indicators are presented in Table 4.

Only two models within the selected ranges are non-SUVs: Volkswagen ID.3 and Tesla Model 3 (ordered based on their price). The price range for this category ranges from €33,105 to €51,621. The cheapest cars are MG 5EV and Renault Megane E-tech. The priciest cars in this category are Ford Mustang Mach-E, Jaguar I-Pace and BMW iX. The lowest battery capacities are reported for Tesla Model 3, Volkswagen ID.3, and Skoda EnyaqiaV, while the opposite is the case with Jaguar I-Pace, BMW iX3, and Volvo XC40 Recharge. The best efficiency is recorded for Tesla Model 3, Skoda EnyaqiV, and Hyndai IONIQ5. Jaguar I-Pace, BMW iX, and BMW iX3 are at the bottom of the list in terms of their efficiency. Volkswagen, Hyundai, Renault and Jaguare have the best ranges. The lowest ranges are reported for Ford Mustang, MG 5EV, and Skoda. MG 5EV, Tesla Model 3, Mercedes EQA, and Renault have significantly higher top speeds than the other models in this category. When costs needed for one re-charging are taken into consideration, the best results are found for Ford Mustang Mach-E, Jaguar I-Pace, and BMW iX. The opposite is the case with Tesla Model X and MG 5EV which stand out as the most extreme cases. For prospective customers it may be relevant to know that with the same amount of money the smallest distances can be passed with MG 5EV, Skoda EnyaquiV, Ford Mustang, and Volvo. The largest distances for the same amount of money can be passed with Ford Mustang, Jaguar I-Pace, and BMW iX. Within that price range, Ford Mustang has the best efficiency. Within the lower price range (€50,371 to €59,978), the best interaction of efficiency and range is exhibited by Tesla Model 3 which has both the highest efficiency and the highest range, and the lowest charging costs. Volkswagen ID.3, Skoda Enyaqi V, and Hyndai IONIQ 5 currently cost from €40,148 to €44,933. The biggest battery capacity is recorded for Hyundai (72.6kWh) while Skoda and Volkswagen have the batteries with the same capacity (58kWh). The highest efficiency is reported for Volkswagen, Skoda, and then Hyndai. Skoda has the highest costs per charging session (€8.1), as compared to Hyundai (€6.53) and Volkswagen ID.3 (€5.22). For the same amount of money, Hyndai can pass the largest distances even though its efficiency is the lowest since it has the best range (480km versus 425 and 412km).

Table 4 *Technical properties and economic indicators (range: 400 – 500km)*

Model	Category	Min. price [€]	Battery size [kWh]	Efficiency [km/ kWh]	Range [km]	Accelerating 0-100 km/h [s]	Top speed [km/h]	Charging costs per charge [€]	[€/100km]
MG 5EV	C, F, SUV	33,015	61	6.55	402	7.56	261	9.0	1.48
Renault Megane E-Tech	F, LD, SUV	37,224	60	0.0	470	7.46	209	6.39	1.75
Volkswagen ID.3	F, LD	40,148	58	7.02	425	9.9	161	5.22	1.28
Skoda EnyaqiV	F, LD, SUV	41,439	58	6.95	412	8.7	-	8.1	2.39
Hyundai IONIQ 5	F, LD, SUV	44,933	72.6	6.60	480	5.4	185	6.53	1.36
Toyota bZ4X	L, LD, SUV	50,372	71.4	6.28	451	7.1	159	6.43	1.43
Ford Mustang Mach E GT	LD, SUV	51,069	75	6.10	401	5.3	180	6.75	1.5
Tesla Model 3	C, F, LD	51,621	55	7.72	430	3.2	261	4.95	1.17
Mercedes EQA	F, LD, SUV	53.428	70	6.00	420	-	-	6.3	1.5
Volvo XC40 Recharge	F, SUV	59,978	78	5.34	417	5.1	180	7.02	1.68
Mercedes EQB	F, LD, SUV	61,239	66.5	6.29	418	6.42	241	6.75	1.33
Volkswagen ID.5 GTW	F, LD, SUV	66,444	77	6.4	496	6.42	-	6.93	1.4
BMW iX3	F, LD, SUV	70,665	80	5.73	459	7.0	185	5.49	1.37
Ford Mustang	F, LD, SUV	78,146	75	6.1	401	-	150	2.16	1.18

Mach-E									
Jaguar I-Pace	F, LD, SUV	78,284	90	5.21	470	4.7	166	3.42	1.09
BMW iX	F, LD, SUV	83,940	71	5.49	425	6.32	150	4.5	1.21

Range: more than 500km

According to the selected database, nine cars have a range higher than 500km (Table 5). The price range goes from €49,166 (KIA EV6) to €120,077 (Lucid Air).

Table 5 *Technical properties and economic indicators of models whose range is above 500km*

Model	Category	Min. price [€]	Battery size [kWh]	Efficiency [km/ kWh]	Range [km]	Accelerating 0-100 km/h [s]	Top speed [km/h]	Charging costs per charge [€]	[€/100km]
Kia EV6	F, SUV	49,166	77.4	6.82	528	3.66	159	5.22	1.29
Volkswagen ID. Buzz	F	60,039	77	-	550	-	-	6.39	1.64
BMW i4	F, LD	62,326	80	7.29	591	4.0	224	7.20	1.23
Toyota Mirai	F, LD	72,046	-	-	805	9.5	180	4.68	1.39
Mercedes EQE	F, LD	84,054	90	-	660	-	209	6.39	1.75
Tesla Model S	F, LD	96,038	100	6.10	591	2.4	-	10.8	2.17
Tesla Model X	All 4	105,644	100	6.18	560	4.56	150	3.2	1.33
Mercedes EQS	F, LD	109,264	108	7.15	771	-	-	6.39	1.64
Lucid Air	F, LD	120,077	90	-	660	3.1	-	4.98	1.58

The differences in prices in models with the selected range (>500km) are huge. The cheapest model is Kia EV6. The most expensive are Tesla Model X, Mercedes EQS, and Lucid Air. The most expensive car is about 2.4 times pricier than the cheapest one. The battery capacity is the worst in KIA EV6, Volkswagen ID. Buzz, and BMW i4 (77kWh, 77kWh, and 80kWh, respectively). The best battery capacity is found in Tesla Model S, Tesla Model X, and Mercedes EQS (100kWh, 100kWh, and 108kWh, respectively). Not all values for efficiencies are reported in the selected source. Based on those that are documented, BMW i4 and Mercedes EQS have the best efficiencies (7.9km/kWh and 7.15km/kWh). The opposite is the case with Tesla Model X and S (6.18 and 6.10km/kWh). By far the largest ranges are recorded for Toyota Mirai and Mercedes EQS. Only BMWi4 and Mercedes EQE can develop speeds higher than 200km/h. The charging costs per one re-charge are the most unfavorable in case of Tesla Model S and BMWi4 (€10.8 and €7.2) while they are the lowest for Tesla Model X and Toyota Mirai (€3.2 and €4.68, respectively). Just for illustration, with the same amount of money for recharging, Tesla

Model S, Volkswagen ID. Buzz, and BMW i4 can pass significantly lower distances than Tesla Model X and Toyota Mirai. Tesla Model S and Tesla Model X are at the top in terms of battery capacity (after Mercedes EQS), however both cars are at the bottom in terms of both efficiency and range. In both aspects they rank as the fourth and fifth best solutions. However, the differences in charging costs make a significant difference for prospective customers. With the same amount of money Tesla Model X can pass the distance that is three times longer than that passed with Tesla Model S. BMW i4's battery ranks as the third worst solution within this capacity, so despite its best efficiency it shares the fourth place with Tesla Model X in terms of range. Taking into consideration the charging costs, which are the second most unfavorable in this range category, BMW i4 can be seen as the second least favorable option for customers. On the other hand, Toyota Mirai follows Tesla Model X in terms of range per the same amount of money so it can be seen as the most attractive option for the customers, especially if we take into consideration that it is cheaper than Tesla Model X for about €30.000. The efficiency of this model is not documented in the selected source, but it has the best range in this category and second best charging costs.

Comparative analysis of different categories

Based on the mean values obtained for each category we can conduct a brief comparative analysis. The obtained values are presented in Table 6.

Table 6 *Technical properties and economic indicators across different range categories*

Range category [km]	**Price [€]**	**Battery size [kWh]**	**Efficiency [km/ kWh]**	**Range [km]**	**Charging costs per charge [€]**
200 – 300	30,412	37.29	6.82	242	3.78
300 – 400	49,384	57.36	6.45	339	5.42
400 – 500	40,416	69.91	6.25	436	6.0
> 500	84,295	90.30	6.71	635	6.14

The results show that the mean prices at least partially correspond to the range. As the ranges increase, so does the price. The only exception are the cars with the range 300 – 400km and 400 – 500km. The latter are cheaper than the previous category. As the ranges increase, so does the mean battery capacity. Even though the cars with higher ranges are notorious for being not efficient enough as cars with lower ranges, this analysis shows that the mean values differ slightly. The selection of the top representatives confirms the same. In the first category (200 – 300km), the best efficiencies are reported for Volkswagen e-UP! and SEAT Mii Electric (8.42 km/kWh). With 8.22km/kWh and 7.72km/kWh, Hyundai IONIQ Electric (300 – 400km) and Tesla Model 3 (400 – 500km) follow this trend. The best efficiency within the range >500km is reported for BMW i4 (7.29km/kWh). The main reasons for the discrepancy found with the highest-range models can be attributed to the fact that efficiencies are not documented for four models. Their values could change the image significantly.

These results prove that car industry has been putting serious efforts to create all-electric cars with higher ranges by simultaneously trying to increase their efficiency. In other words, even though they have kept larger batteries needed for long-range drives, they found a way to make their cars more efficient. Obviously, long-range cars still cannot compete with short-range models in terms of efficiency, but at least their efficiency is becoming more and more acceptable. Finally, we must highlight that discrepancies between the models within each range category can be tremendous, so we should avoid generalizations.

4. CONCLUSIONS

This paper summarizes the main properties and economic indicators of 63 all-electric cars that are currently commercially available. The prices differ drastically, as with conventional cars. However, with conventional cars most customers predominantly know what to look for in a car, while the properties of electric cars remain a mystery for laymen. In addition, the car properties which are theoretically the most crucial ones (energy-efficiency and eco-friendliness) are not the most relevant for prospective customers.

Economic indicators must be taken into account because the budget narrows down the selection. In addition, charging costs may be the second most relevant factor since customers desire to make lucrative investments. Thus, we must find ways to evaluate model performances by combining these four features. This paper demonstrates that the best performances are found in those models which have a favorable combination of price, battery capacity, model efficiency, range and charging costs. These factors are interrelated and since there is no objective measure to calculate their impact, we must invent new ways of comparing them. Namely, this paper demonstrates that the highest battery capacity is very frequently not a guarantee that models will have neither the highest efficiency nor the highest range. The results also show that prices of cars, with all other properties being practically identical, can differ significantly if a car offers better speed and acceleration, or is produced by a company with long tradition and good reputation. We have also found the examples that further confirm our hypothesis about the relevance of charging costs. Namely, there are a few examples in which different charging costs are the most drastic difference between two models that otherwise have similar specifications. First, if for the same amount of money a car can pass longer distances, it means that it will be re-charged less frequently. This can be extremely appealing for prospective customers.

The paper also demonstrates that prices do increase with increases in range. Batteries also increase significantly, but efficiencies decrease slightly. Charging costs also increase due to battery size. It is interesting to note that in the first category analyzed here, the most favorable interplay of technical properties and economic indicators is found in the cheapest models (Volkswagen e-UP!, Dacia Spring, and SEAR Mii Electric) because these cars have lower ranges, smaller batteries, and higher efficiency. In the second category, the most appealing interactions of the features are found in the models whose prices are the lowest. The only exception is Hyndai IONIQ Electric, whose price fluctuates around the mean value. The added price can be contributed to the smallest battery, and the highest efficiency. However, in the third and fourth category, the best combinations of the most relevant features are detected in pricier, but not necessarily the most expensive, models.

Finally we must conclude that the slight mean differences in efficiency between short-range and long-range cars are extremely encouraging. This proves that the car industry has been investing a lot of effort to reconcile what customers want (i.e. higher ranges) with what we all need (i.e. energy-efficient and eco-friendly transportation). Their attempts give results and strengthen the vision that that future of car industry is electric.

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