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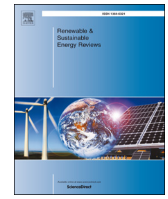

What drives the market for plug-in electric vehicles? - A review of international PEV market diffusion models

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ABSTRACT

The market diffusion of plug-in electric vehicles (PEVs) is a research topic which is often addressed, yet PEV market diffusion models differ in their approaches, the factors they include and results. Here, 40 market diffusion models for PEVs are compared in their scope, approach and findings to point out similarities or differences and make recommendations for future improvements in modeling in this field. Important input factors for the US are the purchase price and operating costs, while for Germany energy prices and the charging infrastructure are mentioned more often. Furthermore, larger sales shares of plug-in hybrid electric vehicles than battery electric vehicles are often found in the short term results (until 2030) while the picture is not so clear for the medium- to long-term. Future market penetration models should include specific PEV features like the limited range of battery electric vehicles or access to charging infrastructure, which are currently not covered by many models. Also, the integration of current policy regulations and, if possible, indirect policy incentives would enhance research in this field.

1. Introduction

The transport sector requires a reduction in CO_2 emissions and petroleum use which forces the automobile industry, researchers and policy makers to think about the diffusion of plug-in electric vehicles (PEVs). For this purpose, a variety of models has been set up to analyze factors that influence the market diffusion and ways to accelerate it, e.g., by subsidies or restrictions [1,2]. These models differ greatly in structure, internal logics and input factors, producing different diffusion results. A comparison of these models can have at least two benefits – explaining the modeling reasons for the differences in results so that the probability of these different results misleading and obstructing policy discussion can be mitigated; and identifying best practices in designing the model structure, formulating the internal logics and choosing the input factors so as to advance the state of art in diffusion modeling.

Al-Alawi and Bradley reviewed market diffusion models for PEVs in the US and compared the various model approaches used (agent-based, discrete choice, diffusion models, etc.) to make recommendations for improved approaches [3]. Daziano and Chiew also compared PEV market diffusion models for the US. They discussed relevant factors that influence the adoption of PEVs in the US and identified additional data needed to develop improved models [4]. Jochem et al. extended the work of Al-Alawi and Bradley and added a detailed mathematical description of models for the market diffusion without focusing only on PEVs [3,5].

A need remains for a broader review of recent models comparing approaches, input factors and findings from markets worldwide. Comparing models developed for different countries as well as models for specific markets provides a new understanding of what factors are (or are thought to be) important and how they have been represented in models. This will help future modelers to learn from earlier modeling attempts when creating or improving their models.

For this reason, the authors of this paper compare recent research papers on PEV market diffusion to determine general conclusions and to address the following research questions:

- *What models are used for the market diffusion of PEVs?*

Abbreviations: BEV, Battery electric vehicle; CAFÉ, Corporate Average Fuel Economy; HOV lane, High-occupancy vehicle lane; MNL, Multinominal Logit; NMNL, Nested Multinominal Logit; O&M, Operations and Maintenance; PEV, Plug-in electric vehicle; PHEV, Plug-in hybrid electric vehicle

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- *What factors do current models include and what data do they use?*
- *According to the papers, which are the most influential factors for market diffusion?*
- *Are there important factors that are not well modeled or not included in models at all?*
- *Are there general results that can be obtained from comparing results?*

The focus here is on papers on at least a national or state level (not local models) and on only those which explicitly describe a PEV market diffusion model. Expert estimates or very simple calculations are not considered here. For those models that are used in multiple publications, the main publications are reviewed here and results of the most recent one are discussed. In the following, the terms “paper” or “model” are used equivalently.

The present work differs from previous studies in several respects. First, models for different geographical regions are compared: Germany, U.S., and other countries. Second, input factors and projected market shares from a wide range of models are compared at a high level without a detailed evaluation of model algorithms or mathematical formulations. This provides a broad perspective of PEV market diffusion and helps to guide the development of future, improved models for PEV market diffusion.

2. Methods and data

This analysis compares 40 models from 16 different countries (cf. Table 1 for details). Since PEV market diffusion has been an active field of research for several years in the US and in Germany, more papers were found for these countries (16 for US, 14 for Germany). The focus here is on most recent publications; the majority (39/40) of papers reviewed were published after 2010. Papers describing models giving estimates or projections of future PEV sales or stock fractions were selected from those found using Google Scholar with the search terms "market diffusion electric vehicles", "market penetration electric vehicles", "market electric vehicles", "electric vehicles market forecast", "electric vehicles forecast" and "projection PEV", as well as articles that cited or were cited by these. Only models for PEV markets at a national or state level were included, not at the local or subnational level.

For each model reviewed, the research questions addressed in the paper were noted, as were methodological approaches, main findings and results. Papers were clustered based on the research questions posed and main findings as stated in the selected articles. The methodological approaches were grouped into three categories, following Al-Alawi and Bradley and Gnann and Plötz: (1) aggregate stock models, (2) models that compute sales by one or more consumer segments, and (3) detailed agent-based models [3,6]. Also noted was whether battery electric vehicles and plug-in hybrid electric vehicles were represented separately or combined as PEVs, and the projected sales shares for the baseline scenario were compared for those papers that gave sales shares. Furthermore, the factors (vehicle attributes, market conditions, etc.) that authors indicated as being influential on PEV market diffusion were identified and papers were reviewed to determine which of these factors were included in the models. These factors were retrieved from the papers under review as well as other literature [3,7–9]. They are

Table 1
Models analyzed including the area of observation.

Citation	Area of observation	Observation period	Model type	Refs.
Argonne, 2014	United States	present-2050	sales modeled	[10]
Barter et al., 2013	United States	present-2050	sales modeled	[11]
Becker and Sidhu, 2009	United States	2010–2030	aggregated	[12]
Brooker, 2015	United States	present -2050	sales modeled	[13]
Brown, 2013	United States	2009–2030	disaggregated	[14]
Bühne et al., 2015	Germany	2010–2030	disaggregated	[15]
de Santa-Eulalia et al., 2011	Germany	2011–2020	sales modeled	[16]
Driscoll et al., 2013	Ireland	today	aggregated	[17]
Duan et al., 2014	United States	2011–2020	aggregated	[18]
Eggers and Eggers, 2011	Germany	2009–2018	sales modeled	[19]
EIA - Annual Energy Outlook 2016	United States	2015–2040	sales modeled	[20]
Fu et al., 2012	China	2011–2050	aggregated	[21]
Gnann, 2015, Gnann et al., 2015, Plötz et al., 2014	Germany	2013–2030	disaggregated	[22–24]
Harrison et al., 2016	European Union	1995–2050	disaggregated	[25]
Hess et al., 2012	United States	not stated	sales modeled	[26]
IEA 2016 -WEO, 2016	World	2010–2050	sales modeled	[27]
Kieckhäfer et al., 2014	Germany	2010–2030	disaggregated	[28]
Kihm and Trommer, 2014	Germany	2015–2030	disaggregated	[29]
Lebeau et al., 2012	Flanders, Belgium	2012,2020,2030	aggregated	[30]
Lee et al., 2012	South Korea	2005–2050	sales modeled	[31]
Lee et al., 2013	South Korea	2010–2050	sales modeled	[32]
Liu et al., 2015	United States	present-2050	sales modeled	[33]
Liu and Lin, 2017, Lin and Liu, 2015, Lin and Greene, 2011, Lin and Greene, 2010	United States	2010–2050	sales modeled	[34–37]
Liu et al., 2013	United States	2010 – 2025	sales modeled	[38]
Nemry and Brons, 2010	European Union	2010–2030	sales modeled	[39]
Noori and Tatari, 2016	United States	2015–2030	disaggregated	[40]
Orbach and Fruchter, 2011	United States	2009–2018	aggregated	[41]
Pasaoglu et al., 2016	European Union	1995–2050	disaggregated	[42]
Pfahl et al., 2013	Germany	2011–2020	sales modeled	[43]
Propfe et al., 2013	Germany	2010–2030	disaggregated	[44]
Qian and Soopramanien, 2015	China	2010–2030	sales modeled	[45]
Redelbach et al., 2013	Germany	2010–2030	disaggregated	[46]
Shafiei et al., 2012	Iceland	2011–2030	disaggregated	[47]
Shepherd et al., 2012	United Kingdom	2010–2050	sales modeled	[48]
Tran, 2012	United Kingdom	2000–2035	aggregated	[49]
Wansart and Schnieder, 2010	United States	2010–2020	sales modeled	[50]
Wu et al., 2015	Germany	2014,2020,2025	sales modeled	[51]
Yabe et al., 2012	Japan	2010–2050	sales modeled	[52]
Zeng et al., 2013	China	2013–2020	aggregated	[53]
Zhang et al., 2011	United States	not stated	disaggregated	[54]

analyzed in Section 3.3.

These results were analyzed to look for patterns in the model approaches, findings, and influential factors across the models and to see how the relative importance of factors, frequency of research findings or modeling approaches varied between different regions (U.S., Germany, and other countries) and over time of publication. Table 1 shows a summary of the papers reviewed, including the country of observation, the observation period and the model type.

3. Results

The results consist of a comparison of the 40 papers which are mentioned above. These are divided into three parts: Firstly, the modeling approaches and research questions which are derived from the “Introduction” and “Method” sections of the papers that are examined (Section 3.1). Secondly, findings from the “Results” of the 40 papers which are compared (Section 3.2). Lastly, the factors that are considered to be important for PEV market diffusion according to the “Discussion” and “Conclusions” of the papers and whether they are covered in the models and described in the sections “Methods”,”Data” or “Assumptions” of the research papers are discussed (Section 3.3).

3.1. Model approaches

In the papers reviewed, five main research questions were found that are examined and correspond to the findings: (1) projected market shares of PEVs for a specific region, (2) determination of most important input factors, (3) policies considered most promising, (4) projected impacts of extensive PEV market diffusion (e.g. for the energy system) or (5) introduction of a new modeling approach. In Fig. 1, these research questions (R1…R5) are shown according to their date of publication. Other research questions were combined and are listed as R6 (Other research questions). The intention of most papers is to determine the market diffusion of PEVs for a certain area or the drivers of PEV market diffusion. The third most mentioned research question is the introduction of a new approach (R5) with a focus on the method rather than the projected market diffusion. Lastly, the determination of important policies as well as the impact of the PEV market diffusion (e.g. on the electricity grid) has gained more attention in the last few years. This shift towards considering the impacts and policies more in recent years may be explained by the increasing maturity of modeling approaches or by a necessity to introduce policy measures to speed up the markets.

When comparing model approaches, there are many possible classifications (see e.g. [3–5] as well as [6, Section 3.1] for a discussion). In this model comparison, a simple classification was chosen, since many models cannot be categorized well according to the above-mentioned categorizations. They were classified with respect to their level of aggregation to highlight the general detail of the models: (1) Very aggregated models that consider only the vehicle stock for their analysis; (2) more disaggregated models that model the vehicle sales and differentiates multiple market or customer segments; (3) the most disaggregated approaches model on the level of individuals and combine them for vehicle sales afterwards. The numbers of each type of published models per year of publication are shown in Fig. 2 (sizes of the bubbles indicate numbers of papers, with numbers shown in some bubbles).

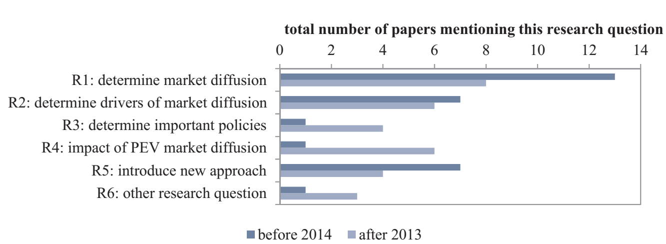

Fig. 1. Frequency of research questions in papers published before 2014 and after 2013.

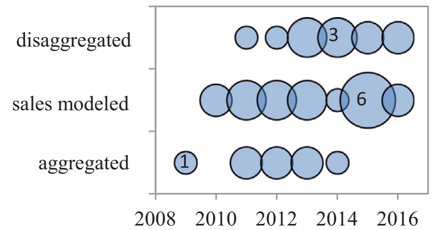

Fig. 2. Model type and year of publication (sizes of the bubbles indicate numbers of papers).

First of all, the majority of publications uses the second approach and models the vehicle sales by year (20 models in total), most of them with multi-nominal logit (MNL; four models) or nested multi-nominal logit (NMNL; eight models) while some use simpler utility functions (eight models). The twelve very disaggregated models also use utility functions for each consumer (five with simple utility functions, five with MNL and two with NMNL). Lastly, the very aggregated models either use simple utility functions (four) or the papers do not explain the approach in detail. Also, a tendency toward more complex models has been observed, which is especially the case for German models. Most German models published prior to 2014 were aggregated or modeled sales only, while most of them published in 2014 or 2015 were disaggregated. This might stem from the very heterogeneous car market in Germany where vehicle sales are distributed between private vehicles (40%), commercial fleet vehicles (30%) and company cars (30%) that have different characteristics in the purchase decision (see [24,29,55] for a discussion). However, fewer simple models appear to have been published in recent years and are being replaced by models that are more realistic and complex. Model results are examined in the following section.

3.2. Comparing model projections

Results are at the heart of each scientific publication. However, a comparison of results from the papers is very difficult since their assumptions are often different. While a comparison of models with the same input factors may be a valuable comparison (e.g. [56]), this was not possible with the models reviewed here. The absolute number of PEVs is not the only and often not the most important outcome. Nevertheless, there are some outputs that may be compared, e.g. the sales shares of PEVs in different years distinguished by battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) as shown in Fig. 3. Results from only the base scenarios of the papers are presented here and only those where a distinction between these PEV types is clearly indicated for the vehicles sales. Projections of PHEV and BEV sales shares are shown for the years 2020, 2030 and 2050.

The first observation in these graphs is that market diffusion results are extremely uncertain and for the German market the market shares in 2020 vary between 0.4% in Propfe at al. and 16.8% in Eggers and Eggers [19,44]. This range is even higher when looking to 2050 where Liu and Lin derive a 60% market share for the US market while Pasouglu et al. determines 23% for the EU in 2050 [34,42]. Without knowing the mathematical form of all the models and the values of all parameters (which were available for very few of the models) as well as the inputs assumed, it is impossible to quantitatively analyze the reasons for differences in the sales projections. For example, for one of the U.S. models (EIA), documentation and additional information on vehicle prices indicate that high incremental prices of PEV relative to conventional vehicles were assumed, and this may have contributed to low PEV sales projections [20]. For other models, this might be derived

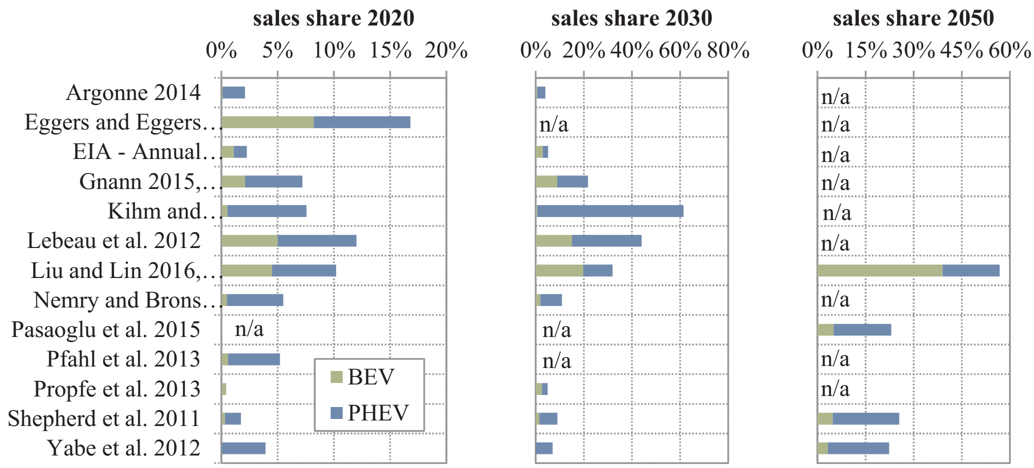

Fig. 3. Sales shares in base scenarios of models for 2020, 2030 and 2050 distinguished by PEV type.

from policies included or even model assumptions. Thus, there is no general reason for different results and rising market shares. Yet again, the absolute market shares should not be in focus when comparing market diffusion model results, as it just shows the great deal of uncertainty in the future market diffusion.

In all studies, PHEVs are projected to have higher market shares than BEVs in 2020. This reflects the current situation in the major car markets where PHEV sell better partly because of their longer driving ranges. However, if battery prices decrease further, larger batteries could become affordable [57–59]. Some studies reflect this change [22,34] and find equal or higher market shares for BEVs compared to PHEVs in 2030 and 2050.[1] Yet, this change of best sellers has to go in line with the ability to recharge on long-distance trips or the consumers' decreasing range anxiety. As discussed in the following section, only a few models consider these factors in more detail which is the case with two of the models which include results until 2050: Pasaoglu et al. do not consider any “limited range factors” in their model and Shepherd et al. do not include charging infrastructure [42,48]. This is not to say that both papers do not contain good models, but both these factors are decisive for the future BEV market diffusion. One critique to the fourth study until 2050 (Yabe et al. [52]) is the focus on the most cost efficient solution for the future [52]. As almost all studies on PEV market diffusion mention global warming and the reduction of GHG emissions as a main driver for PEV market diffusion, the single focus on cost until 2050 might be misleading. Thus, while BEV market shares could be high in the long-term, scenarios for this time horizon depend on several very uncertain assumptions. The last subsection in the results section deals with the most important drivers for PEV market diffusion according to the authors of the papers reviewed.

3.3. Drivers of PEV market diffusion models

This variation in results stems from different input factors in the models, but also from differing country specifics. The discussion and conclusion sections of papers were reviewed to find out which factors are mentioned most often to influence the PEV market diffusion the most. The number of papers considering these factors are shown on the left panel of Fig. 4. In the papers, purchase price (17), energy prices (10), operating costs (9), charging infrastructure (7), policy measures (7) and BEV range (6) are mentioned most often to be the main influencing factors.[2]

Country-specific differences are found as well: Purchase price and operating costs are covered by far more US models than energy prices and charging infrastructure, which are mentioned most frequently by German models. This could stem from higher energy prices in Germany compared to the US. Also, the policy measures are mentioned more often in Germany, probably because there were not any policies worth mentioning in place until 2016.

Now, an interesting question is, whether the models cover these factors appropriately. On the right panel of Fig. 4, the factors covered in the models reviewed are shown. As expected, many factors considered to be important correspond well to the factors included in the models. However, there are some discrepancies when taking a closer look: The count of US studies mentioning operating costs as being important exceed the number of studies covering it. Also, policy measures in Germany are mentioned as being important in three of the papers and three models include them as input factors. Thus, one interpretation might be that only those factors are mentioned that are also covered in the model, probably also so they pass the publication process. Yet, when analyzing the factors mentioned as being important and covered in the models individually for each publication, the availability of PEVs is stated to be important in four papers that do not cover it in the models. Hence, the other interpretation may be, that, apart from some exceptions (especially the PEV availability), most factors are mentioned as being important based on evidence.

In order to look at the individual attributes more closely and to derive recommendations for future modeling attempts, four groups of attributes that are considered in the models were analyzed: (1) factors directly related to the purchase decision, (2) attributes of vehicles that are considered in the models, (3) attributes to describe consumer characteristics and (4) factors especially important for PEVs.

To model the consumer choice, ownership costs are often used which contain vehicle costs and energy prices. Furthermore, a common differentiation in the consumer choice is the number of decision alternatives presented to the consumer.[3] Almost all models cover the purchase price (37/40) as a simple factor for vehicle costs. Fuel costs are also taken into account by 33 models. However, operating costs apart from fuel costs (e.g. operation & maintenance, insurance or vehicle registration tax) are not so often covered (20/40) and the inclusion of resale prices is very rare (5/40). While these other costs are hard to

[1] In the base scenario of Kihm and Trommer [29], the market share of BEVs in new vehicle sales is rising from 0.53% (2020) to 0.56% (2030), yet the share of PHEV is increasing even more, from 7.0% in 2020 to 60.8% in 2030. This might derive from the large number of company cars in their results which, in Germany, tend to be driven more irregularly than private or fleet vehicles and may thus be unfeasible for BEVs (see [22] for a comparison of variability in German driving).

[2] The authors of this review are aware that some of the factors mentioned are correlated. Yet, only factors mentioned in the papers are shown here.

[3] More aspects that might be interesting are covered in the vehicle attributes, consumer characteristics and other factors.

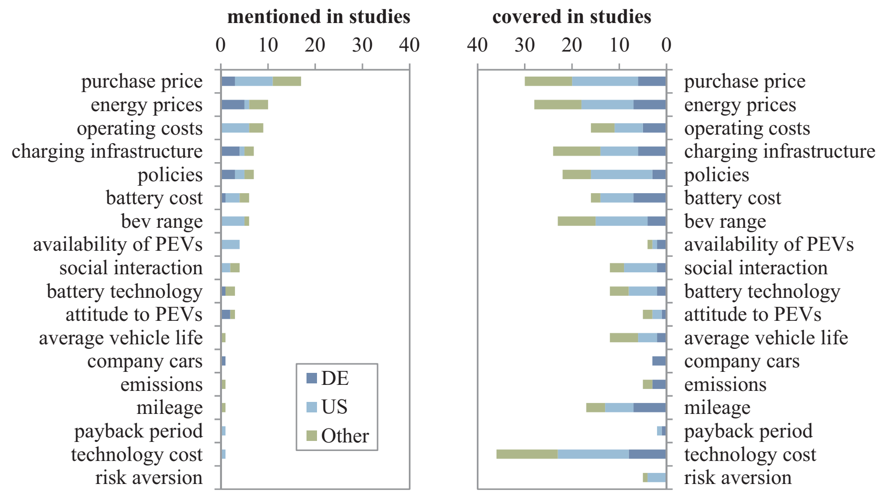

Fig. 4. *Left panel:* Most important factors for PEV market diffusion stated by the authors of the models; *Right Panel:* Factors included in models. For technology costs, all models that contained battery costs and/or purchase price were counted.

determine, the difference in O&M can play an important role in the operating costs and should not be neglected (see e. g. [60] for a good approach when data are available).

Most models include the energy prices in the purchase decision since they differ for conventional and alternative fuel vehicles. A few models do include energy prices endogenously (3/40), thus the energy prices change due to the market diffusion of PEVs (and sometimes other factors). The majority uses exogenously defined energy prices (30/40) while seven models neglect energy prices completely. Since energy price differences typically represent a large part of the difference in ownership costs of vehicles, they should be included in future modeling exercises.

Lastly, the number of decision alternatives varies widely. Most models use conventional cars as benchmarks and more than one type in some markets (gasoline and diesel in Germany, only gasoline in the US). Almost all papers (90%) model BEVs and PHEVs separately while the inclusion of other alternative drive trains (fuel cell vehicles, natural gas vehicles, etc.) is somewhat rare in the set of studies reviewed (which is why only studies that model PEV market diffusion were selected to be included). The inclusion of other alternatives seems to be useful but depends on the countries that are modeled (e.g. natural gas vehicles in the Netherlands or Italy).

Apart from the drive trains, the vehicle attributes considered in this review included vehicle registration attributes, which are: vehicle size class, diversity of makes and models within a powertrain type, and car holder (private, company or commercial fleet ownership). Also reviewed were technological improvements in battery technology or energy consumption, vehicle availability and other vehicle attributes such as comfort, power or emissions.

Three main differentiations in vehicle registration attributes in the models were found, as shown in Fig. 5.

The most common differentiation of vehicle registration groups is according to their vehicle size (24/40). This is useful as in 2016 especially large vehicles sold well, e.g. in Germany or the Netherlands [61], while smaller PEVs should be an option for the future. The

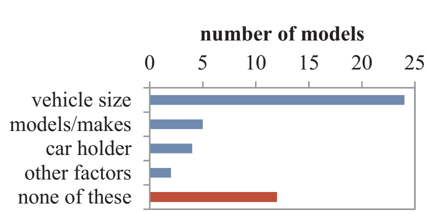

Fig. 5. Vehicle registration attributes covered in models.

differentiation between models or makes is rare (5/40) as that of car holder groups (privately or commercially registered vehicles), which seems to be a specialty of the German car market. Twelve out of forty models use no size differentiation at all.

As the two main technological improvements in the vehicles, the following were investigated: the development of the battery technology and PEV energy consumption. Improved battery technology was represented in models as contributing to lower costs and mass of batteries (and therefore of PEVs). Energy consumption is covered more often (17/40 models) while the majority uses exogenous assumptions (12) and a few model the improvement endogenously (5) with rising market shares. The progress in battery technology is considered in 16 of 40 models with predominantly exogenous assumptions (11). The five models with endogenously improving batteries are also triggered by higher sales shares and investments in battery advancement.

The currently low availability of plug-in electric vehicles for every registration group or every brand is analyzed in some of the models. Eleven models use simple rules to constrain the market (e.g., with sigmoid functions) while four models try to capture the model or make availability or diversity in PEV models offered in the early years. From the authors' of this review point of view, these constraints could be helpful in a young car market, yet not useful to integrate with more maturity when the constraints are not justifiable anymore. Other vehicle attributes were included in the models, yet they seemed to be considered as less important by the authors of the papers.[4]

Several consumer characteristics are examined in the models: differentiation or segmentation of consumers by different characteristics, and the interaction between consumers. The most important attributes for the characterization of certain consumer groups are shown in Fig. 6.

The most common distinction of consumers is according to their driving distances (17/40). The income (11), adopter groups (9) and consumer preferences from surveys (7) are the consecutive factors while some models use no differentiation of consumers at all (10). In our point of view, a segmentation of consumer or vehicle groups is useful to cover the diversity of the car markets and should be chosen according to data available.

About two thirds of the models do not model any interaction effects between the consumers, while 14 models model the interaction explicitly or through feedback loops. These models include social interactions such as word-of-mouth communication that increase familiarity of consumers with advanced-technology vehicles.

The factors especially important for the PEV market diffusion

[4] Vehicle power was mentioned in six models, emissions in seven models.

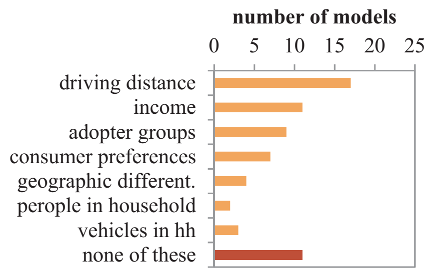

Fig. 6. Consumer attributes used in models.

comprise factors related to vehicle range, charging infrastructure and which type of policy measures are included. The majority of models considers the limited range of BEVs (24), yet there are still quite a few models that do not. When projecting short- to medium-term PEV market diffusion, this is an obligatory factor to consider and together with costs, the main factor preventing many consumers from buying BEVs [62]. A few authors try to include the range anxiety (5) or the charging time (5) explicitly in their models. Since this will remain an issue for some years, a consideration in future models seems to be useful.

Charging infrastructure is also decisive for the market diffusion of PEVs. Yet, 15 models do not contain charging infrastructure at all. In 18 papers, the authors model charging infrastructure without a differentiation between private, semipublic and public charging infrastructure while seven models do. An endogenous infrastructure evolution with a rising number of PEVs is considered in eleven models. The differentiation in different types of charging infrastructure is helpful when considering the benefits of plug-in electric vehicles, and including any kind of charging infrastructure should be a prerequisite for PEV market diffusion modeling.

Lastly, policy inclusion was examined. About half, 22/40, models consider a direct incentive such as purchase price reductions. Four capture indirect incentives, like HOV lane access or free parking, and nine models explicitly model regulations like CAFE or the European Union's CO_2 emissions standards [1,2]. Given the fact that an inclusion of a direct incentive is easy, as the purchase price is considered in most models, the number of capable models is actually low. Additionally, regulations that are in place at present should be considered by models trying to project the future car market evolvement. Lastly, indirect incentives are said to have high impact on PEV market diffusion [63,64]. Although these are difficult to address because they are often granted locally and the reviewed models are operated on the state or national level, it seems to be worth trying.

4. Conclusions and recommendations for further research

Based on the comparison of 40 international PEV market diffusion papers, several conclusions may be drawn. Important factors vary between countries but could indicate future evolutions. Currently, there is a focus on purchase prices and vehicle attributes in the US while more weight is put on energy prices in Germany. Yet, this could change for the US if energy prices rise. Models should not be interpreted beyond the focus of their research questions. Only some results can be compared between models, e.g. PHEV vs. BEV shares. Market shares cannot be exactly predicted, but models help to understand what influences market diffusion (drivers and barriers). A wide variety of results and heterogeneity of research questions are found. Different changeable factors (e.g. vehicle attributes) and external input factors (which cannot be influenced directly, e.g., energy prices) influence PEV market penetration, and a wide variety of these factors are observed (16 in total).

For future research and PEV market diffusion models, several key points stand out. While a market diffusion model should capture the most important factors, what factors these are and how best to model them depends on the intended use of the model. Future models for PEV market diffusion should cover more attributes than purchase price and operating costs. Several models lack the important PEV-specific features: limited range of BEVs (16/40), charging infrastructure (15/40), technological and cost improvement of batteries over time (15/40). These represent the key differences of plug-in electric and conventional vehicles and thus they have to be included or even discussed in future models. Current (and future) policies should be integrated into models designed to assess potential market responses to policies of interest, such as CAFE standards or CO_2 limits. Modeling such standards may be challenging if, as with GHG and fuel economy standards in the U.S., standards are applied to manufacturers' fleet averages, not individual vehicles, or if the policy has flexibilities, such as banking, trading, and extra credits that may complicate the modeling of policy implementation. In addition, the incorporation of indirect (non-monetary) incentives should be considered, although it is difficult (since they often apply on a local level or apply to suppliers rather than to consumers), but could largely influence PEV market diffusion. Such incentives as the provision of public charging may be difficult to monetize, since, e. g., the value of public charging depends on location, station characteristics (power, number of vehicles that can be charged at the same time, accessibility, etc.) as well as how such stations are used, which is likely to depend on the availability of other charging options (home and workplace). Some segmentation is helpful since not all vehicle buyers are equal (e.g. both product and consumer segmentation) and it is especially important when early markets are modeled. A segmentation of specific makes or models can be applied when their specific diffusion is of interest. Otherwise, consumer segmentation may be more important than capturing details of differences between vehicle choices. Finally, authors of future papers should mention important factors for PEV market diffusion especially if they have some quantitative evidence. One may interpret that some of the papers overestimate the importance of the factors they integrate instead of mentioning and discussing other important factors. An objective evaluation and quantitative assessment of the modeled and missing factors would contribute even more to this field of research.

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