TECHNOLOGICAL AND ORGANISATIONAL CHALLENGES FOR E-MOBILITY

TOMASZ LECH STAŃCZYK[1], LECH HYB[2]

Abstract

With the rapid growth of schemes and initiatives to promote e-mobility and numerous measures taken to ensure its quick and effective implementation, there is a wide range of technological and non-technological problems, especially organisational, economic, legal and social in nature, that have to be handled by national and local governments all over the world. This article addresses some of the technological and organisational challenges for electromobility. The key technology-related issues to be coped with are the need for longer ranges of electric vehicles (EVs), shorter charging times and smart power grids (because of a higher demand for electrical energy). Another important problem to be solved urgently is the high battery weight, affecting the vehicle dynamics. Because of the excessive weight of the battery pack, there is a risk of its displacement during a crash, which may jeopardize the safety on the road. The next big concern, also associated with safety, is protection against electrical and fire hazards in the event of a collision. The most important of all the organisational challenges related to EVs is the necessity to create networks of charging stations. Their insufficient number and unsatisfactory distribution are strong barriers hampering the development of e-mobility. The organisational measures also include privileges such as access to bus lanes, already offered in some countries. Finally, there is the need to urgently train a large number of electricians to test and maintain EVs, the need to create a recycling system for used EV batteries, and the need to deal with the organisational aspects of the development of smart power grids.

Keywords: electric vehicles; hybrid vehicles; e-mobility; electric drive

1. Introduction

As long as 10 or 15 years ago, electric and hybrid vehicles were considered solutions of the future and the main reason for the introduction of electromobility was the depletion of oil and gas resources or, generally, the need to reduce the dependence on fossil fuels [12]. Recently, actions in this field have accelerated, but the current key argument for e-mobility, being environmental in nature, is the need to decrease emissions of greenhouse gases, or, generally, emissions of all harmful motor vehicle exhaust gases contributing to the creation of smog in urban areas. According to the 2017 Report of the European Environment Agency on Air Quality in Europe, emissions of greenhouse gases in this part of the world should be reduced by (42–49)% by 2050. The report indicates that in 2015 as much as 19% of the emissions of greenhouse gases originated from

1 Faculty of Mechatronics and Mechanical Engineering, Department of Automotive Engineering and Transport, Kielce University of Technology, Al. Tysiąclecia Państwa Polskiego 7, 25-314 Kielce, e-mail: stanczyk @tu.kielce.pl

2 e-mail: hyb.lech@op.pl

road transport [1]. Road transport is responsible also for the production of other harmful substances. In 2015, its contribution to the emissions of nitrogen oxides was as high as 39% [1]. Another problem raised by experts is the noise generated by motor vehicles, particularly in urban areas. All these factors are associated with an urgent need to promote vehicles with alternative fuels and, accordingly, alternative drive systems. Currently, electric and hybrid vehicles are considered to be optimal. Since electric vehicles use electric motors for propulsion and hybrid vehicles use them as a secondary source of power, this trend in the automotive industry is called electromobility or e-mobility. It is predicted, however, that air pollution will decrease globally if electromobility is combined with energy produced using zero- or low-emission sources [13], [16], [18]. The assessment of CO_2 emissions caused by an electric vehicles, based on the carbon footprint in selected European countries is shown in Figure 1.

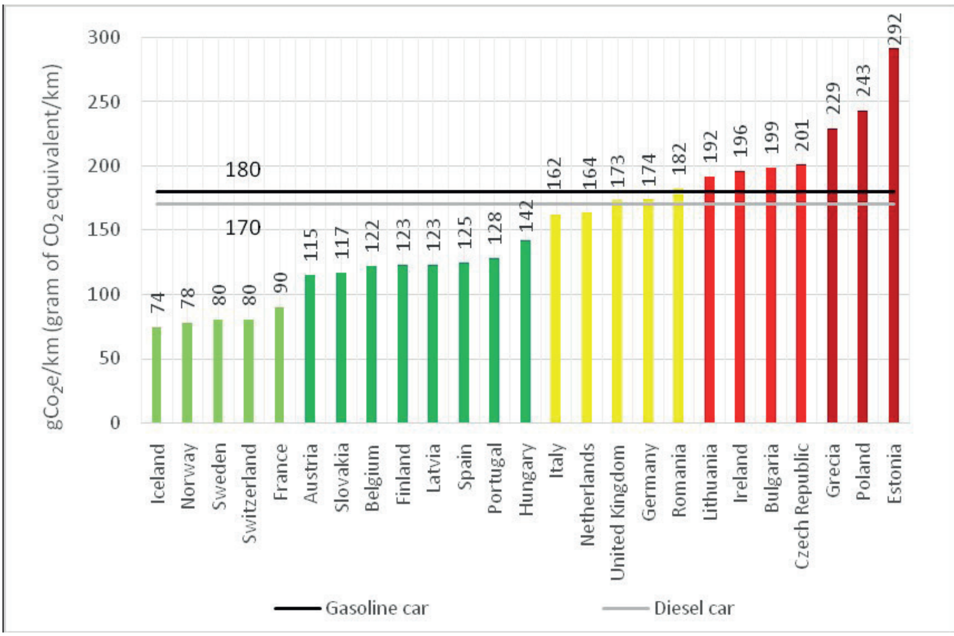

Fig. 1. CO_2 emissions caused by an electric vehicles, according to the LCA method (Life Cycle Assesment), based on the carbon footprint, in selected European countries.

According to the International Energy Agency, electric vehicles contribute to a substantial reduction in the greenhouse gas emissions only if the technologies used to generate electrical energy in a given country ensure a CO_2 emission factor of less than 0.700 kgCO_2/kWh. In Poland, it amounts to 0.825 kgCO_2/kWh [25].

From a formal point of view, an important factor to promote e-mobility is the passage of the European Parliament Resolution of 6 May 2010 on electric cars, containing a series of recommendations for the European Commission and the European Union (EU) member states [6]. The acceleration of plans and activities to facilitate e-mobility as well as their scale have resulted in a great number of technological and organisational problems. Some of them will be described in the next sections of this article. There are also economic, legal and social issues to be dealt with, but they will not be discussed here. Despite the great engagement of the EU authorities and governments of many countries, the problems are very difficult to solve. A report published in May 2017 reveals that the government of Germany does have serious doubts whether their 2011 electromobility scheme aiming at one million electric vehicles can be achieved [15]. The key barriers are the range of electric vehicles, the charging infrastructure and the EV prices.

2. Technological issues for e-mobility

The list of technology-related problems to be solved in order to facilitate electromobility is quite long and differs from author to author. For instance, a report prepared for the National Centre for Research and Development (abbreviated to NCBR in Polish) by a large team of experts [6] specifies 14 research areas that Polish R&D institutes are involved in. As mentioned in the Introduction section, the fundamental challenges are those related to technology. This article focuses on the need:

- to extend the range of electric vehicles, associated with the electrical capacity of the battery pack,
- to develop fast charging methods,
- to create smart power grids,
- to analyse the effects of the high weight of the battery pack on the vehicle dynamics and, consequently, the vehicle safety,
- to ensure reliable protection against electrical and fire hazards in a crash,
- to ensure reliable protection against battery displacement during a collision.

The range of electric vehicles is determined by the battery capacity, normally given in Amp hours (Ah). The most common types of batteries used in electric vehicles are lithium-ion and nickel-metal hydride (the latter used by Toyota). On ways to extend the lifetime of the batteries they worked for many years [19]. The progress in improving the batteries is shown in Figure 2, on an example lithium-ion batteries [25].

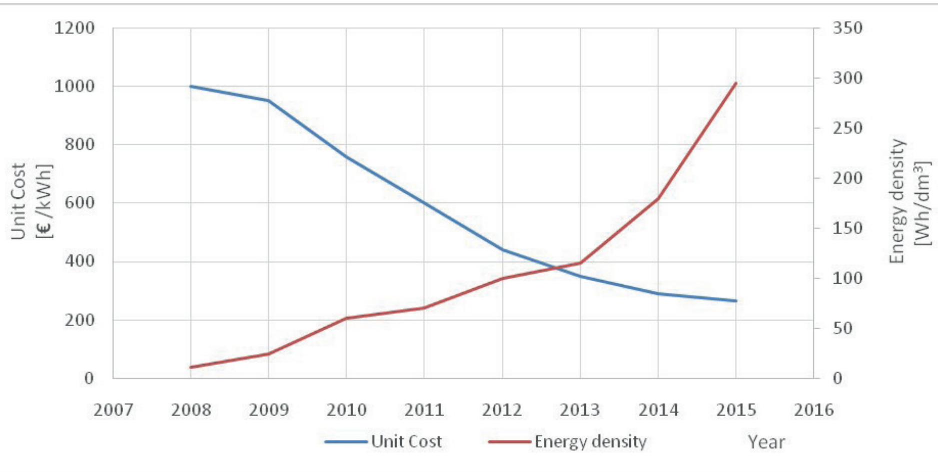

Fig. 2. Unit cost (€/kWh) and energy density (Wh/dm^3) of lithium-ion batteries

Since neither type is able to provide sufficient unit power or unit energy, researchers are looking for new solutions, including semiconductor and lithium-air batteries. The latest developments in the field include lithium-metal hydride and graphene-polymer batteries. As is the case with most novel technologies, it is difficult to predict how long it will take to develop and implement them for mass production.

The range of electric vehicles is primarily dependent on the battery type and design. The range of most D-segment (large family) electric cars is between 100 km and 300 km. Many E-segment cars had similar ranges as long as three or four years ago. Models developed by Tesla have been an exception, offering, on average, a range of (400-500) km [4]. Over the last three years, the other EV manufacturers have launched models (with most, however, being concept models) that are on a par with those produced by Tesla. Examples include Audi Elaine (500 km), BMW and Vision Dynamics (600 km), Mercedes-Benz Concept EQA (400 km), Volkswagen I.D. CROZZ (500 km) and Skoda Vision E (500 km). Still, Tesla is a market leader in the electric car sector. Its Roadster 2 can travel approximately 1,000 km on a single charge. The range of selected electric cars is shown in Figure 3 [10], [26].

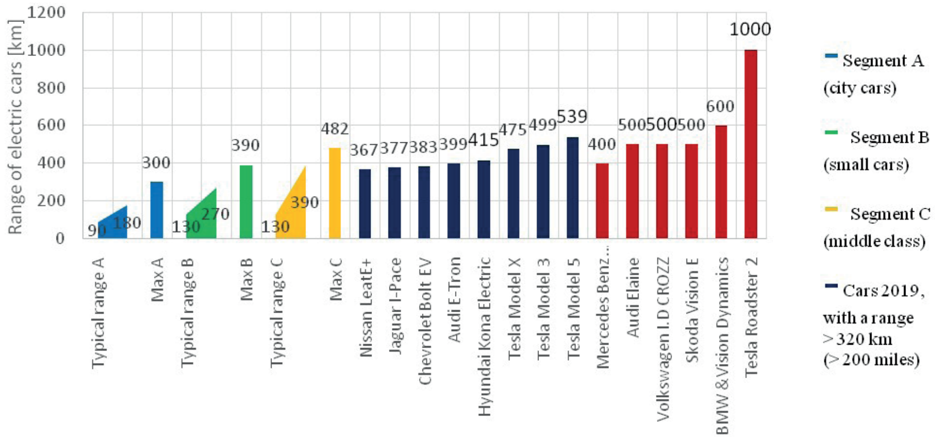

Fig. 3. The range of selected electric cars.

It should be mentioned that the distance covered by internal combustion engine vehicles on a full tank can range from about 500 km (C-segment cars) to more than 1,000 km (D and E-segment cars). It is frequently heard that the popularity of EVs will increase when the range of regular, not concept, models exceeds 500 km per charge. This opinion is roughly confirmed by the results of surveys conducted among customers, shown in Figure 4 [3].

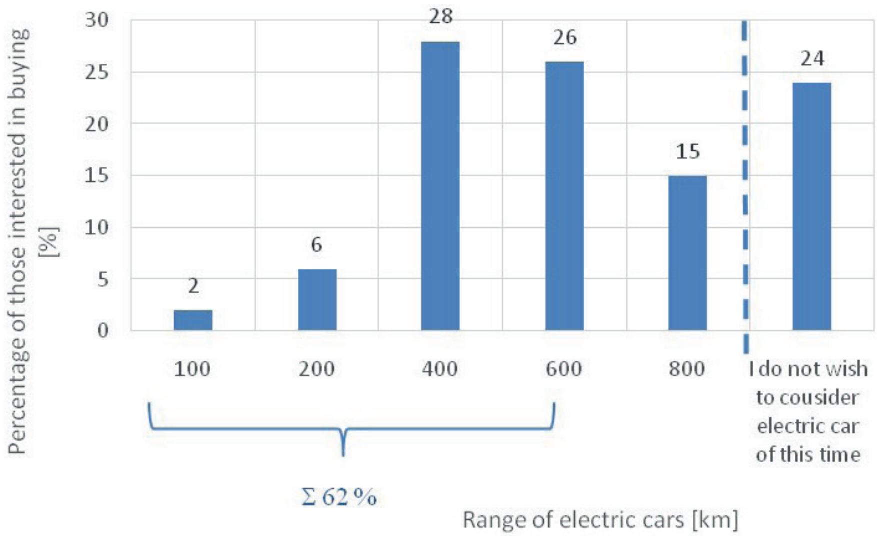

Fig. 4. The results of surveys conducted among customers.

It is worth pointing out that cold temperature lowers the battery capacity, and, consequently, reduces the range of travel [2], [20], [24]. One way to solve this problem is rapid self-heating of lithium-ion batteries in low temperatures [27], [28]. The case study simulations described in Ref. [9], which aimed to determine the effects of various parameters on the electric vehicle performance as well as its energy consumption and range, show that a 20°C drop in ambient temperature may result in higher, up to about 40%, consumption of energy and a decrease, of a similar size, in the vehicle range. Another finding is that very dynamic driving (large accelerations) as well as driving in hilly terrain may be responsible for several-fold higher energy consumption, and, accordingly, a several-fold shorter range.

Increasing the range of electric vehicles implies increasing the battery capacity. However, the more energy a battery can store, the longer its charging time. Thus, another significant problem related to e-mobility is the need for **development of fast charging methods**.

The most common is the plug-in technology, which requires connecting a vehicle to a charging station. Charging times vary, depending on the overall capacity of the battery pack and the output power of the charger. In slow charging (16 A single-phase charging), it takes from several to more than a dozen hours to charge a vehicle up. The basic requirement concerning a charging point is simple: access to an appropriate grid socket. Using a regular household power outlet is possible but not recommended; generally, dedicated sockets are required.

There are several new approaches to ensure shorter charging times:

- combined AC and DC charging,
- fast charging (3x32 A),
- ultra fast charging (125 A_{DC}),
- static and dynamic wireless charging (e.g. wireless charging roads and motorways).

In the case of city buses, charging can also be done using:

- a pantograph system; the time to charge a bus is between 8 h to 15 h;
- an inductive system; this technology consists in transferring energy from road embedded plates, acting as transmitters, to plates attached to the underside of a vehicle (bus), acting as pickups, i.e. electric energy receivers; road embedded plates with inductive loops are installed at bus stops, depots and similar sites; current technologies offer charging times of about 4 h;

As charging times are dependent on the charger type and battery capacity, it is essential to standardize charging systems and chargers.

The enhancement of electromobility will lead to a dramatic increase in demand for electric energy, which will require intelligent energy management strategies. The problems can be handled by **creating and developing smart power grids** [24]. Many concepts have been proposed and analysed in this area and the major goals are:

- to lower the extent of demand at peak times (too many batteries charged at the same time) – Figure 5 [25],

- to increase the share of renewable energy in the total energy consumption (charging from renewables),
- to intelligently integrate the actions of all energy producers (whatever the size and type of resources) and consumers,
- to make the network a self-healing system (decentralized like the Internet),
- to smoothly modernize the existing networks (concepts of grid modernization plans).

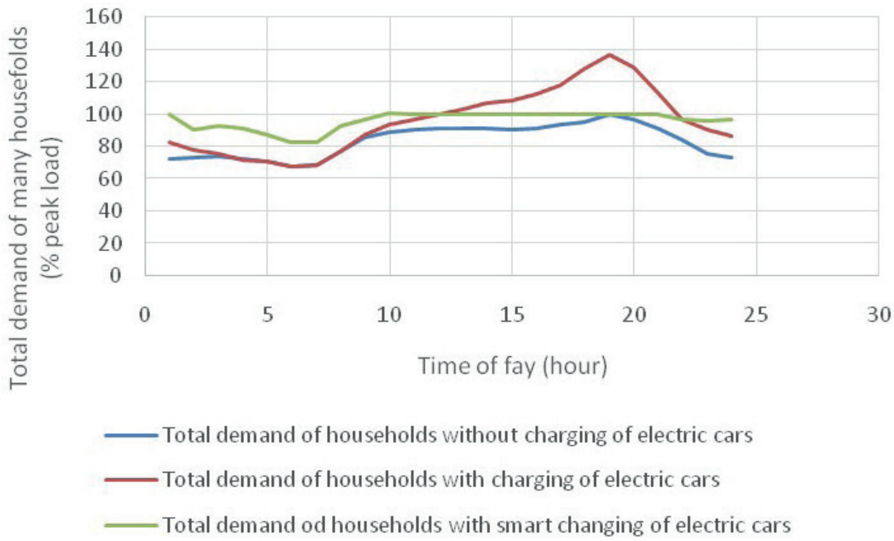

Fig. 5. Total demand of households with smart charging and without smart charging of electric cars.

A very important aspect of the use of electric vehicles is the safety of occupants and other road users. The active safety of such vehicles is largely dependent on their **dynamic properties, which, in turn, are determined by the high weight of batteries**. Tesla, for instance, uses battery packs with an overall capacity of 100 kWh to achieve a range of about 500 km for their vehicles. Batteries used by other EV producers have energy density not exceeding 160 Wh/kg. At this density, a capacity of 100 kWh, and consequently, a range of about 500 km, can be achieved using batteries with a total weight of 625 kg. Such a high weight of the battery pack must have a negative impact on the vehicle dynamics (including stability) both during acceleration or braking and when the vehicle is in curvilinear motion.

A new safety-related problem, observed for electric vehicles but not reported for conventional petrol/diesel vehicles, is a risk of electric shock. There is a need for **reliable systems of protection against electrical hazards**, especially when there is an accident. The people exposed to electrical hazards in such a situation are not only the occupants of the electric vehicle but also others that may come in contact with it, e.g. first responders, rescue workers or occupants of the (conventional petrol/diesel) vehicle it collided with. The electrical system of an electric vehicle needs to meet the requirements provided in Regulation No. 100 of the United Nations Economic Commission for Europe (UN-ECE) [22]. This document outlines safety guidelines for REchargeable Energy Storage Systems (REESS). The most important factors affecting the electrical safety of EVs are:

- the degree of protection (International Protection Marking or IP Code),
- the voltage level; some electric cars have a voltage of several dozen volts; in most models, however, the voltage level of the drive and drive control systems ranges between 200 and 400 V; there are also vehicles where it reaches about 1,000 V (e.g. Opel Ampera – 950 V) [14];
- the insulation resistance; it needs to be at least 500 Ω/V, as stipulated in UN-ECE Regulation No. 100 [22]; it is also desirable that the resistance of materials used in the vehicle should be higher than 1,000 Ω/V [14]; this document also defines the conditions when an on-board system is required for monitoring the insulation resistance.

Another important issue related to EV batteries is protection against fire hazards. Electrical safety requirements for EVs are specified in UN-ECE Regulation No. 100. The regulation provides the acceptance criteria for installations to prevent electric shock, explosion and electrolyte leakage.

As it is particularly significant for electrical hazard protection systems to be reliable in a crash situation, many solutions have been proposed in this area. Examples of auxiliary electrical protection include:

- an electric leakage sensor, which monitors if the high voltage circuit is insulated from the vehicle body;
- a battery isolation system with two relays to disconnect the high voltage cables from the battery when the motor is off;
- a system to automatically open the battery pack relays to stop the electrical flow after the activation of the front air bags in the event of a collision;
- an internal battery circuit breaker activated in the event of a collision.

The problems to be solved in this area, analysed by both EV manufacturers and automotive research institutions, include assessing the effectiveness of electrical and fire protection systems as well as developing new testing methods and new assessment criteria. An interesting concept discussed in Ref. [14] is that of safe use of electric vehicles (abbreviated to BUSE in Polish). The paper suggests further research to investigate certain unknown phenomena not encountered in conventional petrol/diesel vehicles, which are not described in the relevant UN-ECE regulations or EU directives and regulations on safety of EVs.

Electromagnetic compatibility is a serious problem for electric vehicles but not for conventional petrol/diesel vehicles. Despite the fact that the assemblies and systems of electric vehicles operate in more difficult ambient electromagnetic conditions, they need to meet the requirements specified in UN-ECE Regulation No. 10 [21].

The weight of the battery pack adds significantly to the total weight of the electric vehicle. It is necessary **to prevent any displacement of the battery pack during a crash**. Very large decelerations occurring in a crash situation may result in the damage of the mounting mechanism and, depending on the type of collision, a forward, backward or sideward movement of the battery pack, with this posing a serious threat to the life and health of the vehicle occupants. Extending the range of EVs by increasing the number of batteries in the vehicle leads to an increase in the overall weight, which may be an important factor in the course of an accident.

In the case of an internal combustion engine vehicle with a weight comparable to that of an EV, the weight distribution, and therefore, the vehicle behaviour in a crash, will vary. Apart from standard crash tests run according to the European New Car Assessment Programme (Euro NCAP) test protocol, many research institutes, e.g. the Automotive Industry Institute, analyse various pre-crash situations for different speeds and positions of the colliding vehicles. The experimental data can be useful to various automotive engineering consultants, especially forensic investigators and expert witnesses, to better understand the post-crash phase. Published results on the crash tests of electric cars show that even a slight change in a factor causes a completely different behaviour of the vehicle in the post-crash stage [7].

Because of various weight distribution, electric vehicles are certain to behave differently during accidents from conventional petrol/diesel vehicles. It is thus essential that many crash tests should be performed so that specialists such as forensic investigators will have extensive knowledge in this field.

Another safety problem associated with electric cars is that they are more difficult to detect audibly than internal combustion engine vehicles. An approaching vehicle which does not emit enough noise may pose a risk to vulnerable road users. Experts suggest that this may contribute to an increase in the number of pedestrian and cyclist road accidents [25].

3. Organisational issues for e-mobility

Gradual implementation of electric vehicles, which are expected to be in common use, involves not only technological advancements, as discussed in the previous section, but also challenges that are non-technological in character. The effective growth of e-mobility requires addressing a wide range of organisational problems, the most important and most difficult of which are:

- building a network of fast charging points,
- encouraging purchase of electric vehicles by implementing attractive organisational perks to potential users,
- training a large number of electricians to perform roadworthiness testing and provide repair and maintenance services of EVs,
- organising the system and developing facilities to recycle spent batteries,
- solving problems related to the creation of smart grids.

Highly motorized countries find it challenging to **build networks of fast charging stations** because of the scale of changes and investments. As electric vehicles have shorter ranges than conventional vehicles, for long-distance driving they need a charging point network denser than the current petrol and diesel infrastructure.

It can be assumed that the number of charging points in urban environments should be proportional to the number of electric vehicles there. The number of charging stations in cities will thus increase with increasing e-mobility [5].

To reduce public charging, EV owners will be encouraged to rely on residential (home) charging using a standard power outlet or a dedicated charger (with the other preferable), despite a long charge time of up to more than a dozen hours. There are also proposals to install charge points at sites where electric vehicles are left for a longer period of time, e.g. workplace car parks [11]. Whatever approach is taken to solve the charging infrastructure problems, it is vital that plugs and sockets used for this purpose should be standardized to make the system as flexible as possible.

The rate at which the charging infrastructure is growing is one of the fundamental factors adding to the success of electromobility. It is estimated that once a certain critical number of charging points is created, the use of electric vehicles will be more common.

Electric and hybrid vehicles are still much more expensive than conventional petrol/diesel vehicles. Many countries offer a variety of perks to make up for the difference. The financial incentives available for such vehicles include rebates and preferences. With these being insufficient, some national and local governments also **provide organisational privileges to promote electric mobility**, for example:

- access to bus-only lanes,
- access to limited traffic or no traffic zones,
- access to parking spaces in city centres.

It should be noted that at the moment, this type of activity can be assessed positively. However, when the number of electric vehicles is really high, all these privileges will be withheld, making the users unhappy. Norway, which is the European leader of electromobility, assumed to have 50,000 zero-emission vehicles by 2018. The target was reached much earlier, i.e. in 2015. At the end of 2016, the number of electric and hybrids vehicles in that country doubled, reaching 100,000. The reason behind this success has been generous financial and organisational perks, e.g. access to bus lanes, access to and free parking in the city centres, and, finally, free access to chargers. The Norwegian government has announced that, with such a high number of electric vehicles, the privileges will no longer be available in 2020. They expect public disappointment similar to that observed in Denmark after such incentives for electric and hybrid vehicle owners were withheld [23]; the dissatisfaction was accompanied by a sharp decline in the sale of electric vehicles.

Electric vehicles have relatively few mechanical assemblies; this implies a lower need for mechanical repair services. There will be, however, a greater demand for electrical repair services. It is vital **to urgently train a large number of electricians to test, repair and maintain electric vehicles**. There is a high demand for qualified automotive staff to install and repair electrical systems with a supply voltage of up to 1 kV. There is also a need to produce a sufficient number of testing, repair and maintenance equipment for e-vehicles.

Computer-based roadworthiness testing systems require appropriate software. The rate at which new solutions are offered in this field implies that there is an urgent need to develop schemes for the training or retraining of workshop personnel. Electric vehicles will require additional tests, for example, to inspect the condition of the connections, measure the insulation resistance, or check the reliability of the battery pack mounting system.

Roadworthiness facilities offering inspection services to electric vehicles need to meet all the requirements specified in Directive 2014/45/UE, Annex III. Also, technicians performing such tests are expected to have more specialist knowledge of the automotive electric and electronic systems than they require for conventional petrol/diesel vehicles.

Currently, there is no solution to the problem of specialist training to provide repair, maintenance and test services for electric vehicles. It is also not known how urgent the need is, that is, whether or not the number of specially qualified electricians should be proportional to the increasing number of electric vehicles.

The regulations on motor vehicle recycling, developed for so many years, will have to be revised now. The methods and technologies used to recycle car bodies, suspensions, braking systems, steering systems as well as interior parts will not change. However, except for easy-to-recycle elements such as engines, gear boxes or clutches (90% of metal), there will be a **large number of used EV batteries that will require a specially organised recycling system**. The new approach needs to take account of:

- a rapid increase in the number of batteries and their different types,
- the need to recycle because of diminishing resources of materials used to produce batteries, especially lithium (with its resources predicted to last until 2035),
- a chance to recover other materials (e.g. Co, Fe and Ni, used in anodes and cathodes, each constituting 25% of the materials used for batteries),
- the need for environmental protection as the materials used to produce batteries are extremely harmful to the environment.

It should be noted that there has been no research into how fast the need for recycling of EV batteries is increasing with a rise in the number of electric vehicles.

One of the technological issues related to electromobility, mentioned in the previous section, is the development of smart power grids. However, **organisational problems to create smart power grids** are no less important or difficult. Research studies conducted in the countries that are e-mobility leaders indicate that if no additional effective measures are taken, the highest demand for electricity is observed during evening peak hours. The conclusions are as follows:

- it is necessary to develop and implement tools to manage demand for electrical energy;
- smart charging of electric vehicles can reduce the peak demand [17], [25];
- electric vehicles could be integrated into the smart power grid as energy storage modules (control reserves).

Forecasts by strong supporters of e-mobility show that, in more than a dozen years, electric vehicles will predominate, and they will use significant amounts of electrical energy.

Without smart power grids, the functioning of businesses, households, etc., will be disturbed. Smart power grids are expected to solve power problems, including those related to electric vehicle charging. Electromobility may even contribute to better management of electricity [25].

4. Conclusion

Recently, many countries have initiated schemes to facilitate e-mobility. One of the real motives, except for the environmental ones mentioned in the Introduction, is the desire to lead the technological race or at least be an active participant. Countries supporting the development of future technologies realise that these may be a driving force of their economy. Rapid introduction of e-mobility requires overcoming many barriers and limitations. The three major barriers associated with electromobility are:

- the limited range of electric vehicles, being dependent on the battery capacity; this problem is likely to be solved in the next few years; in the years 2008-2015, the battery energy density, measured in Wh/dm^3, increased five-fold, while the price per kilowatt hour decreased four-fold [25];
- long charging times; the problem can be overcome by implementing fast charging systems; the target charging duration is (5-10) minutes, similar to that required to refill a petrol/diesel vehicle;
- lack of or insufficient networks of fast charging stations; dense national networks are required to increase travel comfort.

There is still a fourth important barrier, not discussed in this paper; it is the price of electric and hybrid vehicles, which is too high to be acceptable for most users. Forecasts say that the market prices of electric cars will equal those of petrol/diesel vehicles in 2025 [25]; some experts speculate, however, that this will happen as early as in 2022.

An interesting analysis of various scenarios for the implementation of e-mobility is discussed in Ref. [8]. The work considers three types of scenario: market-dependent, technology-related and politically-supported. It is interesting to note that only the third type of scenario may contribute to dynamic development of electromobility. Political support means engaging national budget funds to overcome any barriers, particularly technological and organisational in nature.

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