

EVALUATION OF ELECTRIC CAR RESEARCH TRENDS THROUGH BIBLIOMETRIC ANALYSIS: A Literature Review

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Abstract: Due to increasing environmental and sustainability concerns, electric cars have become a significant research focus in recent years. To understand the development and Impact of scientific research related to electric vehicles, a bibliometric analysis was carried out. This research collects data from Scopus, using the keywords "electric vehicle" OR "electric vehicles" OR "E.V." AND "product development."

The results of the analysis show significant growth in the number of publications related to electric cars over the last few years. Analysis of publication trends identified periods of substantial growth and declining trends that may reflect changes in research focus. Specific journals and conferences were also identified as crucial platforms for research in this domain.

Mapping of researcher collaborations and analysis of author contributions reveals a growing collaboration network within the electric car research community. Keyword analysis provides an in-depth look at dominant research themes, while citation analysis highlights works that have greatly influenced the field.

This analysis provides valuable insight into the evolution of electric car research, identifying key trends, researcher collaborations, and the Impact of particular works. These findings can be used to guide future research and understand the rapid dynamics of developments in the electric car domain.

Keywords: Evaluation, Trends, Electrical Car.

INTRODUCTION

The growth of motor vehicles in recent years has intensified, raising concerns about deteriorating environmental quality, dwindling petroleum reserves, global warming, and increased greenhouse gases [1] [1]. Rising fuel prices challenge the transportation industry because petroleum is the primary energy source. The transportation sector contributes 23% to global carbon dioxide emissions, of which motor vehicles contribute 17% [2]. In 2021, Indonesia has produced 1.12 million units of cars. This places Indonesia 15th among the world's car manufacturers [3]. Increasing private vehicle ownership will accompany greater energy consumption, contributing to the rise in greenhouse gases[4] and more severe problems related to energy security and environmental conservation[4, 5].

In anticipation of this, and agreed upon by 195 countries in the 21st Climate Negotiations (COP 21) within the framework of the United Nations for Climate Change (UNFCCC), it was held in Paris from November 30 to December 13, 2015. This meeting was historic, and they reached a binding agreement. The Paris Agreement aims to stop the earth's warming temperature to no more than 2 degrees Celsius. Indonesia expressed its commitment at COP21 to reduce CO2 emissions by 29% with its efforts and reduce CO2 emissions by 41% with international support until 2030. This agreement is also the forerunner of the world's shift towards net-zero emissions and achieving the Sustainable Development Goals (SDGs) [6].

Electric vehicles are one of the alternatives that many countries in the world are striving for. Electric vehicles can produce lower greenhouse gas emissions than internal combustion engine vehicles (conventional), which is expected to reduce the transportation sector's emissions [7]. The vehicles in question are battery electric vehicles (BEVs) and Plug-in electric vehicles (PEVs). Unlike conventional internal combustion engine (ICE) vehicles, electric vehicles are electric as a drive. These electric vehicles offer more efficient fuel combustion and produce no exhaust emissions [8]. However, the adoption of electric cars is still shallow [9, 10], although various countries have provided financial and non-financial incentives. Many reasons lead to the low acceptance of electric vehicles. Among them are the economy of ownership [11-13],

initial[11-13] price [13-19], driving range and charging [13-19], lack of charging infrastructure[20-24] [25-29], [25-29] battery price height[30-32].

Research on electric vehicles in the current academic literature primarily focuses on factors influencing electric vehicle adoption behavior [33, 34] and Infrastructure of service facilities for battery charging[28, 33]. Government policies or incentives to aid electric vehicle adoption [[34-36] and operation planning[37, 38].

Electric vehicles (E.V.s) have three essential components that support vehicle operation: batteries as an energy source for electric cars, electric motors as drives that produce mechanical energy, and propulsion systems that transfer mechanical energy to the vehicle's wheels [39].

1. What is the annual publication in the field of Electric vehicle product development?
2. What are citation trends and the number of their uses in the SCOPUS database?
3. How are product development-related publications distributed?
4. What are the most influential countries, journals, and institutes?
5. Which research groups, countries, and organizations are most productive by citation and bibliography?
6. What topics arise related to the development of electric vehicle products?
7. How are existing publications spread?
8. What keywords are related to each other?

RESEARCH METHOD

Data sources

Scopus is used in many countries as a trusted journal for academic advancement or an evaluation for funding by institutions [42] [40]. As a growing bibliographic database, Scopus is increasingly used in academic research and evaluation practice[41]. Data was taken on January 17, 2023, from the SCOPUS collection using the keywords "electric vehicle" OR "electric vehicles" OR "E.V." AND "product development." As many as 300 documents related to the product development of electric vehicles were obtained. The first document was published from 1986 to 2023.

Bibliometric Methods

Vosviewer was used in this study for dataset development[42]. Vosviewer is free software for building and visualizing bibliometric networks [45]. These [43] can consist of journals, research, or personal publications built on keywords, citations, abstracts, bibliographies, shared citations, or co-author relationships [46] [44].

Inclusion and Exclusion Criteria

The search starts with keywords related to electric vehicles ("electric vehicle" OR "electric vehicles" OR "E.V.") and then about product development on the SCOPUS search engine. A total of 300 documents emerged from 1986 to 2023. The publication consists of 6 languages, namely English (285), Chinese (7), German (7), Italian (1), Japanese (1) and Turkish (1). In this study, we agreed only in English. The remaining 285 documents in English consist of a conference paper (130), an Article (112), a conference review (29), a review (7), a Book chapter (4), a short survey (2), and a note (1). It was found that several terms overlapped and were issued manually [47][45], Such as automobile cooling systems, automobile manufacture, and automobiles becoming one term automobiles. Commerce and commercial vehicles have become one term: commercial vehicles. Electric Vehicles and Electrical Vehicles become one term: Electric Vehicle. Hybrid Electric Vehicles, Hybrid Electric Vehicles, and Hybrid Vehicles have become one term, hybrid electric vehicle. Lithium, lithium batteries, and lithium-ion batteries become one term lithium batteries. Powertrain and powertrains became one powertrain term. The set of documents by type can be seen in Figure Figure 1. Types of final documents.

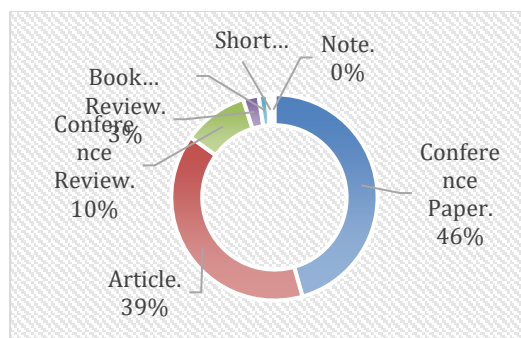


Figure 1. Types of final documents

There are 46% conference papers, 39% articles, conference reviews, reviews, book chapters, and short surveys 10%, 3%, 1%, and 1%, respectively.

Data analysis

The final data is exported from SCOPUS in CSV format and analyzed in detail. The characteristics of bibliometric mapping to be carried out are Co-authorship maps, consisting of authors, organizations, and countries; citation maps, consisting of publications, journals, and authors (first author); bibliographic coupling maps, consisting of magazines, journals, authors, organizations, and countries; Subject mapping/keywords (co-occurrence maps), consisting of keywords and terms from the title and abstract.

RESULT AND DISCUSSION

Global Publications and Excerpt Output

Annual publications can generally be seen in Figure 2. Annual publications. Publications in the field of electric vehicle product development have increased. The increase in the number of publications is divided into three time periods, namely 1986 to 2011 (old paper), 2012 to 2018 (recent paper), and 2018 to 2022 (current paper). In 1986, there was one article with the theme of product development. In 2005, there was a sudden high increase in publications. From 2012 to 2018, the number of publications was relatively stable, and there was an increase in 2015. From 2019 to 2020, there was an increase in publications compared to the previous period. There was a significant increase in citations in 1999, as many as 104 citations, considering that research on electric car design increased that year. The number of citations until December 2022 is 2576 citations.

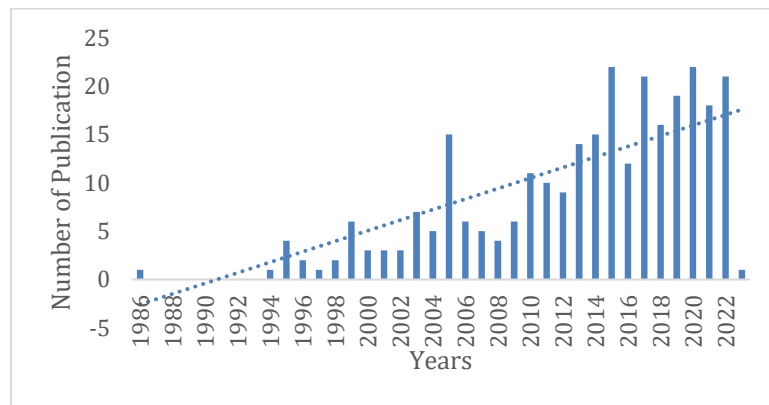


Figure 2. Annual publications

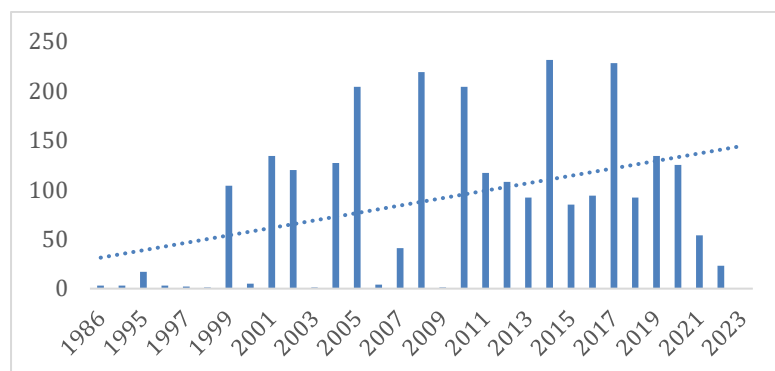


Figure 3. The number of citations

The number of scientific works is directly related to the reader's liking. Generally, readers prefer to read the latest articles; however, frequently cited articles use more old-year publications, whereas the latest articles also include quotes from old articles. This causes the latest article to have fewer citations than the old one because new articles take time to be quoted. This is following Wang's research on Usage patterns of scholarly articles on Web of Science: a study on Web of Science usage count. Scientometrics[46]. The following article is the most summarized quote in Table 1. Top 10 Citation. The table contains details, quotes, and the number of quotes.

Table 1. Top 10 Citation

Authors	Title	Year	Source Title	Cited by	Theme	Source
Kanai K., Koizumi K., Ouchi S., Tsukamoto Y., Sakanoue K., Ouchi Y., Seki K.	Electronic structure of anode interface with molybdenum oxide buffer layer	2010	Organic Electronics	173	Electronic Structure	[47]
Mau P., Eyzaguirre J., Jaccard M., Collins-Dodd C., Tiedemann K.	The 'neighbor effect': Simulating dynamics in consumer preferences for new vehicle technologies	2008	Ecological Economics	170	Consumer Behavior	[48]
Onoda S., Emadi A.	PSIM-based modeling of automotive power systems: Conventional, electric, and hybrid electric vehicles	2004	IEEE Transactions on Vehicular Technology	117	Simulation Tools for Modeling	[49]
Åhman M.	Primary energy efficiency of alternative powertrains in vehicles	2001	Energy	113	Energy Efficiency	[50]
Li B., Gao X., Li J., Yuan C.	Life cycle environmental impact of high-capacity lithium-ion battery with silicon nanowires anode for electric vehicles	2014	Environmental Science and Technology	111	lithium-ion batteries	[51]
Pilkington A., Dyerson R., Tissier O.	The electric vehicle: Patent data as indicators of technological development	2002	World Patent Information	94	Automobile Industry	[52]
Wu S.-M., Liu H.-C., Wang L.-E.	Hesitant fuzzy integrated MCDM approach for quality function deployment: a case study in electric vehicle	2017	International Journal of Production Research	90	Quality function deployment (QFD)	[53]
Schell A., Peng H., Tran D., Stamos E., Lin C.-C., Kim M.J.	Modeling and control strategy development for fuel cell electric vehicles	2005	Annual Reviews in Control	69	development of fuel cell electric vehicles	[54]
Pinkse J., Bohnsack R., Kolk A.	The role of public and private protection in disruptive innovation: The automotive industry and the emergence of low-emission vehicles	2014	Journal of Product Innovation Management	67	disruptive innovation	[55]
Capitelli M., Colonna G., D'Ammando G., Pietanza L.D.	Self-consistent time-dependent vibrational and free electron kinetics for CO2 dissociation and ionization in cold plasmas	2017	Plasma Sources Science and Technology	53	dissociation	[56]

Publication Distribution

In total, 29 countries contribute to the development of electric vehicle products. As of this writing, it is sorted by the most dominant countries in research contribution. The most dominant countries in this study can be seen in Figure 4. The number of publications sorted from the most are United States (56), Germany (60), China (24), India (24), Japan (14), United Kingdom (14), Brazil, France, Italy and the Netherlands 7 documents each, and others (27). Based on these data, it was found that the United States became the dominant country, followed by Germany.

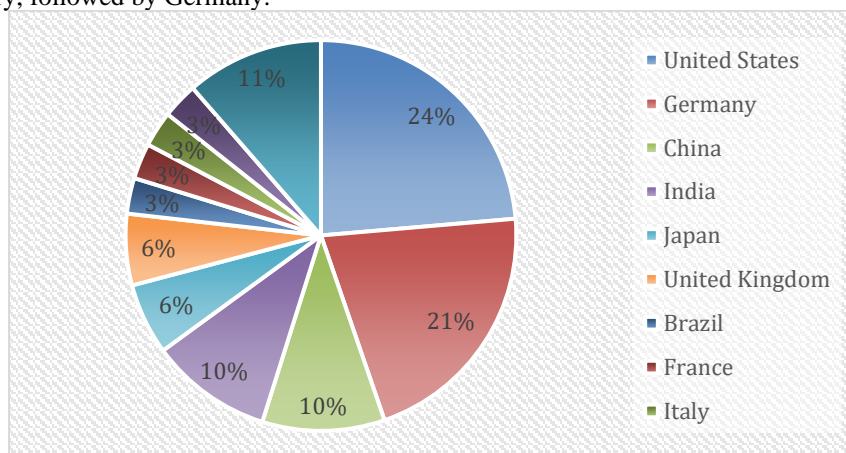


Figure 4. Dominant Countries in Research

A total of 267 organizations or affiliates contributed to the study. The most dominant institutions in this study can be seen in Table The Technical University of Munich is the most dominant institution in this research, followed by Karlsruher Institut für Technologie.

Table 2. shows the top publishing institutions in the research domain

No	Institution Name	Number of Publications
1	Technical University of Munich	11
2	Karlsruher Institut für Technologie	9
3	Rheinisch-Westfälische Technische Hochschule Aachen	7
4	Ford Motor Company	5
5	Tongji University	5
6	Stellantis N.V.	5
7	Universität Stuttgart	4
8	Dr. Ing. h.c. F. Porsche AG Porsche AG	4
9	General Motors	3
10	Humboldt-Universität zu Berlin	3
11	Other	211

The most dominant journals are summarized in F. It can be seen that the National Natural Science Foundation of China is the most popular, with seven articles published, followed by the Bundesministerium für Bildung und Forschung.

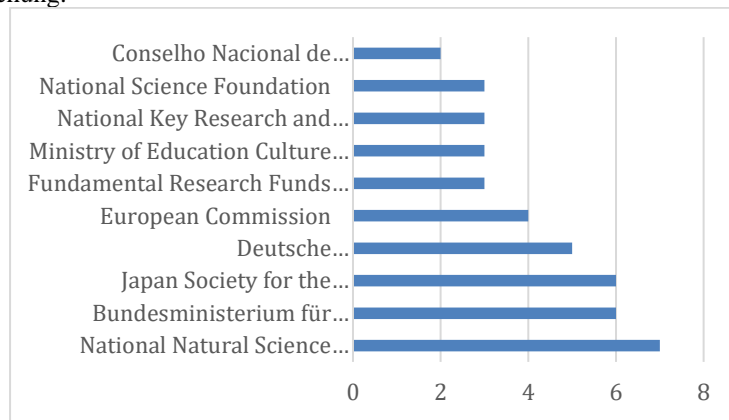


Figure 5. Top published in this research domain.

Subject Categories Research Productivity

Based on the subject categories contained in the Vos Viewer web science, from the data output of research publications related to the development of electric vehicle products spread across 19 subject categories for twenty years. There are 11 subject categories shown in Figure 6. The three most prominent fields are engineering, energy, and computer science.

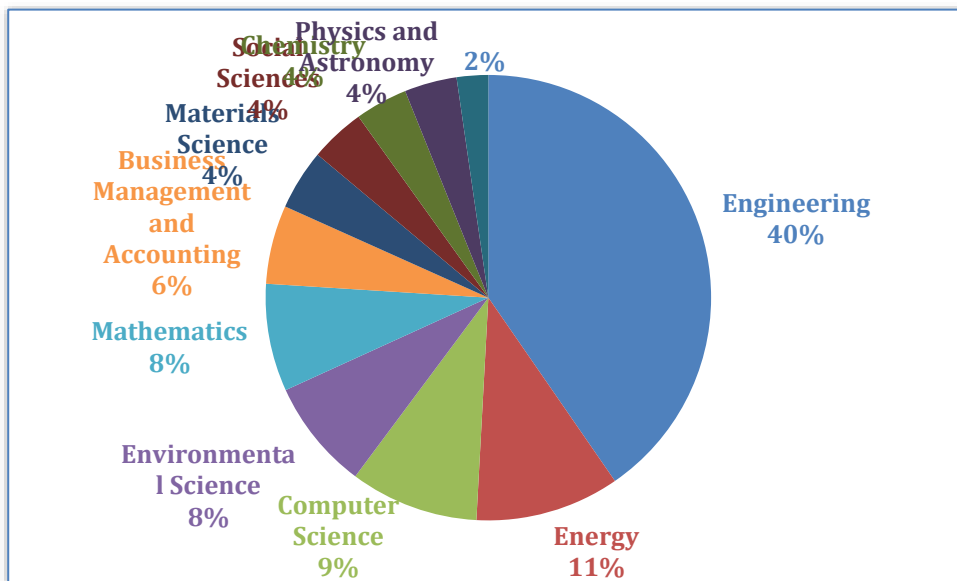


Figure 5. Subject categories by field of research

Co-Emergence of Keywords in the Abstract

Keyword identification based on abstracts from abstracts of entire manuscripts related to the development of electric vehicle products. The size of the circle describes the potential of the keyword. The larger the circle, the greater the keyword potential. As in Figure 7 of the Co-occurrence analysis, the line's thickness indicates the link's strength. The co-occurrence map is based on data obtained using VOSViewer. Graphics are visualized with the network.

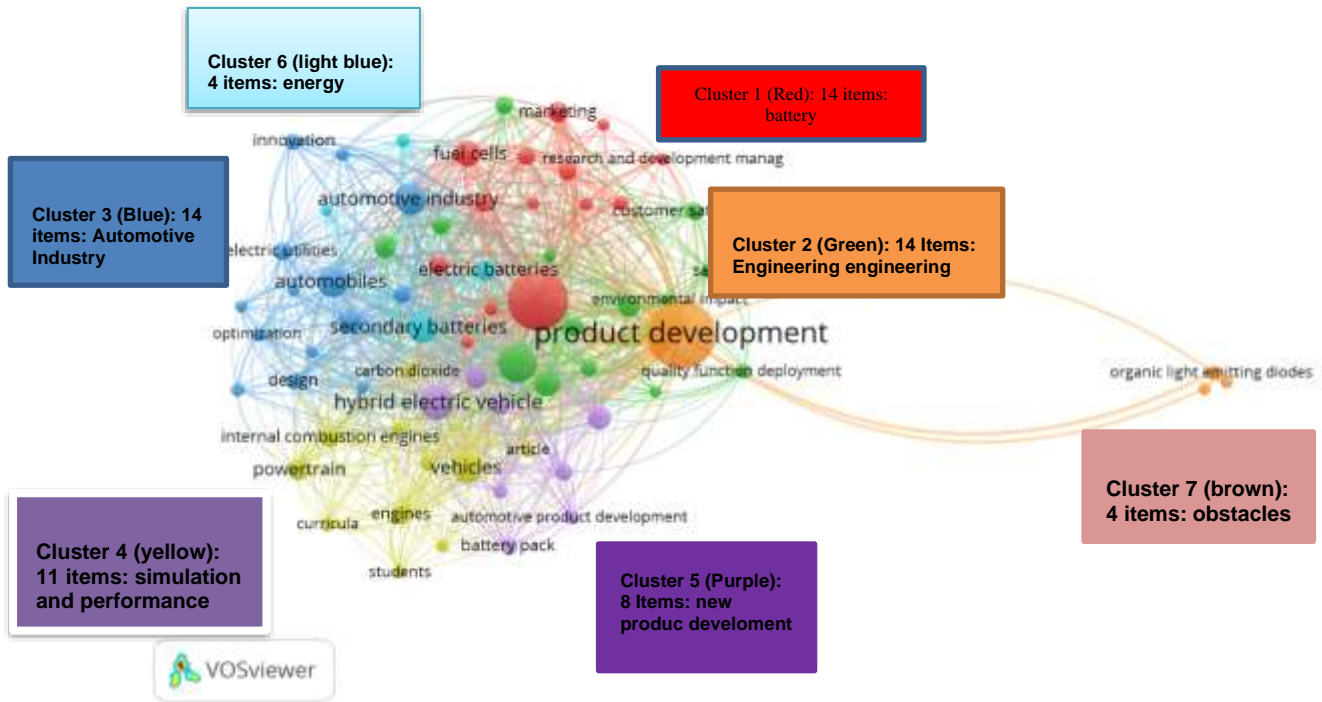


Figure 6. Analysis Co-occurrence of research themes from abstracts

No	Keyword	Occurrences
1	Product Development	147
2	Electric Vehicle	116
3	Product Design	47
4	Hybrid Electric Vehicle	38
5	Automotive Industry	32
6	secondary batteries	30
7	Automobiles	29
8	vehicles	29
9	fuel cells	22
10	Life Cycle	21

- Cluster 1 (Red): 14 items: electric vehicle product development**
 Electric cars are not separated from the battery as a core component of driving power. Based on the main keywords in cluster 1, namely battery management system, charging (battery), electric discharges, and capacitors, some keywords Related to electric vehicles in general: capacitors, computational fluid dynamics, computer simulation, electric automobiles, electric motors, electric cars, fuel cells, fuel economy, marketing, mathematical models, research and development management
- Cluster 2 (Green): 14 Items: Electric vehicle product development engineering engineering**
 Concurrent engineering, ecodesign, energy efficiency, environmental Impact, environmental protection, life cycle, lithium batteries, product design, product development process, quality function deployment, sales, sustainable development, and technology.
- Cluster 3 (Blue): 14 items: automotive industry electric vehicle product development**
 Technology, automotive industry, battery electric vehicles, commercial vehicles, competition, cost engineering, cost reduction, costs, design, electric utilities, innovation, investments, manufacture, optimization

4. **Cluster 4 (yellow): 11 items: simulation and performance of electric vehicle product development**
Article, carbon dioxide, curricula, electric machine control, engines, internal combustion engines, performance, powertrain, simulation, students, vehicles
5. **Cluster 5 (Purple): 8 Items: new product development electric vehicle product development**
Automotive product development, battery pack, decision making, electric drives, electric traction, hybrid electric vehicle, new product development, traction motors
6. **Cluster 6 (light blue): 4 items: energy electric vehicle product development**
Traction motors, energy storage, patents and inventions, secondary batteries
7. **Cluster 7 (brown): 4 items: barriers to electric vehicle product development**
Hole Injection Barriers, Hole Transport Materials, Organic Light Emitting Diodes (OLED), Product Development

CONCLUSION AND SUGGESTION

This study summarizes the research domain regarding the development of electric vehicle products from one view. This paper shows that research in this area has remained attractive for the last 10 years and will remain an exciting topic in the coming years.

Some of the key findings in this study include the most dominant country in scientific publications on the development of electric vehicle products, the United States, with 56 publications, followed by Germany, with 50 publications. Meanwhile, the National Natural Science Foundation of China is the institution that has the most publications, with seven publications, and the second position is the Bundesministerium für Bildung und Forschung, with six publications. The keywords that appear most often are product development, electric vehicle, and product design.

Please note that this study has limitations. Among them, this analysis is based on data provided only by SCOPUS. Of course, this is one of the most trusted sources of information. However, the results may differ when adding sources of information other than SCOPUS. This study does not cover co-authorship from the author, organization, or state.

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