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Which role do hydrogen and battery electric vehicles play in the future of mobility? – A debate without simple answers

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For over seven years, Reiner Lemoine Institute (RLI) has been researching the options of integrating the sustainable transition of both the energy and the mobility sector. Hydrogen fuel from renewable energy is a controversial topic in research, politics and industry, especially when comparing hydrogen electric vehicles with battery electric vehicles, the latter of which are at the center of current public attention. In this article, we offer an overview of the debate's most common lines of argumentation and provide additional details and data from RLI's work on some of the disputed issues.

Transportation is the only sector in Germany, where greenhouse gas emissions have not decreased but rather increased during the last years. A vital step towards decarbonization of transport is the substitution of fossil fuels and the electrification of vehicle power trains. This mainly means the introduction of the battery electric drive technology which is expected to be completely cost compatible by the mid 2020s [1][2]. While Germany is busy cleaning up the diesel emissions scandal and discussing driving bans in cities, other countries such as Norway, France and Great Britain have pledged to phase out of internal combustion engines vehicles (ICEV) between 2030 and 2040. Likewise, Germany's neighbor Austria is debating a ban on new registration of ICEVs starting in 2030. China will be introducing an electric vehicle quota. Thus, it's not surprising to see new vehicle manufacturers from the U.S. and throughout Asia producing solely battery electric vehicles. Conversely, the electrification strategy of established German vehicle manufacturers has been much more cautious since the laborious development of alternative powertrain technologies is to be financed from the revenues of conventional technology. However, the main question remains: Which of the vehicle concepts will be established in an ever-growing vehicle market – those with batteries or those with hydrogen fuel?

Through an argument analysis of the current debate on alternative driving technologies, we display the complexity of pros and cons of fuel cell electric vehicles (FCEV) compared to BEV. The various issues can be sorted into different categories, such as refueling and charging infrastructure, user requirements, public acceptance, energy system, as well as efficiency and energy demand (Figure 1). Using speficic case studies, three lines of argumentation are further explained.

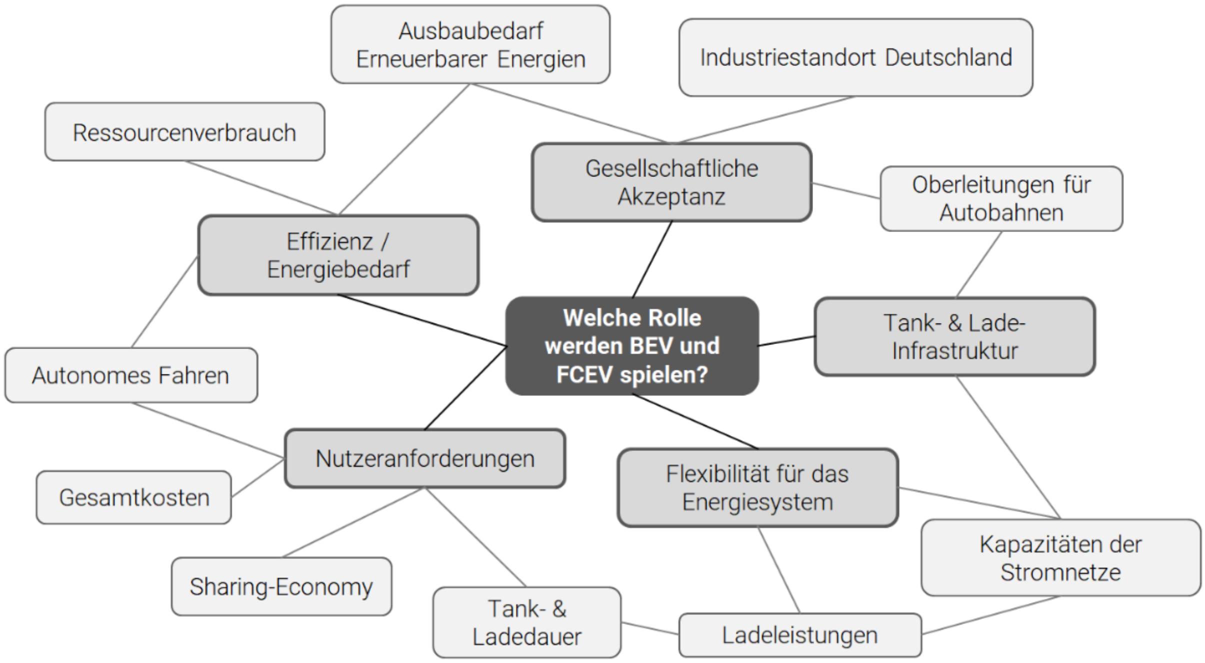

Figure 1: schematic representation of the argument analysis of the debate on BEV and FCEV

Arguments from a user's perspective

User profiles in transport are very diverse, ranging from private and public passenger cars to commercial motor vehicles. Not many years ago, BEV were only discussed as secondary vehicles for small distances in the private sector and for commercial use in city transport. Fleet analyses confirmed that in most use cases, a vehicle range of 100 km was sufficient for 80 % or even 100 % of the routes traveled [3]. Furthermore, the downtimes needed for recharging vehicles are usually also sufficient and can be adjusted as needed through the choice of charging power [4][5]. Most calculable routes with a regular schedule do not (yet) require a comprehensive network of public recharging infrastructure if the necessary recharging infrastructure is installed at home, at work, or along the commercial routes.

Recently announced BEV models also show that long distance travel has become possible. Ranges of over 350 to 400 km in practice and fast recharging options are considered appropriate for long-distance travel [6][7]. Fuel cell vehicles can be refueled and made available for these distances within minutes. BEV are different in this respect: They require a comprehensively available recharging infrastructure, and if there is an increased portion of BEV, they also need an efficient rapid charging system that can recharge several vehicles simultaneously [8][9]. In addition to the impact of refueling and recharging time on user demands, the deciding factor for users is that of the total overall costs of purchase and operation of vehicles (Total Cost of Ownership, TCO) (Figure 2). In the private but especially in the commercial sector, this aspect determines the portion of alternative propulsion systems in large fleets [10].

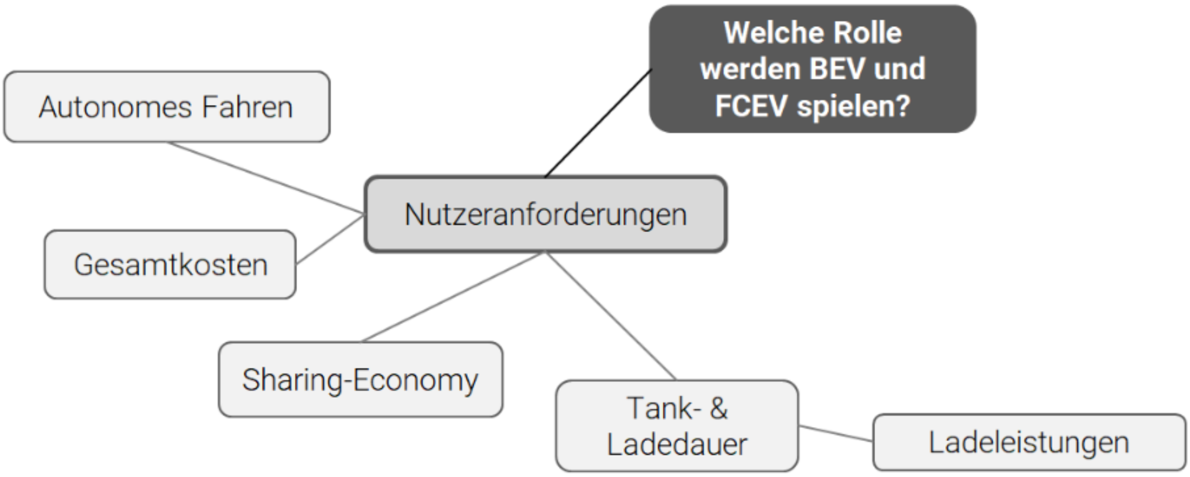

Figure 2: Selected aspects from a users' perspective

Depending on how user patterns will change in the future, i.e. through an increase in car sharing vehicles in major cities or megatrends such as autonomous driving, BEV and FCEV will make use of their specific advantages (recharging and refueling times, ranges, etc.).

Real-life example:

In the study PIOnEER [11], the Reiner Lemoine Institute evaluated the logbooks of two light commercial vehicles (< 3.5 tons) of a wind energy provider over the course of more than two years. About 80 % of all single trips were less than 200 km long. Battery electric vehicles that are currently advertised in this class of vehicles predict a range of 400 km according to NEDC [12]. It can therefore be assumed that a range of 200 km is ensured even in winter when a vehicle is fully charged. However, Figure 3 shows that the remaining 20 % of single trips make up about 62 % of the total annual distance traveled by these vehicles, and therefore require much higher ranges.

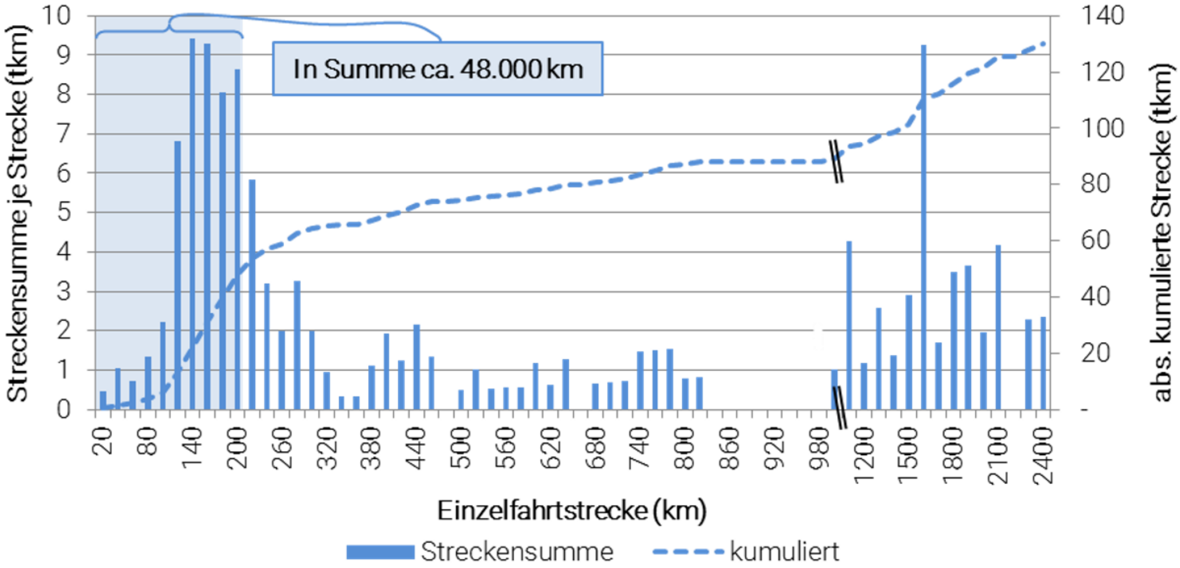

Figure 3: Depiction of the trips of two commercial vehicles according to trip length

In this case, fuel cell vehicles could meet all requirements. Implemented as plug-in hybrid, a traction battery can efficiently cover short distances and guarantee fast refueling and a sufficient range for long distances. For its passenger vehicles segment, Mercedes-Benz has announced a comparable approach for its GLC F-CELL [13]. If BEV were implemented instead, a comprehensive infrastructure for rapid charging as well as an adequate number of power connections for the simultaneous charging of several vehicles would be necessary.

Arguments from the electrical system perspective

Conversion of electrical generation from conventional power plants to renewable energy plants presents a challenge to the electrical system. Increasing market penetration of battery-electric vehicles (BEV) will mean an increase in demand (see Figure 4), particularly on distribution networks. Charging power varies in AC systems from 2.7 kW to 43 kW and in DC systems it can be as high as 350 kW. Commercial vehicles such as busses are sometimes recharged at more than 350 kW [14]. Some studies have shown that, in most cases, lower charging power is sufficient for daily driving patterns [5]. Some OEMs are promising very fast „charging as fast as you fill", which is only possible with high charging power [15]. Although FCEVs require more electrical energy to produce fuel via electrolysis, this is flexible with respect to load distribution and location, which means better system tolerability.

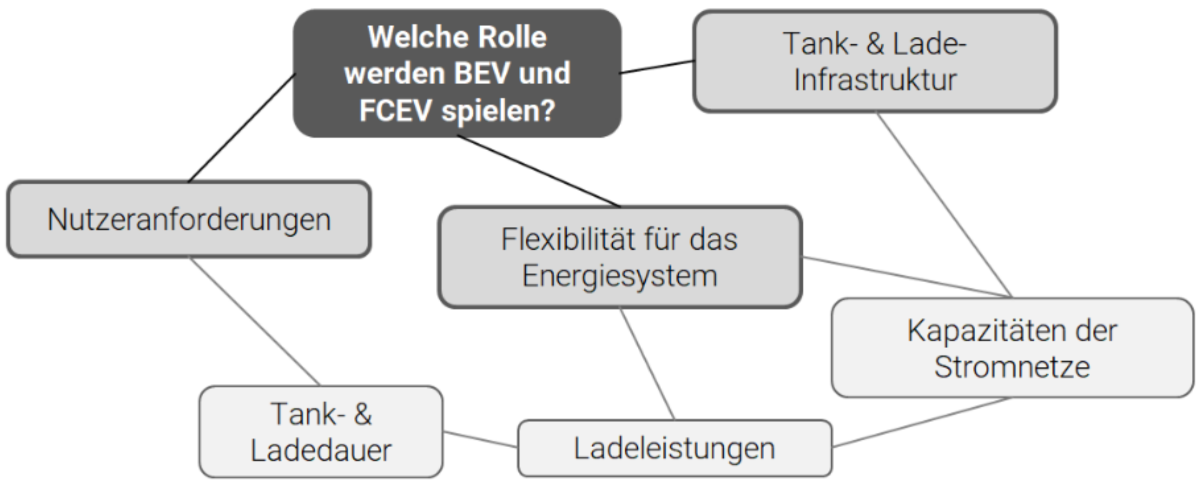

Figure 4: Selected aspects of drive technology and implications for the electrical grid

BEVs can also be flexibly charged, or even feed energy back into the grid (vehicle-to-grid). It is not clear how flexible they can be made in practice, nor whether users will be willing to let others decide when and how quickly their vehicles can be charged. Consequently, it is no simple matter to determine the effects of a large number of BEVs on the electrical system. This is reflected in the widely differing conclusions of researchers investigating this question. Assessments of the impact of BEV vary from „network-compatible" [16] or even „network-supporting"[[17] to „deleterious" [18][19].

Certainly, where a large number of BEVs are parked and charged, high network loads and restrictions are possible. This was a finding of our study of a parking garage at the new Berlin airport BER. The garage has 1,650 parking spaces for rental cars and 1 MVA service, which must supply not only the vehicles but also lighting and car wash installations. The service was sized assuming that up to one third of the vehicles will be BEVs. Different charging power levels and coincidence factors were investigated (see Figure 5). Modest charging power of

22 kW with a coincidence factor just over 0.1 is already enough to overload the 1 MVA service. With a coincidence factor of 0.4, only 100 vehicles can be supplied. Even charging at low power (3.7 kW) almost fully utilizes the available service. Clearly, either this load must be made more flexible, be it through intelligent charging or stationary storage, or the service has to be be expanded. One alternative would be FCEVs: the neighboring hydrogen filling station with on-site electrolyser needs only a 0.5 MVA service and can supply about 400 vehicles with refueling times of about five minutes each.

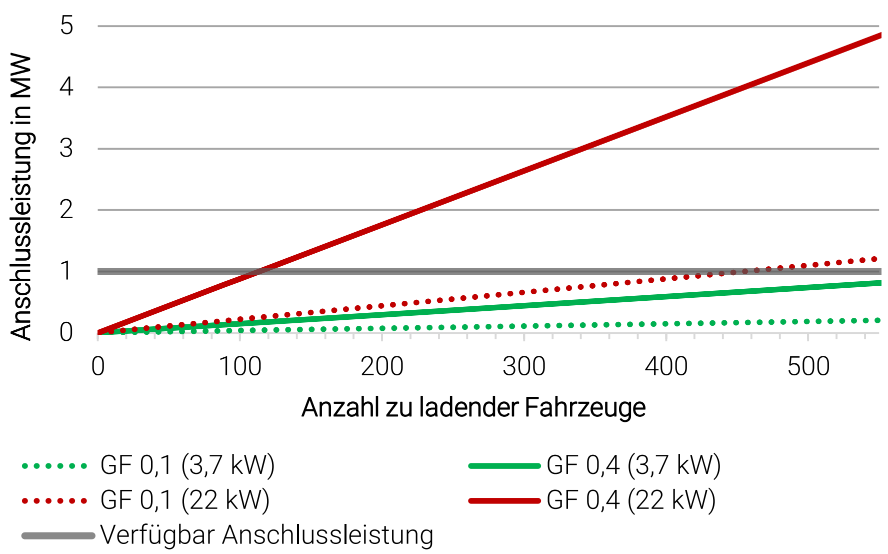

Figure 5: Service requirements for a parking garage as a function of BEV number, charging power and coincidence factor.

Arguments from an energy system perspective

The basic systemic advantage of battery electric technology is its high efficiency in all steps of energy transmission and conversion (well-to-wheel primary energy efficiency). Consequently, battery electric mobility in sum requires less energy than its hydrogen electric counterpart. In a case where it's required that the larger part of Germany's energy demand be generated domestically, battery electric mobility would apply less pressure on the development and necessary installation of renewable energy generation units. On the one hand, this itself can be considered a disadvantage as the deployment of renewable energy is already being criticized in some parts of the country [20], on the other hand greenhouse gas emissions caused by the production and installation of renewable power plants can be avoided [21] (Figure 6). However, BEV's impact on the energy system also depend on the flexibility of its charging. A largely limited flexibility would cause an additional, overall inflexible electric demand load. Conversely, fuel production for FCEV can be conducted most flexibly and thus integrated beneficially into the energy system, which can limit the necessary installation of stationary battery storages. [22].

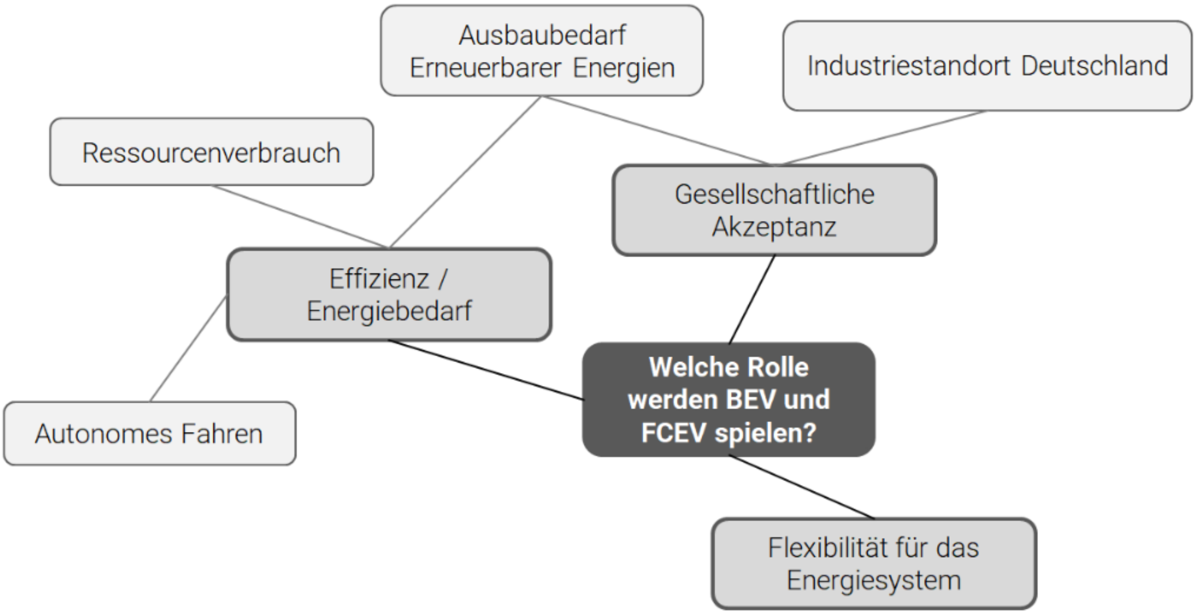

Figure 6: selection of systemic arguments

Additional arguments

In addition to the above mentioned aspects, there are additional arguments which bear the potential to dominate the entire debate by making all other arguments practically obsolete. Recent studies have speculated that both available reserves as well as known resources of some vital elements for battery production (including cobalt and lithium) might be depleted within this century [23][24]. While ongoing research on material alternatives aims to find a remedy, further studies are pointing out that even with sufficient supply of raw material a projected limitation of capacity for battery production might become a bottle neck for deploying lithium battery technology overall [25]. With the kind of modal split we find today, FCEV could become necessary simply from a supply-technical point of view. Moreover, fuel cell technology could be advantageous for the German economy from an industry-political point of view. [26][27]. In any case, the arguments presented here stress the importance of keeping the overall picture in mind. Increasingly certain megatrends concerning the transformation of the mobility sector are being discussed, especially those of autonomization and sharing. Those trends could be more compatible with the developments of battery electric technology than those of hydrogen technology, or vice versa. Either way, these and other megatrends bear the potential of cracking open and restructuring the current lines of argumentation.

Conclusion and Outlook

What does this mean for battery and hydrogen as alternative drive technologies? In the transformation towards sustainable mobility, various aspects and interdependencies must be recognized and taken into account. It is no surprise that there is no “master plan” for the development of battery or fuel-cell infrastructure. The complexity of the topic should, however, be an incentive for an integrated debate among all who are involved in the transformation towards a sustainable energy and mobility system. Ultimately, significant greenhouse gas emissions reduction depends on Germany’s car industry – as do many jobs.

Join in the debate

This article outlines an argument analysis discussing only some of the debate’s aspects. It is based on a more extensive argument map which was developed by Reiner Lemoine Institute and is currently being refined and extended. To map the debate as comprehensively as possible and guide research in this field, further perspectives are explicitly encouraged and welcome. We invite all readers to join the discussion and contribute to the argument map (www.reiner-lemoine-institut.de/mobilitaet_argumap). With additional arguments, the map will grow in scope and detail and become the basis for a differentiated and comprehensive debate.

References

[1] International Energy Agency: Global EV Outlook 2017, Paris, IEA Publications, 2017

[2] Bloomberg New Energy Finance: Electric Vehicle Outlook 2017, New York, 2017

[3] Bundesministerium für Verkehr und digitale Infrastruktur: Verkehr und Mobilität in Deutschland - Daten und Fakten kompakt, Berlin, 2016

[4] Höfler, F.; Neumann, M.: Nutzung der mittelständischen Tankstelleninfrastruktur. Berlin/Cottbus/Magdeburg, MEW e.V., 2016

[5] Schumann, D.: Status quo Ladeinfrastruktur - Begleit- und Wirkungsforschung Schaufenster Elektromobilität (BuW) Ergebnispapier Nr. 36. Frankfurt am Main, Deutsches Dialog Institut GmbH, 2016

[6] Kreyenberg, D.: Fahrzeugantriebe für die Elektromobilität, Wiesbaden: Springer Vieweg, 2015

[7] Schühle, F.: Die Marktdurchdringung der Elektromobilität in Deutschland. München/Mering: Rainer Hampp Verlag, 2014

[8] Passier, R.; Raupbach, A.: Elektromobilität funktioniert!? - Alltagtauglichkeit für die Langstrecke. Dresden, TU Dresden, 2016

[9] Bundesverband der Energie- und Wasserwirtschaft e.V.: Hochlauf der Elektromobilität in Deutschland bis 2020. Berlin, 2017

[10] Duddenhöffer, K.: Akzeptanz von Elektroautos in Deutschland und China. Wiesbaden: Springer Gabler, 2015

[11] Elektromobilität: RLI legt Studie zum Ausbau der öffentlichen Ladeinfrastruktur in Brandenburg vor. Online: http://reiner-lemoine-institut.de/elektromobilitaet-rli-legt-studie-zum-ausbau-der-oeffentlichen-ladeinfrastruktur-in-brandenburg-vor/, aufgerufen am 14.08.2017

[12] Volkswagen e-Crafter: Transporter mit E-Motor vorgestellt. Online: https://www.heise.de/autos/artikel/Volkswagen-e-Crafter-Transporter-mit-E-Motor-vorgestellt-3329025.html, aufgerufen am 14.08.2017

[13] Unter der Lupe: Mercedes-Benz GLC F-CELL: Die Brennstoffzelle bekommt einen Stecker. Online: http://media.daimler.com/marsMediaSite/ko/de/11111320, aufgerufen am 14.08.2017

[14] eBus-Schnellladelösungen von Siemens. Online: https://www.siemens.com/press/pool/de/events/2015/mobility/2015-06-uitp/praesentation-ebus-d.pdf, aufgerufen am 14.08.2017

[15] Der Weg in die E-Mobilität aus Sicht der Audi AG. Online: https://www.siemens.de/Digital-Factory/download/EventDocs/Der%20Weg%20in%20die%20E-Mobilit%C3%A4t_Audi_Marcel%20Aslund.pdf, aufgerufen am 14.08.2017

[16] Linssen, J.; et al.: Netzintegration von Fahrzeugen mit elektrifizierten Antriebssystemen in bestehende und zukünftige Energieversorgungsstrukturen. Jülich: Forschungszentrum Jülich GmbH Zentralbibliothek, 2012

[17] Ciechanowicz, D.; et al.: Ökonomische Bewertung von Vehicle-to-Grid in Deutschland. In: Tagungsband der MKWI 2012, Braunschweig, 2012

[18] Nobis, P.; et al.: Netzstabilität mit Elektromobilität. München: Forschungsstelle für Energiewirtschaft e.V, 2015

[19] Lienkamp, M.: Status Elektromobilität 2014. München, 2014

[20] Walter, G.: Erfolgsfaktoren für die Akzeptanz von Erneuerbare-Energie-Anlagen. Energiewirtschaftliche Tagesfragen 61 (2011), Nr. 3, S. 2-4

[21] National Renewable Energy Laboratory: Life Cycle Greenhouse Gas Emissions from Solar Photovoltaics. Golden, 2012

[22] Goldammer, K.; et al.: Energie- und Verkehrswende – eine nationale Betrachtung. In: 2. ATZ-Fachtagung: Netzintegration der Elektromobilität 2017, Konferenzbeitrag, Berlin, 2017

[23] Deutsches Zentrum für Luft- und Raumfahrt e.V.: Begleitforschung zu Technologien, Perspektiven und Ökobilanzen der Elektromobilität. Stuttgart, 2015

[24] Fraunhofer ISI: Lithium für Zukunftstechnologien. Karlsruhe, 2009

[25] Rasilier, T.: Reichweitenabschätzung der Lithiumvorkommen. München, Forschungsstelle für Energiewirtschaft e. V., 2010

[26] Schade, W.; et al.: Sieben Herausforderungen für die deutsche Automobilindustrie. Berlin: edition sigma, 2014

[27] Peters, A.; et al.: Konzepte der Elektromobilität und deren Bedeutung für Wirtschaft, Gesellschaft und Umwelt. Berlin: Büro für Technikfolgen-Abschätzung beim Deutschen Bundestag, 2012