Thomas DÖRING, Birgit AIGNER

Carinthia University of Applied Sciences – Research Centre for Interregional Studies and International Management (isma)

E-mobility: realistic vision or hype – an economic analysis

***Abstract**. This paper focuses on the question if forms of e-mobility have a feasible chance of market penetration from an economic point of view. As positive ecological benefits are the most frequently mentioned advantages of e-mobility, first of all, potential ecological effects in relation to e-mobility are highlighted. Subsequently, the likely switch of consumers from conventional vehicles to e-vehicles is considered from a micro-economic perspective by taking into account the related opportunity costs of such a substitution.*

***Streszczenie.** Artykuł skupia się na pytaniu czy e-mobilność ma realną szansę penetracji rynku z ekonomicznego punktu widzenia. Jako pozytywne strony e-mobilności podaje się efekty ekologiczne. Kolejne korzyści to prawdopodobne odejście konsumentów od konwencjonalnych pojazdów na rzecz e-pojazdów co może być rozpatrywane z makroekonomicznego punktu widzenia przez wzięcie pod uwagę związane z tym zmniejszenie kosztów. (**E-mobilność: realistyczna wizja czy krzykliwa reklama – analiza ekonomiczna**)*

Keywords: e-mobility, economic attitudes, ecological effects
Słowa kluczowe: e-mobilność, postawa ekologiczna, efekt ekologiczny

Introduction

The topic e-mobility is increasingly present in media and public in Austria. Just recently the Austrian Federal Ministry for Transport, Innovation and Technology announced an implementation plan for e-mobility with the aim to optimize the national transportation system by linking industry, research and politics in order to reach an effective and on individual preferences oriented use of alternative driving technologies (in particular forms of e-mobility). Every fourth Austrian car should have an ecological alternative drive mechanism up to 2020 and ease the way to a sustainable energy management due to the federal plans [1]. Close to the visions of e-mobility is the scepticism.

This paper focuses on the question if forms of e-mobility have a feasible chance of market penetration from an economic point of view. If we discuss alternative driving possibilities (in particular forms of e-mobility) from an economic perspective, we have to consider the following issues:

- Potential ecological effects of e-mobility
- Micro-economic aspects (personal acceptability)
- Macro-economic benefits and costs of e-mobility

The following paragraphs present arguments and results from economic research dealing with these three aspects.

Potential ecological effects

The most frequently mentioned advantages of e-mobility are their ecological benefit in terms of less energy consumption and reduced air pollution. Considering the energy needs, electric vehicles are far more efficient compared to ‘traditional’ ones. Depending on the type of vehicle two to four times more energy is needed for the operation of conventional cars. Current ultra-light vehicles consume approx. 10 kWh for 100 km (approx. 1 liter fuel). If one takes heavier serial vehicles for four passengers as a basis the consumption lies at approx. 20 kWh (approx. 2 liter fuel). In combustion engine version the same vehicles consume 5 liter diesel resp. 8 liter fuel. Furthermore, electric vehicles produce less noise, no dust and zero emissions during driving [2].

In contrast, studies show that e-cars with an identical size and endowment produce – in consideration of the whole life-cycle of the product – as much greenhouse gas per kilometer as conventional cars with gasoline engines. E-vehicles would only have an ecological advantage if they could use electricity from renewable energy resources [3]. Due to the high rate of electricity from water power, Austria is the worldwide leading country within the renewable energy sector (rate of renewable energy in 2007: 23%). Newer studies expect that the share of renewable energy within the energy mix will achieve 34 % [4]. But also in case that the rate of renewable energy would significantly increase it is still questionable in light of the state of technology whether it would be an economic as well as ecological sound solution to use energy from renewable resources prior within the transport sector.

The prime reason for this assessment is the most problematic part of each e-vehicle: the battery. This is not because only 86 % of the energy of a Lithium-Ione-Battery is used for the power train of an e-vehicle during driving while 14 % become lost by chemical reactions inside the battery [5]. More significant is that a lot of energy is used within the manufacturing process of a battery. A critical discussion regarding batteries has not only to focus on the manufacturing process itself but also on the digging process of the raw materials, which are needed for the production of a battery (in particular lithium and silicium). A real problem is the pollution during the digging of these scarce sources. It should be imagined how many tracks, mine working, wheel loaders etc. have to be used to get these raw materials. A lot of gasoline has to be burned within this process and therewith a lot of carbon dioxide is emitted only for searching and mining the elements.

The high degree of energy consumption within the battery production process is reflected in the eco-balance of an e-car by the average value of 48 gram carbon dioxide per kilometer. Together with the carbon dioxide emission of the power station for generating the 0.2 kilowatt hour which is used by an e-car per kilometer the overall emission balance results in 162 gram carbon dioxide per kilometer [5]. It can be also stated that in case of driving a conventional gasoline engine driven car in a very “green” way the existing pollution would decrease rapidly.

There is an additional (critical) aspect concerning material questions which should be taken into consideration: Standard gasoline engines have turbo boosts or compressor units with oil cooling sets for further power made of very light aluminum. Only the crankshaft, con rod and camshaft and some bearings are made of steel. In contrast, the whole electric machine is heavy: steel or special ferrite materials for magnetic circuits, heavy permanent magnet materials of rare alloys, and also the very heavy copper coils are problematical in weight. Furthermore, the connection lines – copper cables – are heavy especially in respect of the charging of the high currents up to 1000 A. A higher weight of a vehicle usually correlates with a higher energy demand.

To sum it up: With respect to the existing energy-mix, but also concerning the weight of a comparable e-vehicle, a boosted implementation of e-vehicles cannot be justified by ecological advantages.

Micro-economic aspects: personal acceptability

The (potential) usage of e-mobility can also be considered within a micro-economic framework. From this perspective, the demand of a good (here: e-vehicles) is determined by several factors like the given price of the good, the price of close substitutes (here: vehicle with gasoline engines), the income of a person, the individual preference for the good as well as the expectations concerning the future development of the market for this good [6, 7]. Against this background, the basic question is how likely would be a switch from conventional vehicles to e-vehicles by taking into account the related opportunity costs of such a substitution.

In order to estimate these opportunity costs the comparative driving expenses provide a first benchmark. Economic studies show that the energy-costs for using an e-vehicle amount to 4 Euro per 100 kilometer on average what is only about half of the costs of a vehicle with a gasoline engine. However, additional costs develop due to the abrasion of the battery up to the amount of 20 Euro per 100 kilometer. Or in relation to the capacity of the different energy sources: One liter gasoline has a capacity of approx. 10kWh, the same as a 333kg Plumb battery, a 55 kg Lithium type and a 167 kg NIMH battery [8]. And that by prices of 1.10 Euro for one liter gasoline, around 5,000 Euro for a Plumb battery, 35,000 Euro for a Lithium one and 20,000€ for NIMH batteries.

In relation to the preferences it can be assumed that the costumers will ask for the same quantity and quality of the good "mobility" as they did experience in the past (i.e. crash behavior, spatial range, temporal availability, filling/service stations). In this dimension batteries and electric storage are a challenge again. Batteries have high heating losses which is a potential problem regarding safety. Cooling and damaging through heating has to be engineered otherwise the demand for e-vehicles will be low [9]. In addition, batteries and their behavior in case of crashes are problematical in respect to their heavy weight. Light car structures with best crash behaviors for safety should be the main research in the next years. Another big problem is the life cycle of the batteries. The main parameter for that is the load cycle, the number of how often you can discharge and load the battery. It depends on the materials, the temperature, the usage and the number of load cycles. Silicium gel batteries for bicycles exceed up to 250 cycles before breaking away. The best battery types currently available on the market attain a maximum of 1250 cycles before new ones have to be bought [8].

Also of high importance for the future demand of e-vehicles is the geographical range of this type of mobility. To create a positive incentive for substituting gasoline driven cars by e-vehicles the geographical range of both types of vehicles should be more or less the same. At present with respect to the state of technology, the maximal range of e-vehicles is from 100 up to 200 kilometers before the battery must be reloaded. Compared to a conventional car (range: 700 – 1,000 kilometers) the geographical range of an e-car is much lower and, for this reason, reflects a high competitive disadvantage. In addition, the range of an e-vehicle depends on the topographical structure of the landscape as well as on climate factors [9].

This creates further opportunity costs which are characterized by the matter of fact that e-vehicles are only convenient for a low-range usage. That denotes at the same time, that private households in order to satisfy all of their mobility preferences in a flexible manner (low-range as well as high-range) need more than one vehicle. Two consequences can be derived: On the one hand, the willingness to pay for e-vehicles will – ceteris paribus – be low (especially where a high-range vehicle definitely is needed). On the other hand, the acceptance of e-vehicles will be determined by the income level of private households (i.e. only households with a high income will be able to pay for two or more vehicles whereas the budget restriction of low-income households will retard a wide-spread demand of e-vehicles). But also if a decision to buy an e-car is taken, it could be hard to find an appropriate one as the availability of e-vehicles on the market is still low [8].

From a theoretical view, it can also be ascertained that as a precondition for a wide-spread usage of e-vehicles much more high power electric grids for electric energy distribution are needed. In addition, the existing infrastructure for charging as well as service and repair workings must be assessed as insufficient [8]. Furthermore, the fueling of the vehicle itself is a comparative challenge. Compared to the time which is needed for refueling a gasoline engine driven car (5 minutes for the energy of around 100,000 kWh) the equivalent time for charging an e-vehicle takes incommensurable longer (8 up to 10 hours). And the energy losses during the refueling process are with 10-30% considerable [3]. That creates additional opportunity costs which would prevent benefit maximizing actors switching from conventional to alternative forms of mobility. Against this background, long charging times present not only a technical challenge but also a commercial barrier that must be addressed.

A current study of the Boston Consulting Group [10] analyses several technological options for efficient, low-carbon dioxide power trains which can be categorized into three groups (alternative fuels, advanced internal-combustion-engine (ICE) technologies and electrification). The study not only shows that advanced ICE technology will be the most cost-effective way to reduce carbon dioxide on a broad scale (between 50 and 100 Euro for each percentage of reduction in carbon dioxide emissions, while a fully electric vehicle can achieve even greater reductions in CO_2 emissions than those based on advanced ICE technologies, albeit at a higher cost: between 98 and 197 Euro per percentage point in carbon dioxide reduction). It also exposes that from a total cost of ownership (TCO) perspective, which is a key criterion influencing consumers' buying decisions, the e-vehicle is expected to remain relatively unattractive to consumers when oil prices are moderate and unless its cost is subsidized. The BCG study looks at the likely five year TCO for the mentioned competing technologies, for cars bought in Germany today and in 2020, as a function of the price of oil. At expected battery costs of 500 Euro (700 USD) per kWh the TCO of an electric car will be higher than those of advanced ICE vehicles and hybrids when oil prices are below 197 Euro (280 USD) per barrel. Only if the battery costs would drop to a very low level – 353 Euro (500 USD) per kWh – the e-vehicle will gain attraction at an oil price between 70 Euro and 84 euro per barrel.

Macro-economic benefits and costs

The macro-economic perspective is concentrated on effects which harm or benefit the economy as a whole. In this dimension, the impact of an increased demand for e-vehicles on variables such as the gross domestic product (GDP), the employment rate, the overall market and price development, innovations and patent activities, or the public budget is under consideration [7]. Due to the fact that there is a lag of economic studies which analyze the potential macro-economic effects of e-mobility in a comprehensive way only some aspects can be highlighted within the subsequent considerations.

Although the current economic crisis might appear to mitigate strong market development of alternative technologies of mobility, the interest in long-term sustainability remains keen in the public as well as among governments and their regulatory bodies. Against this background, one key variable for an emerging market for e-vehicles will be the future development and cost of various types of batteries. On the one hand, without a major breakthrough in battery technologies, fully e-vehicles that are as convenient as conventional vehicles – meaning that they are driving 500 up to 700 kilometers on a single charge and can be recharged in a matter of minutes – are unlikely to be available for the mass market by 2020 [9]. On the other hand, the cost of batteries will play a critical role in determining the commercial viability of e-vehicles. Estimates of current and future cost levels vary widely and are further complicated by a lack of clarification about which costs are (precisely) estimated. To forecast battery costs, the Boston Consulting Group [9] constructed a line-item model with the individual component costs involved in making a battery in 2009 and assigned variables likely to influence each component cost under an assumed level of production.

Considering this model, it is assumed that about 70 % of cell costs and 75 % of battery pack costs are volume dependent (that is economies of scale can be realized in case of an increasing production volume). This means that the more batteries are demanded the lower the production cost per unit (battery) will be. Using this model for an outlook of battery costs up to 2020, it is estimated that overall battery costs will decline steeply because individual parts will become less expensive due to experience and scale effects. There has already been a clear price drop in the case of Lithium-Ion-batteries since 1999 [8]. However, about 25 % of current battery costs (primarily the cost of raw materials and standard commoditized parts) are likely to remain relatively independent of production volumes and to change only modestly over time. It also cannot be precluded that these raw materials – especially in case of an expanding battery market – become “trading toys” for brokers and traders on the stock-markets round the world. Rising costs would be the consequence. In addition, the currently known raw material deposits which must be exploited in order to satisfy a higher demand of batteries are located in only a few countries (in particular in the case of lithium). Like in the existing oil market, oligopolistic structures adherent with a high chance for collusive behavior of the market actors can be expected. The result could be an increase in the price level of these raw materials.

One further important problem is the fact, that in most cases only two or four from 100 up to 1000 cells of a damaged battery are inoperative. The amount of work (and related to that the costs) for replacement of the damaged cells are most of the time very high. Consequently, many good battery cells, which were paid by the customers, will be thrown away without any monetary compensation. Here, recycling technologies could be the key action for the future. But at present, recycling-costs are very expensive. There is a need to reuse the scarce elements from old batteries, but the separation procedures are energy and cost-intensive.

With focus on the future market for e-vehicle batteries the BCG study also points out correctly that competition for share in this world-wide estimated 17 billion Euro market will be under way all along the industry value chain. Nevertheless rivalry will particularly be keen in the field of cell manufacturing, reflecting the critical importance of cells to overall battery performance. Taking this matter into account in the medium and long term, cell producers will play a crucial role in defining the balance of power (and the way revenues are shared) within this market. Additionally, it is for sure that the continuing growth of the market for e-vehicles will depend on new battery technologies. Looking at the past, patent filings related to energy storage did increase by 17 % per year from 1999 up to now, twice as fast as during the previous ten years and some ten percentage points faster than overall worldwide patent growth during the same period. Of the energy storage patents filed in China, Japan, the United States, and Western Europe in 2008, Lithium-ion technologies accounted for 62 %, having grown by 26 % per year from 2005 to 2008. The recent explosion in innovation is – and still will be – driven by the need to break some fundamental compromises in battery technology.

Another important aspect is the charging infrastructure cost. Anticipating approximately 14 million cars with electric drive mechanism to be sold in 2020 in China, Japan, the United States, and Western Europe (consisting of approx. 1.5 million fully e-cars, 1.5 million range extenders, 11 million hybrids), the total cost of the needed charging infrastructure is estimated at approximately 14 billion Euro – whereas 40 % will be located in the US, 30 % in Europe, and 30 % in the rest of the world. It is also estimated that the anticipated number of e-cars on the road between 2020 and 2030 would increase the demand for electricity by as much as 1 % per year [9].

Within a second study, the Boston Consulting Group [10] tries to forecast the future market shares of new-car sales in 2020 concerning different types of technology (fully e-vehicle, range extender e-vehicle, hybrid e-vehicle, diesel vehicle, gasoline vehicle), three different scenarios (slowdown – the price of oil has fallen to 40 Euro per barrel; steady paces – the oil price has risen to 110 Euro per barrel; the oil price is around 220 Euro per barrel), and four key markets (Western Europe, North America, Japan, China). Under all three scenarios and in all four markets the BCG model anticipates that internal-combustion engines will remain the dominant technology in 2020. Cars equipped with alternative propulsion technologies will together achieve market penetration somewhere between 12 % and 45 %, whereas the steady pace scenario seems to be the most likely characterized by a market share of alternative propulsion technologies of 28 %.

In terms of market segments, fully e-vehicles are most likely to be introduced in the city car segment in form of small city cars used mainly for commuting within the city. This type of technology will play a lesser role within the small-car segment. Reason for this suggestion is the range limitation in combination with constrains by the absence of interurban charging infrastructure. For the small-car segment it is assumed that it will probably contain the broadest spectrum of available technologies, whereas hybrids will have significant penetration at above 20 %, along with range extenders at around 7 %. Among the larger-car segment it is expected that hybrids again will gain a relatively high market share of 18% up to 26 % [10].

With respect to Austria, a forecast concerning the economic effects of a higher number of e-vehicles was currently conducted by PriceWaterhouseCoopers [11]. The study which is mainly focused on the impact of e-vehicles on the electricity industry covers also a shortened benefit-cost-analysis in order to highlight some relevant macro-economic effects. The underlying model assumes a market share of 20 % of e-cars in 2020 (i.e. around 1 Mio. cars). Following the study, such a percentage of e-vehicles would increase the Austrian energy demand by approx. 3 %

without constituting a need for an extension of the existing number of generation stations.

The costs to endow Austria with a sufficient number of charging stations are estimated at approx. 650 Mio Euro. At present, a part of the petroleum tax is used for the building and maintenance of road transport infrastructure. If the revenues from petroleum tax would decrease due to an increased usage of e-cars, there would be a fiscal lag concerning the financing of the transport infrastructure which is needed by both types of vehicles (conventional ones as well as e-vehicles). A higher number of e-vehicles would lead to lower tax revenues (petroleum tax as well as value added tax) amounting to 894 Mio Euro. In contrast, benefits can be expected due to additional tax revenues related to e-vehicles (95 Mio Euro), reduced expenditures for oil imports (739 Mio Euro), reduced carbon dioxide emissions (73 Mio Euro), a lower energy demand (349 Mio Euro) as well as lower investment costs within the energy generation sector (1,053 Mio Euro). Comparing benefits and costs, the PWC study shows a positive net effect for Austria at the amount of 750 Mio Euro.

None of the cited studies contains any conclusion concerning the expectable GDP or employment effects linked to a higher market share of e-vehicles. Against this background the overall macro-economic effects are still an open question particularly in the case of Austria.

Conclusion

At present and with respect to given opportunity costs relevant within a micro-economic framework, the performance in terms of geographical range, charging time, infrastructure costs etc. of e-vehicles is lower compared to gasoline engine driven vehicles. While a wide-spread usage of (fully) e-vehicles seems to be unrealistic, market niches (like city usage) can constitute a competitive option. From a macro-economic perspective the expected positive ecological effects will only take place if the future energy mix of an economy consists of a high percentage of renewable energy sources. To estimate the whole ecological value the total energy consumption over the whole life cycle of technology (i.e. from mining over manufacturing up to recycling) must be considered. Additional macro-economic considerations show that, on the one hand, the development on the battery market (including technological progress in this sector) will be a key aspect for the future of e-mobility. On the other hand, the development of the oil price constitutes an important determinant for the competitiveness of e-vehicles.

REFERENCES

[1] bmvit, Strategie und Instrumente sowie prioritäre Anwender- und Einsatzbereiche für den Nationalen Einführungsplan Elektromobilität, Vienna, 2010

[2] Engel T., Das Elektrofahrzeug als Regelenergiekraftwerk des Solarzeitalters, Online: http://www.objectfarm.org/Solarkonzepte/Mobilitaet/V2G/V2G_Regelenergiekraftwerk_Solarzeitalter_112005.pdf, 2005

[3] Pehnt M., Höpfner U., Elektromobilität und erneuerbare Energien, Heidelberg/Wuppertal: ifeu und WI, 2007

[4] Buchacher R., Menasse S., Zukunftsreich, *Profil*, 33 (2009), 74-79

[5] Asendorf D., Die Mär vom emissionsfreien Fahren, *Die Zeit*, 39 (2009), 38

[6] Mas-Colell A., Whinston M.D., Green J.R., Microeconomic Theory, Oxford: Oxford University Press, 1995

[7] Mankiw N.G., Taylor M.P., Economics, London: Thomson Learning, 2006

[8] Klima- und Energiefonds, e-connected Abschlussbericht, Wien, 2009

[9] Boston Consulting Group BCG, Batteries for Electric Cars. Challenges, Opportunities, and the Outlook to 2020, Boston: BCG, 2010

[10] Boston Consulting Group BCG, The Comeback of the Electric Car?, Boston: BCG, 2009

[11] PriceWaterhouseCoopers, Auswirkungen von Elektrofahrzeugen auf die Stromwirtschaft, Wien: PWC, 2009

***Authors**: FH-Prof. Dr. habil. Thomas Döring, Carinthia University of Applied Sciences, Research Centre for Interregional Studies and International Management (isma), Europastraße 4, A-9500 Villach, Austria, E-mail: t.doering@fh-kaernten.at; Mag. (FH) Birgit Aigner, Carinthia University of Applied Sciences, School of Management, Europastraße 4, A-9500 Villach, Austria, E-mail: b.aigner@fh-kaernten.at.*