Economic analysis of behavioral aspects of electromobility with a focus on consumer behavior – A Review

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Abstract

Electromobility has achieved a significant breakthrough in recent years, and numerous studies have been carried out in this field. However, the focus has mainly been on technical aspects, and current economic analyses and derived policy implications are based on these technical aspects. With the rising share of electric vehicles, the importance of efficient coordination and their integration into power systems and markets is increasing. This depends, above all, on the behavior of consumers, who make a series of decisions ranging from purchase and usage to disposal. Although there is a large variety of consumer research on electromobility, related reviews primarily focus on distinct aspects, such as acceptance, usage behavior, or incentives. This paper provides a comprehensive overview of the current state of research, with a clear separation of behavioral aspects. To this end, we summarize the different elements of current efforts in the field: the research on purchasing, tariff choice, charging, and driving. There are few studies on tariff choice between 2016 and 2023, while most of the published articles have focused on charging. Unexpectedly, the citation frequency for articles published in 2016 is lower than that of articles published in 2017 and 2018. This might indicate the growing importance of behavioral research on electromobility. The identified research gaps call for further research on tariff design and associated interactions at the system level to further develop the markets and leverage the potential of integrating electromobility into power systems. The latter concerns economic potential, such as avoiding grid expansion through smart tariffs or technical potential in the context of system services.

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Content

List of Figures

List of Tables

1 Introduction

The development of electromobility represents one central element of transforming existing energy systems to phase out fossil fuels and reduce global warming (European Commission 2020). Global quantities of new and existing electric vehicles[1] (EVs) have been increasing significantly since 2010 (Figure 1) (Muratori et al. 2021; IEA 2022). Concerning market share—which affects transition speed—the development of national EV markets differs noticeably. For instance, the transition is faster in Nordic countries and the Netherlands than in other countries (see the blue lines in Figure 1). New practical developments in the context of electromobility, such as charging concepts (vehicle-to-X), technical improvements (faster charging, larger battery capacities), or payment services (variable price components), constantly raise further questions that need to be explored (see Section 3). With the ramping up of electromobility, there have also been more discussions on the involved actors and their perspectives, both in society and in the academic world. One important focus is on technical aspects, as analyses of power systems are not conclusive without technical understanding. Against this background, the system view, or the role of companies and grid operators, is discussed. Examples include research on infrastructure requirements (Sathaye and Kelley 2013; Pagany et al. 2019; LaMonaca and Ryan 2022) and impacts on energy systems (Mwasilu et al. 2014; Klaassen et al. 2017; Amjad et al. 2018; Cao et al. 2019; Tavakoli et al. 2020). Moreover, a large body of literature deals with the CO_2 emissions of EVs over their life cycle (Burchart-Korol et al. 2018; Qiao et al. 2019; Verma et al. 2022).

[1] In the following, we use "EV" as a collective term for both battery EVs (BEV) and plug-in hybrid EVs (PHEV), as long as a more specific addressing of one these groups is not necessary for the context.

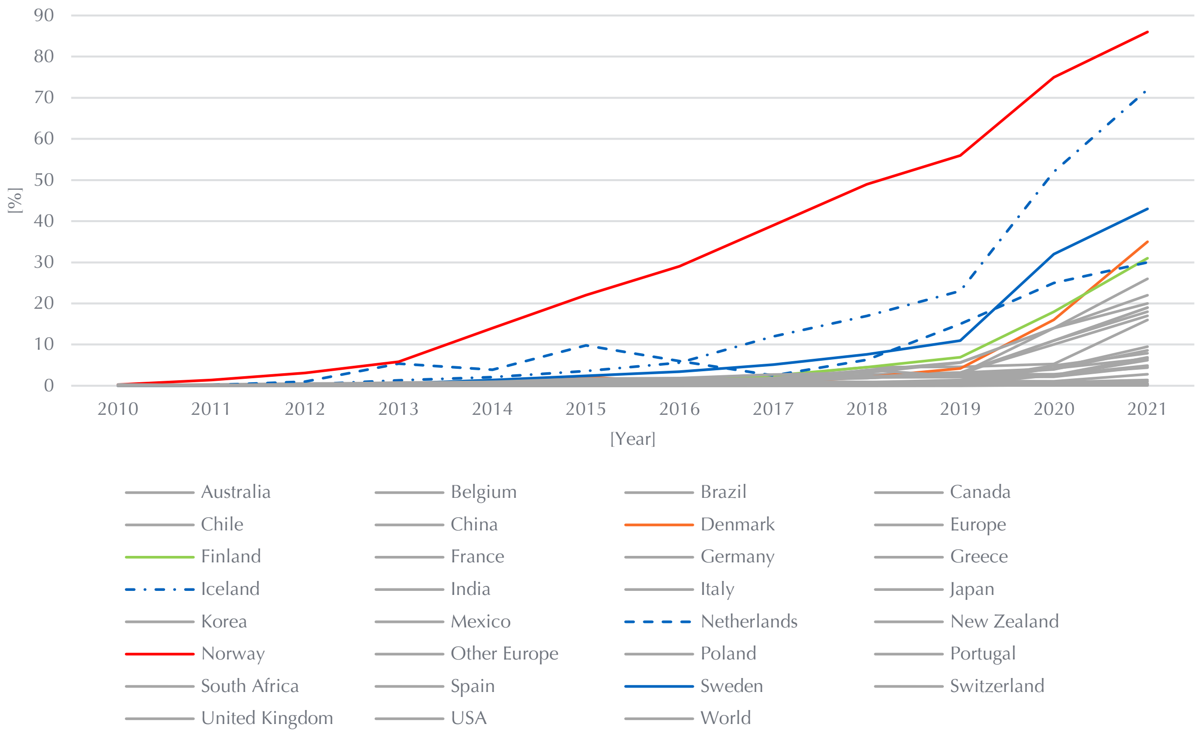


Figure 1: Market Diffusion of EVs - EV Sales Shares since 2010 (IEA 2022).

Furthermore, consumer behavior is a relevant aspect that cannot be explained solely by technical relationships. Dumb charging of EVs—as a striking example—leads to high peak loads and, thus, grid congestion when many EV drivers charge at the same time in a highly developed EV market (Lopes et al. 2009; Wu et al. 2011; You and Segerberg 2014; Deconinck et al. 2015; Anastasiadis et al. 2019). Charging is not only a technical process but also a decision by the human driver, taken within a certain technical and institutional context. More generally, considering consumer behavior, such as purchase, tariff choice, charging, and driving, in different situations is crucial, as decisions affect the whole system. The purchase of an EV is an investment decision in economic terms, and the decided price determines its charging capacity and battery size. The tariff choice represents a periodic consumer decision that has implications regarding the incentives for charging and usage of the EV. As electromobility becomes more important, the diversity of consumer-related research in the field of electromobility increases. To date, various aspects have already been considered in review papers, but these have mostly focused on distinct aspects such as vehicle-to-grid (Sovacool et al. 2017), consumer preferences regarding charging infrastructure (Hardman et al. 2018), consumer preferences regarding adoption (Liao et al. 2017; Stockkamp et al. 2021), or modeling approaches for various aspects (Daina et al. 2017; Gnann et al. 2018; Gómez Vilchez and Jochem 2019). However, a comprehensive review of behavioral elements in electromobility is still lacking.

In this paper, we aim to fill this gap and develop a systematic framework for the analysis of consumer and user behaviors relevant to electromobility. We outline the current state of electromobility and utilize research methods. In addition, we motivate why it is useful to aggregate the research on various aspects of consumer and user behavior into four different categories: "purchasing," "tariff choice," "charging," and "driving." This review highlights the discrepancy in the intensity of research between the aspects and identifies gaps for further research. The remainder of this article is organized as follows. In the next section, we present the concept of this review. The third section consists of an analysis of the reviewed articles. In the fourth section, we discuss the identified research gaps derived from Section 3. We conclude with a summary of our main findings in the last section.

2 Concept of Review

Reviewing the existing literature on consumer behavior related to electromobility can be done with a broad or narrow focus. Review papers with a narrow focus in this context might deal with geographic aspects (Krause et al. 2013), methods used (Daina et al. 2017; Gnann et al. 2018; Gómez Vilchez and Jochem 2019), or specific consumer behaviors, such as charging (Sovacool et al. 2017; Hardman et al. 2018) or adoption (Li et al. 2017). By contrast, we have decided to apply a broader scope, including behavioral aspects related to four major decisions regarding electromobility: purchase, tariff choice, usage (driving), and charging. The four categories cover all important user decisions along the life cycle of an EV, except for resales and decommissioning. Figure 2 is a graphical summary of the four aspects, emphasizing the different temporal frequencies of the decisions and their interdependence. The fact that the decisions are, on the one hand, interdependent and that, on the other hand, they bear very different characteristics is of major importance in designing future energy and mobility systems incorporating large shares of EVs.

This comprehensive review of the state of knowledge regarding the behavioral aspects of electromobility complements the multiple attempts of engineers and planners to design future electromobility systems. An integrated mobility system is not purely technical but rather a complex socio-technical system (Geels 2004). It is important to consider technical artifacts, such as EVs, charging facilities, grid infrastructures, control algorithms and communication protocols, and the relevant actors. The latter include automotive manufacturers, electricity suppliers, governments, and individuals who purchase and use EVs. Knowledge about these actors and their decisions is somewhat scattered. However, such knowledge is primordial for practitioners and researchers who aim to contribute to a well-designed and sustainable future mobility system. From this perspective, it is important to focus the review on key concepts and insights regarding the different behavioral aspects rather than providing an extensive compilation of all scientific material available on behavior and electromobility. Such a focus is instrumental in identifying research gaps that need to be filled in view of the successful construction of sustainable sociotechnical systems for electromobility.

As covering different aspects of behavior would lead to many relevant articles, we considered reviewing selected articles in each category in detail (see Figure 2). This procedure also guarantees that the articles chosen for detailed analysis cover the most frequently considered aspects.

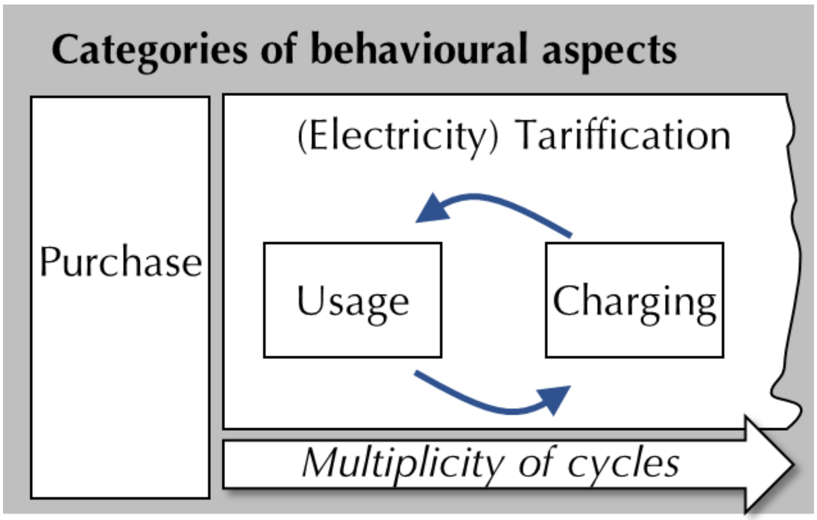


Figure 2: Scope of behavioral aspects.

[**Selection procedure**] Given the preceding considerations, we proceeded with a two-step approach. In the first step, we extensively searched for relevant scientific publications. In the second step, we identified the most pertinent sources with a view to a more in-depth discussion of the state of the art. Elsevier's Scopus®[2] database was chosen to identify relevant papers. According to the information given on its homepage[3], Scopus comprises more than 84 million records, and independent subject matter experts curate the source-neutral abstract and citation data. Furthermore, the possibility of entering keywords or phrases enclosed in quotes and combined with Boolean operators to narrow a basic search to a specific topic is beneficial for the setup of this review (Ballew 2009). Regarding the relevant publication period, we considered publications from 2016 onwards. This decision was taken to reflect current developments in electromobility research. Furthermore, we excluded contributions in book chapters or conference

[2] www.scopus.com

[3] www.elsevier.com/solutions/scopus/how-scopus-works

papers; thus, only journal articles were considered. This procedure enabled a focus on research contributions validated through peer review. As this review considers articles that focus on behavioral aspects of buyers and users of EVs, we acknowledge that the frontier between the main scope of this review and other issues, such as technical analyses, may be somewhat blurred. We intentionally applied a search in scientific databases using specific keywords. Following this, we excluded analyses focusing purely on technical aspects or neglecting consumer behavior.

Papers covering the four behavioral aspects were sorted in descending order according to their citation frequency to identify relevant articles. This procedure enabled the identification of the most pertinent and actual challenges related to the four behavioral aspects for more detailed coverage, as not all papers could be included in this review.

[**Final Selection**] For the selection, we used a set of advanced filters listed in the Appendix. The search algorithm identifies specific keywords in titles, abstracts, and articles' keywords. Overall, we retrieved 871 articles published in scientific journals between January 1t, 2016, and November 27, 2023[4]. For each behavioral aspect, we modified the search to filter the sub-level of interest, as presented in the Appendix. The search algorithm used led to duplicates between the four behavioral categories. Duplicates occurred because an article might deal with several aspects; explicitly, the keywords were mentioned within the title, abstract, or as keywords. Of the 871 articles, 278 were listed in more than one of the four behavioral categories. We addressed this duplicate issue by (1) counting the number of duplicates to provide transparency (see Figure 3) and (2) manually assigning the selected articles for further analysis in Section 3 to a single category.

The extensive search led to 326 articles for the category purchase, 60 articles for tariff choice, 483 for charging, and 280 articles for usage (Figure 3). In this review, we selected the nine most cited articles in each category for discussion. A detailed analysis of the total list is provided in Section 3.

[4] The search revealed four papers with official publication in 2024. None of them has been cited so far. To avoid confusion, those papers have been placed in the "2023" blocks, as a separate block would be hard to detect due to the small number in relation to the overall number of publications.

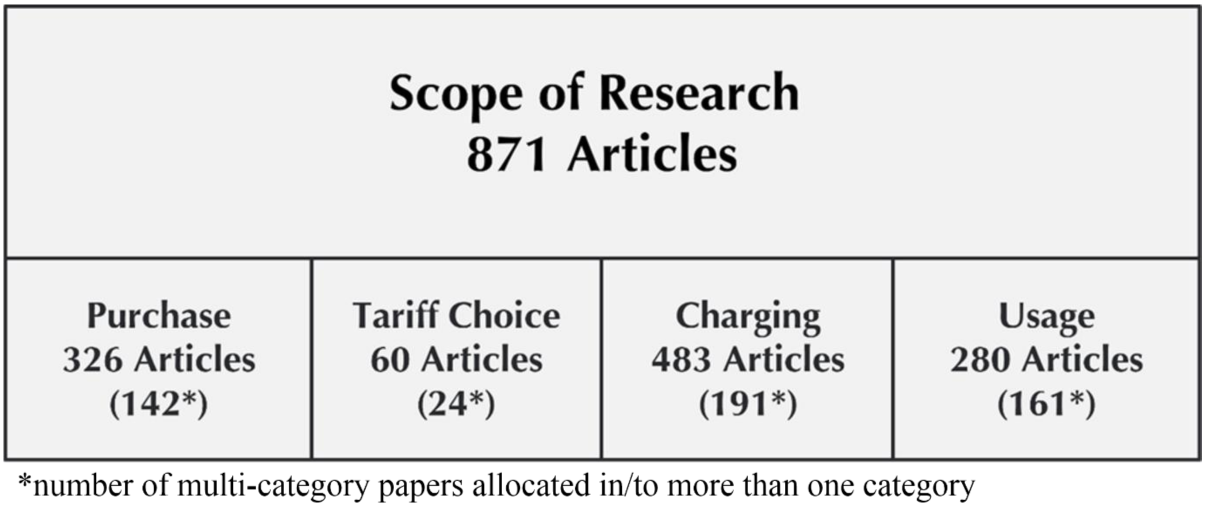


Figure 3: Review article selection.

For the selected articles discussed in detail, we enrich the qualitative discussion through a standardized classification of the key criteria, as described below (Figure 4).

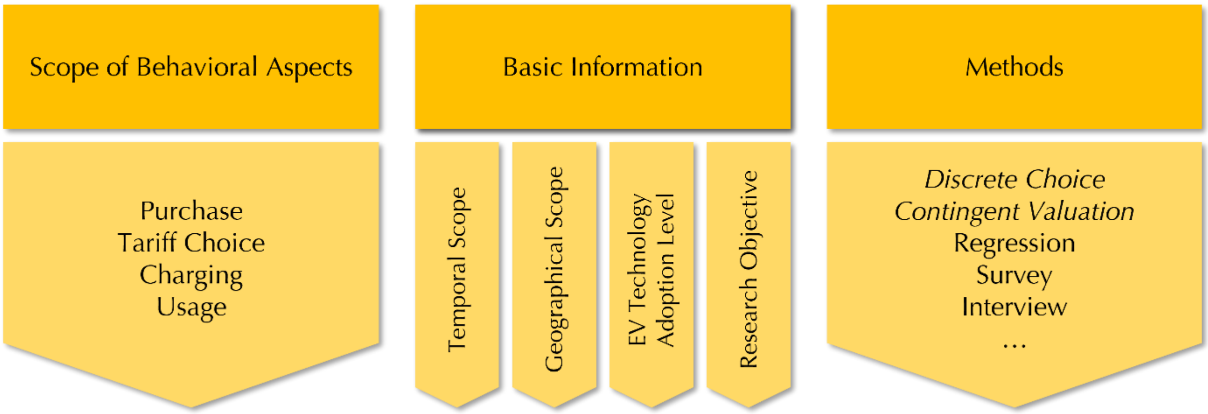
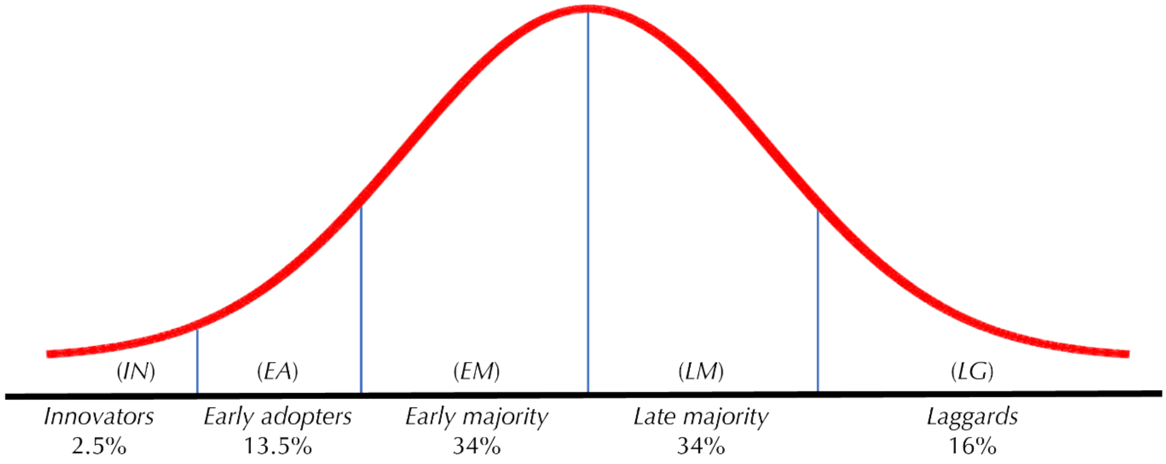


Figure 4: Key criteria for classification.

[**Scope of Behavioral Aspects**] As mentioned before, we distinguished between four behavioral aspects: the purchase of an EV, tariff selection regarding charging contracts, charging of an EV, and usage of an EV. This enabled us to identify the decision aspects covered by the papers and facilitate identifying research gaps.

[**Basic Information**] The decision-making and preferences of consumers and related aspects may be highly affected by the overall context in which the study takes place. Therefore, we report the articles based on the temporal and geographical scope, followed by the level of EV technology adoption and the research objective. For the temporal scope, we considered the respective year of observation, for example, the year when field test data were collected. Most data were obtained before the year of publication. This attribute helped us contextualize the results, as knowledge about electromobility had evolved over the years among experts and laypersons. This is relevant because the people interviewed a decade ago might have changed their perceptions and preferences. The geographical scope indicates the countries of data collection. Combined with the temporal scope and EV sales data from industry statistics, this may be used to derive a rough indication of the market phase in which EVs are located in the respective country. A more detailed classification, notably into rural and urban regions, would be advisable, yet it is prevented by limited information.

The indicator ‘EV technology adoption level’ refers to the level of innovation according to Rogers (1962) (Figure 5). This proxy enables the distinction of different market phases, which are also characterized by differences in public acceptance and familiarity. We distinguished between the states of innovators (IN), early adopters (EA), early majority (EM), late majority (LM), and laggards (LG) based on the share of EV sales in the year (or during the period) of data collection.



Source: Own illustration based on Rogers (2003, p. 181).

Figure 5: Adopter categories in Rogers’ diffusion model

For transparency, we marked all studies where we could not identify any date or geographical scope of data collection or where it was irrelevant. For those cases, we applied the first submission date, as it provides an upper limit for the data collection period. The indicator research objective sums up the target of the study, for example, whether the focus was on measuring the willingness to pay or the influence of nudges on decision-making. This attribute helped identify which aims have been pursued in the existing literature and where research gaps may exist for future studies.

[**Methods**] We further classified the methods used. Theoretical frameworks and methodological implementations were sometimes blurred or difficult to separate, and research communities have used and interpreted terms differently. Consequently, we used the formulations given by the authors as an orientation. We referred to Louviere et al. (2010) and Carson and Louviere (2011), who delved into this issue regarding discrete choice, contingent valuation, and conjoint analysis. Evaluating the methods utilized helped identify the preferred concepts for analyzing behavioral aspects in the context of electromobility.

3 Literature: Results and Discussion

We begin by making significant statements about the research intensity in the individual areas during the selected period.

[**Total research activity**] For each behavioral category, a dedicated sub-level search of publications was performed in the Scopus database (cf. Section 2). The different quantities of relevant publications indicate the importance of this specific aspect of electromobility for the scientific community. The percentage of scientific articles dedicated to a particular aspect of consumer behavior within electromobility is shown in Figure 6. Please note that the sum of all articles identified by Scopus searches is 871; however, the cumulative sum of the four sub-categories yields 1149. This can be explained by the four 2nd-level search algorithms, which allocated 278 "multi-category" papers to more than one category. We indicated this in Figure 3 for transparency reasons. To determine the shares of categories relative to the 871 reviewed publications, we identified each of the 278 multicategory papers and attributed a share equal to the inverse number of their occurrences to each relevant category. For example, 73 papers were identified by the search queries in the categories "charging" and "usage." Each of these papers was attributed to those two categories, with an equal weight of 0.50. Analogously, all 37 papers identified for three of the four categories were considered in each category, with a weight of 0.33.[5]

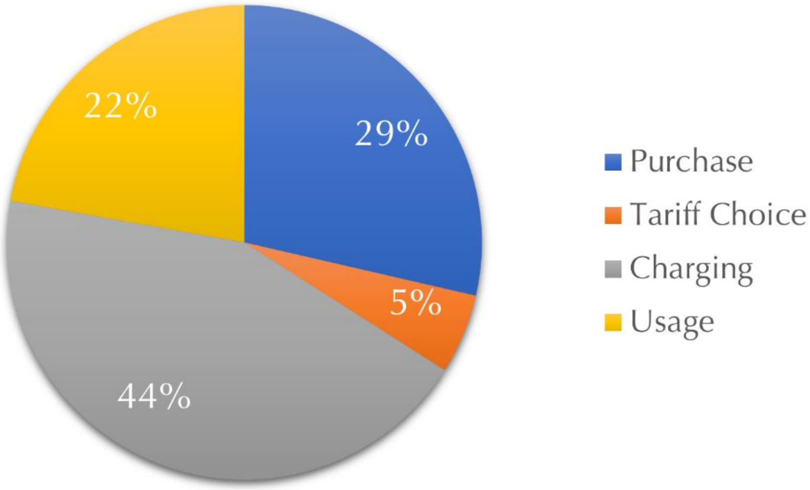


Figure 6: Shares of categories related to all publications identified by Scopus searches.

A deeper analysis of the findings obtained with the Scopus search algorithms showed the following shares of articles in the four behavioral categories: Charging represented the most researched behavioral aspect (44 percent) within the publications under consideration. Articles

[5] None of the papers was allocated into all four categories by the four 2^{nd} level search algorithms.

regarding purchase (29 percent) and usage (22 percent) accounted for one-half of the publications. By contrast, articles regarding tariff choice accounted for merely 5 percent of the considered publications.

Including the temporal dimension, Figure 7 indicates that in each category, the frequency of publication increased over time. This might underline a trend toward higher recognition of behavioral aspects within research on electromobility. Due to the sorting, we expected a more substantial weighting of the articles published in 2016. However, this was not the case, as Figure 7 indicates. One possible reason may be the importance of the topicality of studies on behavioral aspects related to electromobility, which has increased in recent years.

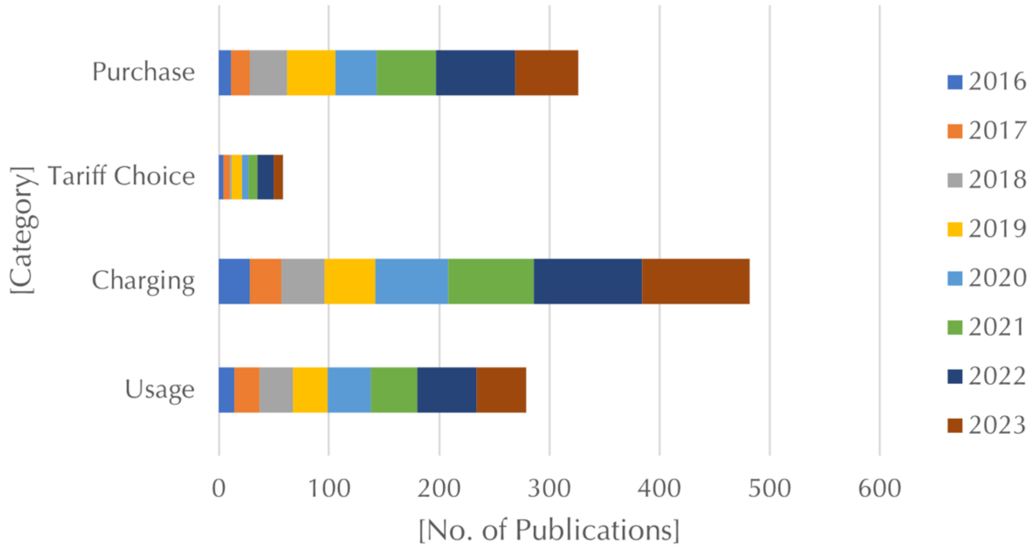


Figure 7: Absolut temporal development of research categories.

Figure 8 summarizes the relevant publication outlets, focusing on the top ten journals selected for publication. The numbers given were cumulated over all four behavioral categories. Interestingly, the frequency of publications strongly fluctuated within the journals over time.

Citation frequency is another indicator of research activity, next to the number of publications (Figure 9). Compared to the other categories, tariff choice again turned out to be an outlier with a much lower citation frequency. Moreover, articles published in 2016 were less cited than articles published between 2017 and 2019. For this somewhat surprising result, we hypothesized that specific scientific interest has increased significantly in recent years due to the dynamic market developments (Figure 1). Publications from 2016 may then be considered either outdated or may have even fallen into oblivion. Findings related to a specific category of consumer behavior in electromobility are discussed in the following sections. Further information on the total sample is also provided in the Appendix.

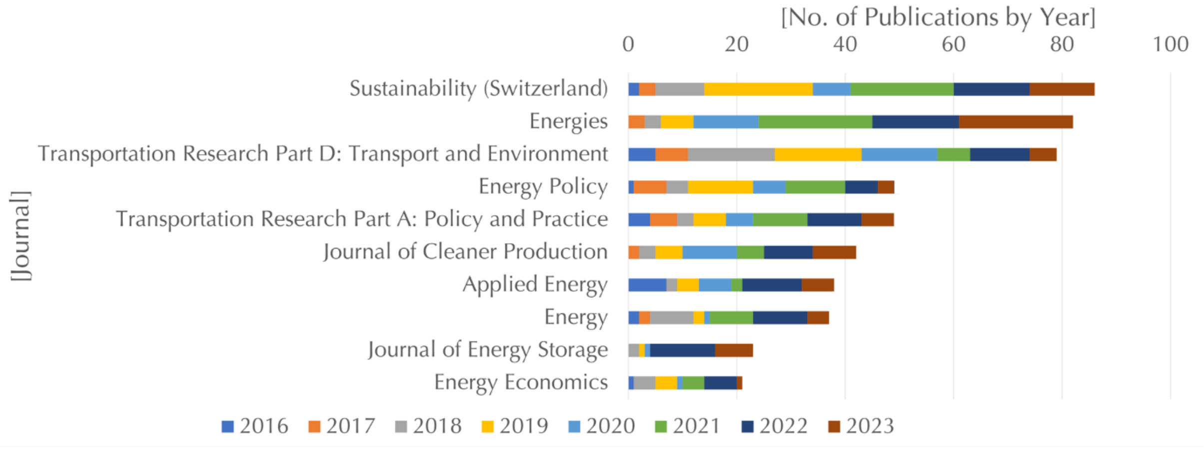


Figure 8: Number of publications by year.

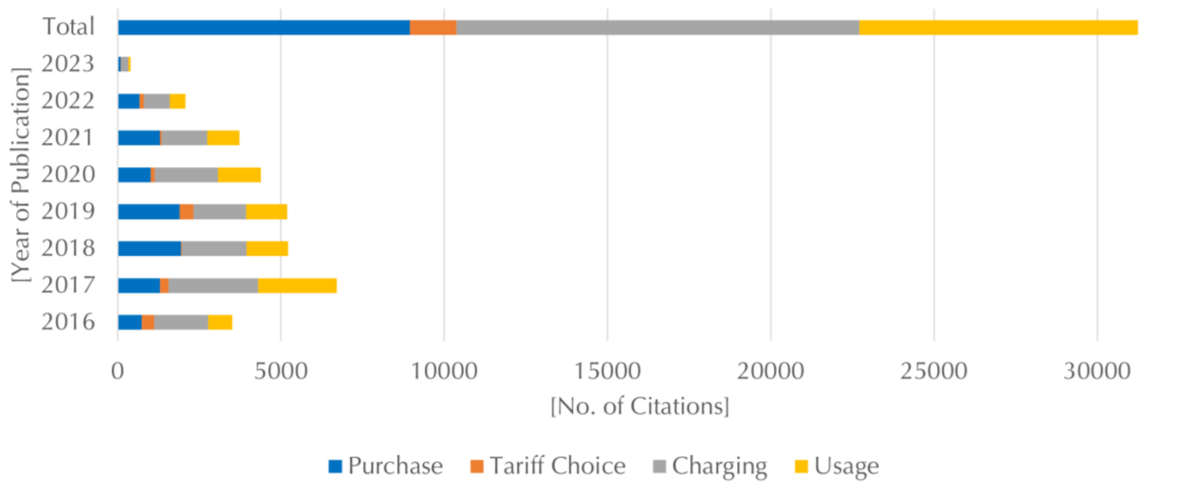


Figure 9: Citation frequency.

Table 1 shows the articles selected for a detailed review. The results are discussed within the subchapters. The publication years ranged from 2016 to 2020. Note that the most cited articles selected for this review were all published in 2020 or earlier. The most represented journals are Transportation Research Part D: Transport and Environment (8), Journal of Cleaner Production (7), Energy Policy (4), and Energy Research and Social Science (3). The frequency of citations ranged from 8 to 152. The data collection period ranged from 2009–2020, while 50 percent of the data was collected after 2015. The average difference between data collection and publication was about two years. The outlier with a difference of 10 years used travel data from 2009 (Argade et al. 2019). The geographic focus was spread over North America (8), Europe (13), and Asia (12). Three articles did not provide a clear geographic scope, or they focused on multiple areas. EV technology adoption reached the innovator stage in 27 articles, the early adopter stage in 6 articles, and the early majority stage in 3 articles. This reflects that in most countries, market penetration is still limited. Norway was the most advanced market, with adopters in the country corresponding to the early majority.

We divided the research objectives of the articles into four areas: behavioral patterns (11), preferences, and attributes (10), consumer behavior under system integration (9), and willingness to pay (WTP) or accept (WTA) (6). Since a clear delineation of research objectives was not feasible, this classification must be interpreted as approximate. Thus, the articles on behavioral patterns were more concerned with observable actions. Articles on preferences and attributes emphasized the study of product and consumer characteristics more strongly. Studies on consumer behavior under system integration set a higher focus on the overall system level and the integration of consumer patterns into energy systems. Articles on WTP or WTA were more in line with research on price sensitivities and overall acceptance. The applied methods are discussed within the four sub-chapters.

Table 1: Selected Articles for Review.

Source	Citation	Scope of behavioral aspect	Temporal	Geographical	Subject	EV Percentage	Objective	Methods
Degirmenci and Breitner (2017)	152	EV-Purchase	2015	Germany	IN	0.72	Preferences/Attributes	Interview + Survey + Structural equation modeling
Jenn et al. (2018)	104	EV-Purchase	2010-2015	USA	IN	0.78	Behavior Patterns	Regression analysis
Wang et al. (2017)	102	EV-Purchase	2015	China	IN	0.94	Preferences/Attributes	Survey + Structural equation model (based on TPB)
Huang and Ge (2019)	101	EV-Purchase	2018	China	EA	4.50	Preferences/Attributes	Survey + Structural equation model
He et al. (2018)	93	EV-Purchase	2018	China	EA	4.50	Behavior Patterns	Survey + Personality-perception-intention framework
Zhang et al. (2018)	86	EV-Purchase	2016-2017	China	IN	2.30	Preferences/Attributes	Survey (Questionnaire) + Structural equation modeling
Ferguson et al. (2018)	66	EV-Purchase	2015	Canada	IN	0.45	WTA/WTP	Latent class discrete choice model based on stated preferences choices
Matthews et al. (2017)	66	EV-Purchase	2014	Canada	IN	0.34	Behavior Patterns	Field Experiment (mystery shopping) + Questionnaire + Multiple Regression
Wang et al. (2018)	62	EV-Purchase	2017*	China	IN	2.30	WTA/WTP	Survey + Factor analysis method + Structural equation model + Descriptive statistical analysis
Nicolson et al. (2017)	61	EV-Tariff Choice	2015*	UK	IN	1.10	WTA/WTP	Survey (Field experiment) + Regression analysis
Talwariya et al. (2019)	33	EV-Tariff Choice	2018**	India	IN	0.03	Consumer behavior under system integration	OR/ Game-theoretic models + Monte-Carlo Simulation
Alilou et al. (2020)	27	EV-Tariff Choice	2020**	Not specified***	EA	10.00	Consumer behavior under system integration	Multiobjective Optimization
Delmonte et al. (2020)	19	EV-Tariff Choice	2019*	UK	EA	3.10	WTA/WTP	Semi-structured interviews + Inductive analysis
Hoarau and Perez (2019)	19	EV-Tariff choice	2014/2016	EU/US	IN	1.20	Consumer behavior under system integration	OR / Game-theoretic models (non-cooperative game)
Fan et al. (2020)	15	EV-Tariff Choice	2020**	China	EA	16.00	Consumer behavior under system integration	OR / Game-theoretic models
King and Datta (2018)	12	EV-Tariff choice	2018*	Not specified***	IN	2.20	Consumer behavior under system integration	Qual. Case study
Argade et al. (2019)	9	EV-Tariff Choice	2009****	USA	IN	0.01	Consumer behavior under system integration	Optimization (non-linear minimization of Costs and Anxiety)
Küfeoğlu et al. (2019)	8	EV-Tariff choice	2018	UK	IN	2.10	Behavior Patterns	Qual. Case study
Moon et al. (2018)	91	EV-Charging	2016	South Korea	IN	0.33	Behavior Patterns	Survey + Discrete Choice Method (mixed logit model)
Kester et al. (2018)	70	EV-Charging	2016-2017	Scandinavia	IN-EM	39.00	Consumer behavior under system integration	Interview + Qualitative comparative analysis
Fang et al. (2020)	57	EV-Charging	2019	China	EA	4.60	Preferences/Attributes	Evolutionary game model
Axsen et al. (2017)	52	EV-Charging	2013	Canada	IN	0.22	Preferences/Attributes	Semi-Structured Interview + Data Analysis
Hao et al. (2020)	45	EV-Charging	2016	China	IN	1.40	Behavior Patterns	k-means Clustering Method
Levinson and West (2018)	41	EV-Charging	2014	USA	IN	0.89	Consumer behavior under system integration	Nested Multinomial Logit Model
Motoaki and Shirk (2017)	40	EV-Charging	2011-2013	USA	IN	0.74	Behavior Patterns	Regression + Descriptive Analysis
Globisch et al. (2019)	28	EV-Charging	2018*	Germany	IN	1.90	WTA/WTP	Survey + Conjoint analysis
Miele et al. (2020)	24	EV-Charging	2017	Canada	IN	1.00	Preferences/Attributes	Agent-based model (considering stated preference choice model)
Jansson et al. (2017)	128	EV-Usage	2014	Sweden	IN	1.40	Preferences/Attributes	Survey + Regression analysis (binary logistic regression)
Sovacool et al. (2018)	100	EV-Usage	2018*	Scandinavia	IN-EM	49.00	Preferences/Attributes	Survey+ Descriptive Analysis
Diao et al. (2016)	75	EV-Usage	2015	China	IN	0.94	Consumer behavior under system integration	Life-Cycle-Assesment
Fetene et al. (2017)	72	EV-Usage	2012-2014	Denmark	IN	0.85	Behavior Patterns	Unobserved effects model (for panel data)
Weldon et al. (2016)	37	EV-Usage	2011-2014	Ireland	IN	0.59	Behavior Patterns	Descriptive analysis (incl. ANOVA and further tests)
Bennett and Vijaygopal (2018)	29	EV-Usage	2016*	UK	IN	1.40	Preferences/Attributes	Survey + Structural equation model + Conditional process analysis
Wang and Yan (2016)	29	EV-Usage	2014	China	IN	0.35	WTA/WTP	Survey + Choice Experiment (multinomial logistic regression)
Jensen and Mabit (2017)	26	EV-Usage	2011-2013	Denmark	IN	0.28	Behavior Patterns	Regression analysis (mixed non-linear regression model) + Choice Model (mixed logit model on GPS data)
Bauer (2018)	22	EV-Usage	2016	Norway	EM	29.00	Behavior Patterns	Survey + Regression analysis

*No date identified; ** Sample data, ***No geographical scope; ****based on 2010 data

3.1 Research on Purchase

[**Scope of Behavioral Aspects**] In general, behavioral aspects of purchasing relate to the intention, result, or consequence of a decision for or against an EV. Changing the attitudes of potential customers toward purchasing an EV through incentives is also within the scope of this section. Degirmenci and Breitner (2017) evaluated the role of environmental performance in relation to price value and range regarding the confidence of (potential) consumers intending to purchase an EV. The authors stated that the environmental performance of EVs is a stronger predictor of attitude and, thus, purchase intention than price value and range confidence. A similar aspect was discussed by Matthews et al. (2017), who investigated shopping experiences at dealerships selling EVs in the Canadian province of Ontario. The authors showed that a common barrier for shoppers was the unavailability of EVs at the dealership, including a lack of EV models on site to view or test drive and a three- to four-month waiting period to receive the vehicle once ordered. Concerning the availability of EV models to date, this study described the situation at a specific point in time, and the issue might be irrelevant today as more EV models become available from multiple car brands (see, e.g., EU Commission (2024), EV Database (2024)).

Wang et al. (2017) evaluated the potential of different factors to positively change Chinese citizens' purchasing intentions toward EVs. The factors found by the authors to have a significant impact were financial benefit, infrastructure readiness, environmental concern, and policy privilege but not the vehicle's cruising range. The facets of low openness to electromobility were also addressed by Ferguson et al. (2018). During their data collection (in mid-2015), the market for EVs in the US was approximately 2.5 times more advanced on a per capita basis than its Canadian counterpart, despite EV purchase price incentives in the most populated Canadian provinces of Quebec, Ontario, and British Columbia.

Regarding the low openness observed by Ferguson et al. (2018), He et al. (2018) confirmed that consumer perceptions and individual characteristics play an important role in increasing EV acceptance based on their research on determinants of consumer EV adoption behavior in China. Jenn et al. (2018) examined the impact of both monetary and non-monetary incentives to stimulate EV sales and overcome these barriers in the US. The authors explicitly mentioned the high-occupancy vehicle lane allowance for EVs as a positive example of a non-monetary incentive, independently from the minimum required number of passengers carried to use these lanes. Jenn et al. (2018) analyzed US markets, and Wang et al. (2018) presented a study on (potential) EV buyers from Shanghai to evaluate the reasons for low public acceptance of EVs. The authors listed technical level, marketing, perceived risks, and environmental awareness as significant impact factors for EV acceptance. Beyond the discussion of incentives in general, Zhang et al. (2018) evaluated the degree of sustainability of EV adoption. The results of their questionnaire from 264 potential Chinese EV buyers showed that some stimulating effect on purchase intention persisted after governmental subsidies for EVs expired. Finally, Huang and Ge (2019) focused on policy implications for improving EV purchase intentions and promoting EV development in Beijing. The authors pointed out the positive effects of EV performance on the attitudes of potential buyers. In partial contradiction to the work of Wang et al. (2017), the authors highlighted relevant performance parameters that included increased cruising range, shortened charging time, prolonged battery life, and improved safety and charging infrastructure of EVs.

[**Key Characteristics**] To summarize the screened articles, we identified two general points. First, the articles discussed in the previous subsection provide answers to why a consumer would buy or rather refuse to purchase an EV. This relates to the broad concepts of preferences and attitudes. Second, several studies have identified measures to overcome these barriers, such as purchase subsidies, the introduction of privileges, or infrastructure improvement. Generally, the research on purchase deals with behavioral patterns in the form of observable actions and often collects own field data (Matthews et al. 2017; He et al. 2018; Jenn et al. 2018). Other contributions focus on the analysis of preferences and the role of various car attributes, considering purchase intentions under different conditions (Degirmenci and Breitner 2017; Wang et al. 2017; Zhang et al. 2018; Huang and Ge 2019), or measurements of willingness to accept or pay (Ferguson et al. 2018; Wang et al. 2018). The most cited articles considered in this review collected data between 2014 and 2018. Given their geographical and temporal scopes, the data reflected EV markets within the innovators and early adopter phases. The considered articles on purchase provided insights for China, Canada, the US, and Germany. There is a correlation between research on purchase activities and early market phases, as purchase corresponds to the start of the vehicle lifecycle from a customer perspective and represents the starting point for most other topics.

[**Methods**] With a scope on the consumer, economists use several methods to measure behavior, preferences, or attitudes. In this review, the interest lies in the effects caused by real-life consumer behavior. We assume that an idealized "homo oeconomicus" would lead to inexpedient conclusions, as this economic model of human behavior is based on strictly rational decisions and therefore does not deal with any cognitive biases or heuristics, particularly moral motives such as altruism. For a detailed explanation of different biases and heuristics, see, for example, Richter et al. (2018). A comprehensive scientific picture of the "homo oeconomicus," including a discussion of the limits and problems of its application, is provided by Kirchgässner (2008). Regarding the listed potential research objectives, data collection in the form of surveys or interviews is key to considering consumer-related insights. Thus, most of the considered articles on purchase started with the collection of specific data (Degirmenci and Breitner 2017; Matthews et al. 2017; Wang et al. 2017; He et al. 2018; Wang et al. 2018; Zhang et al. 2018; Huang and Ge 2019). For further analysis, the studies used different methods, such as structural equation models—mostly for measurements regarding preferences and attitudes (Degirmenci and Breitner 2017; Wang et al. 2017; Zhang et al. 2018; Huang and Ge 2019)—or regression analysis in the case of research on behavioral patterns (Matthews et al. 2017; Jenn et al. 2018). Other methods include discrete choice models for WTP/WTA analysis (Ferguson et al. 2018) or personality-perception-intention frameworks (He et al. 2018).

3.2 Research on Tariff choice

[**Scope of Behavioral Aspects**] One central aspect of research on tariff choice is customer perception of tariff models. An example of such a tariff is the time-of-use tariff. Time-of-use pricing is best known for its static variant, which makes use of large time blocks of several hours. Within a time block, the price is set in advance and remains constant (IRENA 2019; Hildermeier et al. 2019). A basic configuration consists of a standard price during the daytime and a reduced price valid in the late evening and at night.

Nicolson et al. (2017) pointed out that tariff design without incorporating consumer preferences has little effect. In their survey experiment conducted on a representative sample of British energy bill payers, the authors showed that loss aversion as a personal trait was connected to a lower willingness to choose a fixed time-of-use tariff. According to the authors,King and Datta (2018) described the role of tariffs suitable for EV operations and discussed key challenges concerning their implementation. Focusing specifically on V2G and V2H,[6] Küfeoğlu et al. (2019) discussed tariff designs and EV consumer behavior in bidirectional charging schemes using the UK as a case study country. Alilou et al. (2020) applied a much more complex tariff design. The authors discussed real-time pricing tariffs as price-based demand response programs in managing a residential smart microgrid under the stochastic penetration of solar panels and EVs.

Argade et al. (2019) proposed a so-called price-based virtual power plant (VPP) with a two-class EV-charging tariff. The management of the charging impact on the distribution network and the impact of consumer dissatisfaction due to delayed charging were also addressed. Hoarau and Perez (2019) investigated a game theory model that considers a regulator who sets tariffs to recover grid costs and different network users. Some network users are EV users, while others are prosumers who use distributed energy resources to produce or store electric energy, mainly in the form of solar photovoltaic or lithium-ion batteries. The authors showed that EVs and

[6] Similarly to V2G, vehicle to home (V2H) shows bidirectional energy flows, although the energy out of the EV's battery is specifically used to buffer the micro-grid of the operator's home.

distributed energy resources conflict through network tariffs, creating "winners and losers" between EVs and prosumers.

Talwariya et al. (2019) adapted game theory concepts to regulate the retail electricity market within the constraints of the so-called stepwise power tariff for economical energy consumption. The authors pointed out that the objective is to increase the adoption level of renewable energy sources and EVs. Another game-theoretic model was applied by Fan et al. (2020), who investigated the optimal pricing strategies of EV manufacturers and the government's optimal decisions on subsidies and tariffs to maximize social welfare. Delmonte et al. (2020) investigated perceptions of actual and potential plug-in EV users in the UK with respect to "smart charging" (controlled charging) tariffs.

[**Key characteristics**] The considered studies on tariff choice are a special case, as they also included articles without any geographical or temporal scope (King and Datta 2018; Talwariya et al. 2019; Alilou et al. 2020; Fan et al. 2020). These articles are not less relevant, but the arguments they presented were on a general level. Nevertheless, empirical investigations relate to clear temporal and geographical scopes and might, correspondingly, reveal more specific insights for local policymakers. The period for actual data collection ranged from 2014–2019. The articles especially reflected the design of charging in the UK (Nicolson et al. 2017; Küfeoğlu et al. 2019; Delmonte et al. 2020) and the US (Argade et al. 2019; Hoarau and Perez 2019). The market phases ranged from innovators to early adopters and thus might reflect markets in which tariffs are a new phenomenon. This is in line with the effect of tariffs on EV charging. The research objectives mainly focused on behavioral aspects as an element of system analysis (King and Datta 2018; Argade et al. 2019; Hoarau and Perez 2019; Talwariya et al. 2019; Alilou et al. 2020; Fan et al. 2020) and on measurements of acceptance (Nicolson et al. 2017; Delmonte et al. 2020).

[**Methods**] The selected articles with a focus on consumer behavior under system integration mainly applied optimization methods, including game theoretical elements or multi-objective formulations (King and Datta 2018; Argade et al. 2019; Hoarau and Perez 2019; Talwariya et al. 2019; Alilou et al. 2020; Fan et al. 2020). This does not imply that surveys, regression analysis (Nicolson et al. 2017), interviews (Delmonte et al. 2020) or qualitative case studies (Küfeoğlu et al. 2019) are irrelevant in general. For example, the field experiment by Nicolson et al. (2017) was the most cited article (61) in the category of tariff choice.

3.3 Research on Charging

[**Scope of Behavioral Aspects**] Behavioral elements of EV charging encompass the supply of electrical energy to the battery and the availability of appropriate and timely filling levels. Current research in the field of EV charging aims to meet the challenges posed by the expected strong increase in electromobility. A huge quantity of additional vehicles would cause a significant extra load on the electricity distribution grids, particularly during peak load periods. On weekdays, the most significant load peak occurs in the evening, when the users of the EV return home from their workplace (Moon et al. 2018). There are two main strategies to address these peak loads to avoid excessive and costly expansion of the electricity distribution infrastructure. The burden might be mitigated by centrally coordinating the charging period of EVs to prevent the majority of EVs from charging at the same time. Such central coordination of EV charging times is called smart charging (Lyon et al. 2012).

In addition, EV batteries connected to an electricity distribution network may serve as a dynamic buffer. Any single battery might contribute to compensating for peak loads by feeding back stored energy into the electricity distribution network. This strategy of bidirectional energy flows is known in the literature as vehicle-to-grid (V2G) (Kempton and Letendre 1997). Figure 10 summarizes the alternatives regarding the degree of (external) charging coordination and the energy flow between the power grid and the EV's battery, based on Blumberg et al. (2022).

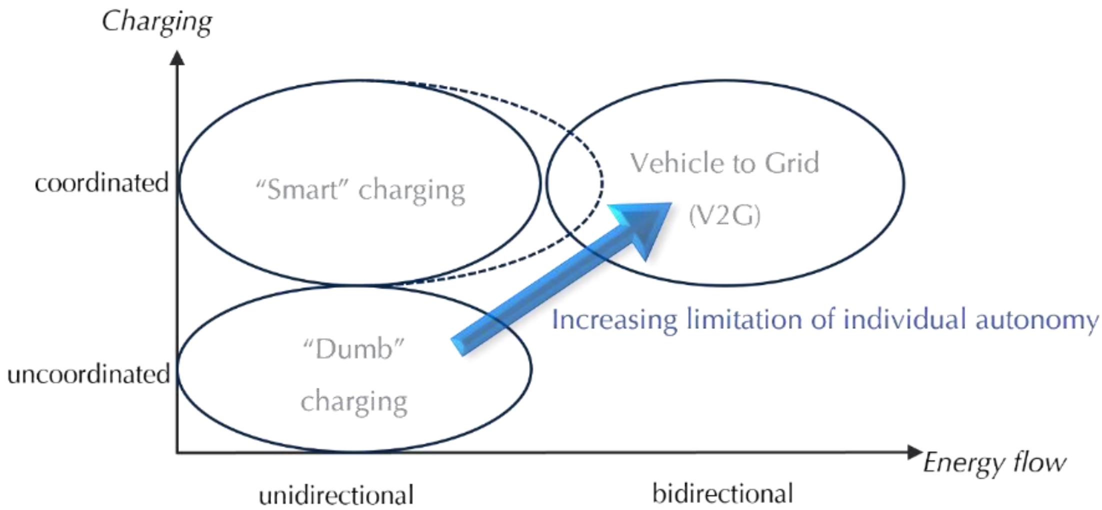


Figure 10: Classification of EV charging strategies[7].

Both coordinated charging and, to an even greater extent, bidirectional charging imply interference in the individual autonomy of the EV user. Such reduced individual autonomy[8] might negatively affect the acceptance of these tariff schemes by potential or actual adopters (van Heuveln et al. 2021; Lee et al. 2020)). The arrow in Figure 10 symbolizes the path from the charging alternative with the lowest limitation of individual autonomy to the alternative with the highest limitation. A related topic also included in this section is considerations by EV users

[7] In some publications, "smart charging" is applied in a more general sense to address coordinated charging concepts independent of the direction of energy flow (e.g., Schmalfuß et al. 2015; King and Datta 2018, p. 25). This ambiguity is symbolized by the dashed line immersing into the V2G area.

[8] The reduction of individual autonomy is called "perceived behavior control" by van Heuveln et al. (2021.

regarding the required minimum charging level in the battery as a safety margin for unforeseen needs.

Axsen et al. (2017) focused their research on Canadian EV users, whom the authors characterized as mainstream. The research data collected by a survey was the basis for analyzing the perceptions and misperceptions of EVs and charging programs. Focusing on a specific aspect of perception, Motoaki and Shirk (2017) analyzed real-world field data to examine the usage parameters of direct current fast charging in the US based on whether the charging service was free or subject to a charge. According to the authors, a flat-rate fee can harm the usage efficiency of direct current fast charging stations. In a similar context, the simulation model used by Levinson and West (2018) allowed both scenario and parametric analysis to verify whether an extension of the public charging infrastructure in the US had a positive impact on battery EV sales, national electrified mileage, and the reduction of greenhouse gas emissions. Similarly, Globisch et al. (2019) analyze factors that influence the attractiveness of public charging infrastructure in Germany from the perspective of potential users by means of rating-based conjoint analysis. The data processed by the authors consisted of assessments by 1003 German motorists on possible future charging infrastructure systems with different configurations regarding spatial coverage, charging duration, and usage costs.

Kester et al. (2018) presented research results in the context of V2G incentives and policy mechanisms, with a focus on the Nordic region. The qualitative comparative analysis was based on 227 semi-structured interviews of EVs with both transportation and electricity experts. Moon et al. (2018) used a survey to investigate consumers' charging patterns to forecast the electricity demand of EVs in South Korea and evaluate the sufficient performance of the domestic power grid to cope with the expected strongly increasing demand for electrical energy, particularly in the evening during peak load times. Fang et al. (2020) evaluated different methods that facilitate the installation of EV charging stations in China in the context of government policies and consumer preferences. For this purpose, the authors applied Monte Carlo simulations based on an evolutionary game model to find optimal strategies to motivate investment companies to engage in the expansion of EV charging infrastructure. Another article focusing on EV charging in China was published by Hao et al. (2020). The data collection was conducted over 12 months and represented real driving information from 197 battery EVs (BEV) of the same model. The BEVs were divided into groups of private vehicles, taxis, and ride-sharing vehicles. The authors also quantified the negative influence of winter conditions on the range of batteries. Finally, Miele et al. (2020) evaluated charging and refueling infrastructure in Canada in the context of fostering zero-emission vehicle[9] sales within the time horizon by 2030.

[**Key characteristics**] As previously discussed, research on charging aspects has focused on behavioral patterns in the context of charging in general, fast charging, or on differences between private, taxi, and ridesharing vehicles (Motoaki and Shirk 2017; Moon et al. 2018; Hao et al. 2020). This stream also differentiates consumer behavior under system integration aspects—for example, V2G or public infrastructure aspects (Kester et al. 2018; Levinson and West 2018)—preferences, and attributes (Axsen et al. 2017; Fang et al. 2020; Miele et al. 2020), as well as acceptance (Globisch et al. 2019). The geographic scope reflects the most relevant markets, especially Canada, China, Europe, Korea, and the US. Data collection ranged from 2011 to 2019, and six of the nine articles in this category collected data after 2016. The data mainly reflected charging patterns within the innovators' market phase. Kester et al. (2018) were an exception, as they focused on Scandinavia with market phases ranging from innovators to the early majority between 2016 and 2017. This study reflects more mature markets and, thus, might function as an outlook into the future. However, the geographical scope must be considered, as Scandinavian charging patterns might not reflect those of other nations. Overall, energy system aspects were more salient in the analysis of charging patterns compared to pure analyses of purchase patterns.

[**Methods**] A key aspect of research on charging patterns is data acquisition. Surveys (Moon et al. 2018; Globisch et al. 2019) or interviews (Axsen et al. 2017; Kester et al. 2018) were preferred methods for measuring preferences or behavior patterns in the scrutinized papers. Real charging data played only a minor role in this specific research context. Depending on the research objective, different methods were used for further analysis. We found that regression analyses, descriptive analyses, *k*-means clustering, and discrete choice modeling were applied for the analysis of behavior patterns (Motoaki and Shirk 2017; Kester et al. 2018; Hao et al. 2020), as well as discrete choice models for advanced analysis of system integration (Levinson and West 2018). The analysis of preferences and attributes relied on agent-based models (Miele et al. 2020), evolutionary game models (Fang et al. 2020), and qualitative approaches (Axsen et al. 2017). Conjoint analysis was used by Globisch et al. (2019) for the measurement of acceptance (WTP/WTA concept). As this sample of the nine most-cited articles revealed, there was a wide variety of methods regarding charging pattern analysis, also framed by differing research objectives.

[9] The authors used "zero-emissions vehicles" as a group term to address battery electric, plug-in hybrid, and hydrogen fuel-cell vehicles.

3.4 Research on Usage and Driving

[**Scope of Behavioral Aspects**] Behavioral aspects of usage substantially relate to the driving habits of the EV driver. Data on driving patterns play an essential role in determining differences between EV usage behavior and conventional vehicles with an internal combustion engine (ICEVs). The shared usage of EVs and general aspects of EV ownership are also within the scope of this section.

Diao et al. (2016) evaluated the inclusion of both economic incentives (like subsidies) and non-economic incentives (e.g., traffic policies) on the usage of BEVs and ICEVs in Chinese mega-cities. The authors emphasized that non-economic incentives significantly affect consumer behavior and decision-making, suggesting that these factors are crucial for effectively promoting EVs. They concluded that although national and local subsidies are important, by themselves, they cannot sufficiently alter consumer behavior; intangible aspects must also be considered to achieve a more comprehensive shift towards BEVs. Shanghai is one of the most prominent Chinese mega-cities and was the location of an empirical study by Wang and Yan (2016), who focused on the shared usage of EVs. Based on multinomial logistic regression developed for different groups, the authors listed monthly transportation expenditure, driving range of EVs, gender, age, marital status, and occupation as significant factors influencing the willingness to use (potential) consumers.

EV usage was also the subject of research outside of China by Weldon et al. (2016), who examined a fleet of EV users in Ireland and evaluated their charging and trip-making behavior. Fetene et al. (2017) show that technical and behavioral aspects are closely intertwined. To investigate the energy consumption rate and driving range of EVs, the authors considered a large number of vehicles, trips (over 230,000), and kilometers traveled (about 2.3 million) as behavioral aspects, as well as additional information concerning vehicles, roads, weather, and seasons. Jansson et al. (2017) investigated the influence of norms and opinion leadership in Sweden on the adoption of EVs. The authors also showed that EV adopters differed in relation to non-adopters on several factors.

In the neighboring country of Denmark, Jensen and Mabit (2017) collected real trip data from EV and IECV usage to evaluate the distribution of daily use and types of home-based journeys. Here, the households that participated in the study already owned ICEVs. Their driving behavior was recorded during a total test period of 5 months. From the second until the fourth month of the trial period, an EV was made available to the households for free usage, except for the costs for electrical energy. Bauer (2018) evaluated the impact of the large-scale introduction of EVs in

Norway. Using an online survey on driving habits, they revealed that EV purchases lead to a moderate increase in traveling.

Attitude aspects of EV usage and non-usage were addressed by Bennett and Vijaygopal (2018). The authors investigated the connection between personal attitude and willingness to purchase an EV by testing hypotheses that the connection may be moderated by factors related to EV usage, namely self-image congruence[10] in the case of EV ownership and stereotype formation with respect to EV drivers in the case of not owning an EV. In the context of a study of the influence of demographic factors on electric mobility preferences, Sovacool et al. (2018) provided evidence that the kilometers driven also influence electric mobility preferences, at least in Scandinavia and Iceland.

[**Key characteristics**] Articles regarding EV usage were found for Scandinavia, China, and the UK. The data collection period ranged from 2011 to 2018 and indicated market phases ranging from innovators to the early majority. The market phase of the early majority was thereby only valid for Norway (Bauer 2018; Sovacool et al. 2018). The research objectives of the considered articles mainly focused on behavior patterns (Weldon et al. 2016; Fetene et al. 2017; Jensen and Mabit 2017; Bauer 2018), as well as preferences and attributes (Jansson et al. 2017; Bennett and Vijaygopal 2018; Sovacool et al. 2018).

[**Methods**] Aggregate (annual) driving data and other data on driving behavior were collected via surveys (Wang and Yan 2016; Jansson et al. 2017; Bauer 2018; Bennett and Vijaygopal 2018; Sovacool et al. 2018). Only one study used data tracking (Weldon et al. 2016). For the analysis of behavioral patterns as well as for measuring preferences and attitudes, again a variety of methods was used, including regression analysis (Jansson et al. 2017; Jensen and Mabit 2017; Bauer 2018), descriptive statistics, particularly ANOVA models (Weldon et al. 2016; Sovacool et al. 2018), choice experiments (Wang and Yan 2016), structural equation models (Bennett and Vijaygopal 2018), calculation of "intangible" costs of less strict driving restrictions for BEVs in Chinese mega-cities (Diao et al. 2016), and unobserved effect models (Fetene et al. 2017).

4 Research Gaps

Based on the current state of research described in the previous section and elaborated on from the total sample (Figure 3), we discuss relevant research gaps for each behavioral aspect. Figure

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[10] Sirgy and Danes 1982, p. 556) stated this term more precisely as "congruence between self-image (actual self-image, ideal self-image, etc.) and product image in relation to product preference, purchase intention, and product ownership".

11 provides an overview of category keywords we used to cluster the main research topics within the research categories. This heuristic approach led to the identified gaps discussed below.

Scope of Behavioral Aspects: Relevant keywords per category	
Purchase	Barriers to adoption, complexity, EV promotion, incentives, influencing factors, infrastructure readiness, public acceptance, purchase experience, purchase intension, (ICEV) purchase restriction, range anxiety, rebate, tax credit, technology adoption.
Tariff Choice	Behavioral economics, demand(-side) response, EV rates, EV standards, EV-only tariffs, game theory, loss aversion, peak-load pricing, pricing strategy, real-time-pricing, retail electricity market, social welfare, subsidy and tariff policies, sub-metering, stepwise power tariff, tariff design, time-varying rates, time-of-use (tariff).
Charging	Charging behavior, charging stations, demand charges, demand forecast, electricity demand, fast chargers, power grid, public charging infrastructure, recharging, scenarios, "smart" charging (centrally coordinated), V2G (bi-directional), willingness to pay.
Usage	Attitude change, behavior change, big data, consumer behavior, (ICEV) driving restriction, eco-innovation, energy consumption rate, EV kilometrage (milage), EV ownership, EV sharing, gamification, life-cycle cost, low-carbon transport, range limitation, self-image congruence, stereotyping, sustainability, usage patterns, use willingness.

Figure 11: Summary of category keywords per behavioral aspect.

[**Research on purchase]** Due to the early market phases of new EVs, the market for used EVs has been relatively small so far. Thus, the research question assessing the degree to which customers accept used EVs on a large scale compared to used ICEVs of the same size and performance has hardly been addressed. In our entire sample, we identified only one study dealing with consumer intentions to buy new versus used cars in the case of Poland (Ščasný et al. 2018). The authors applied a discrete choice experiment to elicit the preferences of Polish consumers for three types of EVs against the background of Akerlof's (1970) seminal theory of 'market for lemons'. According to the theory, if potential buyers of a used EV have little or not enough information with respect to the remaining battery capacity of the EV they want to buy, they are inclined to assume a bad quality of the battery and are only willing to pay a very low price for the entire EV. This would lead to market failure. Otherwise, research that considers used EVs is still underrepresented. Another effect might be worth investigating using theoretical and empirical approaches: Given the rapid progress in EV battery size and general car technology accompanied by simultaneous cost reductions, the loss in resale value may be even more pronounced for EVs than for ICEVs.

[**Research on tariff choice**] As is evident in the entire sample of included articles (Figure 7), a few studies have focused on tariff choice. Nevertheless, existing studies are mostly at the conceptual level. The lack of field studies might be a consequence of the low share of EVs so far. This is driven by two factors. First, as indicated in this review, most markets are still in an early stage, except for Norway. Topics on tariff choice will become more relevant as the shares of EVs increase and affect energy systems. Second, tariff choice models, including bidirectional or controlled charging, are some topics for future analysis, which have already been acknowledged by some researchers (Table 1). Third, tariff designs for EVs are likely to be molded on the model of standard retail electricity tariffs. However, the simultaneity may be much higher for EV charging than for other electricity uses. Correspondingly, local distribution system operators may face the risk of higher peak loads. Without preventive measures, including specific tariffs, and the use of flexibility, this problem may induce costly grid extension. We expect that researchers will intensively publish studies in this category.

Furthermore, tariff designs were mostly described or analyzed from a system perspective. This normative approach generally does not address the customer perspective, for example, regarding the perceived complexity of tariff designs or individual risk perceptions. For example, Azizi et al. (2021) applied a normative analysis, developing an algorithm for optimal system tariff choice, while entirely disregarding the positive analysis of consumer acceptance. The contrast between tariffs in which charging is actively controlled by the system operator (or a similar entity via an energy management system) and tariffs in which the charging behavior is influenced only indirectly via cost-reflective pricing appears to be crucial with regard to the aspects of loss of autonomy and public acceptance.

[**Research on charging and usage]** Our review reveals that current research on user mobility behavior tends to focus on specific modes of transportation—in this case, types of EVs—rather than modal split analysis. Thus, this focus does not necessarily allow for a more 'distanced' point of view in a broader context. However, the transition from ICEVs to EVs might have an impact on the modal split. In our entire sample, we identified two papers with deeper insights into modal choice: Herberz et al. (2020) focused on mobility motives and purchase intentions for a diverse set of mobility products to understand the gap between stated preferences and actual behavior. Nguyen and Schumann (2020) aimed to simulate the short-term transportation modal choices (i.e., car, bus, tram, trains, walking, and biking) of individual households in Switzerland to understand electromobility systems by relating causes and effects. However, two research questions remain open: How different are customers' perceptions regarding the environmental impacts of EVs compared to ICEVs? What interdependences exist between EV usage and the choice of other modes of transport, such as bicycle or public transport?

Another rarely addressed aspect from a behavioral perspective is the analysis of multi-application households and local community connections, that is, smart homes or prosumers with EVs. Only a few studies focus on this aspect in our sample, and these studies apply rather technical investigations. Notably, Barone et al. (2020) combined smart metering and smart charging to help local energy communities increase self-consumption. Buonomano (2020) investigated the energy and economic performance of different vehicle-to-building energy management schemes, including a residential building, an office building, and an electric vehicle, which feature a basic cluster of human-linked energy consumers. Future research might elaborate on the perceived gains and losses of community members from participation as well as from being controlled by smart programs or losing rights to self-determination.

[**Duration of data collection**] The temporal 'gap' between the data collection and answering a research question is not surprising. The issue is particularly relevant when market penetration increases, while the data collected in the past still primarily represent consumers with characteristics of innovators. This gap may lead to biased results, as the data might be subject to sampling bias and may not reflect current behavior or broader consumer groups. Consequently, the data collected are mostly useful for "descriptive" purposes. Caution should be exercised with normative usages, such as recommendations to decision-makers, because selective data may lead to erroneous conclusions if results based on samples from specific clusters, such as early adopters or pioneers, are treated as representative of the mainstream. For example, this might lead to overestimated expectations regarding participation in dynamic tariffs, which may be perceived as significantly more complex than flat tariffs. There is no straightforward way to overcome this issue, as most research is individual in design and hence regarding the data collection method. Nevertheless, these biases can be corrected using various methods, such as statistical approaches, including the so-called Heckman correction (Heckman (1974), Heckman (1976)) and other qualitative analyses, or by assessing different characteristics of the samples, for example, non-EV users.

[**Research directions**] Currently, most markets in developed countries and beyond (notably China) have already reached or even passed the first market penetration phase. In addition, regulations tend to phase out CO_2-emitting internal combustion engines in the medium term. Thus, alternatives to EVs will become rare. This also implies that research on new car purchasing might become less interesting compared to other issues affecting EV adoption. Research activities may then focus on concepts related to EVs, such as smart charging, V2G, and tariff choice, to maintain the upward trend in citation frequency shown in Figure 7. To drive this outcome, future research should address topical questions. Beyond a better understanding of consumers in electromobility, there is a need for contributions that foster energy system transformation by providing insights from another perspective. Dedicated behavioral research may help avoid purely technical debates, based primarily on ideal techno-economic solutions but lacking considerations of actual consumer choices and preferences.

5 Conclusion

This review focuses on the role of consumers in electromobility. Therefore, we used a broad approach to assess the different behavioral aspects relevant to electromobility. We applied an extensive search and identified four main categories of consumer behavior related to EVs. Here, we found that the topics related to purchase and usage are covered more extensively, whereas tariff choice is underrepresented. Furthermore, we found a broad range of research objectives within each category. Furthermore, the range of applied methods and empirical data sources is considerable. This indicates an emerging research field, and we anticipate consolidation of both conceptual frameworks and empirical methods in the future.

As stated earlier, the research topics and findings are related to the market penetration level achieved so far. Future research should focus on investigating the behavioral aspects of novel concepts at the interface of EVs and societal challenges, including V2G technology, which is promising in terms of the additional value provided to electricity systems. Yet, in this specific case, as well as more generally regarding tariff design, a better understanding of the interplay between techno-economic aspects at the system level and behavioral aspects is key to further developing the markets and unlocking the potential of integrating electromobility into the energy system. Notable potential aspects to be explored include the avoidance of grid expansion through the implementation of 'smart' tariffs and the use of vehicle batteries for providing system services. Detailed research into tariff designs and consumer acceptance of more complex tariff structures, such as real-time pricing or time-of-use tariffs, is expected to provide key insights for the successful promotion of such system-oriented EV operations.

Finally, this review highlights the adoption of EVs and the transformation of the transport sector as topics of international interest and underlines how the research contributes findings from different markets with various challenges. Regions that are less developed, that is, with a lower market penetration, might learn from the issues and solutions found in other regions. The developments in the Scandinavian countries may here be particularly insightful, yet country-specific aspects deserve particular attention to obtain robust results, especially when behavioral aspects are considered.

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Declaration of generative AI and AI-assisted technologies in the writing process.

During the preparation of this work the authors used DEEPL and ChatGPT in order to check for grammar and spelling. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

Data Availability

Data will be made available on request.

CRediT authorship contribution statement

Marco Sebastian Breder: Conceptualization, Methodology, Investigation, Formal analysis, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization.

Arnd Hofmann: Conceptualization, Methodology, Investigation, Formal analysis, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization.

Michael Bucksteeg: Supervision, Conceptualization, Writing - Review & Editing.

Christoph Weber: Supervision, Project administration, Funding acquisition, Writing - Review & Editing.

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Appendix

Scopus filter hierarchy (most recent data update on 29th November 2023):

1st level:

TITLE-ABS-KEY ((″consumer* behavior*″ OR ″consumer* preference*″ OR ″Consumer″) AND (″purchase″ OR ″charging″ OR ″tarif*″ OR ″DRIVING*″ OR ″DRIVER*″) AND (″e mobility″ OR ″electric car*″ OR ″electric vehicle″ OR ″electromobility″ OR {PHEV*} OR {EV*} OR {PEV*} OR {BEV*} OR ″Plug in*″ OR ″battery electric vehicle*″) AND NOT (″Scooter″)) AND PUBYEAR > 2015 AND (LIMIT-TO (SRCTYPE , ″j″)) AND (LIMIT-TO (DOCTYPE , ″ar″)) AND (LIMIT-TO (SUBJAREA , ″ENER″) OR LIMIT-TO (SUBJAREA , ″ENVI″) OR LIMIT-TO (SUBJAREA , ″SOCI″) OR LIMIT-TO (SUBJAREA , ″BUSI″) OR LIMIT-TO (SUBJAREA , ″ECON″) OR LIMIT-TO (SUBJAREA , ″DECI″))

2nd level:

[**Purchase**]

TITLE-ABS-KEY ((″consumer* behavior*″ OR ″consumer* preference*″ OR ″Consumer″) AND (″purchase″) AND (″e mobility″ OR ″electric car*″ OR ″electric vehicle″ OR ″electromobility″ OR {PHEV*} OR {EV*} OR {PEV*} OR {BEV*} OR ″Plug in*″ OR ″battery electric vehicle*″) AND NOT (″Scooter″)) AND PUBYEAR > 2015 AND (LIMIT-TO (SRCTYPE, ″j″)) AND (LIMIT-TO (DOCTYPE, ″ar″)) AND (LIMIT-TO (SUBJAREA, ″ENER″) OR LIMIT-TO (SUBJAREA, ″ENVI″) OR LIMIT-TO (SUBJAREA, ″SOCI″) OR LIMIT-TO (SUBJAREA, ″BUSI″) OR LIMIT-TO (SUBJAREA, ″ECON″) OR LIMIT-TO (SUBJAREA, ″DECI″))

[**Tariff choice**]

TITLE-ABS-KEY ((″consumer* behavior*″ OR ″consumer* preference*″ OR ″Consumer″) AND (″tarif*″) AND (″e mobility″ OR ″electric car*″ OR ″electric vehicle″ OR ″electromobility″ OR {PHEV*} OR {EV*} OR {PEV*} OR {BEV*} OR ″Plug in*″ OR ″battery electric vehicle*″) AND NOT (″Scooter″)) AND PUBYEAR > 2015 AND (LIMIT-

TO (SRCTYPE, ″j″)) AND (LIMIT-TO (DOCTYPE, ″ar″)) AND (LIMIT-TO (SUBJAREA, ″ENER″) OR LIMIT-TO (SUBJAREA, ″ENVI″) OR LIMIT-TO (SUBJAREA, ″SOCI″) OR LIMIT-TO (SUBJAREA, ″BUSI″) OR LIMIT-TO (SUBJAREA, ″ECON″) OR LIMIT-TO (SUBJAREA, ″DECI″))

[**Charging**]

TITLE-ABS-KEY ((″consumer* behavior*″ OR ″consumer* preference*″ OR ″Consumer″) AND (″charging″) AND (″e mobility″ OR ″electric car*″ OR ″electric vehicle″ OR ″electromobility″ OR {PHEV*} OR {EV*} OR {PEV*} OR {BEV*} OR ″Plug in*″ OR ″battery electric vehicle*″) AND NOT (″Scooter″)) AND PUBYEAR > 2015 AND (LIMIT-TO (SRCTYPE, ″j″)) AND (LIMIT-TO (DOCTYPE, ″ar″)) AND (LIMIT-TO (SUBJAREA, ″ENER″) OR LIMIT-TO (SUBJAREA, ″ENVI″) OR LIMIT-TO (SUBJAREA, ″SOCI″) OR LIMIT-TO (SUBJAREA, ″BUSI″) OR LIMIT-TO (SUBJAREA, ″ECON″) OR LIMIT-TO (SUBJAREA, ″DECI″))

[**Usage**]

TITLE-ABS-KEY ((″consumer* behavior*″ OR ″consumer* preference*″ OR ″Consumer″) AND (″DRIVING*″ OR ″DRIVER*″) AND (″e mobility″ OR ″electric car*″ OR ″electric vehicle″ OR ″electromobility″ OR {PHEV*} OR {EV*} OR {PEV*} OR {BEV*} OR ″Plug in*″ OR ″battery electric vehicle*″) AND NOT (″Scooter″)) AND PUBYEAR > 2015 AND (LIMIT-TO (SRCTYPE, ″j″)) AND (LIMIT-TO (DOCTYPE, ″ar″)) AND (LIMIT-TO (SUBJAREA, ″ENER″) OR LIMIT-TO (SUBJAREA, ″ENVI″) OR LIMIT-TO (SUBJAREA, ″SOCI″) OR LIMIT-TO (SUBJAREA, ″BUSI″) OR LIMIT-TO (SUBJAREA, ″ECON″) OR LIMIT-TO (SUBJAREA, ″DECI″))

Sample Statistics


0 5 10 15 20 25
Sustainability (Switzerland)
Energies
Transportation Research Part D: Transport and Environment
Energy Policy
Transportation Research Part A: Policy and Practice
Journal of Cleaner Production
Applied Energy
Energy
Journal of Energy Storage
Energy Economics
Energy Research and Social Science
Transport Policy
International Journal of Sustainable Transportation
Technological Forecasting and Social Change
Energy Reports
Environmental Science and Pollution Research
Environmental Research Letters
Sustainable Energy, Grids and Networks
Case Studies on Transport Policy
Journal of Power Sources
Environment, Development and Sustainability
International Journal of Electrical Power and Energy Systems
Electric Power Systems Research
Sustainable Cities and Society
Transportation Research Part B: Methodological
Electric Power Components and Systems
International Journal of Energy Research
International Journal of Hydrogen Energy
Renewable and Sustainable Energy Reviews
Transportation Research Part C: Emerging Technologies
eTransportation
Energy and Environment
Environmental Science and Technology
International Journal of Electric and Hybrid Vehicles
International Transactions on Electrical Energy Systems
Production and Operations Management
Research in Transportation Business and Management
Resource and Energy Economics
Transportation Research Part E: Logistics and Transportation Review
Business Strategy and the Environment
Dianwang Jishu/Power System Technology
Energy Conversion and Management
Energy Efficiency
IEEE Transactions on Transportation Electrification
Journal of the Electrochemical Society
Nature Energy
Chinese Journal of Population Resources and Environment
Dianli Xitong Zidonghua/Automation of Electric Power Systems
Energy Strategy Reviews
IEEE Power and Energy Magazine
IEEE Transactions on Power Systems
IEEE Transactions on Sustainable Energy
International Journal of Emerging Electric Power Systems
International Journal of Environmental Research and Public Health
International Journal of Transport Economics
Journal of Retailing and Consumer Services
Jurnal Optimasi Sistem Industri
Renewable Energy
Research in Transportation Economics
Sustainable Production and Consumption
2016 2017 2018 2019 2020 2021 2022 2023 2024


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Transportation Research Part F: Traffic Psychology and Behaviour
Vision
Benchmarking
Clean Technologies and Environmental Policy
Cleaner and Responsible Consumption
Electricity Journal
Energy Sources, Part A: Recovery, Utilization and Environmental Effects
Environmental Research Communications
European Journal of Marketing
European Journal of Operational Research
Frontiers in Energy Research
Frontiers in Environmental Science
IEEE Transactions on Engineering Management
IET Generation, Transmission and Distribution
International Journal of Energy Economics and Policy
Journal of Environmental Economics and Management
Journal of Green Engineering
Mitigation and Adaptation Strategies for Global Change
Resources, Conservation and Recycling
Transport Reviews
Transportation
Transportation Letters
Transportation Research Interdisciplinary Perspectives
Advanced Science Letters
American Economic Journal: Economic Policy
Applied Ergonomics
Asia-Pacific Journal of Operational Research
Business Strategy and Development
China Report
Climate Policy
Communications in Transportation Research
Computers and Operations Research
Ecological Economics
Economy of Regions
Energy Conversion and Management: X
Energy Informatics
Energy Storage
Energy for Sustainable Development
Energy, Sustainability and Society
Geography Compass
Global Journal of Flexible Systems Management
IEEE Transactions on Power Delivery
IEEJ Transactions on Power and Energy
Indian Journal of Marketing
International Journal of Advanced Science and Technology
International Journal of Automotive Technology and Management
International Journal of Business Excellence
International Journal of Consumer Studies
International Journal of Production Economics
International Journal of Smart Grid and Clean Energy
International Journal of Transportation Science and Technology
Journal of Advanced Transportation
Journal of Decision Systems
Journal of Distribution Science
Journal of Environmental Protection and Ecology
Journal of Industrial Integration and Management
Journal of International Studies
Journal of Logistics, Informatics and Service Science
Journal of Policy Analysis and Management
Journal of Transport Geography
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Naval Research Logistics
Patterns
Progress in Industrial Ecology
Quanqiu Nengyuan Hulianwang
Review of Environmental Economics and Policy
Service Science
Sustainable Energy Technologies and Assessments
Sustainable Operations and Computers
Technology and Economics of Smart Grids and Sustainable Energy
Travel Behaviour and Society
World Review of Intermodal Transportation Research
ABAC Journal
ACS Energy Letters
Advances in Transportation Studies
African Journal of Business and Economic Research
Annals of Operations Research
Asia Pacific Journal of Marketing and Logistics
Asian Journal of Management Cases
Atmosphere
Australasian Marketing Journal
Automotive Experiences
Baltic Region
Batteries
Big Data and Cognitive Computing
CIGRE Science and Engineering
Central European Business Review
Clean Energy
Cleaner Logistics and Supply Chain
Communications - Scientific Letters of the University of Žilina
Dianli Zidonghua Shebei/Electric Power Automation Equipment
Discover Sustainability
Economic Modelling
Economics and Policy of Energy and the Environment
Electrical Engineering in Japan (English translation of Denki Gakkai Ronbunshi)
Electricity
Electronic Markets
Energy Journal
Energy Sources, Part B: Economics, Planning and Policy
Energy and AI
Energy and Environmental Materials
Engineering Management in Production and Services
Environment and Social Psychology
Environmental Innovation and Societal Transitions
Environmental science & technology
EuroMed Journal of Business
Foresight
Fuel Cells
Global Environmental Change
IEEE Industry Applications Magazine
IEEE Open Access Journal of Power and Energy
IEEJ Journal of Industry Applications
IET Renewable Power Generation
IET Smart Cities
Industrial Management and Data Systems
Innovative Marketing
International Energy Journal
International Journal of Business and Management Science
International Journal of Economics and Business Research
International Journal of Energy Production and Management
International Journal of Product Lifecycle Management
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International Journal of Production Research
International Journal of Technology
International Journal of Transport Development and Integration
International Review of Electrical Engineering
Iowa Law Review
Jiaotong Yunshu Xitong Gongcheng Yu Xinxi/Journal of Transportation Systems Engineering and Information Technology
Joule
Journal of Brand Strategy
Journal of Business Economics
Journal of Business Research
Journal of Contingencies and Crisis Management
Journal of Energy Chemistry
Journal of Environmental Management
Journal of Global Business and Trade
Journal of Industrial Ecology
Journal of Innovation and Knowledge
Journal of International Consumer Marketing
Journal of Islamic Marketing
Journal of Materials Chemistry A
Journal of Modern Power Systems and Clean Energy
Journal of Operations Management
Journal of Optimization Theory and Applications
Journal of Organizational Behavior Education
Journal of Property, Planning and Environmental Law
Journal of Psychology: Interdisciplinary and Applied
Journal of Public Policy and Marketing
Journal of Real Estate Research
Journal of Technology Management and Innovation
Manufacturing and Service Operations Management
Market-Trziste
Marketing Letters
Men and Masculinities
Nankai Business Review International
Operations Research Letters
Polityka Energetyczna
Proceedings on Engineering Sciences
Psychology and Marketing
Psychology of Men and Masculinity
Reliability: Theory and Applications
Resources Policy
SAGE Open
SN Applied Sciences
Science of the Total Environment
Security Dialogue
Simulation and Gaming
Smart Cities
Socio-Economic Planning Sciences
Solar Energy
Supply Chain Management
Sustainable Development
Sustainable Futures
Sustainable Materials and Technologies
Systems
TEM Journal
Taiyangneng Xuebao/Acta Energiae Solaris Sinica
Technical Electrodynamics
Technology Analysis and Strategic Management
Technology in Society
Ultrasonics Sonochemistry
Urban Planning
Urban, Planning and Transport Research
Young Consumers
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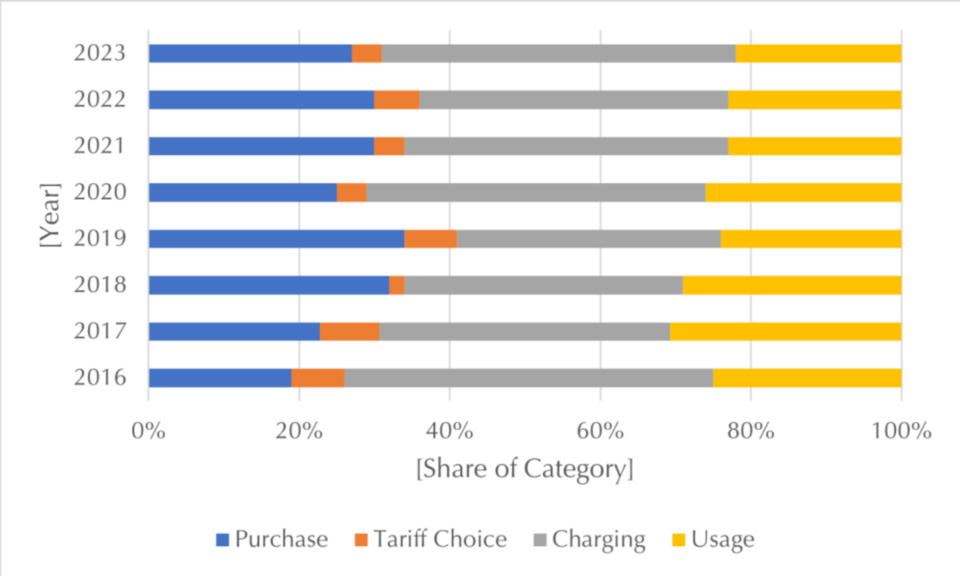
Analysis on Sample



Temporal relational development of “Research Categories.”

EV Market Data (IEA)

Share of Electric Vehicles Sales [2010-2021]

Year	Australia	Belgium	Brazil	Canada	Chile	China
2010		0.0064				0.01
2011	0.0065	0.052		0.041	0.0025	0.034
2012	0.03	0.25999999	0.003	0.15000001	0.002	0.062
2013	0.034	0.14	0.0055	0.22	0.0018	0.083
2014	0.16	0.43000001	0.0022	0.34	0.0068	0.34999999
2015	0.2	0.76999998	0.0041	0.44999999	0.017	0.94
2016	0.15000001	1.70000005	0.01	0.73000002	0.013	1.39999998
2017	0.25999999	2.70000005	0.017	1	0.049	2.29999995
2018	0.41999999	2.5	0.015	2.70000005	0.056	4.5
2019	1.20000005	3.20000005	0.084	3.20000005	0.11	4.5999999
2020	1.10000002	11	0.15000001	4.19999981	0.1	5.30000019
2021	2.79999995	18	0.47	6.5999999	0.19	16

Year	Denmark	Europe	Finland	France	Germany	Greece
2010	0.031	0.014		0.0085	0.0049	
2011	0.25	0.075	0.025	0.13	0.052	
2012	0.28999999	0.2	0.17	0.34	0.11	
2013	0.28	0.41999999	0.20999999	0.55000001	0.23	0.0051
2014	0.85000002	0.63999999	0.41	0.72000003	0.41999999	0.055
2015	2.20000005	1.20000005	0.63	1.20000005	0.72000003	0.1
2016	0.80000001	1.20000005	1.20000005	1.5	0.73000002	0.12
2017	0.58999997	1.70000005	2.5	1.79999995	1.60000002	0.22
2018	2.0999999	2.20000005	4.5	2.20000005	1.89999998	0.30000001
2019	4.19999981	3.20000005	6.9000001	2.79999995	2.9000001	0.41999999
2020	16	10	18	11	14	2.5999999
2021	35	17	31	19	26	6.9000001

Year	Iceland	India	Italy	Japan	Korea	Mexico
2010	0.06	0.021	0.002	0.055	0.005	
2011		0.056	0.0065	0.33000001	0.023	0.00039
2012	0.31	0.0072	0.033	0.52999997	0.041	0.011
2013	1.29999995	0.016	0.075	0.63999999	0.048	0.0013
2014	2.0999999	0.038	0.1	0.67000002	0.093	0.0049
2015	3.5999999	0.017	0.14	0.56	0.22	0.0085
2016	5.5999999	0.026	0.15000001	0.57999998	0.33000001	0.056
2017	12	0.031	0.25	1	0.94	0.09
2018	17	0.03	0.50999999	0.94	3.79999995	0.14
2019	23	0.024	0.88999999	0.75	2.29999995	0.063
2020	52	0.13	4.30000019	0.63999999	2.5	0.31
2021	72	0.38	9.5	1	6.19999981	0.5

Year	Netherlands	New Zealanc	Norway	Other Europ	Poland	Portugal
2010	0.025	0.0063	0.28		0.0015	0.31999999
2011	0.16	0.0099	1.39999998	0.044	0.0046	0.12
2012	1	0.017	3.0999999	0.093	0.0052	0.055
2013	5.4000001	0.019	5.80000019	0.076	0.0051	0.17
2014	3.9000001	0.14	14	0.19	0.018	0.14
2015	9.80000019	0.2	22	0.23999999	0.029	0.56
2016	6	0.56999999	29	0.34	0.052	0.80000001
2017	2.5	1.20000005	39	0.54000002	0.12	1.89999998
2018	6.30000019	1.89999998	49	0.77999997	0.14	3.70000005
2019	15	2.79999995	56	1.20000005	0.28	5.69999981
2020	25	2.79999995	75	2.5999999	0.83999997	14
2021	30	4.4000001	86	4.9000001	1.39999998	20

Year	South Africa	Spain	Sweden	Switzerland	United Kingc	USA	World
2010		0.0077	0.0013	0.047	0.014	0.011	0.012
2011		0.049	0.054	0.14	0.063	0.17	0.072
2012		0.076	0.31	0.22	0.13	0.41	0.16
2013	0.0075	0.12	0.52999997	0.43000001	0.17	0.74000001	0.27000001
2014	0.0034	0.2	1.39999998	0.95999998	0.58999997	0.88999999	0.41999999
2015	0.058	0.20999999	2.4000001	1.70000005	1.10000002	0.77999997	0.68000001
2016	0.1	0.31	3.4000001	1.89999998	1.39999998	1	0.88
2017	0.053	0.60000002	5.0999999	2.70000005	1.79999995	1.20000005	1.29999995
2018	0.04	0.87	7.5999999	3.20000005	2.0999999	2	2.20000005
2019	0.064	1.39999998	11	5.5999999	3.0999999	2.0999999	2.5
2020	0.098	4.9000001	32	14	11	2.20000005	4
2021	0.089	7.9000001	43	22	19	4.5999999	8.60000038

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