Chapter 9

# Patent Research in a Period of Industry Transformation: A Focus on Electromobility

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http://dx.doi.org/10.5772/intechopen.75579

**Abstract**

Patent, as a valuable collection of technical information, is gaining momentum as proxy measures of innovative activities and is ascribed a unique role in tracking the rise of emerging technologies. The last 30 years have seen a dramatic transformation of the world's manufacturing landscape, for instance, a greening development in the automotive sector. A typical example of this practice is the emergence of electromobility (e-mobility)—an integrated approach addressing issues from sustainable transportation to revolutionary driving behavior adopted to circumvent problems concerning both resources and pollution while meeting mobility demands. Since novel technologies covered by e-mobility are not yet entirely attainable in the market, the only metric particularly is patent data. However, a correspondingly bright light seems not to be shined on e-mobility patent research, even in the area of engineering. This paper employs bibliometric and sentence-by-sentence analysis coupled with visualization tools to illustrate how the patent examines e-mobility-oriented issues in a contextualized and multivalent way. The conclusion reached is that patent research on e-mobility still has more spaces to move up, not only in improving its efficiency in plotting evolution of technologies but with regard to interpreting patents across the historical background of the industrial revolution.

**Keywords:** patent research, electromobility, bibliometric analysis, methods and design practices, conclusive and citing parts, sentence-by-sentence analysis

## 1. Introduction

As reported by WIPO, after 7 years of straight increases, global patent filings reached new highs in 2016—3.1million with annual growth of 8% [1]. It has correspondingly caught considerable interests ranging from social science research to economic analysis [2–4],

accumulating more than 16,000 international publications over the past 10 years. Conversely, patent study on e-mobility failed to go up by the same proportion even though it plays a tremendous role in promoting the development of technological innovation while being the focal point of a thoroughly international academic discourse. Referring to vehicles that rely on plug-in electricity for their primary energy [5], e-mobility is currently supported as a favorable approach to transform road transport by reducing carbon emissions and discussing drivers of change in the automotive industry [6, 7]. For accelerating technological progress, e-mobility has been extensively explored from commercial, political, and social network perspectives [8–10], indicating that this field represents a significant technical challenge and requires complex social changes. Even some deficiencies inherent in patent research are not to be neglected, for instance, not every technical invention is patented [11, 12]. Patent data as a special type of literature still has the advantage of being more retrievable and well organized in research for supporting scientific and technological decision, creating preferential development domains and protecting enterprise rights. Amid the rising concern and limited publication counts, new questions arise: How are patents integrated into e-mobility studies? How do e-mobility studies in turn shape them? And how, if at all, might scholars intervene in these processes?

In retrospect, patent documents have been assessed in conjunction with data extracted from scientific publications and industry products to examine recent developments and research progress on cold startup of automotive proton exchange membrane fuel cells (PEMFC), complete oxidation of methane at low temperature over noble metal, powertrain architectures, adsorbed natural gas technologies, and robust battery pack for electric vehicles (EVs) [13–17]. To trace the commercial pathway for ultra-capacitor technology, patents, especially the assignment information, are analyzed combined with investment figures [18]. However, the reason for applying patents to those studies has not been pointedly outlined and reviewed. Recent articles focus on patent-based indicators as to counts, families, portfolios, and citations in evaluating the effectiveness of e-mobility technology forcing policies and identifying technological changes, particularly around EVs [19–22], while the existing literature lacks details in conclusion on specific approaches and findings. The methods and design practices of e-mobility patent studies deserving of greater attention are the ones that place references at the forefront of the discussion about technology-driven innovation.

The present study, with a data set of 48 journal papers, is developed to review the patent research in the field of e-mobility by integrating a bibliometric overview on keywords and citations for insights into relevant research topics and knowledge base, then to trace back to the texts for an in-depth understanding of patent-use in practice and its contexts for answering the question: Does a lower share of international publications correspond to a less useful or more difficult intersection of patent analysis, especially into a field like e-mobility involving both traditional and emerging technologies? This special issue is a bridging effort to bring together patent study and bibliometric analysis by putting a spotlight on research progress, limitations, and potential topics in a period of industry transformation.

http://dx.doi.org/10.5772/intechopen.75579

## 2. E-mobility and significance of patent research

The invention of automobiles has been perceived as the promotion of global economic development and improvement of living standards by enabling mobile freedom. However, the growing concern for energy, environment, traffic safety, industrial competitiveness, and technology improvements raises the question of whether this freedom of mobility would be sustainable in the new era [7, 23]. The current and renewed interest in e-mobility can be explained in accordance with drivers of change earlier in the automotive industry. This term is not entirely new, and its central idea is urban electric cars which can be traced back to 50 years earlier than the first petrol-powered internal combustion engine vehicle (ICEV) [24, 25]. For stimulating technological progress, EVs in principle should now have a bright future; however, a lighter, cleaner, and smarter automobile era with adoption of wireless connections is in the movement [8, 9]. There is still considerable concern that efforts to date on making conventional powertrains more fuel efficient and less-polluting are insufficient [26]. This study thus is more inclined to adopt an expanded scope of e-mobility technologies other than the single category of EV-based technologies. Academics in this field are traditionally identified as having strong connections to governments and industries, as it is associated with the shift to a broader network of actors and stakeholders, ranging from automotive giants to battery-charging services providers [10, 27]. Thus, research on e-mobility not only seeks to answer the question of technology updating but is designed to give a sharp focus on changes caused by automotive industry transformation.

A wealth of technological, geographical, and industry information provided by patent has generated it to be a frequently used measure for studying basic research and anticipating emerging trends in automobile innovation [19, 21]. Bibliographic data extracted from patent documents is largely publicly available and quantitatively measurable [28, 29], which offers clear benefits in comparison with other indicators, for example, the one built upon R&D, to identify and measure patterns concerning innovative activities in uncertain technological fields [21]. Despite the controversial debate on the use of patent statistics to evaluate technological progress, the advantages prevail and empirical studies, particularly in research-intensive areas like e-mobility, support the application in obtaining an adequate output with a minimized input [11, 30]. The current publication counts contrast starkly with the significance of delving into patent issues of e-mobility. Hence, to drive further adoption of patent analysis as for e-mobility, scrutinizing related articles for progress, limitations, and potential topics is causally necessary.

## 3. Data and methodology

Advanced bibliometric analysis is regarded as a powerful method to answer questions, such as "How can we keep track of the increasing number of scientific articles? Are there specific patterns hidden in this mass of published knowledge at a meta-level, and if so, how

can these patterns be interpreted?" which enable us to analyze structures and dynamics of fields [31, 32]. Forty-eight articles in English identified by merging the query of terms[1] in the scope of e-mobility (e.g., electric vehicles, hybrid electric vehicle, etc.) with the topic search of patent (TS = patent*) from the Web of Science™ Core Collection (WoS) database up to 2017 are discussed in this chapter aiming to investigate the current progress of patent research on e-mobility. Visualizations are addressed throughout the discussion by explaining how they are produced and how they can be interpreted. Extrinsic data to the text such as the publication year, keywords, and citations are synthetically measured in a co-occurrence analysis, a technique that captures the frequency of pairs of words, phrases, or references in and between articles [33]. The first step is to represent the association of research topics and to observe the progress along with the time, source, and flow of knowledge, eventually to understand the development of scientific fields. The common base and expansion of knowledge are structured through backward and forward references by performing a co-citation and bibliographic coupling analysis, respectively, and the former depends on the frequency when two documents are cited together whereas the latter occurs when two works reference a common third work [33, 34]. Then, intrinsic information regarding the reason for performing patent analysis of e-mobility issues, research limitations, and trends dug out from abstracts, methods, conclusive parts, and recent highly cited papers are collected and categorized on a sentence-by-sentence basis in order to advocate for greater attention to article content in addition to the bibliometric analysis.

## 4. Patent research on e-mobility

### 4.1. A bibliometric overview

#### *4.1.1. General trend and main research topics*

The earliest publication involved in the present data set could be traced back to 1993 [35] and the pressing environmental concern has renewed calls for a shift toward internationalization of e-mobility research since 2012. Even the number of patent researches is limited, the sources are relatively scattered (132 authors from 58 affiliations), and their collaborations could not be captured in an extensive network (only 3 authors are engaged in the co-authorship more than once). In **Figure 1** 323 authors' keywords are cleaned up manually considering the problem of variants (e.g., "electric vehicles" and "EVs") and then 48 terms meeting the threshold (occurrences ≥2) are processed into 6 main clusters and colored using average publication year by VOSviewer. Patents have been employed to reveal the hype cycle for emerging technologies between 2001 and 2013 and then are discussed by introducing novel techniques (e.g., Google search) after 2014. Terms of "innovation" and "EV" as key nodes have been continuously

[1]Each term in the present query is sorted and filtered based on expert advice received from National Science Foundation of China (No.71673036) and Consulting Project of Chinese Academy of Engineering (2016-XZ-03-05).

http://dx.doi.org/10.5772/intechopen.75579

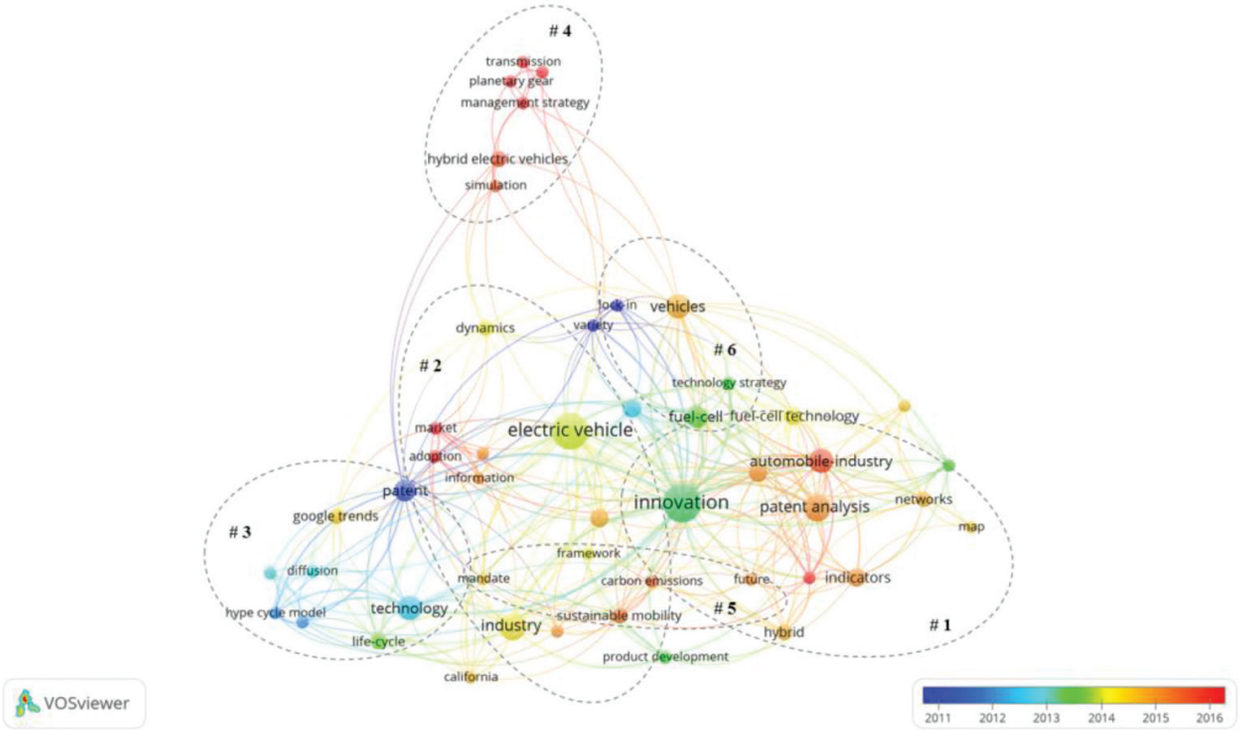


**Figure 1.** Co-occurrence analysis of keywords with average publication year.

explored ranging from the topics of patent-based indicators and approaches to technologies and the automotive industry as well as green products and market since 2013. Recently, the focus of patent research lies with the emergence of hybrid devices. E-mobility issues are inevitably tied to carbon emissions, efficient strategy, and sustainable development, which is proved in cluster 5 and 6.

### *4.1.2. Citation-based knowledge flows*

Filtered by the minimum number of citations, 51 of 1788 references are collected and form four main clusters (**Figure 2**). The paper published by van den Hoed in 2005 [36] is represented as a key node among a group of emerging technology-based studies in red at the interface between discussions on emerging eco-innovation evaluation (green nodes on the top) and the cluster of papers adopting patent-based indicators in measuring technological change (yellow nodes in the middle). Note that citation is more frequent and probably more disciplined on the overall innovation performance research side, which also provides us with different kinds of evidence for the deficiency in e-mobility patent study. Among the technological forecasting-focused papers on the right side of **Figure 2** (blue nodes), the co-citation analysis highlights authors [37–39] who have engaged in discussions with the joint use of bibliometric and patent analysis. The first cluster indicated in red is led by research from van den Hoed and Bakker [36, 40], who share an interest in the development of fuel cell technology. Citations categorized into the second cluster have an earlier average publication year than that of the first cluster, including studies on e-mobility innovation coupled with policy, economic, and

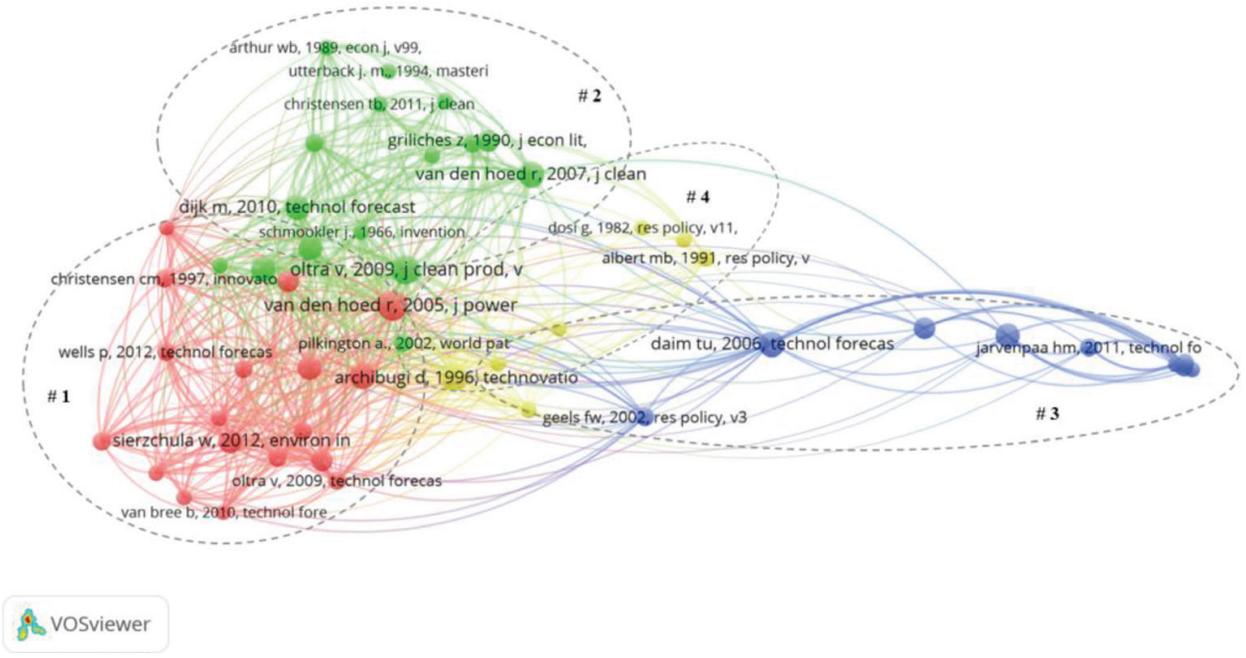


**Figure 2.** Co-citation analysis of references listed in 48 papers.

technology analysis [41–43]. Patent citation analysis is the central topic of discussion involved in the fourth cluster with the earliest average publication year of 2000 [44–46]. Namely, the core documents providing a common knowledge base for e-mobility patent study are relatively new and it is partly an effect of emerging technologies and the changing field.

By contrast, an analogous network structure could not be found through a bibliographic coupling analysis of 462 citing papers owing to the unclear layout of nodes and their links. It may indicate that the knowledge of these 48 patent studies is expanded to a much broader scientific field with more creative and diverse approaches to exploring e-mobility issues. Moreover, the share of self-citations is comparatively high and implies that there has existed specific groups of authors in this research area and their studies possess certain coherence.

### 4.2. The usage of patent

For answering the question of how patents are involved in e-mobility study and thus providing a reference point for further adoption of patent research, three main categories of the introduction of patents differed in research perspectives, and data formats are identified. **Table 1** outlines the direct use of patent-based indicators (e.g., counts, families, and citations) or patent documents (e.g., abstracts and literature) in view of reasons, including main routes as tracing the technological and industry trend, evaluating policies and innovation, as well as improving patenting activities and patent-based analysis [19, 22, 47–50]. Besides, the importance of patented technologies is highlighted while the rise in patenting activities and their commercialization indicate that a clean technology revolution staged by e-mobility is approaching [51, 52].

| | | |
|---|---|---|
| Reasons | Patent as the proxy for innovative output is the most common way in the automotive industry to protect intellectual property. | Patent documents include potential information on developed technologies |
| Measures | Patent—applications, counts, grants, families, origin countries and priority years, publications, citation networks, assignees, organizations, portfolios, keywords, International Patent Classifications (IPC) | Patent—pending applications, abstracts, literatures |
| Aims | To assess industry structure; examine the patterns of technological change; forecast diffusion or adoption patterns of new technologies; understand technology maturity; evaluate the effectiveness of technology-forcing policies; measure the incentive and opportunity to innovate; operationalize the R&D and commercialization aspects of innovation strategies; study the relationship between competitive forces and technological development; propose a predictive model of the patent registration time; find differences between patents and research publications for technology road mapping; filter the irrelevant patent citations; and verify components of the hype cycle | To describe technology in detail; explore technology clusters; give an indication as to main technical challenges for the relevant technology; assess technological evolvement or accelerate literature-based science discovery |

**Table 1.** The usage of patent in an e-mobility study extracted from abstracts and methods.

### 4.3. Limitations and potential topics

#### *4.3.1. Recent research limitations*

Some of the deficiencies inherent in patent research are synthesized and divided into groups of limitations regarding patents or data sources [21, 53, 54] and patent-based indicators or approaches [47, 55, 56], respectively, thereby pinpointing areas of improvement in the further study on e-mobility. However, the following limitations should not be viewed in isolation, and the specificity of e-mobility field, especially the novelty and complexity of technologies [19, 21], needs to be considered in addition to patent-oriented issues (**Table 2**).

#### *4.3.2. Potential topics*

A series of up-to-date topics captured from citing articles based on recent highly cited ones in **Table 3** could be classified into the extension of the specific technology discussion, patent-based analysis, and research on innovation system or policies in the field of e-mobility [47, 57–62]. The classification of additional research perspectives is inevitably influenced by the usage of patent in highly cited papers (**Table 1**). More specifically, a review on patented technologies has developed the base for further experimental studies, and papers adopting patent-based indicators could arouse growing interests in examining the pattern of technological change [21, 63]. Patents combined with other format of data, such as scientific literatures, surveys, interviews, or press releases, may contribute to a more comprehensive understanding of relevant policy and innovation system research [48, 54].

| Category | Limitations of patents or data sources in itself | Shortcomings of patent-based indicators or approaches |
|---|---|---|
| Limitations and drawbacks | -Not all technological knowledge is covered by patent data as not all inventions are patentable and not all patentable innovations are really being patented.<br>-Web search is relied on secondary, and other sources are emerging, which may cause a shift in the category of search engine users.<br>-Firms may exhibit differences in their tendencies to patent and their willingness to publish strategic decisions, thus affecting patent database.<br>-It is difficult to cover every value chain step with relevant IPC codes. | -The analysis of the revealed technological advantage (RTA) is always subject to consideration of absolute numbers within the technologies.<br>-Forming technology clusters through affinity propagation (AP) is susceptible and the interpretation of the technology clusters by using extracted core keywords is qualitative judgment.<br>-Identifying important groups and the total groups that form a particular technology affects forecast.<br>-Patent counts are not always representative for the success of the invention as its commercialization is not guaranteed. |

**Table 2.** Recent research limitations stated in conclusive parts of publications (since 2015).

## 5. Discussion and conclusion

The present findings drawn from the bibliometric and sentence-by-sentence analysis of 48 journal papers indicate that patents, as indicators or references alike, still occupy an irreplaceable position in tracking the rise of emerging technologies. Since 2001, a sequence of structural data extracted from patents, like counts, grants, or classifications, has been employed to assess industry structure and examine the patterns of technological change. Assignees, organizations, and portfolios involved in patents are analyzed to measure the R&D and commercialization aspects of innovation strategies. New technologies' forecasting has been increasingly produced by keywords and patent citations accompanied with the emergence of advanced data search and mining techniques. Details of e-mobility technologies, ranging from batteries to smart grids, are scrutinized as references based on patent documents. Contents are continuously being specified and updated in line with the overall trend in the development of e-mobility, accounting for elements behind pure statistics. Even the patent study on e-mobility has not already accumulated a remarkable number of publications; the potential topics revealed by extended use of recent highly citied papers are researchable, including the analysis of automotive supply industry, technology diffusion, and landscape as well as the evaluation of green innovation system and policies. A specific focus in latter the e-mobility patent study is to expound key technical problems regarding free-piston linear generator. Drivers, the current momentum, and policies are constantly analyzed to answer the question of how EV development is accelerated. However, limitations rooted in patent data concerning patentability, search engine, willingness to publish, and the IPC-based bias with the one-sidedness of certain patent-based indicators mentioned as earlier should be noticed in further adoption of patents in e-mobility analysis, especially for improving its efficiency in plotting evolution of technologies and interpreting patents in a specific context. The limitation of such a study is that characteristics of patent study could not be fully identified because they are only identified from publications in an emerging field and the relevant search terms have not been unified in the past research. Nevertheless, it could be a sign of renewal when issues highlighted by those articles are explored in depth.

| Times cited/Tittle (purpose) | Cited idea | Further study |
|---|---|---|
| 18/Recent commercial free-piston engine developments for automotive applications (reviewing commercial developments in free-piston engine systems by looking at recent publications and patent documents) | "…discussed the basic features of a free-piston engine generator and the dynamics of the engine …" | Experimental study of a free-piston linear generator |
| 15/Identifying trends in battery technologies with regard to electric mobility: evidence from patenting activities along and across the battery value chain (applying patent families as technological indicators in order to analyze the research activities of each step of the designed battery value chain individually and in comparison with each other to identify and discuss trends regarding the technologies associated with electric vehicles) | "…lithium-ion batteries have dominated very quickly…"<br>"…the booming consumer electronics industry rapidly changed the economic and social landscape…"<br>"…patent based studies have noted strong interest in radical innovation paths…" | Patent study on the automotive supply industry, technologies' diffusion, technological distance, technology landscape, and innovation network |
| 9/Business strategies of incumbents in the market for electric vehicles: Opportunities and incentives for sustainable innovation (analyzing how environmental regulation and the firm's incentive and opportunity to innovate affected EV sales) | "…finds the same contrasting technology strategies employed by electric passenger vehicle manufacturers and companies need both incentives and opportunities…" | Review the proposal of conceptual framework regarding green innovation system; evaluate environmental policy and innovation |
| 5/On the relation between communication and innovation activities: A comparison of hybrid electric and fuel cell vehicles (analyzing the relation between research and innovation activities and communication activities in the automotive industry using patent statistics, press releases, and interviews) | "…vehicle electrification can ease environmental problems …"<br>"…the changing perception of the hybrid technology led to a 'hybrid race' testified by the significant increase in patents…" | analysis on drivers, the current momentum, and policies for accelerating EV development |

**Table 3.** Highly cited publications and cited ideas (times cited ≥5 since 2015).

## Acknowledgements

The author would like to thank for financial support provided by the China Scholarship Council (No.201506060153), the National Science Foundation of China (No.71673036), and the Consulting Project of Chinese Academy of Engineering (2016-XZ-03-05).

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