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Review

Exploring the Impact of Technological Innovation on the Development of Electric Vehicles on the Bibliometric Perspective of Innovation Types

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Abstract: Innovation has always been the driving force behind social progress. Enterprises will adopt different types of technological innovations according to their goals, resources, and market strategies. The industry generally pays attention to the development and application of electric vehicle technology innovation, but a single method may not be able to fully explain the innovation of electric vehicle technology. Furthermore, the results of technological innovation must be presented in terms of market benefits. Otherwise, insufficient cash flow will lead to innovation interruption. Therefore, this study uses the innovation matrix proposed by Rothaermel to classify the matrix formed by the market and technology. This study collects 43 periodicals and special publications published in 2010–2022 and 40 related electric vehicle literature that can be downloaded, summarizes the literature content according to the innovation matrix using literature bibliometric perspective and analysis, and obtains (1) most of the innovative technologies of electric vehicles originated from the extension of previous technologies and (2) batteries and power supplements that are the key items of electric vehicles. The proportion of radical technological innovation is relatively high, and they are also the main factors of market sales. Theoretically, this study can provide a basis for studying the combination of Rothaermel's "innovation matrix" and Ansoff's "expansion matrix". In practice, this is the first time the electric vehicle industry is taken as an example, combining the two models, aiming at technology/production/market/performance for electric vehicle industry managers, the technological innovation direction, and the formulation of market strategy operations and advanced deployment.

Keywords: innovation type; technological innovation; electric vehicle; Rothaermel's matrix; Ansoff's matrix; marketing strategy

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1. Introduction

With the development of science and technology, the automobile industry has undergone tremendous changes in innovation and technology applications. New types of mobile manned vehicles such as electric vehicles have changed human driving habits and mobile demands [1]. The global automobile industry is facing the trend of electrification. Although traditional car manufacturers started slowly, they have gradually completed the development of pure electric vehicles and launched new brands or new series to cope with and defend the original market size [2]. New start-up manufacturers surpass traditional car manufacturers with brand, quality, and different types of technological innovations and accelerate production expansion to seize their market shares. Global sales of electric vehicles are increasing rapidly. According to Trend Force [3] research in 2021, the total sales of new energy vehicles (including pure electric vehicles, plug-in hybrid electric vehicles, and fuel cell vehicles) will reach 6.473 million, with an annual growth rate of 122%. Japan's Fuji Keizai predicts that the market size of electric vehicles will surpass gasoline–electric hybrid vehicles in 2021 and become the mainstream of the new energy passenger vehicle market, and the global electric vehicle market is expected to increase nearly 11 times in 2035 [4].

Optimistic about the development of electric vehicles, scholars have successively published research based on innovative technologies related to electric vehicles, such as artificial intelligence on electric vehicle technology innovation [5], electric vehicle technology and patents [6–8], comparison between electric vehicle batteries and internal combustion engines [9], and electric vehicle powertrain patent data [10]. The previous literature mostly investigated the context of technological innovation, and there are fewer works in the literature regarding market and technology-based innovation types. We carefully evaluate that no matter how good the technological innovation is, if the innovative product cannot achieve good market performance, this kind of innovation is equivalent to an invalid innovation. Ineffective innovation will also lead to the inability of the firms to survive and the interruption of innovation. Therefore, we combine the market/product Ansoff's "Expansion Matrix" [11,12] and the market/technology Rothaermel's "Innovation Matrix" [13,14], and this clear combination defines different innovation types corresponding to different markets to generate the best market strategy and achieve the best market performance. To the best of our knowledge, this is the first paper to combine two models recognized by academia and successful in the market that are combined for innovation evaluation, which has sufficient novelty and use value.

This study attempts to analyze different types of technological innovation literature via bibliometric analysis, sorting 43 related electric vehicle papers published in journals and special publications in 2010–2022, which can be downloaded, and summarizes the content of the periodicals classified according to the "Innovation Matrix" [13] with market and technology as the coordinate axis. Finally, it is explained according to the classification results to prove the impact of different types of technological innovation strategies in different markets on corporate performance. Finally, it proposes theoretical and management implications of the practice, explaining the technological innovation strategy of the electric vehicle market development in Taiwan. The remainder of this paper is organized as follows: Section 2 explains the important studies in the field of technological innovation and notes on innovation classification; Section 3 describes the methodology used; Section 4 shows the results, followed by a discussion; Section 5 outlines the conclusions, implications, and scope for future research.

2. Theoretical Development

2.1. Innovation

Innovation can have different forms of processes and different outcomes. Innovation can occur at the product, process, organizational, market, or input level and is a central action in all economic development and productivity [15]. In terms of innovation, it can refer to changes made to an existing product, idea, or field. In other words, innovation is thinking oriented, using existing knowledge and materials to meet social needs to improve or create new things, methods, elements, paths, and environments and to obtain certain beneficial effects. Innovation is a topic of interest to both academia and the industry. But, the concept of innovation is complex and multifaceted [16], often overlapping, without clear and authoritative rulings [17]. In general, the simplest definition of innovation is doing something different [17]. The Oslo Manual [18] defines innovation as a new or improved product or process (or a combination thereof). Scholars such as Baregheh, Rowley, and Sambrook [19] pointed out that innovation is a multi-stage process in which enterprises transform ideas into new or improved products, services, or processes in order to be competitive in the market. Boer and During [20] also defined innovation as the creation of a new product–market–technology–organization combination. In these definitions, "new" is the main focus of innovation [21]. Based on the above definition of innovation, this study believes that Boer and During [20]'s description, which combines market and technology with products, is more in line with the focus of this study.

2.2. Technological Innovation

Technological innovation is mainly about the product or service, and the connections between its components, methods, processes, and technology [15]. Many authors [22–26] have combined technology and market perspectives in the development of innovation theory. Yam et al. [26] added that technological innovation resources are heavily invested in innovation activities, which are the most direct to performance improvement. According to Baden-Fuller and Haefliger [27], a radical improvement in a product or service will automatically bring about an increase in the profits of the innovative company. Huang et al. [28] explained that the competitive advantage comes from the R&D owned by the firm and the R&D capability executed. Its so-called R&D and execution capabilities are technical capabilities, and continuous innovation can maintain a competitive advantage. In other words, technological innovation is the core of a company's competitiveness. Hafeez, Zhang, and Malak [29] also proved that companies develop technological innovations to obtain durable competitive advantages. Tirupati [30] pointed out that technology is regarded as a mechanism for transforming input into output. The higher the degree of innovation, the better the performance of output and market. Generally, product innovation has higher visibility than other technological innovations, so it is easier to identify. Comparing the sales of electric vehicle products, as scholars have put forward, people pay attention to new vehicles rather than innovative technologies. The phenomenon presented in the market also shows that the sale volume of new brands is still higher than that of traditional brands, as shown in Table 1 [31]. In addition, the OECD also pointed out that all innovations must contain a certain degree of novelty, whether technical (product or process) or non-technical (marketing and organization) [32].

Table 1. Top 10 global sales of electric vehicles.

Ranking	Group Name	Sales (10,000 Vehicles)	Compared with the Same Period Last Year (Times)
1	Tesla	56.4	1.5
2	BYD (BYD)	32.4	3.5
3	SAIC Motor	31	1.3
4	Volkswagen	21.7	1.3
5	Hyundai + Kia	16.9	2
6	Nissan + Mitsubishi + Renault	13.3	1.5
7	Zhejiang Geely Holding Group	12.3	3.7
8	Stellantis group	11.6	1.4
9	Chery Automobile Group	11.1	3.3
10	Guangzhou Automobile Group	10	2.3

Source: [31], first half of 2022.

2.3. Innovation Matrix

The type of innovation will have different classifications according to the needs of enterprises. The outcome of an innovation then depends on the type of innovation used [15]. Linton [33] calls for the consideration of innovation inputs, outputs, and firm perspectives. In other words, what innovation pursues is enterprise performance. Therefore, some scholars have successively proposed related innovation matrices. For example, Kovacs et al. proposed a matrix of "Novelty/Impact" (radical, discontinuous, destructive, and breakthrough innovations) [34]. Lichtenthaler [35] proposed a matrix based on a "Service innovation/Business model". There is also a matrix focusing on the "Technology/Business model" (matrix content: incremental, Semi/Radical, and radical innovation) [36]. In addition, there is a "Technology (process)/Market" matrix (matrix content: incremental, disruptive, and breakthrough innovations) [37]. Medhat et al. [38] focused on Rothaermel's "Technology/Market" matrix. Harvard scholars also proposed a matrix related to problem-solving [39]. Although the content of the matrix is closer to market technology, the main axis is to solve problems, not to create a performance. Therefore, this research adopts the innovation matrix proposed by Rothaermel [13] as the focus of this research. It mainly takes enterprise performance as the goal, market, and technology as the coordinate axis and divides innovation types as shown in Figure 1: 1. Incremental Innovation, 2. Disruptive Innovation, 3. Architecture Innovation, 4. Radical Innovation.

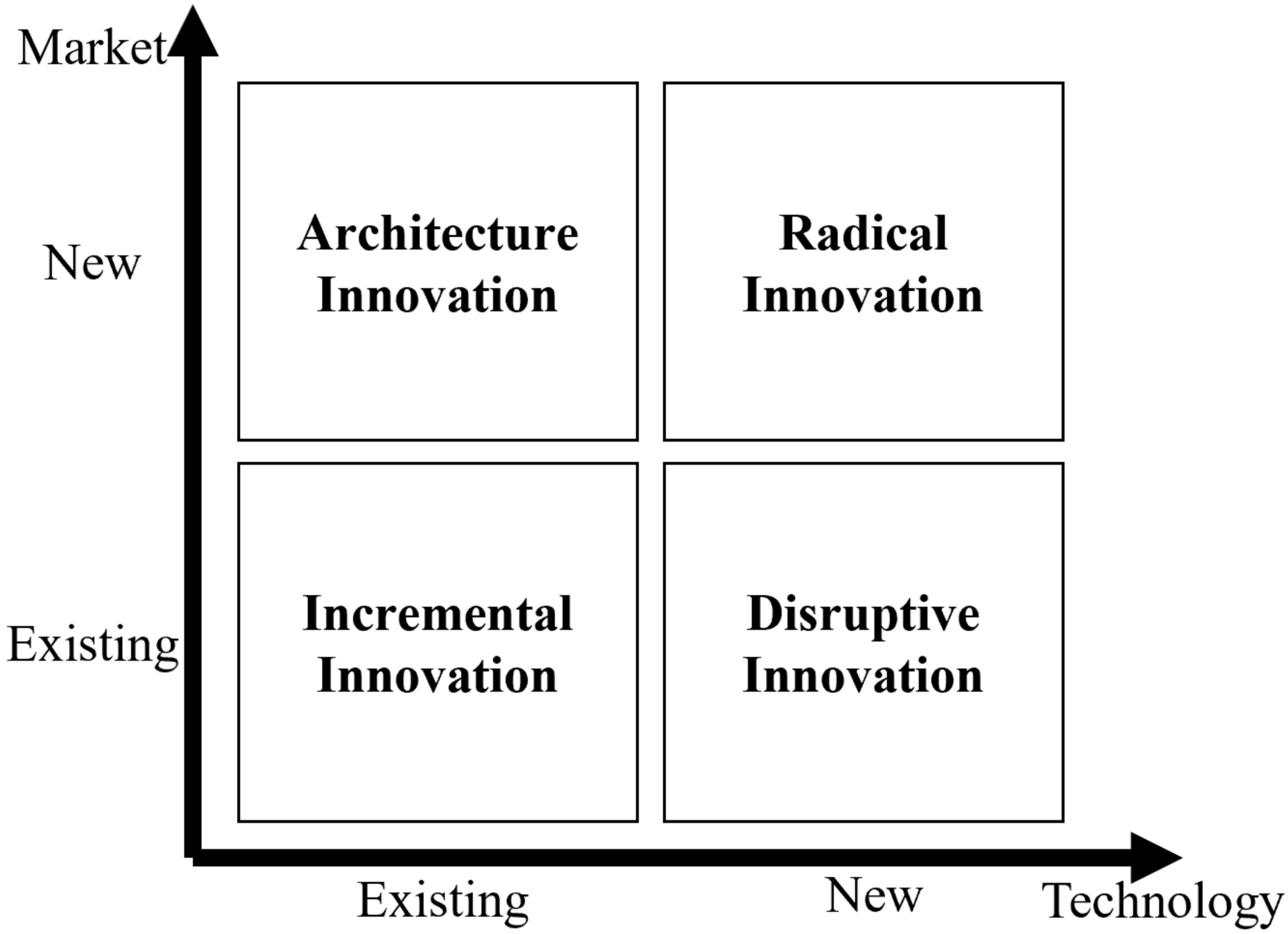

Figure 1. Innovation matrix [13].

Incremental Innovation: Applies to existing technologies and existing markets. It is mainly based on existing technology and known content to further enhance or improve the technical level [40]. This type of innovation takes less time. However, continuous incremental innovation may also lead to radical changes [41] and then become Radical Innovation, for example, car computer upgrades, navigation, assisted driving, evolution to automatic driving, etc. In addition to the car following, vehicle dynamic stability, fuel consumption, and driving comfort during car following are also considered [42]. All are changes brought about by the improvement of existing technologies. Its benefits are manifested in consumers' satisfaction with technical parameters and auxiliary functions.

Disruptive Innovation: Suitable for new technologies and existing markets. It is to create an opportunity for new entrants to surpass the existing market leaders and tends to provide suitable technologies for non-mainstream markets to seize the market; then, technology upgrades to return to the mainstream market [43,44]. Danneels [45] pointed out that the core of disruptive innovation technology is that it changes the basis of market competition. For example, electric vehicles are causing a shift in consumer expectations despite their higher prices than conventional cars and hybrids [46]. But we argue that disruptive innovation is not just a supply versus demand issue [47]. It is also related to consumer satisfaction and technological performance [48]. In other words, the disruptive innovation benefit of electric vehicles is that consumers are satisfied with the value of technical performance, not the disruption of price.

Architecture Innovation: Applicable to existing technologies and new markets. According to the market and strategy, ideas are combined with existing technologies, and concepts are transformed into products. Then, they are developed, produced, and put on the market. The enterprise's market strategy is made to conform to the existing market changes [49–51]. The use of architectural innovation depends on the number of patents or the number of self-owned innovative technologies, for example, GU [52] for Tesla Motors.

Tesla has designed an architectural innovation of component function modularization. The connection between components remains unchanged, but changing the component function will also change the module function. This type of improvement means that the final product can be improved by replacing the entire module while keeping these modules linked; newer and better products will come out, and customers will benefit from not having to wait for the next model and year and purchase a brand-new vehicle.

Radical Innovation: For new technologies and markets. Involving the exploration of unknown technologies and leaps and bounds in technology upgrades, many new inventions, patents, or business models represent such innovations. This type of innovation requires a long period of R&D, experimentation, regulatory approval, and market acceptance. Its ultimate goal is to develop the blue ocean market and create new product value and new corporate profits [53]. For example, incremental and radical innovation represent the complexity of innovative technology (incremental = low complexity; radical = high complexity) [54]. However, converting an internal combustion engine into an electric motor is technically a radical innovation. This means that the vehicle's powertrain is completely different, requiring entirely new parts and maintenance. And the benefits reflected are environmental protection, carbon reduction, and no pollution.

The "Innovation Matrix" of Rothaermel [13] has similarities and differences with the "Expansion Matrix" of Ansoff [11]. The same parts are all strategic operations proposed in response to different markets; the different parts are that the "Expansion Matrix" only talks about original products and new products, while the "Innovation Matrix" is all new products corresponding to the market but will propose different types of innovation strategies to develop different new products for different markets. By providing new products to consumers, companies establish a strategy to create new products and provide real new functions in order to be truly accepted by the market [13]. However, it is still unclear who the customer is before the innovation no matter what type of innovation is used. But Sandberg [55] pointed out that for an innovation type to be successful, it must ultimately meet customer needs. And the willingness to take risks is an important success factor [56].

3. Research Methodology

In recent years, many scholars have paid more and more attention to interpreting disciplinary research in a structured and systematic comprehensive narrative way [57,58]. "Bibliometrics" mainly measures the influence of an article by the number of citations after the article is published. If the source of an article is cited many times, it means that its publication is useful to many people and has a high impact and high value [59]. This study attempts to use the "Bibliometrics" combined with the "Innovation Matrix" dimension to examine 43 electric vehicle-related and downloadable journals published in 2010–2022, sort out and summarize the contents of the journals, and systematically fill into the model frameworks of "Incremental Innovation", "Disruptive Innovation", "Architecture Innovation", and "Radical Innovation" of Innovation Matrix". The review agreement is shown in Table 2. In terms of data reliability, 48 articles are selected that have been published in periodicals and special publications, and the word string "Electric Vehicle 2010–2022" is used as the range. A total of 45 downloadable articles were searched, analyzed, and compared, and the "Innovation Matrix" was filled in, respectively. In the appropriate column, in terms of validity, in addition, to accurately recording the operational factors in the process of data classification and sorting, it is ensured that subsequent researchers can follow the same research context to conduct research and obtain the same results. In addition, during the literature review, 5 periodicals with content that could not be classified were excluded to increase the validity of the content. In the end, a total of 43 journals were available for bibliometric analysis, and the selection rate was 87.75%, meeting the requirements of reliability and validity [60].

Table 2. Review protocol.

Document Type	Type Description
Articles with the title "Electric Vehicle"	(1) with the keyword "Electric Vehicles 2010–2022" search string, which matches the words and sentences in the title, abstract, and keywords. (2) Articles must be from academic journals (peer-reviewed) and published and downloadable.
Special purpose	(1) White papers of research units related to electric vehicles.
Journal Field Analysis and Consolidation	(1) Select only the areas of business administration and policy. (2) Select only the Transportation and Environmental Science fields together. (3) Select only the fields of Industry and Technology Development.
Timeline	2010 publications after the year.

4. Analysis and Discussion

According to the content attributes of the selected 43 periodical documents, this research fills in the innovation matrix (multiple selections are allowed) and makes an electric vehicle innovation matrix document arrangement, as shown in Appendix A; then, according to Appendix A, the year number of periodicals is sorted out, as shown in Table 3 and Figure 2; additionally, depending on the document type, organized into a table of the number of periodicals by category, as shown in Table 4; according to the content of the review, the number of years, and the number of countries in which the periodicals are published, it is organized into Table 5 and Figure 3.

Table 3. The Number of journal years.

Journal	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Total
Renewable and Sustainable Energy Reviews				1		2	1							4
Journal of Cleaner Production										1	1			2
Journal of Nature Energy									1					1
IEEE Xplore	1	3	1	1	1				1			1		9
Elsevier:	1		1	1	1			1				2		7
Springer:			1	1		1								3
Intellect:			1											1
Inderscience:								1			1			2
ScienceDirect:											1			1
MDPI:											2	1	2	5
Science										1				1
McKinsey									1					1
ICCT										1				1
Unique articles for review								1			1		2	4
IET								1						1
Summary	2	3	4	4	2	3	1	4	3	3	6	4	4	43

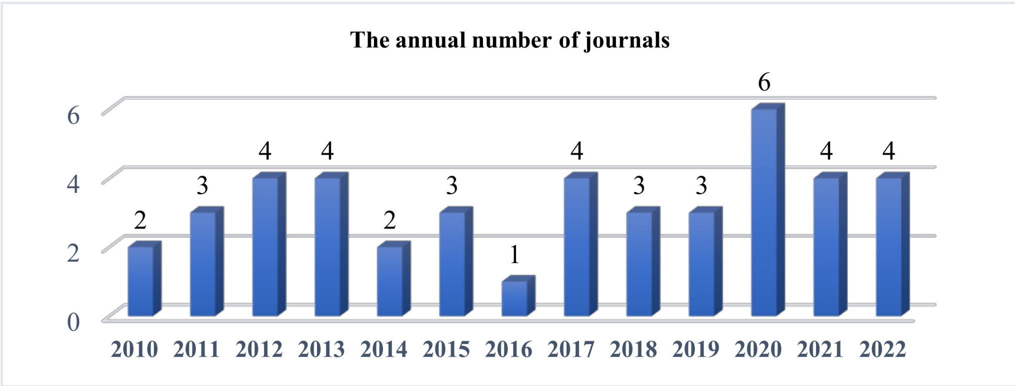

Figure 2. The annual number of journals.

Table 4. Number of journal categories.

Journal Classification	Quantity
Content Direction	
Business Management and Policy	17
Transportation and Environment	7
Industry and Technology	19
Research Design	
Qualitative	25
Quantitative	18
Methodology Used	
Case Study	7
Literature Review	14
Design Test	22
According to Source	
Observation Based	7
Survey Based	23
Theory Based	13

Table 5. Journal review contents and number of years.

Censor Content	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Research Design													
Qualitative	1	3	3			3	1	3	3	3	4		1
Quantitative	1		1	4	2			1			2	4	3
Methodology Used													
Case Study	1	2	1			1				1			1
Literature Review			1			2	1	3	1	2	4		
Design Test	1	1	2	4	2			1	2		2	4	3
According to Source													
Observation Based			1			1	1	1		1			2
Survey Based	1	3	3		2	2		1	3	2	5		1
Theory Based	1			4				2			1	4	1

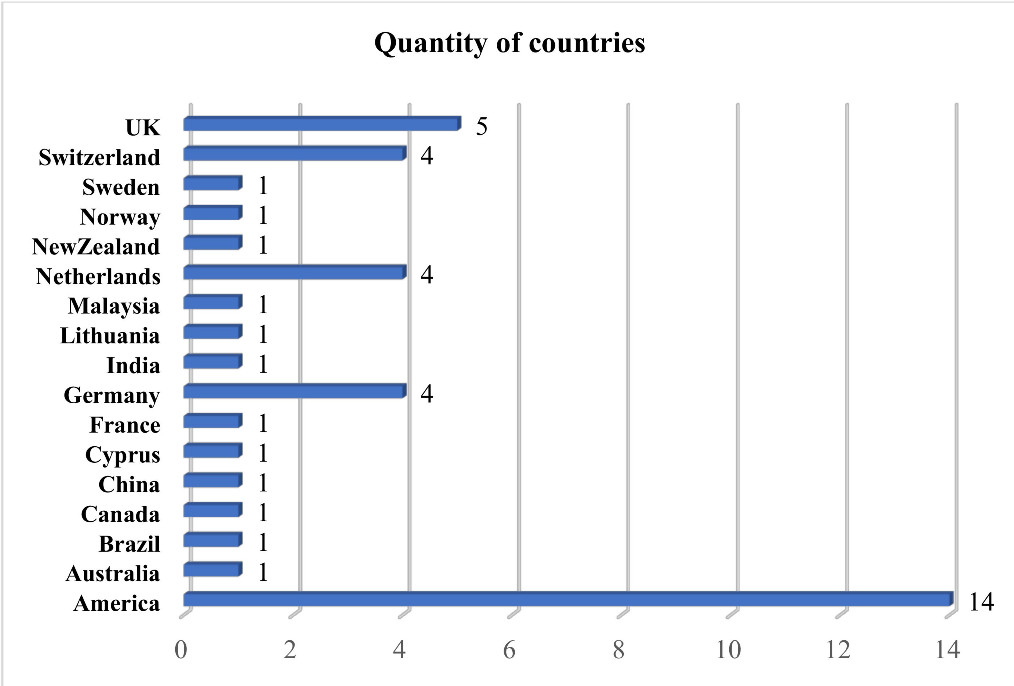

Figure 3. Number of journal publishing countries.

Findings

First, according to Appendix A, there are 28 times in "Incremental", accounting for about 40%; 23 times in "Radical", accounting for about 32.85%; 5 times in "Architecture", accounting for about 7.69%; 14 times in "Disruptive", accounting for about 18.46%, as shown in Table 6. Therefore, it can be concluded that most of the current innovative technologies of electric vehicles are derived from the extension of previous technologies. The conversion of electric vehicles from the original internal combustion engine system to the electric motor system involves a very large technological change and conversion, which can be proved by the figures and proportions of radical innovation.

Table 6. Quantity table of innovation types.

I	D	A	R	Total
28	14	5	23	70
40%	20%	7.14%	32.86%	

Secondly, there are 10 articles in the literature that mention ☆ batteries, and 10 articles that mention ★ charging equipment; its proportion is 46.51%. A total of 20 articles are all about the development of batteries for electric vehicles and the installation of charging equipment, approximately accounting for half, as shown in Table 7. Electric power is a key optimization item for electric vehicles, which determines the travel distance of electric vehicles. In addition, the storage capacity and life of batteries, as well as the equipment and places for supplementing power, become the main key factors for electric vehicles to be favored by market consumers.

Table 7. Number of documents on batteries and charging equipment.

	Journal			
	☆ Battery	★ Charging Equipment	Other	Total
Quantity	10	10	23	43
percentage	23.255%	23.255%	53.49%	100%

★: charging equipment, ☆: battery.

Finally, the most important key of the bibliometric method is the number of citations. According to Appendix A, we sorted out the top 10 citations of the literature. As shown in Table A2. Among them, there are four works in the literature examining power equipment and four works in the literature focusing on batteries. There are a total of eight papers discussing issues related to electric vehicle power supplements.

5. Conclusions and Suggestions

5.1. Theoretical Implications

The automotive industry is undergoing a deep technological transformation from internal combustion engine vehicles to new energy vehicles [61]. Innovative types of technological change may revolutionize the fundamentals of the automotive industry [62]. Additionally, the trend of substituting conventional power sources with batteries, chargers, and motors is becoming increasingly pronounced. Based on the literature published in journals over the past 10 years, the results of this study prove that power optimization and supplementation approximately account for half, showing the importance of power supplementation for electric vehicles. This is consistent with the academic patent literature. In addition, the recent innovation and development of energy storage technology systems in CATL (Contemporary Amperex Technology Co. Limited, Ningde, China), as well as the technology development of Tesla and BYD in the battery part, can prove that the industry attaches great importance to the power of electric vehicles. Therefore, this study makes the following contributions: firstly, the review protocol framework improves the reliability and sustainability of literature sources; secondly, the analysis of this study confirms the status of the industry and helps us understand the literature classification, trends, technologies, and research results; third, for the first time, this study utilized two market-verified success matrices to fully explain the application from the production end to the market end for electronic vehicles. It is novel and valuable enough for theoretical research. Therefore, this study holds great importance and makes a valuable contribution. Moreover, the conclusion carries significant practical significance.

5.2. Management Implications

When discussing technological innovation, our minds often associate it with the development of new products. If we consider new technology as equivalent to new products, we can utilize the "Expansion Matrix" [11] (as depicted in Figure 4), which bears similarities to the "Innovation Type Matrix" [13]. This allows us to apply cross-functional strategies for market and product development. In other words, each innovation type corresponds to a specific market strategy. For instance, "Market Penetration Strategy" aligns with "Incremental Innovation", "Market Development Strategy" corresponds to "Disruptive Innovation", and "Product Development Strategy" complements "Architecture Innovation". By doing so, we ensure that the products being innovated and developed will deliver outstanding market performance.

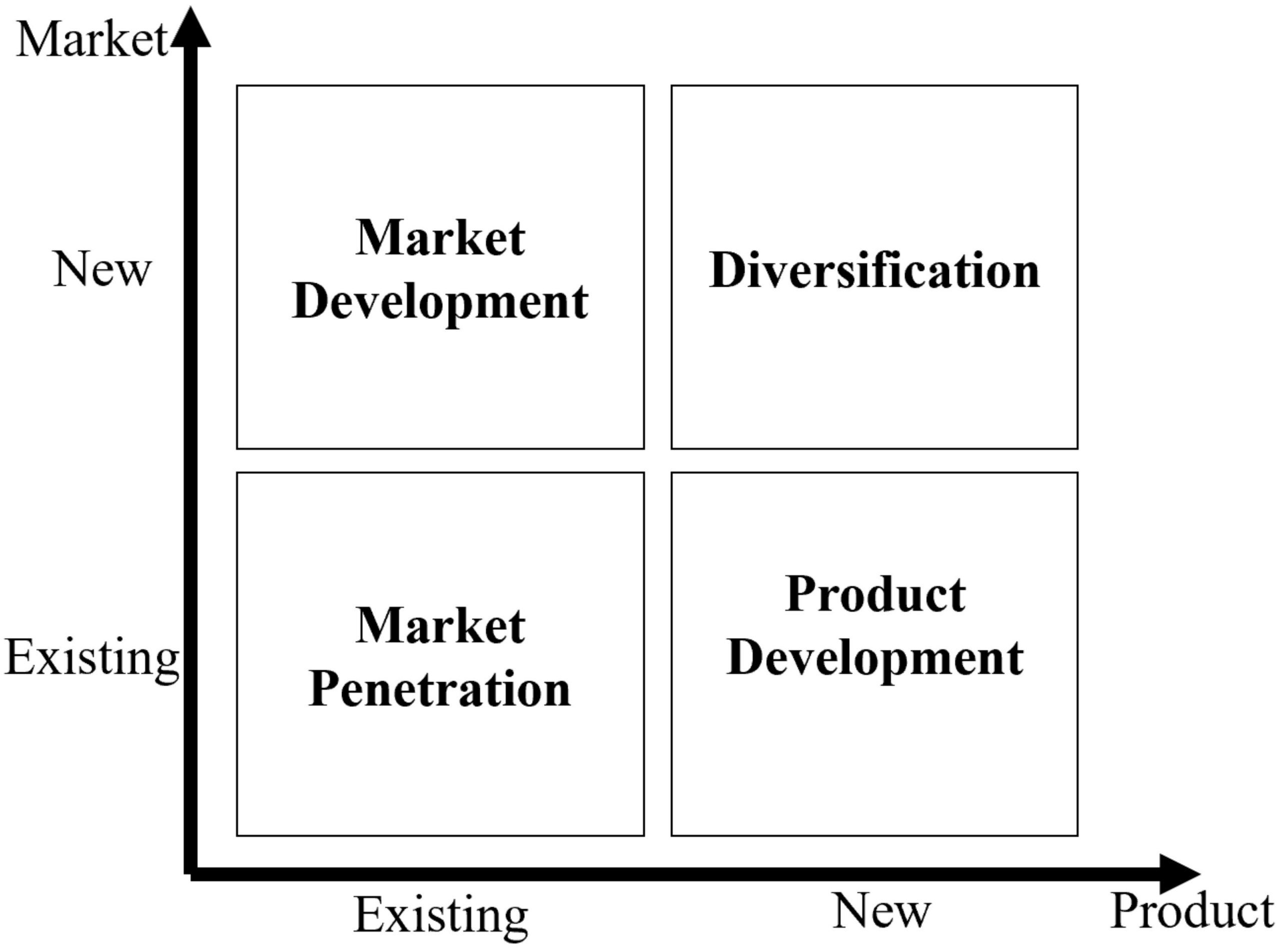

Figure 4. Ansoff Matrix [11]. Source: www.free-management-ebooks.com (accessed on 19 June 2023), Ansoff Matrix. Strategy Skills, 2013.

Furthermore, radical innovation involves the creation of new products using novel technologies, which prove advantageous whether introduced in existing or new markets. By employing a combined approach of [11,13], managers gain the ability to anticipate the direction of technological innovation in advance. They can then devise appropriate market strategies, ultimately achieving optimal market performance. This holds exceptional practical significance and value for managers responsible for development and operations. In essence, the outcomes of this study empower managers to predict the results of technological innovation and market performance beforehand, allowing them to make strategic deployments to maximize profitability.

5.3. Insights

Innovation is a central activity in the development and productivity of all economic activities, and its investment activities and outcomes depend directly on the type of innovation used and are related to products, technologies (processes), and markets [15]. The type of technological innovation of electric vehicles must first consider the characteristics of the targeted market and mainly meet market demand. The second is to apply for patent technology so that when the electric vehicle market is saturated in the future, two strategies of the "Product Development Strategy" correspond to "Architecture Innovation " and "New Market Strategy", which corresponds to "Disruptive Innovation", and make the market economic return of technological innovation more significant.

5.4. Future Research Suggestion

The development of electric vehicles is an inevitable trend, and there will be an increasing amount of research on electric vehicles. In this study, through a bibliometric analysis, we have organized the literature on electric vehicles from 2010 to 2022. The results show that the current focus of technological innovation in electric vehicles lies in batteries and power equipment. In fact, electric vehicle models with higher driving ranges are more favored in the market. With the promotion of technological innovations such as Industry 4.0 and Web 3.0, AI (Artificial Intelligence) is gradually gaining attention, and there have been recent studies on the application of ChatGPT in assisting circuit design. Therefore, it is a research direction to explore the potential widespread application of AI in electric vehicles in the future. Additionally, exploring business model innovation for electric vehicles is also a promising area for in-depth research in the future.

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Data Availability Statement: The detailed dataset supporting this study is available at https://docs.google.com/spreadsheets/d/1lWl3nwpwbP194Vc9uAs1apFUOc-UHTf8/edit?usp=drive_link&ouid=109541623913836932469&rtpof=true&sd=true (accessed on 19 June 2023).

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Literature review of innovation classification of electric vehicles.

No	Author	I [a]	D [b]	A [c]	R [d]	Contents	Contributions	Be Quoted
1 ☆	[63]	•			•	Combining a conventional internal combustion engine (ICE) with one or more electric motors powered by a battery pack that can be charged using an onboard generator and the regenerative braking technology to power the transmission.	It combines the advantages of traditional internal combustion engine vehicles and electric vehicles (EVs). The most significant advantages that HEVs possess over BEVs are superior mileage and flexibility in component size [9]. It is characterized by less complex configuration, lower hardware requirements, and lower cost.	466
2 ☆	[64]	•				The continual development of electric vehicle power train, battery, and charger technologies has further improved the electric vehicle technologies for wider uptake.	Electric vehicles show better performance than internal combustion engine vehicles (ICEV) due to the use of more efficient drivetrains and electric motors [3].	834
3 ★	[65]	•				Focused on electric charging infrastructure development, total cost of ownership, and purchase-based incentive policies.	Technologies related to electric mobility have been changing exponentially; therefore, literature covering these changes has also increased significantly.	308
4 ★	[66]	•				The analysis focuses on key policies and the effects of incentives, charging infrastructure, and model availability on electric vehicle uptake.	1. Multi-faceted application of electric vehicles and a combination of promotional activities.2. Introducing a significant cost advantage.3. Support charging infrastructure to ensure consumer convenience.	37
5 ☆	[67]	•				A comprehensive evaluation of various batteries and hydrogen fuel cells that have been successful in commercial applications.	The growing success of EVs can be attributed from a technological perspective to advances in electrochemical energy storage technology.	1684
6	[68]	•		•	•	It studies the optimal value of Connected Autonomous Electric Vehicles (CAEV) business models for their successful commercialization in the global market.	It combines a variety of techniques and high-tech elements to perceive its surroundings, including cameras, radars, ultrasonic sensors, and GPS. It also uses "Light Detection and Ranging" technology known as "LIDAR".	15

Table A1. *Cont.*

No	Author	I[a]	D[b]	A[c]	R[d]	Contents	Contributions	Be Quoted
7	[69]				•	This paper will present a study of how latecomer firms approached the development of radical technologies by focusing on the actual experiences of China's EV industry in which modular product architecture or modular industry platforms may play a fundamental role in the implementation of industrial innovation.	The discontinuous innovation can be achieved by establishing an industry platform enabled by modular product architecture.	7
8 ★	[70]	•			•	On-Line Electric Vehicle (OLEV) draws its electric power from underground electric coils without using any mechanical contact.	Batteries are recharged whenever OLEV draws electric power from the underground coils and, thus, do not require expensive separate charging stations. The infrastructure cost of installing and maintaining OLEV is less than those required for other versions of electric vehicles.	166
9	[71]	•	•			We explore the difference between technological growth and customer satisfaction by comparing the Electric Vehicle Business Model with the Hybrid Business Model on three parameters: channels, value propositions, and customer relationships.	Electric vehicles are rapidly gaining acceptance and adoption, further challenging classic diesel and gasoline, and even plug-in hybrid engine technologies.	24
10 ☆	[72]	•				It is to understand the basic chemistry of the different batteries and specific EV battery requirements of energy density, specific energy, power density, cost, durability, etc.	Electric vehicles (EVs), including hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), and pure battery electric vehicles (BEVs), will dominate the clean vehicle market [1,2].	345
11 ★	[73]			•	•	Innovative road dynamic wireless charging technology OLEV for electric vehicles. OLEV is an integrated invention and innovation system that combines automotive, electric, Electronics, power grids, road infrastructure, and information technology (IT). Road electrification will become a key R&D area related to the smart grid in the next few decades.	The wireless transmission of power to running vehicles can be a competitive design solution for future electrified roads and vehicles [4]. Therefore, wireless charging of electric vehicles, whether it is stationary charging or dynamic road charging, can be A technological innovation for the mass promotion of automobiles.	83
12	[74]			•	•	1. The main goal is to explore different technologies.2. Electric vehicle propulsion technology and product architecture.	The results show that innovations in product architecture can provide niche markets for electric vehicles.	43
13	[75]	•			•	Most innovations within the automotive domain are driven by embedded systems and software solutions.	The most noticeable effects are improved drivability and comfort and enhanced passive and active safety.	99
14 ★	[76]	•			•	We analyzed whether the electric vehicle market share is linked with the availability of more electric vehicle models, charging infrastructure, fiscal and non-fiscal incentives, high-occupancy vehicle lane access, and other activities.	Because these next-generation electric vehicle models are expected to enter the market at lower prices and higher volume, this is an important time for governments to consider their support policies and investments in charging infrastructure.	33
15	[77]	•			•	In mobile systems, emissions from internal combustion engine vehicles (ICEVs) have a significant impact on climate change and the atmosphere. Technologies such as battery electric vehicles (BEV), hydrogen fuel cell vehicles (HFCV), and hybrid electric vehicles (HEV) offer a good alternative to setting up ICEV.	When an increased number and higher diversity of firms move into a new trajectory leading to more technological competition, the new technology is more likely to be continuously developed, improving its chances of commercial success.	110
16	[78]					This paper reviewed the technologies in the WPT area applicable to EV wireless charging. By introducing WPT in EVs, the obstacles of charging time, range, and cost can be easily mitigated.	WPT technology is developing rapidly in recent years. At kilowatts power level, the transfer distance increases from several millimeters to several hundred millimeters with a grid to load efficiency above 90%. The advances make the WPT very attractive to electric vehicle (EV) charging applications in both stationary and dynamic charging scenarios.	1789
17	[79]	•				Using a policy-oriented technological innovation system, a comprehensive theoretical framework for development, use, and enterprise levels to verify efficient incremental innovation in the automotive industry.	Technological change often depends on a combination of policy and firm-level efforts.	71

Table A1. *Cont.*

No	Author	I[a]	D[b]	A[c]	R[d]	Contents	Contributions	Be Quoted
18 ★	[80]	•			•	The proposed framework covers two different domains: the grid technical operation and the electricity market environment.	Large-scale deployment will have a considerable impact on power system design and operation but will also facilitate and favor the use of non-polluting energy.	1555
19	[81]	•	•		•	What is traditionally thought to be good at incremental innovation is actually a fundamental shift; that is, from the internal combustion engine via hybridization to "pure" electric propulsion and facilitates the restructuring of the industry.	Case companies are able to innovate not just incrementally but beyond incrementally, as their position in the Electric vehicles race demonstrates.	10
20-	[82]	•				This study employs the vehicle policy analysis tool developed at Oak Ridge National Laboratory to systematically quantify the potential impact of "passenger vehicle enterprise average fuel consumption and alternative energy sources".	The BEVs with long electric ranges (such as 400 km) and the plug-in hybrid electric SUVs could be the most popular PEV types.	3
21	[83]		•	•		Proof that Tesla Motors is not following a disruptive innovation strategy. Its commercialization strategy is executed via architectural innovation and attacker advantage.	A performance trajectory describing Tesla's entry into the automotive market is constructed.	51
22 ★	[84]	•			•	This study integrates charging infrastructure usage in households, public places, and workplaces into a market dynamics analysis tool to systematically evaluate the impact of charging infrastructure on plug-in electric vehicle (PEV) ownership cost and market share impact.	The explosive growth of the PEV market requires a systematic and extensive charging infrastructure, including charging places such as homes, public places, workplaces, and highways for long-distance travel.	43
23	[85]		•			Norwegian purchase incentives are large enough to make electric vehicles a competitively priced alternative for vehicle buyers.	Increased selection of models, improved technology, reduced vehicle prices, and extensive marketing have spurred further sales.	211
24	[86]		•			Market trends and strong government policies suggest that national and regional PEV-related incentives can play an important role in kickstarting the PEV market.	The introduction of plug-in electric vehicles (PEV) for transportation represents one of the most promising pathways for reducing oil and GHG emissions, as well as for improving local air quality.	210
25	[87]	•			•	The empirical context of this study is the automotive industry, a classic example of the transition to electric vehicles (EV) or hybrid vehicles (HV) via internal combustion engine (ICE) refresh-dominated design.	Dominant design is embedded in product architecture, technology, and usage specifications via regulations and design rules, customer practices, or performance standards.	97
26 ★	[88]	•			•	Technical performance across different spatial and temporal scales, the importance of the key interplay between Charge infrastructure construction and consumer behavior.	The potential advantages of electric vehicles depend on breakthroughs in technology and engineering design.	273
27	[89]			•		Modeling HEV, PHEV, and EV penetration should include improvements to interfaces with consumer surveys, modeling of automaker behavior, federal and state policies and their impact on the automotive market, competition between technologies, market volume, vehicle classification, and model parameter sensitivity analysis.	Hybrid, plug-in hybrid, and electric vehicles (HEV, PHEV, and EV) improve vehicle fuel economy, reduce petroleum consumption and increase efficiency. Life cycle economic benefits are provided for consumers, society, automakers, and policymakers.	489
28 ☆	[90]	•				The differences in BEV technology in terms of drivetrains are assessed, with a focus on examining the possibilities regarding EV architectures, electric motors, optimization techniques, and their development as a future of green mobility.	The tailpipe of electric vehicles has zero emissions, so it can effectively curb the pollution caused by vehicle exhaust emissions.	192
29	[91]	•				The research focuses on innovative circular economy (CE) in the automotive ecosystem and sustainable tires; and also helps to clarify product characteristics and target group characteristics.	Integrating customer needs into product development in the automotive industry is key to success. Just as the CE ecosystem must be innovative and user-centric [13] to achieve sustainable development.	16

Table A1. *Cont.*

No	Author	I[a]	D[b]	A[c]	R[d]	Contents	Contributions	Be Quoted
30 ★	[92]	•			•	Basic types of vehicles and their technical characteristics, fuel economy and CO2 emissions, EV charging mechanisms, and concepts of grid-to-vehicle and vehicle-to-grid architectures.	From the perspective of full cycle analysis, the electricity available to recharge the batteries must be generated from renewable or clean sources in order for such vehicles to have zero emissions.	314
31 ☆	[93]		•		•	When comparing electric cars to gasoline cars, all the shortcomings of electric cars come from the battery. How far electrification can go depends largely on one factor... battery technology.	Solid-state electrolytes bring several advantages to lithium-ion batteries [8]. They are not flammable, eliminating the primary safety hazard of lithium-ion batteries, and have high lithium-ion conductivity at room temperature, enabling the high power performance needed for fast charging.	149
32 ☆	[94]	•			•	Plug-in hybrid electric vehicles (PHEVs) offer improvements in power electronics, energy storage, and support to deliver competitive driving range and fuel economy.	Given the current state of battery technology, the economics of hybrid electric vehicles (HEV) appear to be more favorable than pure electric vehicles (PEV).	100
33	[95]		•			Battery Electric Vehicles (BEVs) currently account for 66% of the global EV market. BEV sales are growing faster than plug-in hybrid electric vehicles (PHEVs). However, it will be affected by the preferences of specific markets, different government supervision policies, customer choice, and availability of specific models.	China has improved with higher EV sales, significant monetary and non-monetary incentives, a greater variety of vehicle models, and investment intensity in charging infrastructure.	64
34 ★	[96]	•	•		•	The aim is to provide an innovative way for electric vehicles to charge their batteries from another vehicle while driving, known as vehicle-to-vehicle charging (VVR).	Electric vehicles can receive power via wireless power transfer (WPT) to charge their batteries. Among the innovations are mainly (1) infrastructure changes, (2) device-level innovations, they(3) autonomous vehicles.	19
35 ☆	[97]		•			The best battery pack and electric vehicles component cost data available as of 2018 was collected.	The falling cost of batteries is the main reason for the falling cost of electric vehicles.	177
36	[98]		•			The results showed that the vehicles replaced by electric vehicles were relatively fuel-efficient: the average fuel economy of electric vehicles replacing gasoline vehicles was 4.2 mpg higher than the fleet average, and 12 percent of them replaced hybrid vehicles.	Even if tax credits boost EV sales, the emissions impact is likely to be small if EVs displace lower-emission class vehicles.	113
37 ☆	[99]		•		•	The electric vehicles market is becoming a mass market driven by economies of scale. Its cost and speed of market push are affected by the speed at which battery costs are falling.	The first is that the raw materials for making batteries are relatively scarce. Second, the main EV market is China, giving the company a strategic advantage in supplying key metals and mass-producing batteries.	10
38-	[100]	•			•	The example of the Tesla Roadster model shows that it is entirely possible for electric vehicles to equal or even surpass internal combustion engine vehicles in terms of speed, ride quality, and range.	The analysis of the main technical characteristics of EVs shows that they can travel more than 100 km on a single charge, which can fully meet the needs of urban driving.	10
39-	[101]		•			In this study, electric vehicle (EV) technology is analyzed using an energy demand model, with the benefits and trade-offs of penetration of motorcycles and passenger vehicles in Thailand's road traffic.	Electric vehicle technology consumes less fossil fuels and produces fewer greenhouse gas emissions.	33
40 ☆	[102]	•			•	Streamwise development of counter-rotating vortices induced by three different types of chevron Vortex Generators (VGs) placed upstream of Electric Vehicles (EV) dummy battery modules is experimentally visualized using a smoke-wire method.	The smoke-wire visualization setup consists of a thin, electrically heated Nickel-Chromium wire and a pressurized white oil container. A continuous smoke layer is produced as the oil drips along the heated wire.	1
41	[103]		•		•	The magnets are removed from the stator to the rotor, and magnetized in a unique direction, resulting in a significant alleviation of stator tooth saturation level for the RPM-FS machines.	The predicted results indicate that the proposed RPM-FS machine exhibits the largest power density, greatest torque capability, highest efficiency under rated operation, and improved flux-weakening ability.	27

Table A1. *Cont.*

No	Author	I[a]	D[b]	A[c]	R[d]	Contents	Contributions	Be Quoted
42	[104]		•		•	Flux barrier design to increase torque capability of RPM-FS machines	RPM-FS motors have a higher electromotive force than conventional structures, with only a slight increase in cogging torque. In addition, the insertion of a flux barrier can reduce flux leakage, improve magnetic saturation capability, enhance the working harmonics of the air gap flux density, and gain efficiency.	3
43	[105]	•				Development and optimization of a special hybrid electric vehicle setup for a four-quadrant rotary converter.	Find the optimal mass distribution of the permanent magnets, optimizing the permanent magnet material, shape, and thickness to achieve maximum efficiency of the device. The results show that the overall theoretical efficiency of the external rotor unit increases from 90.2% to 94.4% after optimization.	5

I[a]: denotes Incremental innovation; D[b]: denotes Disruptive innovation; A[c]: denotes Architecture innovation; R[d]: denotes Radical innovation; ★: charging equipment, ☆: battery.

Table A2. The top 10 literature citations.

References	Be Quoted	☆ Battery	★ Charging Equipment
[81]	1789		
[70]	1684	1	
[83]	1555		1
[67]	834	1	
[92]	489		
[66]	466	1	
[75]	345	1	
[95]	314		1
[68]	308		1
[91]	273		1

★: charging equipment, ☆: battery.

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