WIDESPREAD ADOPTION OF ELECTRIC VEHICLES

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PREDDIPLOMSKI STRUČNI STUDIJ PROMET

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Kolegij: Engleski jezik
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WIDESPREAD ADOPTION OF ELECTRIC VEHICLES

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Sažetak rada:

Današnje generacije se suočavaju sa velikim ekološkim katastrofama koje se povezuju sa prekomjernim ispuštanjem stakleničkih plinova u atmosferu. Pokrenute su brojne međunarodne inicijative u cilju očuvanja okoliša ali bez značajnijeg uspjeha. Transportni sektor je jedan od najvećih onečišćivača okoliša i u bliskoj budućnosti više nećemo moći izgarati fosilna goriva za dobivanje korisnog rada zbog ekološke neodrživosti takvog sustava, već ćemo se morati potpuno okrenuti alternativnim oblicima dobivanja (pretvaranja) energije. Takav oblik energije u cestovnim vozilima je električna energija. Sveprisutna je u našim životima, ali se rijetko koristi za pogon vozila. Postoje i drugačije vrste ekoloških vozila naprimjer one koje koriste alternativna goriva koje su manje ili nimalo štetna za okoliš, ali transportni sektor sa vozilima na električni pogon se nameće kao dugoročno najodrživiji sustav. Proizvodnja takvih vozila je počela već početkom ovog stoljeća, ali ih ni danas ne viđamo često jer su ona u očima javnosti još nedokazana tehnologija i skuplji su odnosu na konvencionalna vozila.

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WIDESPREAD ADOPTION OF ELECTRIC VEHICLES

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Abstract

Our generations are facing huge environmental disasters that are linked to excessive emissions of greenhouse gases into the atmosphere. Governments created a number of international initiatives trying to preserve the environment but without greater success. Transport sector is one of the leading polluters and in the near future we won't be able to burn fossil fuels in order to create useful work due to ecological unsustainability of that kind of system. We will have to completely turn to alternative forms of producing (converting) energy. One kind of alternative energy used in vehicles is electric energy. It's omnipresent in our day to day lives, but we rarely see it propelling vehicles. There are some other forms of ecological vehicles like the ones using alternative fuels that are less harmful or aren't harmful at all, but transport sector made of electric vehicles is the only one that is seen as sustainable for long term use. Production of such vehicles began with the turn of the century, but we rarely see them even today because in the eyes of the public they are still an unproven new technology and are more expensive in comparison to the conventional vehicles.

(30 pages / 14 Figures / 5 tables / 40 references / original language English)

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SADRŽAJ

1. INTRODUCTION

At the end of the 19th century, mass production of rechargeable batteries encouraged the use of electric vehicles. The paper describes the occurrence of electric vehicles, basic division, problems, performance, their disappearance from the road and return. Electric vehicles are all vehicles that use electricity to power the drive. They can be divided into five main groups:

• traditional electric vehicles
• hybrid vehicles
• electric fuel cell vehicles
• electric vehicles on solar cells
• electric vehicles on flywheels and superconductors.

The real development of electric vehicles occurs in the 80s and 90s of the 20th century by the development of high power and frequency semiconductor valves, and the development of microcontrollers. The use of electric vehicles does not necessarily mean a reduction in total consumption. The main reason for their further development is solving the environmental problem of pollution and depletion of oil reserves that is currently the primary fuel for hundreds of millions of vehicles, and at the same time irreplaceable basis for plastics production, for the chemical industry and most importantly - for most medical equipment. Technology development and rising fuel prices lead to a debate on the economic viability of the electric vehicle in the last decades of the 20th century. There are more advantages of electric cars compared to cars with internal combustion, such as:

- greater energy efficiency; because they convert more energy gained from the network into workforce
- mechanical simplicity of the engine and high energy utilization rate - over 90%
- they are more environmentally friendly due to much lower CO2 emissions and thus less polluting the environment
- have better performance in terms of quiet operation, better acceleration and less maintenance
- there is no need for a gearbox because the motors have a great moment even at low revs
- they are less energy-dependent as electric energy is ubiquitous. An electric car can be easily plugged through any socket and continue the journey;

- the price of 'fuel' is a very important item. The consumption of electric cars is 15-20 kWh per 100 km, ie a daily rate of 15 to 20 kn. So, far less than the price of petroleum products, it can also be even lower if for charging people use cheaper electricity tariffs (nightly tariff that is twice as cheap) or currents from their own sources, especially those obtained from solar panels.

Today, the electric car is particularly interesting because modern sustainable development is based on ecology and energy savings. High fuel prices and bad climate conditions have led to increased consumer awareness, so the electric vehicle has found its place with the aim of further development and usage. The aim of the paper is to analyze the current electric vehicle's market position in order to create a realistic picture of its further, potential use. That is why it is necessary to explore the utility of electric vehicles around the world: in Europe, USA, Asia, but also in Croatia. The analysis of the use of electric cars over a certain period of time provides an answer to the question whether electric cars are being used more or less, ie whether the interest in electric cars is decreasing or increasing.

In this paper the following methods are used:

- the induction method - based on individual or specific, facts lead to the conclusion about the general attitude. When writing this work induction will be used to draw conclusions on the basis of the collected data and literature
- the method of deduction - from general attitudes specific and individual conclusions are performed. Deduction always presupposes existence of general knowledge; on its basis the knowledge of particular or individual is being developed
- the methods of analysis and synthesis - analysis is the breakdown of complex concepts, judgments and conclusions to their simpler component parts. This is the study of each component, which are compared to other parts. Synthesis is the process of scientific research through the merger of parts or elements in the whole assembly of simple thought creations into complex;
- the description method - the process of describing the facts and empirical confirmation of their relationship
- the method of comparison - a way of comparing the same or related facts and their determination.

2. ELECTRIC VEHICLE

The electric vehicle is powered by an electric motor. The electric drive of such vehicles is also called electric traction, and sometimes these vehicles are also referred to as electro-trailer vehicles. Electric vehicles generally do not discharge exhaust gases if they are not hybrid vehicles. These vehicles do not produce noise, have a better level of performance and better drive performance than vehicles powered by an internal combustion engine of equal strength, and their advantages are considerable. However, due to the limited autonomy caused by technical difficulties related to electricity supply and the problem of battery capacity, these vehicles have been widely used in public transport (railways, trams, etc.) and for cases of autonomous freight and personal transportation (for the transportation of small cargoes factory drives, warehouses, etc., electrostatic and other light electric vehicles for the transport of persons and cargo, for transporting urban quarters and personal transports, electric bicycles, motorcycles, etc.)[1].

2.1 Independent electric vehicles and dependent electric vehicles

Independent electric vehicles pump the electrical energy needed to drive the electric motor from the source built into the vehicle itself (accumulator battery). In the case of battery vehicles, electricity is stored in an accumulator (eg in an electric car), and in some other independent vehicles, electricity is generated by combustion of fuel, generated by the operation of an electric generator in combination with a diesel or gasoline engine, relatively rare with a gas turbine (vehicles with hybrid drive). The source of electricity can also be a fuel-based article with direct conversion of chemical to electricity, or a solar battery (like a solar or a solar car)[2].

The dependent electric vehicles take electricity from the power grid via the contact line and the pantograph that slides on it (eg electric locomotives, trams), or by a special rail (underground). The technical and economic advantages of electric drives are particularly noticeable in railway traffic. Compared to the steam and diesel engines, it is emphasized by the reliability, the increased installed power (per axle), the conveyance and the permeable power of the lines, and

[1] Egbue, O. (2012) A socio-technical analysis of widespread electric vehicle adoption. Dissertation, Missoury University of science and technology. p. 9. – 10.

[2] Egbue, O.; Long, S. (2012) Barriers to widespread adoption of electric vehicles: An analysis of consumer attitudes and perceptions. Volume 48, September 2012, Pages 717-729

lower energy consumption, the cost of exploitation and the damaging effect on the environment. Due to the large investments in the electrification of the railroad, the above mentioned advantages are reflected in higher traffic density[3].

On electrified railway lines, electric power is supplied to electric substations, which directly supply the contact nets of certain strip shares. In them, the alternating current of high voltage is transformed into a DC or alternating current of the same voltage and frequency corresponding to the type of electric drive system. DC voltage systems are rated voltages of 1.5 kV or 3 kV while the systems of urban traffic are rated with a voltage between 600 V and 750 V. Their disadvantages are a relatively massive contact line and a densely spaced electroshield substation. Alternating power systems to a significant extent eliminate the shortcomings of DC systems[4].

15 kV and 16 2/3 Hz and new 25 kV and 50 Hz frequency systems are in use. Their application encouraged the development of semiconductor power electronics in the 1960s. For electric drive, collector DC or single-phase electromotors and three-phase asynchronous electric motors are used. Three-phase asynchronous motors are characterized by a much better ratio of mass and nominal power, easier to maintain, and is also possible to fine tune the driving force and drive speed[5].

Electric vehicles have several potential advantages over conventional vehicles with internal combustion engines. They include a significant difference between the price of electricity compared to the price of petroleum products, the reduction of air pollution in the cities because they do not release pollutants during operation, reduced greenhouse gas emissions, depending on the fuel and technology used to generate electricity for battery charging, lesser oil dependence. It also reduces the noise from the traffic, through the almost silent operation of electric vehicles[6].

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[3] Egbue, O.; Long, S. (2012) Barriers to widespread adoption of electric vehicles: An analysis of consumer attitudes and perceptions. Volume 48, September 2012, Pages 717-729

[4] Gordić, M. et al. (2017) Electric vehicle conversion: optimisation of parameters in the designe process. Tehnički vjesnik 24, 4(2017), 1213-1219

[5] ibid

[6] Changala, D.; Foley, P. (2011) The legal regime of widespread plug-in hybrid electric vehicle adoption: a Vermont case study. Energy law journal, Vol. 32:99

2.2 The principle of electric vehicle operation

The electrical system of an electric vehicle is a closed circuit with an independent power source or a battery, or, in the case of a hybrid vehicle, the power source can be combined with an internal combustion engine that converts mechanical energy into electricity that accumulates in the battery. Also, in today's cars, electricity can also be obtained by regenerative braking (KERS) whereby part of the kinetic energy that would be lost as heat, by the flywheel or generator principle, is saved in another form of energy[7].

For electric vehicles with a battery that do not have an internal combustion engine, the vehicle's operating circuit is based on a battery pack. Such a system must be charged through the power supply network. Chargers for charging the battery pack are used to convert the AC voltage to the DC voltage of the battery, which can be charged on the domestic battery terminal for an average of 6 to 8 hours. Modern cars have 12 volt voltage batteries[8].

Battery capacity is measured in (amp) so, for example, the battery of 56ah should be able to supply 1 amp current for 56 hours, or 2 amplifiers for 28 hours. If the battery voltage drops, there is less current, and in the end, the voltage and current values are not enough to make the components work. The battery pack is the only source of energy and it sends a direct current to the amplifier that amplifies the current, and the voltage, increasing to larger amounts. After the amplifier, the current that is converted to the alternating current in the transducer goes into the electric motors that are the most important components of each electric vehicle. Electric energy is transformed into mechanical energy using the principle of electromagnetic induction, and this mechanical energy is transmitted through the transmission to the wheels. The controller is also essential and is in charge of controlling the operation of an electric motor and is a functional unit with an electric motor[9] (figure 1.):

[7] EEA (2016) Electric vehicles in Europe. Copenhagen. p. 11. – 17.

[8] ibid

[9] ibid

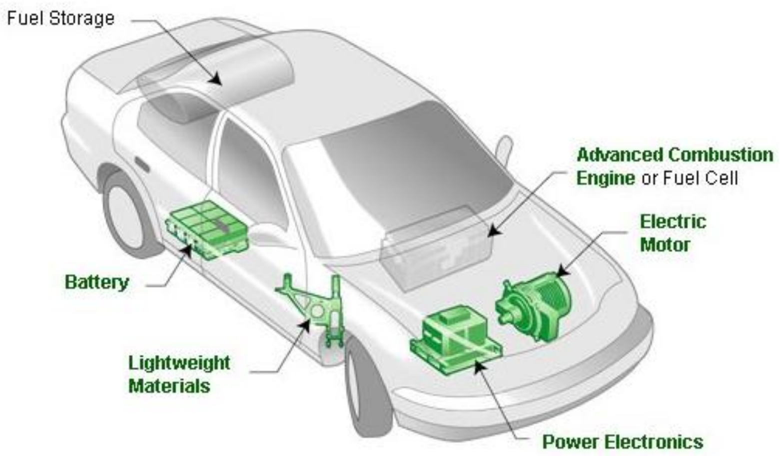

Figure 1. The principle of electric vehicle operation. Source: Intechopen.com https://www.intechopen.com/source/html/41416/media/image16.png. Date: 20.11.2017.

2.3 Electrical vehicle elements

The basic elements for the electric drive are the electric motor, the electric drive battery and the controller or motor controller. The other parts of the electric car are: analogue-digital gas pedal signal converter, which provides the desired speed information; contactor; fuse or switch; a DC voltage converter for the drive of a conventional 12V power supply (lights, direction indicators, wipers, sound signals, radio devices and the like); measuring instruments for vehicle control (indicator of remaining battery capacity, voltage, current, power, speed); battery charger[10].
Other parts that an electric drive vehicle must include are: power supply cables, 12 V auxiliary cables, 12 volt auxiliary batteries, cable lugs and cable connections. The battery is a component that determines the overall characteristics of an electric vehicle and defines its cost, autonomy and availability. There are two factors that determine battery performance: energy (distance traveled) and power (acceleration). Other parts that an electric drive vehicle may contain are: key switch; emergency shutdown switch; inertial switch; rapid discharge of electric drive battery; battery management system; heaters for interior vehicle heating; electric vehicle control

[10] Larminie, J.; Lowry, J. (2003) Electric Vehicle Technology Explained. John Wiley & Sons Ltd, England. p. 7. - 18

system; vacuum pump; an electric drive pump for the servo steering system if it exists and is not solved by the transmission belt hydraulic pump[11] (figure 2.):

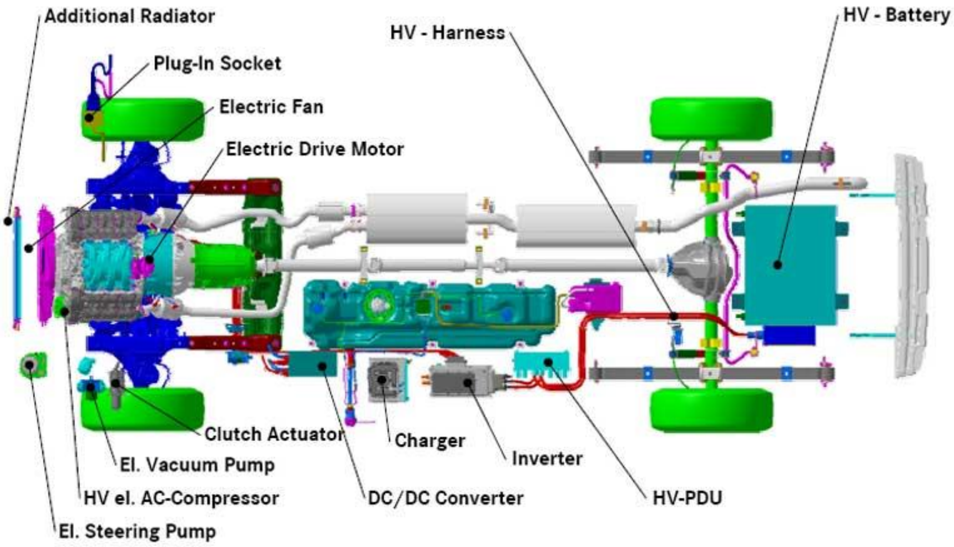

Figure 2. Electrical vehicle elements. Source: Srpe.ca http://www.srpe.ca/wp-content/uploads/2013/07/diagram-electric-vehicle.jpg. Date: 20.11.2017.

[11] Larminie, J.; Lowry, J. (2003) Electric Vehicle Technology Explained. John Wiley & Sons Ltd, England. p. 141. – 144.

3. ELECTRIC MOTOR

The most important component of each electric car is an electric motor. The electric motor is an electric machine that transforms electrical energy into a mechanical using the principle of electromagnetic induction. The motors in the construction sense have two windings, stator and rotor.

Basic types of electrical machines by power source can be divided into DC motors, alternating motors (AC) and stepping motors.

The advantages of alternating electric motors with respect to the DC, per unit of power, are: smaller mass, smaller dimensions, lower inertion moment, lower price, higher rotation speed, higher degree of useful performance (0.95 - 0.97 compared to 0.85 - 0.89), simple and inexpensive maintenance. The advantage of dc electric motors in relation to alternating is simpler but also cheaper control, ie lighter and cheaper control modules. The electric motor should provide the most suitable system operation in stationary and transient operating modes such as acceleration, braking, load change or other influential sizes. The external characteristic of the engine serves as the basic criterion when choosing a type of engine for a working mechanism[12].

3.1 AC induction electric motor

The alternating asynchronous or induction motor is powered from the alternating three-phase or single-phase voltage network. In the asynchronous motor, the rotating magnetic field is generated by the passing of the three-phase current through the three-phase windings located on the stator. It can also be created by connecting the motor to a single-phase grid if the two phase windings are displaced spatially to a suitable angle and if a coil is added to the capacitor, which causes the phase shift between the currents to power the two windings to obtain a capacitor motor. The resulting rotating static magnetic field induces in the rotor guides the voltages and currents that create their rotating magnetic field[13].

By interaction of these two fields, electromagnetic forces are created and rotational moments cause rotor rotation. These forces and moments exist only as long as the force of the rotary field

[12] Larminie, J.; Lowry, J. (2003) Electric Vehicle Technology Explained. John Wiley & Sons Ltd, England. p. 141. – 143.

[13] ibid, p. 169.

hits the rotor guides and would disappear at that moment if the rotor speeds and the rotary field equals, that is, when the synchronous ratio of the rotation speed would be established, i.e. if the relative rotation of the rotor guide the field, and therefore induced voltage and current in rotor guides. For the proper operation of such a motor it is necessary that the rotation speed of the rotor is slightly less than the synchronous speed, that is to say, rotor sliding, hence the name of the asynchronous motor (figure 3.):

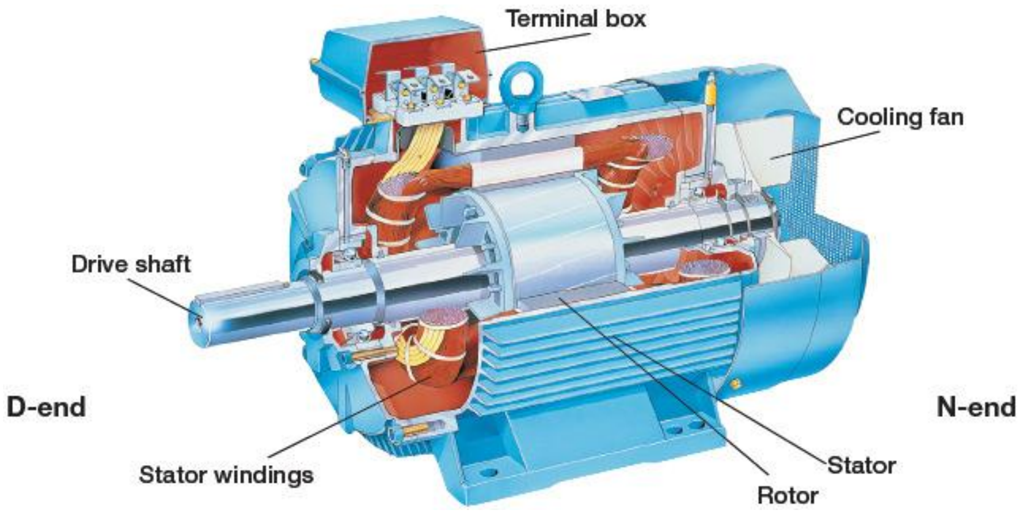

Figure 3. AC induction electric motor. Source Clrwtr.com
http://www.clrwtr.com/Images/Articles/Motors/Asynchronous-Motors.jpg. Date: 20.11.2017.

3.2 A classic DC electric motor

The DC motor converts the DC electric current into the rotational motion. The machine is so constructed that it can work as a DC generator if it is mechanically driven by external force. Through the collector and the brush, electric contact is made with the rotor winding, and it converts alternating current in the same direction. The engine is run with an independent, serial, complex excitation or permanent magnet. Due to the possibility of continuous change of the turning speed, the DC motor is used in the industry and for the operation of track and some special vehicles such as trams, locomotives, electromagnetics etc. Speed is changed in a variety of ways, and in modern drives is controlled by a computer. Due to battery power, the DC motor is also used as a ICE motor starter, for example in cars and diesel aggregates. However, due to the commutator design and its maintenance of brush wear and subsequent sparking, the DC motor, due to its purchase price and operational reliability, is less useful than an asynchronous motor[14] (figure 4.):

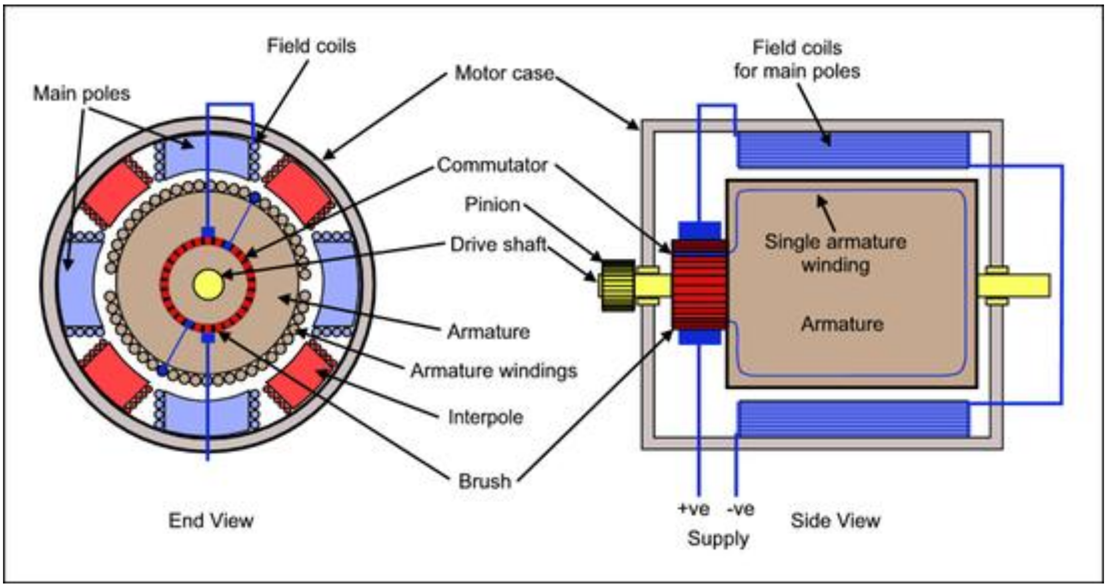

Figure 4. A classic DC electric motor. Source: Railway-technical.com http://www.railway-technical.com/_Media/motor-basic-2_med_hr_med.png. Date: 20.11.2017.

3.3 BLDC electric motor

The BLDC (Brushless Direct Curent) engine is a synchronous motor that converts the DC motor to the AC drive via the regler or ESC (Electric Speed Controller) device (figure 5.):

[14] Larminie, J.; Lowry, J. (2003) Electric Vehicle Technology Explained. John Wiley & Sons Ltd, England. p. 149. – 151.

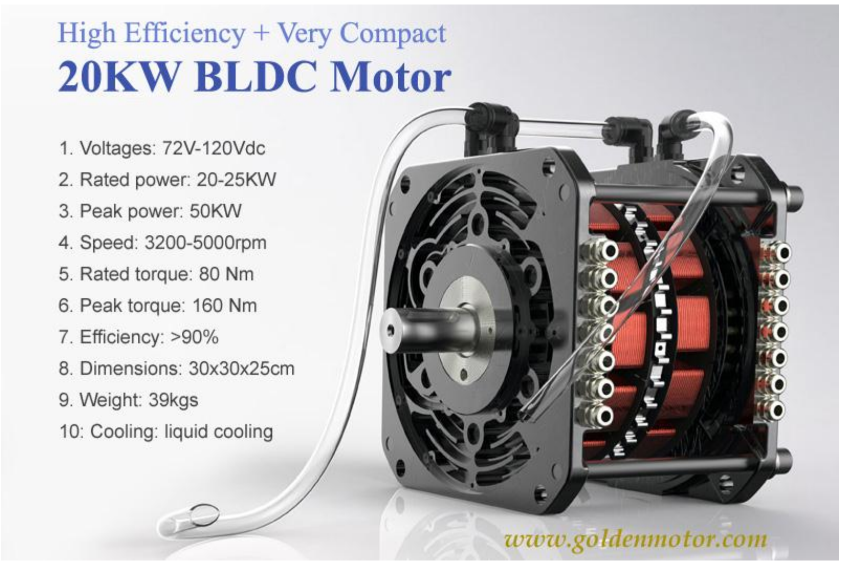

Figure 5. BLDC electric motor. Source: Goldenmotor.com
https://www.goldenmotor.com/img/BLDC-20KW.jpg. Date: 22.11.2017.

This alternating current does not have a classic sine waveform, but it is a two-way current without any restriction on the waveform. The motor consists of a rotor with a permanent magnet and an armature winding stator. The magnetic field created on the stator and the magnetic field generated on the rotor are of equal frequency and thanks to the appropriate excitation current the moment in this motor is held constant. The static windings give rise to electric current causing rotor motion. In this case, the control is controlled by the current supplied to the static windings from the DC power supply through the exchanger. In this way the stator winding has been replaced by an alternating current, so it can be said that it is about electronic switching. The BLDC engine has a number of advantages over its construction with respect to the "classic" DC brush motor[15]:

• Simplified maintenance that makes it more durable,

• Smaller and lighter,

• 85% -90% efficiency,

• Has shorter response times at higher operating speeds,

• Allows you to simulate speed control and walk backwards,

• Less prone failures and

[15] Larminie, J.; Lowry, J. (2003) Electric Vehicle Technology Explained. John Wiley & Sons Ltd, England. p. 167. – 169.

• Can start independently.

Likewise, the BLDC engine itself keeps the other components of the vehicle colder and more heat-resistant. In addition, as a brushless engine, there is no risk of sparking. The name "brushless" indicates that no brush is used for switching, but the motor is electrically switched, that is, the power converter with the rotor position measuring member performs the function of the brush collector[16].

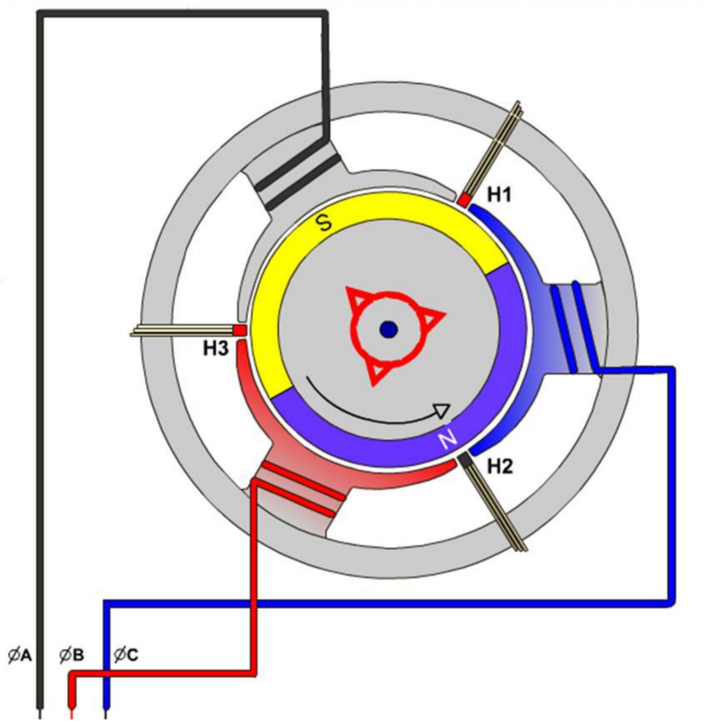

Figure 6. Running BLDC engine. Source: Educypedia.com
http://educypedia.karadimov.info/library/2-pole_bldc_motor.swf. Date: 22.11.2017.

The figure (6.) shows a three-phase two-pole BLDC engine running in such a way that the two phases that produce the largest torque are energized, while the third phase is off. The position of the rotor determines which two phases will be included. The current flowing through the phase winding of the H1 stator creates a magnetic field that will attract a permanent magnet rotor. This process starts turning the rotors of the electric motor. When at one point the voltage

[16] Larminie, J.; Lowry, J. (2003) Electric Vehicle Technology Explained. John Wiley & Sons Ltd, England. p. 167. – 169.

of one phase is shifted to a second phase, from phase H1 to phase H2, the stator magnetic field moves in the positive direction by 120° and the rotor will continue to move in the same direction. The rotor movement continues due to the generation of a rotational electromagnetic field resulting from the switching of the current from one phase winding to the second phase winding. In case the sequence of phase switching is changed, the rotor will start to rotate in the opposite direction.

3.4 Batteries

One of the key elements of every electric vehicle is its battery. The battery is an electrochemical storage device that can discharge the electrical charge when needed. It generally consists of anodes, cathodes and electrolytes which serves as a separator between two electrodes. Different types of batteries are typically designated according to the materials used for their manufacture. Usually, these are combinations of lithium ion, lithium polymer, nickel metal hydride, etc. Batteries can consist of one or more cells that can be connected in series to obtain a higher output voltage[17].

For example, a typical 12V battery consists of six connected cells, while the battery pack for electric vehicles can have hundreds of individual cells. The characteristics of batteries that are of particular significance for use in electric cars are the specific strength and energy density. The energy density is the measure of the capacity of the battery, ie it tells how much energy one battery can store. The higher the energy density or the capacity, the longer the time between two charging of batteries. Specific power is how much battery power it can deliver when it comes to the demand, how fast it can deliver the energy contained in it and vice versa, how fast it can be charged. Batteries for recent EVs are primarily based on Li-ion technology (figure 7.):

[17] Larminie, J.; Lowry, J. (2003) Electric Vehicle Technology Explained. John Wiley & Sons Ltd, England. p. 23. – 24.

Figure 7. Lithium ion battery pack. Source: Electric-cars-are-for-girls.com http://www.electric-cars-are-for-girls.com/images/xnissan-leaf-battery-pack.jpg.pagespeed.ic.7XblzcPhTK.jpg. Date: 29.11.2017.

Variation comes in the size of the cells and the type of cathodes used[18] (figure 8.):

- "Small-format cells. Tesla's small-format, the Li-ion-based battery cell (the Panasonic 18650) is believed to be a combination of cathode materials mainly used for consumer electronics (such as NMC, LCO, etc,). Currently, Tesla appears to be the only OEM using these cells and has signed a deal with Panasonic as the preferred supplier to deliver nearly 2 billion cells over the course of four years. This type of cell has been produced at scale for more than two decades and is primarily used in consumer electronics. The cell's composition (the cobalt in the cell does not bind oxygen very tightly, so heating the cell dissociates oxygen and can create a self-sustaining thermal reaction) creates a risk of a reaction if overheated, so the cells require advanced cooling and battery management systems (BMS) to manage cell temperature. Tesla has proprietary cutting-edge technology in cooling and BMS, and the models it has brought to market have qualified for governmental safety requirements. Tesla has started to produce its technology for Mercedes (B-Class) and Toyota (Rav4), with Daimler and Toyota holding small stakes in Tesla.
- Large-format cells. Large-format cells are the battery pack of choice for almost all other (traditional) OEMs that have ventured into the EV space. Given the lower energy density of the cathodes used (primarily LiMn2O4), these cells are potentially less exposed to overheating issues than small-format cells. However, battery packs based on large-format cells are more expensive because they do not benefit from the same economies of scale seen

[18] EEA (2016) Electric vehicles in Europe. Copenhagen. p. 24.

for the 18650 cells. Alternative cathodes such as NCA (LiNiCoAlO2) and LFP (LiFePO4) are also being tested, each with its own cost versus safety versus energy density trade-off."

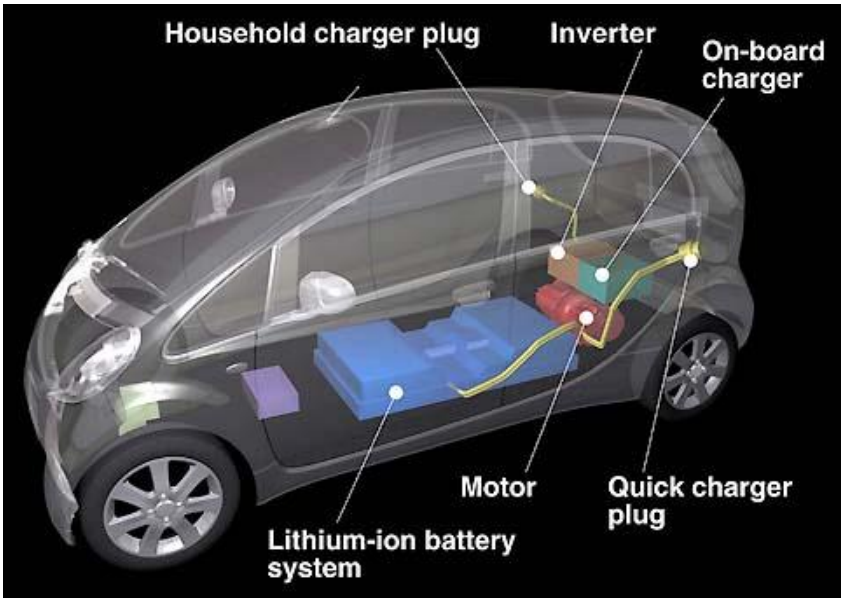

Figure 8. Battery. Source: Exchangeev.aaa.com http://exchangeev.aaa.com/wp-content/uploads/2012/09/battery_ev.jpg. Date: 29.11.2017.

3.5 Electromotor Controller

Controllers are electronic devices that supply power to electric motors (figure 9.). At BLDC motors, they take DC power from the battery, and with the bridge of 6 powerful MOSFET transistors, they form an AC three-phase voltage that is fed to the windings of the motor. Changing the voltage frequency changes the engine speed. The microcontroller as the heart of the controller reads the signal from the accelerator pedal obtained with the potentiometer and the rotor position signals obtained by Hall's probes. The controller gives frequency and power depending on the received signals. The controls provide regenerative braking, which means that the braking is carried out by means of a motor that switches to the generator operating mode and the current supplied is recharged by the accumulators. In this way, greater utility and greater vehicle reach is achieved. The principle scheme of the BLDC electric motor controller is shown in the figure. Asynchronous cage motors are more manageable than the BLDC engine, ie the management program is much more complicated. At the output, it also generates three-phase voltage from the MOSFETs which must be sine-wave. No Hall position probes are set, but the position of the rotor is determined by measuring the induced voltage on the stator[19].

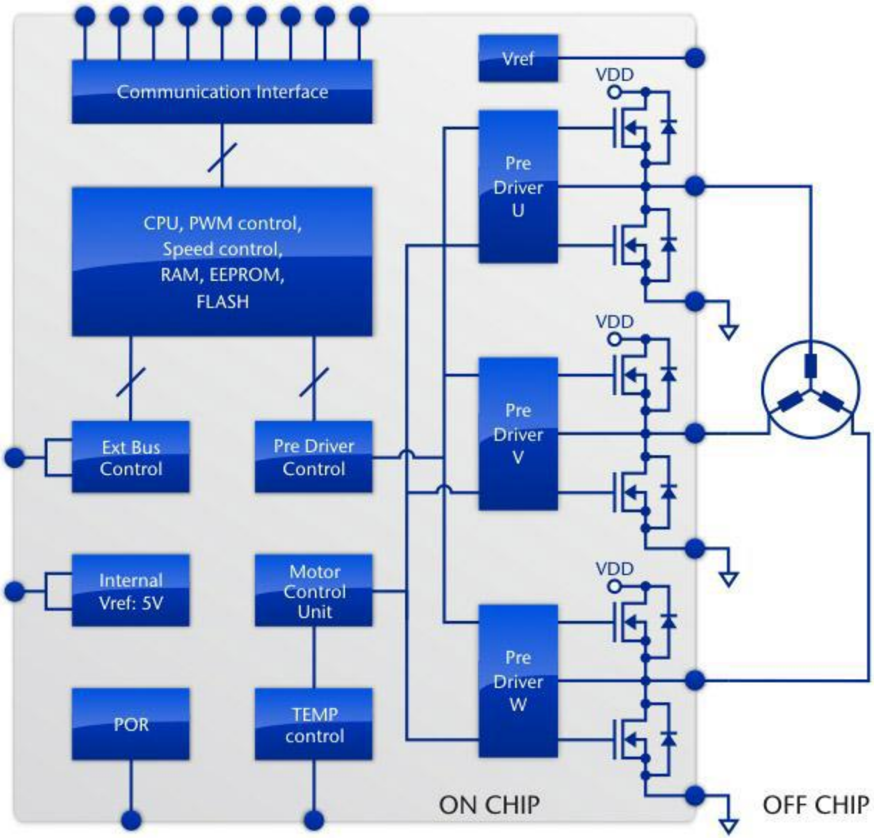

Figure 9. Electromotor Controller. Source: Izrada električnog automobila (2013) TŠ Pula, TŠC Nova Gorica, ITIS Cardano Pavia, Pula. p. 14. Date: 29.11.2017.

[19] Izrada električnog automobila (2013) TŠ Pula, TŠC Nova Gorica, ITIS Cardano Pavia, Pula

4. IMPORTANCE OF DESIGN

The design, as the visual appearance of a vehicle, with the likes of a designer is largely dependent on aerodynamics. The main goals of the designer are to reduce the noise caused by wind blows from the vehicle body and to increase the aerodynamics of the vehicle so that the vehicle has the least resistance to movement. At the same time, it prevents unwanted engine power increase, which results in increased fuel consumption and other aerodynamic factors that contribute to high-speed vehicle instability. The aerodynamic look has a crucial impact on energy consumption by reducing wind resistance to the outside shape of the vehicle, and reducing the losses associated with airflow and engine cooling requirements. For certain car classes, this can also be very important in order to achieve better acceleration and holding and bending capabilities as the friction force, ie, resistance increases significantly with the speed of the vehicle. Aerodynamic design begins with vehicle concepts based on its shape and proportions, looking at the ultimate look, purpose and space required inside. When the outer shape is defined, aerodynamic efficiency is then parameterized, such as angles, radius angles and dimensions. By parameterizing, remarkable improvements in aerodynamics can be achieved with minimal impact on the external aesthetics of the vehicle[20].

As the vehicle design progresses further, aerodynamic panels, spoilers, wheel deflectors and chassis cover most of the parts of the vehicle that are in direct contact with the wind blows, so they are positioned to get the best aerodynamic capability. The challenge faced by vehicle manufacturers at every stage of design is the urgent need for information on how to improve design (figure 10.):

Figure 10. Design of a car. Source: Auto.infoniac.com http://auto.infoniac.com/wp-content/uploads/2011/02/alcotraz-concept-design-panels.jpg. Date: 30.11.2017.

[20] Larminie, J.; Lowry, J. (2003) Electric Vehicle Technology Explained. John Wiley & Sons Ltd, England. p. 213. – 217.

Aerodynamic information can be expensive and unreliable, and require the construction of a detailed model or prototype of the test vehicle in the tunnel. Modifications in the late stage of model development are long-lasting and costly because it is difficult to make significant changes to the model or change any surface during the air tunnel testing. The prototype involved in aerodynamic parameterization is a major factor in the vehicle development costs and the time needed to design a vehicle. Software aerodynamic simulation changes the vehicle development process, reducing the cost of development and time required for design. Because of the speed it takes advantage of the physical test methods because the simulation can bring a lot more feedback on design at each stage of development and brings improvements to innovation designers in balancing aesthetics and aerodynamics designs. Simulation is more accurate than physical testing because of its ability to recognize small details that could not be present on the physical model at an early stage of design, and the additional ability to simulate real conditions on the road[21].

Physical testing can lead to expensive errors and delays due to problem accuracy. Computer simulation can reduce the cost of the ultimate vehicle by revealing design enhancements to earlier design stages that do not require additional costs in producing new parts for new vehicle testing. The need for accuracy and design sets high demands on aerodynamic simulation quality. The simulation must show many parameters, geometry of the vehicle, reproduce a realistic test in conditions such as on the road, rotating wheels and airflow at their rotation, and parameters such as wind turbulence. Aerodynamics is influenced by all vehicle elements such as wipers, roof rails, curtains, spoilers, rearview mirrors, radios, etc[22].

The air resistance coefficient (Cd) is a common measure in a vehicle design related to vehicle aerodynamics. Resistance is a force that acts in parallel and in the same direction as the air flow. When a car is designed by a car company, it must take into account the coefficient of resistance along with other characteristics. Reducing car resistance coefficients improves vehicle performance as it relates to speed and fuel efficiency. The development of electric vehicles is of great importance to the aerodynamics of vehicles. Due to their characteristics, range and energy consumption, they are greatly improving the design and aerodynamics of the vehicle as this is crucial to their development. Battery charging in electric vehicles is due to the aerodynamic and rolling resistance of the vehicle and the materials used to manufacture the

[21] Larminie, J.; Lowry, J. (2003) Electric Vehicle Technology Explained. John Wiley & Sons Ltd, England. p. 217. – 218.

[22] ibid, p. 226. – 228.

vehicles. Reducing the air resistance also results in a reduction in engine performance, making the vehicle faster and easier to reach speeds, which significantly impacts energy consumption. Almost every vehicle manufacturer tries to increase the efficiency of the vehicle through aerodynamics and the use of new materials. Compared to most today's vehicles on the road, in the future these vehicles will probably be aerodynamic miracles. Many of the design features are now being developed to increase efficiency[23] (figure 11.):

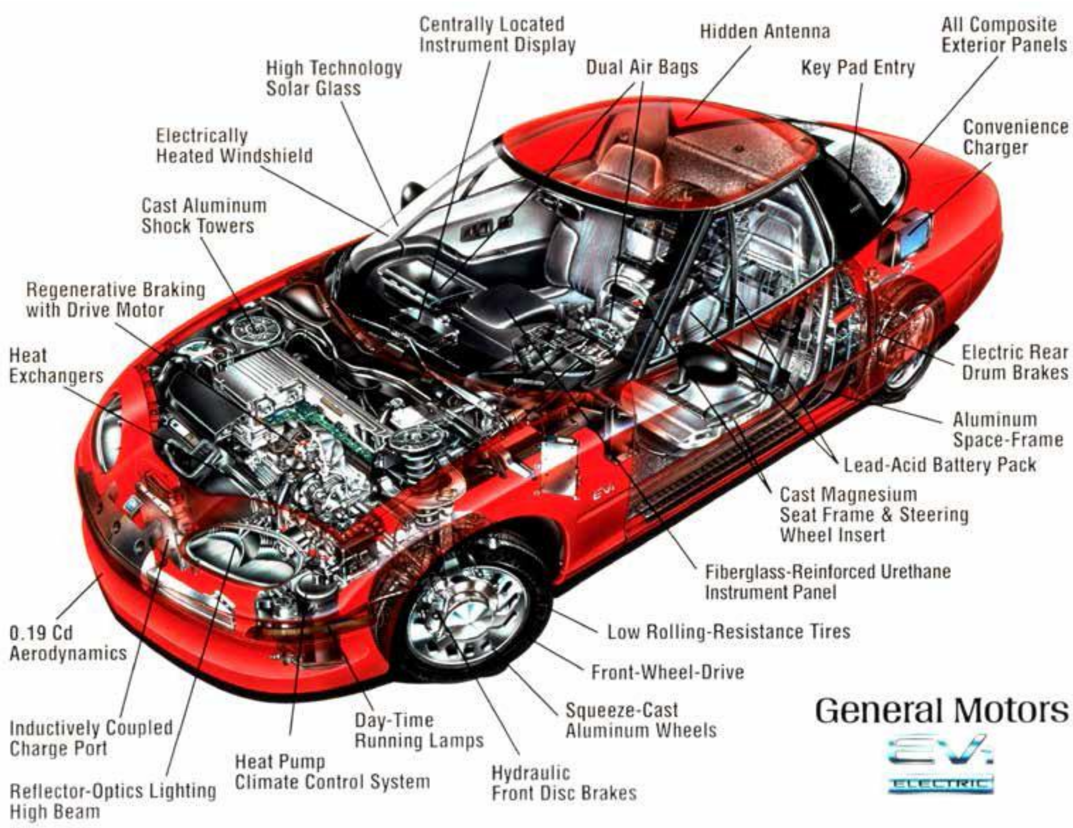

Figure 11. Components that influence the design. Source: Americanhistory.si.edu http://americanhistory.si.edu/sites/default/files/EV1_poster.jpg Date: 30.11.2017.

[23] Larminie, J.; Lowry, J. (2003) Electric Vehicle Technology Explained. John Wiley & Sons Ltd, England. p. 234.

5. ELECTRIC VEHICLES – COMPARISMENT OF CROATIA WITH EU COUNTRIES, USA and CHINA

According to data from the Croatian Vehicle Center, the number of registered ecological vehicles in 2016 is steadily increasing.

The largest increase in category M1 (passenger car/van) is expected to be recorded in hybrid vehicles, more precisely 496 vehicles more than in 2015. Vehicles with a fully electric drive make up 1/9 compared to hybrid vehicles, with a total of 224 registered vehicles. This is an increase of + 44% compared to 2015, which means that 68 electric more cars are on domestic roads than in 2015 (table 1.)[24]:

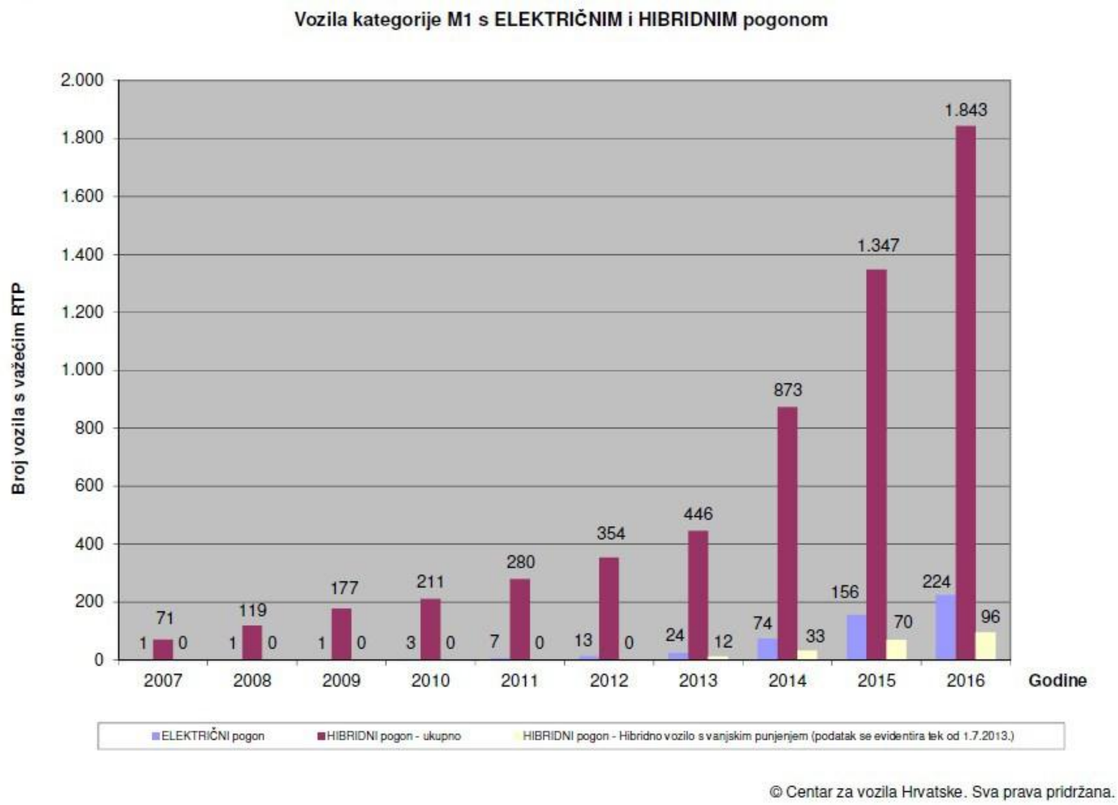

Table 1. Vehicles of M1 category. Source: Centar za vozila Hrvatske (2017) Broj vozila s električnim i hibridnim pogonom. Republika Hrvatska, Zagreb. Date: 2.12.2017.

[24] Centar za vozila Hrvatske (2017) Broj vozila s električnim i hibridnim pogonom. Republika Hrvatska, Zagreb

The largest number of electric vehicles is classified as category L (light vehicle, motorcycle, moped), a total of 445 registered vehicles, and in the same category there are 2 hybrid vehicles. The increase in electric vehicles in the L category compared to the previous one is + 33%, ie 111 more vehicles[25] (table 2.):

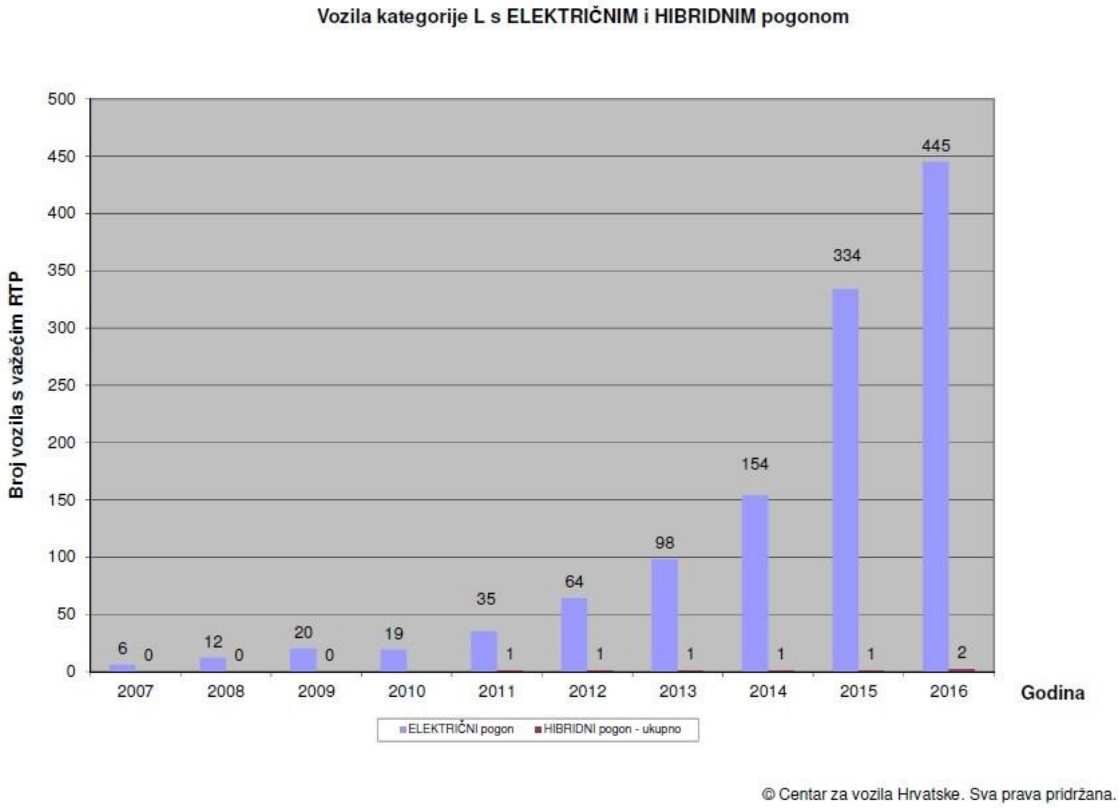

Table 2. Vehicles of L category. Source: Centar za vozila Hrvatske (2017) Broj vozila s električnim i hibridnim pogonom. Republika Hrvatska, Zagreb. Date: 2.12.2017.

Croatia has a total of 71 publicly available boilers for electric and plug-in hybrid vehicles in 27 cities (figure 12.). Thus at the same time, through 71 fillers, 119 vehicles can be loaded because there are so many sockets (type 2 and hex). Up to now, Hrvatski Telekom has installed and put into operation a total of 20 filling stations, and HT provides active access to 31 publicly available punchers. HT punching works are offered in Zagreb, Samobor, Gospić, Rijeka, Split, Kaštel Štafilić, Makarska and Velika Gorica (picture below). Their use reduced the

[25] Centar za vozila Hrvatske (2017) Broj vozila s električnim i hibridnim pogonom. Republika Hrvatska, Zagreb

consumption of petroleum products by 4500 liters and thus the environmental burden of three tons less CO_2 emissions[26].

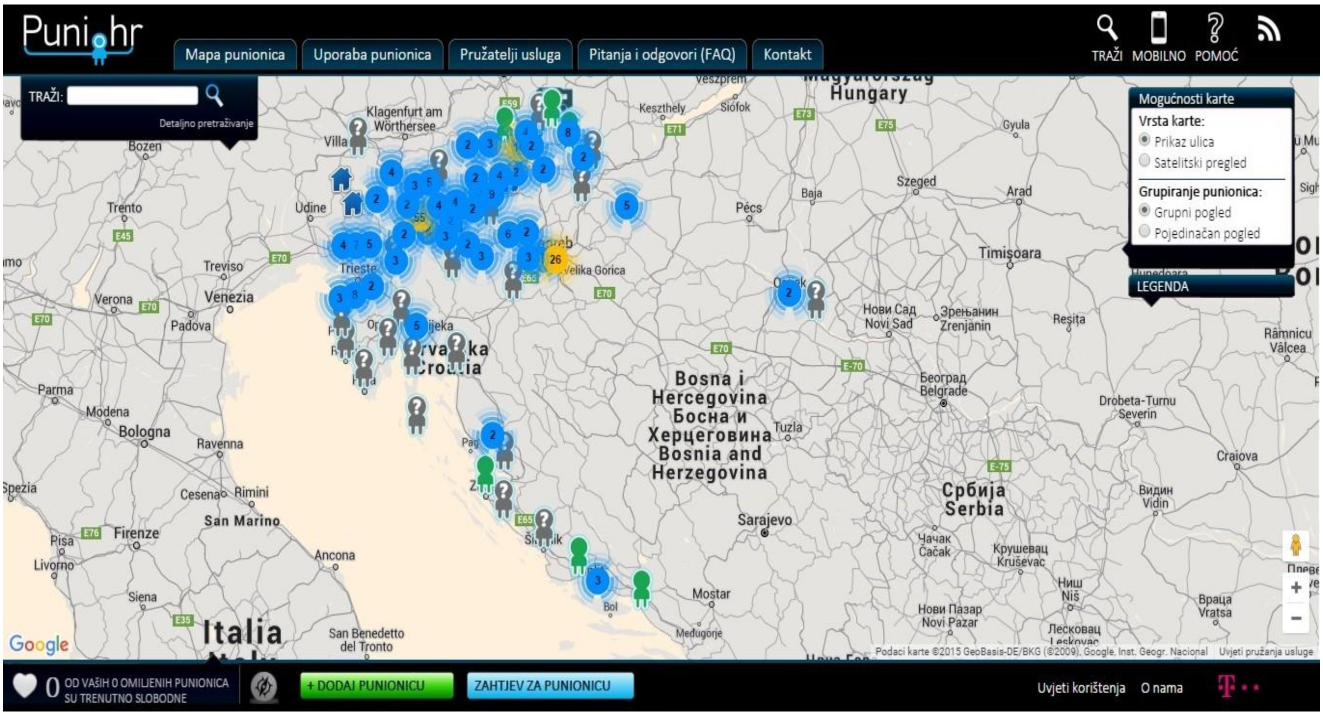

Figure 12. Maps of bottlers. Source: Vidiauto.com http://www.vidiauto.com/var/ezdemo_site/storage/images/media/images/mapa-punionica-za-elektricna-vozila-u-hrvatskoj/230714-1-cro-HR/Mapa-punionica-za-elektricna-vozila-u-Hrvatskoj.jpg. Date: 2.12.2017.

In the period from July 2011 to September 2015, 875 filling sessions were registered at all HT bottling plants. 6312 kWh of electricity was delivered, providing more than 50,000 kilometers of distance to electric vehicle users. The average charging time is 65 minutes. Only 25% of the charging power of 22 kW has been achieved, indicating that most of the current three hundred electric vehicles in Croatia still do not support supercharging[27].

Compared to the first quarter of 2016 with the first quarter of 2017, a 60.5 percent decline in electric vehicle sales was recorded in Denmark, according to the European Association of

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[26] Centar za vozila Hrvatske (2017) Broj vozila s električnim i hibridnim pogonom. Republika Hrvatska, Zagreb

[27] Bičak, D. (2017) Ponovo kreću subvencije za kupnju električnih vozila http://www.poslovni.hr/hrvatska/od-2018-ponovo-krecu-subvencije-za-kupnju-elektricnih-vozila-332083

Vehicle Manufacturers (ACEA) data. Such a drop is an exceptionally strong contrast to other European countries, where growth is generally growing, such as in Germany, where growth is almost 80 percent. Generally, in the European Union, electric car sales are up by 30 percent. The decline has been due to the abolition of state incentives for more environmentally friendly vehicles such as electric vehicles, hybrids, and plug-in hybrids. Denmark is the world's leading producer of electricity generated through wind power plants. Denmark's approach to electric vehicles began in the 1980s when the Danish car Hope Whisper W1 was introduced. Though the expectations were huge, they made only 32 prototypes, of which 14 are still driving on Danish roads[28].

Looking at 2015, sales figures of almost 5,300 electric vehicles can be noticed. In comparison, Italy bought the same number of vehicles in the same year, despite a tenfold larger population. Exceptional sales figures were also associated with tax incentives, so no tax was paid on a vehicle of up to 2 tons. For vehicles weighing more than two tons, and classic hybrids that do not have plug-in capability, the standard toll rate applies. Denmark has one of the highest tax rates on vehicle imports. Vehicles worth up to 79,000 kronor (10,600 €) were taxed 105 per cent, while vehicles above the above mentioned figures were taxed with astronomical 180 percent. But the convenience of all electric vehicles is free parking at the center of Copenhagen[29].

In the first version of the Danish government's plan, tax reliefs should slowly disappear from 2016. to 2020. Then electric vehicles should be treated as well as fossil fueled vehicles. Encouraged by catastrophic results, the Danish government has decided to revise the decision, and by late April 2017 they have changed the legal provisions. Old provisions are in force, and rules change when selling reaches 5,000 new vehicles between 2016. and 2018. In 2019, the tax should be 40 percent of the standard import costs, with about 1,400 euros from the state to buy a new vehicle. The tax will rise to 65 percent of the maximum in 2019, and in 2021 all the benefits will be lifted. The tax will again go up giant 180 percent. In comparison, Sweden has about € 4,400 for the purchase of a new electric car, and the tax does not have to be payed for it for the following five years[30].

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[28] Levring, P. (2017) Denmark Is Killing Tesla (and Other Electric Cars) https://www.bloomberg.com/news/articles/2017-12-19/trump-asks-how-s-your-401-k-but-most-voters-don-t-have-one

[29] Noel, L. et el. (2017) The status and challenges of electric vehicles in Denmark 2017. Aarhus University http://btech.au.dk/fileadmin/user_upload/Initial_Observations_about_EVs_on_Denmark.pdf

[30] ibid

A similar situation from Denmark can also be observed in Croatia. No incentives were given in 2016, and this was repeated in 2017. The data available on the Environmental Protection and Energy Efficiency Funds page show solid figures for 2014 and 2015. 15.5 million kunas is targeted to citizens and businesses in 2014. They bought a total of 440 energy-efficient vehicles. In 2015, growth was recorded, and the Fund paid out HRK 18.5 million to purchase 506 vehicles[31].

As in Denmark, the vehicles had to be bought as brand new, and most of them were hybrids. In 2014, only 53 electric vehicles were sold, while in 2015 the figure jumped to 179 vehicles. The aids were also respectable, and the biggest ones were for electric vehicles, almost incredible 70,000 kunas. The plug-in hybrids (electric and conventional engines with power and plug-in power) were 50,000 kunas. Classical hybrid vehicles have received somewhat weaker aids, 30,000 kunas[32].

The benefits could have been obtained for one vehicle, while the vehicle owned had to be kept for at least a year. Legal persons could buy more vehicles, but the total value up to 700,000 kuna, with the obligation to hold the vehicle for at least three years. As there are no wide-ranging network of electric vehicle retailers in Croatia, vehicles could be purchased in any country of the European Union.

The top six European countries for electric vehicles on the road in 2020 will be Germany, France, Norway, the United Kingdom, the Netherlands, and Sweden, with this group representing more than 67% of the total market, and each having a volume in excess of six figures. The situation is slightly different for plug-in hybrids, where only four countries are expected to exceed a volume of greater than 100,000 vehicles – Germany, France, Italy, and the United Kingdom – and these four represent 52% of the total (table 3.). By 2020, Pike Research forecasts that more than 1.8 million electric vehicles will be on Europe's roadways, along with 1.2 million plug-in hybrids and 1.7 million hybrid electric vehicles[33].

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[31] Fzoeu.hr (2017) Sufinanciranje nabave električnih i hibridnih vozila
http://www.fzoeu.hr/hr/energetska_ucinkovitost/cistiji_transport/sufinanciranje_nabave_elektricnih_i_hibridnih_vozila/

[32] ibid

[33] Electriccarsreport.com (2017) Pike Forecasts 1.8m EVs on European Roads by 2020
https://electriccarsreport.com/2013/01/pike-forecasts-1-8m-evs-on-european-roads-by-2020/

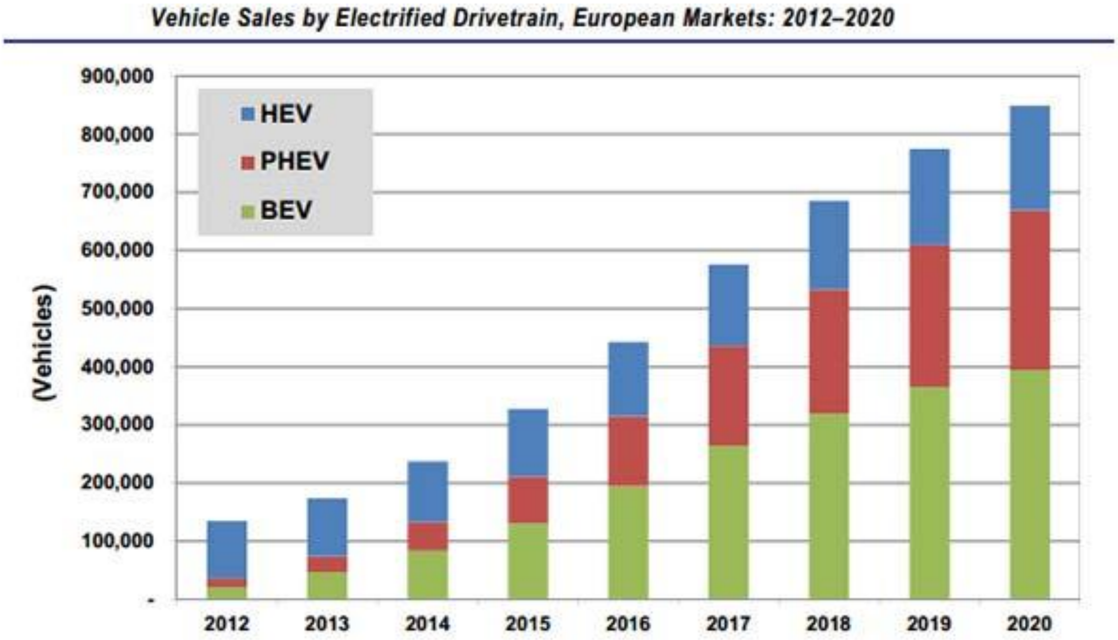

Table 3. Vehicle sales. Source: Electriccarsreport.com (2017) Pike Forecasts 1.8m EVs on European Roads by 2020 https://www.electriccarsreport.com/wp-content/uploads/2013/01/European-EV-Sales.jpg. Date: 2.12.2017.

There are more and more vehicles on Europe's roads. While electric passenger vehicle sales have increased rapidly over past years, they represented just 1.2 % of all new cars sold in the EU in 2015. In all, approximately 0.15 % of all passenger cars on European roads are electric. Like passenger vehicles, sales of electric vans also made up a very small fraction of total EU sales in 2015. The number of electric vehicles sold has increased steeply in each year since. Preliminary data for 2015 indicate that almost 150 000 new plug-in hybrid and battery electric vehicles were sold in the EU that year. Almost 40 % of these were BEVs. Collectively, just six Member States account for almost 90 % of all electric vehicle sales: the Netherlands, the United Kingdom, Germany, France, Sweden and Denmark. The largest numbers of BEV (battery electric vehicles) sales within the EU‐ 28 were recorded in France (more than 17 650 vehicles), Germany (more than 12 350 vehicles) and the United Kingdom (more than 9 900 vehicles). The largest numbers of PHEV sales were recorded in the Netherlands (more than 41 000 vehicles) and the United Kingdom (more than 18 800 vehicles)[34].

[34] EEA (2016) Electric vehicles in Europe. Copenhagen. p. 47.

Outside the EU, a clear frontrunner in terms of high sales is Norway, where 22.5 % of all new cars sold in 2015 were electric. Almost 34 000 new electric vehicles were sold, of which 77 % were BEVs[35].

Around 0.5 % of new vans sold in the EU in 2015 were battery electric vans. Sales have increased over recent years, by 15 % per year on average. The total number of electric vans sold rose from 5 700 in 2012 to more than 8 500 in 2015. Most battery electric vans are sold in France, where around 3 900 were sold in 2015, followed by Germany (around 950), the United Kingdom (800), Spain (500) and Italy (450). However, in most countries very few are sold; in each of 13 other Member States fewer than 10 battery electric vans were sold in 2015. One main reason for the low sales is a lack of available models for consumers to choose from[36].

Another great comparison is USA, known for their large automobile market. Estimates put the number of cars and trucks in the United States at between 250-260 million vehicles for a country of 318 million people. In 2016 alone, around 17.5 million brand new trucks and cars were sold. It is visible how an "average American" is really attracted to cars, and even electric vehicles. In November of 2016, there were 540,000 electric cars on the road in the USA (only .22% of all cars on the road in the USA) as seen in figure 13. In 2016, there were around 17.5 million cars produced of which only 134,000 were electric (about .77%). 13.[37]:

Figure 13. Growth of sales. Source: Nanaylze.com https://cdn.nanalyze.com/uploads/2017/03/Growth-of-Electric-Cars.jpg. Date: 2.12.2017.

Electric vehicles are not equally popular in all states (Figure 14.):

[35] EEA (2016) Electric vehicles in Europe. Copenhagen. p. 49.

[36] ibid

[37] Nanalyze.com (2017) How Many Electric Cars Are There in the USA? https://www.nanalyze.com/2017/03/electric-cars-usa/

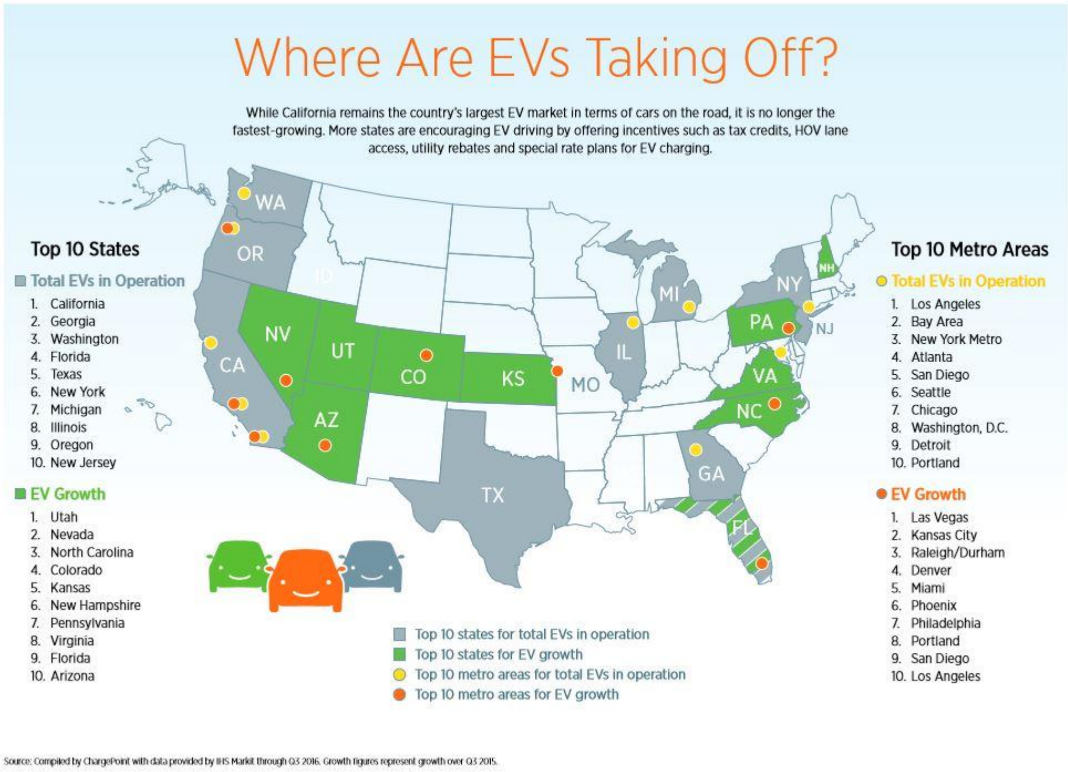

Figure 14. Usage of cars through states. Cdn.nanalyze.com https://cdn.nanalyze.com/uploads/2017/03/Electric-Vehicles-by-State.jpg. Date: 2.12.2017.

U.S. EV sales have grown an average of 32% annually from 2012-2016 and 45% over the year ending June 2017. But not all cars are being sold at the same rate because some are more popular than other[38] (Table 4.):

[38] Rissman, J. (2017) The Future Of Electric Vehicles In The U.S., Part 1: 65%-75% New Light-Duty Vehicle Sales By 2050. Forbes.com https://www.forbes.com/sites/energyinnovation/2017/09/14/the-future-of-electric-vehicles-in-the-u-s-part-1-65-75-new-light-duty-vehicle-sales-by-2050/#6b943e36e289

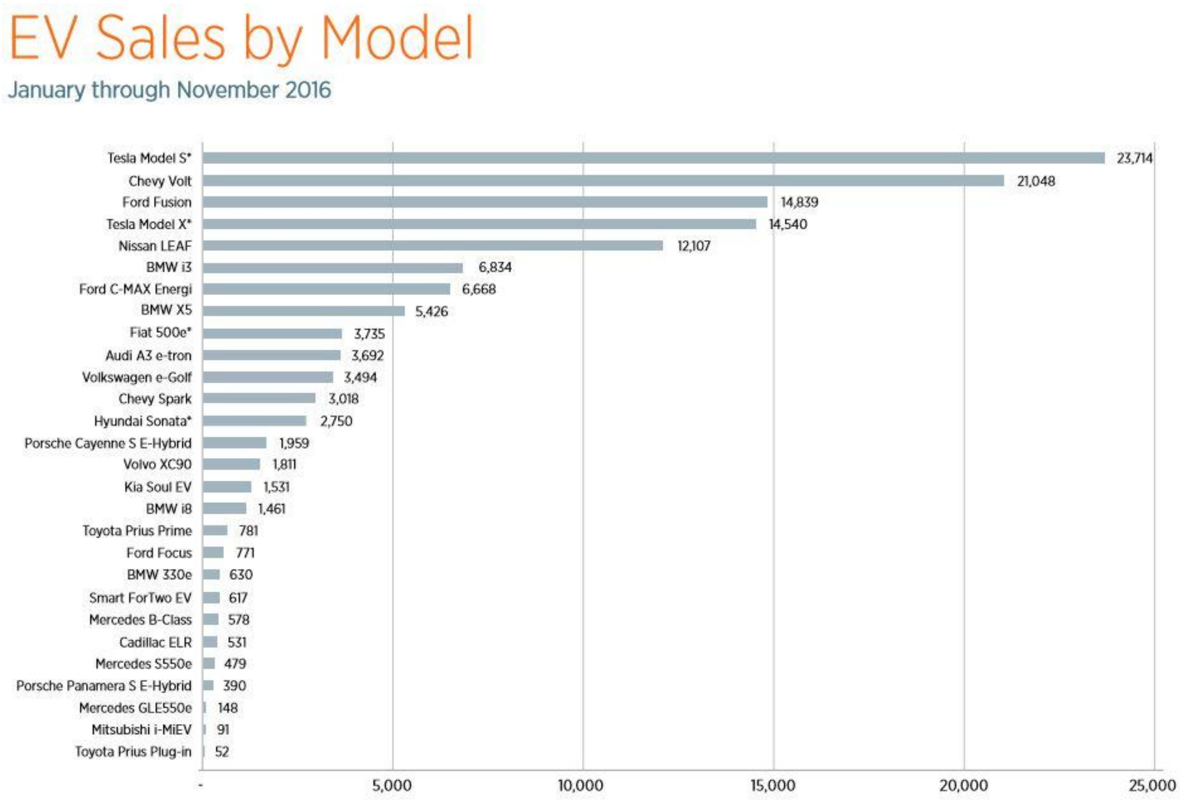

Table 4. EV sales by model. Cdn.nanalyze.com

https://cdn.nanalyze.com/uploads/2017/03/Electric-Vehicles-by-State.jpg. Date: 2.12.2017.

China is also a big market for electric vehicles. Over 490 000 plug-in passenger cars were delivered from January to November 2017, including imports. China continues to be the largest market for Plug-ins (or New Energy Vehicles, NEV, as they are called in China). Pure electric vehicles (BEV) are increasing 5 % in the mix, to 81 % of all NEV sales. From 2017 onwards, central NEV subsidies are reduced by 20 %, local subsidies are cut in half. The increase over the same period in 2016 is less than in previous years and now stands at 60 %, although it has been growing in the last months. Most NEVs are sold in China's mega-cities, where ownership restrictions for ICE cars make BEVs an easy choice. NEV passenger car sales reached a new high in November, with 84 000 units delivered and an estimated share of 3,2 % in an otherwise sluggish overall car market. Another record is expected in December, not in terms of share, but in terms of volume - a total of 577 000 units for the complete 2017, a 65 % growth over 2016. The NEV passenger car sales is growing 20 times faster than the car market as a whole (Table 5.). The Chinese Government has announced ambitious NEV share mandates of 10 % credits for 2019 and 12 % for 2020, causing strong concern among many foreign OEMs. As one NEV unit sales receives a boost of up to a factor of 4 in the share calculation, the actual NEV shares to be achieved are considerably lower. Non-Chinese brands stand for nearly 50 % of the total passenger car sales, most of it produced in China, in J/Vs with Chinese companies. For NEV sales, non-Chinese brands stand for only 4 %, with the lion share going to Tesla. Other foreign brands need to multiply plug-in sales until 2019 in order to comply. They also need to localize their offers to receive subsidies and to avoid import duties. The alternative is acquiring emission certificates from over-achievers[39].

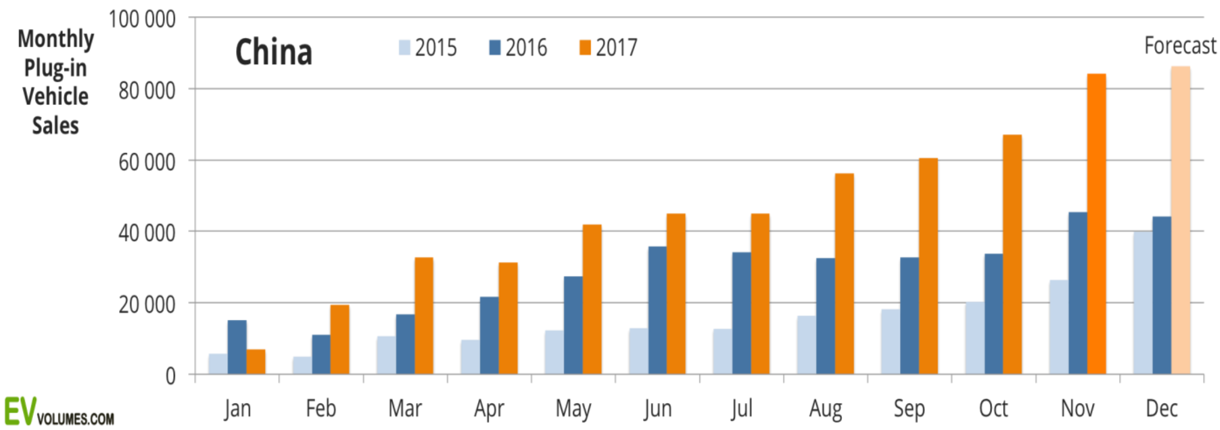

Table 5. Monthly sales in China. Ev-volumes.com (2017) China Plug-in Volumes for Q3-2017 and October-November http://www.ev-volumes.com/country/china/. Date: 2.12.2017.

China is the top market for electric and hybrid cars, accounting for roughly half of global sales, and the government is pushing the development of the industry within its borders. That calls for a lot of lithium, a key component of the vehicles' batteries. This will also have further implications on worldwide markets and trade relations[40].

[39] Ev-volumes.com (2017) China Plug-in Volumes for Q3-2017 and October-November http://www.ev-volumes.com/country/china/

[40] Shane, D. (2017) China is winning electric cars 'arms race'. CNN.com http://money.cnn.com/2017/11/20/investing/lithium-china-electric-car-batteries/index.html

6. CONCLUSION

The 21st century is characterized by exceptional technological advances that undeniably affects all aspects of human life. The fact is that the transport industry is changing due to this new and interesting technology. Electric vehicles are gradually experiencing a shift in development and usage. Developed states, as well as those overcrowded, recognize the usefulness of these new vehicles, whose importance is gradually acknowledged.

The Republic of Croatia is also gradually recognizing and accepting this new technology. Economy of the state and the conservatism of the population are at present the main obstacles to further use of electric vehicles, as well as some technical barriers such as insufficient charging infrastructure in some countries, long charging time and relatively short range of electric cars. However, it is evident that over time the number of vehicles becomes more significant.

Electric vehicles provide positive opportunities in a current unfavorable situation regarding global warming and ecological disasters. Such a vehicle type is, in a realistic sense, a more favorable solution to which modern civilization needs to be relied upon. As the results and work analyzes prove, more and more electric vehicles are gradually being used in the world. China, the US and Western European countries are at the forefront of this statistic. Croatia also has some progress, pointing to the fact that both manufacturers and drivers, or citizens, are becoming aware of the positive and realistic potential that electric vehicles have.

While many have tried, no one seems to be able to precisely determine when the electric vehicle will become the dominant model. Different analyzes reveal different results because there are so many factors to be taken into consideration. Governments around the globe are announcing prohibition of petrol and diesel cars in the near future. One thing that we do know for sure is that energy transition in the transport sector is currently in motion and that there is clean future ahead of us.

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VISUAL CONTRIBUTION