

Review

# The Electric Bicycle: Worldwide Research Trends

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**Abstract:** The bicycle has gone from being an old-fashioned recreational product to a less polluting means of transport and a compact, ultra-light personal mobility tool. This is how electrical bicycles will be used as the pillar that could support individual public transport in large cities worldwide. The objective of this manuscript is to detect how worldwide research on the electric bicycle is being developed, and, especially, around which scientific domains is it clustered, to finally identify the main trends in the field. This study has been carried out based on the Scopus database, where all the publications related to the topic of the electric bicycle have been analyzed up to the year 2017. Therefore, research on the global research trends of this topic was conducted. Its evolution over time shows that since 2008 the growth of publications is much higher than in the previous period. The main countries are China and the USA, and it can be inferred that there are two major trend countries with high environmental awareness, which also have a large population and that the electric bicycle is a suitable and sustainable form of transport. Among the main scientific fields, engineering leads in research. The keyword analysis shows that the central theme is electric, then battery and motor stand out. A community detection was applied to detect the six main clusters of this research, largely dedicated to the following topics: Transportation–Environment, Electrical Engineering, Safety, Batteries, Sporting Goods–Urban Planning, and Mechanical Engineering. This manuscript shows that global research trends about the electric bicycle are increasing, and that it should be considered a means of sustainable urban transport and will therefore contribute to energy saving and sustainable energy.

**Keywords:** batteries; electric bicycle; electric vehicle; energy saving; transportation

## 1. Introduction

An electric bicycle is a type of electric vehicle based on a traditional bicycle to which an electric motor has been added to help propel it [1]. It is an ecological and urban means of transport and its source of energy is a battery. In the 20th century, electric bicycles began to play a more important role because they were an economic and simple option for urban transport problems and had environmental advantages [2], especially in highly populated countries like China [3]. To highlight this fact, it is enough to indicate that over 31 million e-bikes were sold in 2012 [4]. The main advantages of an electric bicycle are both economic and environmental. Among the economic advantages we can find the total cost per kilometer travelled by an electric bicycle (including the energy, purchasing and maintenance), is less than 0.7 cents, compared to \$0.031/km for a gasoline scooter [5], or \$0.62/km travelled by car.

The batteries of the electric bicycles can be recharged by connecting them to a plug or when pedaling in some gears. In addition, a typical electric bicycle needs 6–8 h to charge the battery [6] and has a range of travel of 35 to 50 km at a speed of about 20 km/h (depending on rider weight) [7]. This means that, with a single battery charge, it would be enough to go to work, visit friends, and return

home on a normal day, since statistics show that about half of the trips and procedures of a normal urban person are carried out within a distance of 15 km from his/her house, therefore within the reach of these bicycles [3].

From an environmental point of view, for petrol car consumption in urban areas, the emissions are: HC (Hydrocarbons) 3.57 g/km, CO 3.15 g/km, CO<sub>2</sub> 1.82 g/km, and NO<sub>x</sub> 2.29 g/km [8]. Therefore, the electric bicycle, as an alternative means of transport to the car, shows that for every 100 km an average of 8.5 L of gasoline is saved, and this pollution would be avoided.

The electric bicycle as a new form of private transport has led to a new approach to mobility, especially in cities, both for countries with large populations and for countries that are concerned about the environment. The research on the electric bicycle is relatively new, but today, nobody clearly knows where the efforts are being focused, nor what the main points of interest of the scientific community are. The objective of this manuscript is to detect how the worldwide research of the electric bicycle is being developed, and, especially around which scientific domains it is clustered. Finally, the main trends in this field can be identified.

## 2. A Brief Overview of the Electric Bicycle

Electric bicycles began almost at the same time as traditional bicycles. In the 1890s, several patents were granted for electric bicycle engines. In 1895, Ogden Bolton was granted in the United States the patent (US Patent 552,271, 1895) for a bicycle battery with six brush poles, a DC collector and a hub motor mounted on the rear wheel [9]. In 1897, Hosea W. Libbey in Boston invented an electric bicycle (US Patent 547,441, 1895) that was powered by a double electric motor. That same design was later used by the Giant Lafree e-bikes (electric-assist bicycles) brand in the 1990s [10].

In 1920, Heinzmann, a German company, started to mass produce electric motors for bikes. Their first motor was mounted on a tandem. Later, it continued to develop engines that incorporated German mail distribution bicycles. In the 1930s, Minneapolis-based Lejay Manufacturing registers patents that are the germ of the GoBike, an electric bicycle with a generator of a Ford T coupled to the rear wheel. Later, Moulton Consultants Ltd. manufactured a double chain transmission, one from the bottom bracket and another from the electric motor. In the 1940s, electric bicycles registered an increase due to a shortage in large motorized vehicles, as a result of the war efforts of the Second World War. Several patents were granted for prototypes that were eclipsed by the development and investment in the motorcycle industry, which played a more important role during that war. In post-war Europe and Asia, due to the prohibitions to countries like Italy and Japan to build and rearm their aeronautical industry, many engineers who were dedicated to the development of engines for airplanes saw a niche and dedicated themselves to the motorcycle industry, and in the shadows of this development were electric bicycles, which went a bit ignored but nonetheless benefited from the new technologies and innovations in that industry.

However, it was not until the first oil crisis in 1973, that the use of electric bicycles began to be promoted, although they did not have much popularity. It was in the United States where electric bicycles played a preponderant role in urban transport as a clean option for the oil problem. This first mass-marketed model was a bit rough and heavy compared to the current models, as it had a solid steel frame and was cumbersome to transport. However, it proved to be very versatile and economical compared to the large and powerful engines of the cars of the seventies. This bicycle, like its predecessors, did not harm the environment nor depend on the fluctuations of the oil market. In 1982, the inventor Egon Gelhard developed a subtype of electric bicycles that worked with the electric cycle pedal principle, where the driver is aided by the electric traction of the engine when pedaling.

Electric bicycles began to gain more notoriety in the nineties. In 1992, Sinclair Research Ltd. sold the Zike, a bicycle that included nickel-cadmium batteries. It was a portable bicycle that weighed 11 kg with a small electric motor driving the rear wheel and with batteries built into its frame. Only 2000 units were sold. In 1993 the Japanese company Yamaha helped spread the model of "bicilec" or "pedelec" (pedal electric cycle) in Japan, with the name "Power assist", which was highly successful.

At the end of the 1990s, various models of torque sensors (US Patent 4,966,380, 1990) [11] and power control [12] were developed, as well as new types of more durable batteries [13]. Furthermore, at the end of the 1990s, the big bicycle brands dominated the market, but at the beginning of the year 2000 the sales of electric bicycles diminished radically, only to resurface in the year 2005 with the boom of the lithium battery. This boom at the beginning of the 21st century began thanks to the reduction in the weight of the bicycle: Panasonic built the lightest electric bicycle on the market (19.9 Kg). Soon after, Honda released its Step Compo model, the first electric folding bicycle to weigh 18.7 Kg. Later Panasonic adopted the Lithium ion battery to revolutionize the market again. So, in 2012, 854,000 e-bikes were sold in the EU27, which means 1.7 e-bike sales per 1000 inhabitants, and for the total number of bicycles sold means 4.2% [4]. In France, 134,000 e-bikes were sold in 2016, compared to 37,000 in 2011. In Italy, more than 124,000 e-bikes were sold in 2016 and nearly 24,000 were produced in the same year, growing by 40.5% compared to the previous year [14].

It is estimated that around 21 million electric bicycles were circulating in China in 2009, which is more than the total number of cars in China (9.4 million autos) [15]. In fact, Xinri is the largest worldwide manufacturer of electric bicycles [16]. Their customers are, for example, the Chinese police, and the postal service. However, the rapid expansion in the use of e-bikes in this country has led to a consequent increase in the number of injuries [4]. From a global point of view, in 2015, just over 40 million e-bikes were sold worldwide, of which more than 90% were in China, 5% in Europe, and only 0.7% in USA.

From the point of view of the main performance regulations of the global e-bike markets by Motor power limit (W) and Top speed (km/h), in the USA it is 750 W and 32 km/h, in the EU it is 250 to 100 W and 25 km/h, and in China it is 25 km/h with no limit on Motor power but the bike must weigh <45 kg [17,18].

The greatest advantages provided by this means of transport are:

- In the morning time while leaving home, our time is appreciated at every minute and speed makes this model of electric transport attractive for many urbanites, as the time of preparation of the vehicle is considerably reduced.
- It also eliminates the need to look for parking, which not only means an inestimable time saving but above all significant money savings in the urban economy.
- It is possible to convert a routine displacement carried out under pressure into an opportunity to do exercise, since we work on our cardiovascular system during the ride. In addition to avoiding traffic jams, we are taking care of our body, so the known excuse of not having time to exercise can be resolved in the most practical and comfortable way possible. In short, it is compatible to take care of yourself while going to work.

Given the advantages of the electric bicycles both from an environmental and energy savings point of view, especially in urban transport, in this work we set out as an objective to study the research trends about scientific publications related to electric bicycles.

### 3. Material and Methods

The existence of two major databases, Web of Science (WoS) and Scopus, raises the important question of the comparability and stability of statistics obtained from different data sources [18]. Several studies have measured the overlap between databases and the impact of using different data sources for specific research fields on bibliometric indicators, demonstrating a larger number of journals indexed by Scopus compared to WoS [19]. Regarding the overlap, 84% of the WoS titles are also indexed in Scopus, while only 54% of the Scopus titles are indexed in WoS [20,21]. For this reason, Scopus was selected for this work.

In this study, a search of Elsevier's Scopus database was performed using the key to search the subfields of Title, Abstract and Keywords, to identify publications that address the issue of the electric bicycle. The search was conducted over the whole data series, that is, the last 44 years, from 1973

to 2017. The search query was: TITLE-ABS-KEY ("Electri\* bicycl\*" OR "Electri\* Bik\*" OR "e-bike"), since the scientific literature presents different ways to refer to electric or electrical and bicycle or bike, in addition to singular or plural forms, and recently e-bike. This methodology has been used successfully in other bibliometric studies [22–24]. In this way, with the publications that referred to the electric bicycle, the evolution of scientific production can be studied in accordance with years, type of publication, language, distribution of publications by country, indexation categories of publications, and analysis of key words; this last aspect is the one that provides the most information for the research carried out.

Once the manuscripts related to the electric bicycle have been obtained, the study on research trends is carried out through the study of their keywords. The first step is to analyze which keywords are the most frequent among all these manuscripts; this shows which topics have been the most studied for the electric bicycle. To compare the relative importance among them, these results are usually represented by a cloud word. The second step was a specific search for the ten main countries that have published on this topic. For China, the specific query was: TITLE-ABS-KEY ("Electri\* bicycl\*" OR "Electri\* Bik\*" OR "E-bike") AND (LIMIT-TO (AFFILCOUNTRY, "China")). These results will show the main keywords used in the manuscripts published by this country. The third step was another specific search for the main keywords obtained from the main query; e.g., TITLE-ABS-KEY ("Electri\* bicycl\*" OR "Electri\* Bik\*" OR "E-bike") AND (LIMIT-TO (EXACTKEYWORD, "Transportation")). These results will show the evolution of the keywords during the study period.

The set of articles obtained in the main search are represented by a network that is noded and linked. Nodes are the keywords and their importance is represented by the size of the node and its centrality in the network. The size of the connection between two nodes represents the number of relationships between the two keywords, thus the larger the relationship between those two keywords the thicker the link will be. If it is desired to know around which topics the articles are grouped, that is to say, which parts of the network are more interconnected with each other, it is necessary to use a community detection algorithm [25]. Finally, the community detection algorithm is applied to the network of the main query to group the global trends to the search criteria. As less strongly related elements are associated with this nucleus, the peripheral elements are structured. In this work the Sw VOSviewer has been used (<http://www.vosviewer.com/>) specifically for this type of scientific production analysis [26,27]. Figure 1 shows the summary of the described methodology.

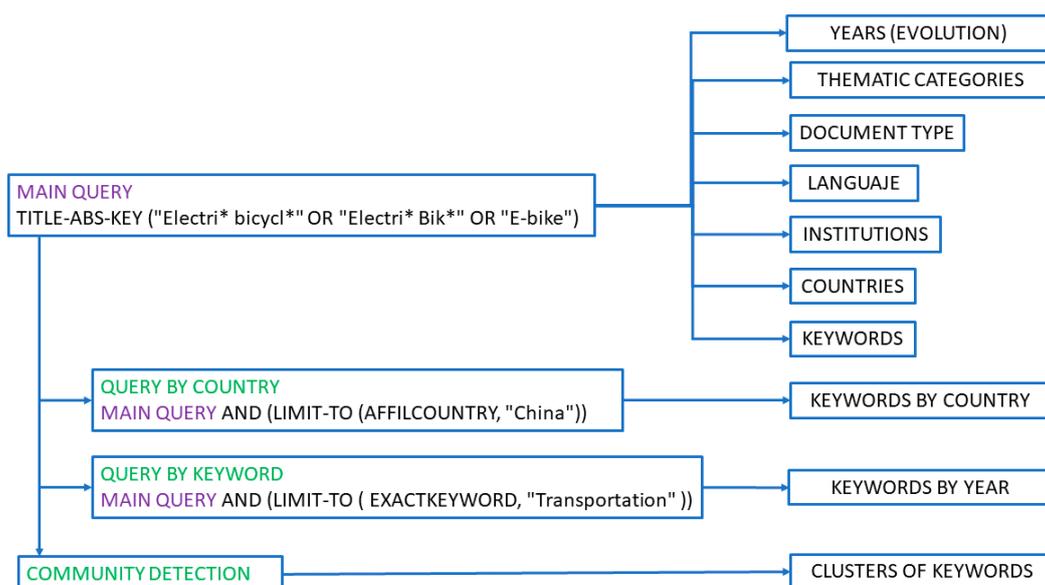


Figure 1. Methodology.

## 4. Results

### 4.1. Evolution of Scientific Production

From 1973 to 2017, the search yielded 896 document results, whose temporal distribution is shown in Figure 2. It must be noted that the search has no data prior to this date, for this reason 1973 is considered the first year of this search. It is observed that the increase begins in 2003, and 2008 is the year when scientific production increases significantly. These publications are written mostly in English in more than 90% of cases, although the Chinese language also appears strongly since 2001, with 7.5%, other languages are already anecdotal with less than 1% and included Japanese, Dutch, German, Polish, Russian, Spanish, and French.

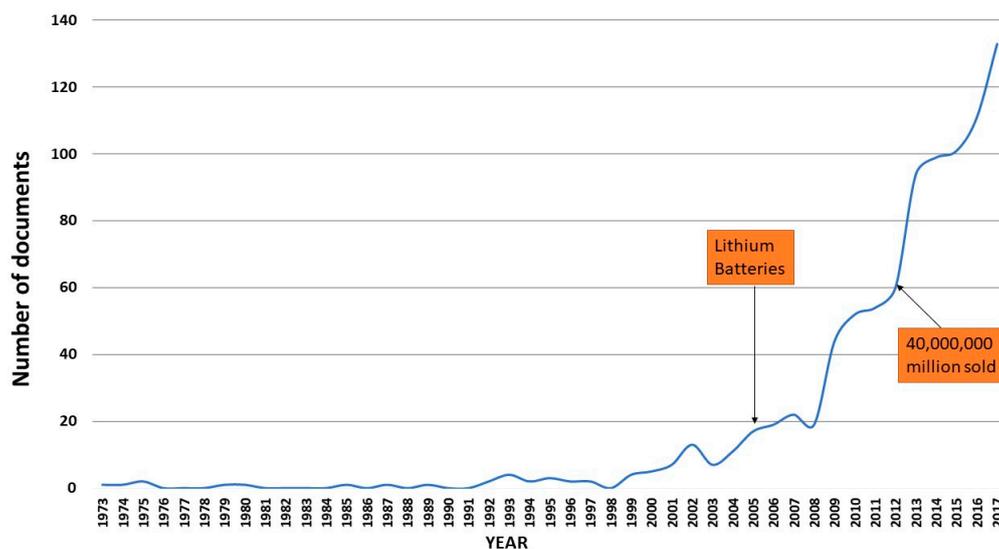


Figure 2. Evolution of the scientific production in relation to the electric bicycle (1973–2017).

### 4.2. Types of Publications and Thematic Categories

In the analysis of the means of scientific diffusion, generally, the most used means are journal articles [28], except in areas of novel research, where the search terms appear mostly in specialized scientific conferences. This is what occurs in our case, where conference papers account for the most part, 54% of the total, while articles in journals account for 43%. Figure 3 shows the percentage of the types of scientific production distributed on the theme of electric bicycle.

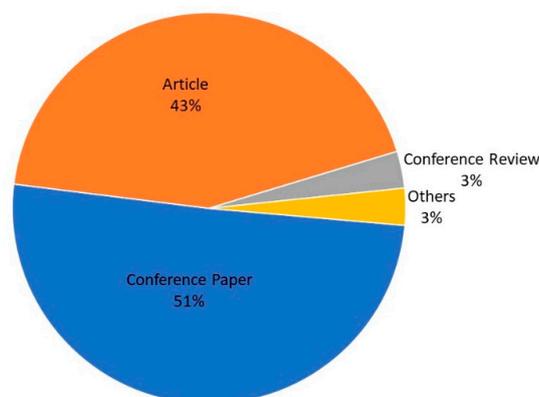


Figure 3. Types of scientific production referred to the electric bicycle (1973–2017).

The thematic categories in which the scientific work is classified show the approaches from which the problem under study is approached (see Figure 4). In our case, it is observed that the principal categories are: Engineering (42%), Computer Science (12%), Energy (10%), Social Sciences (10%), and Medicine (4%).

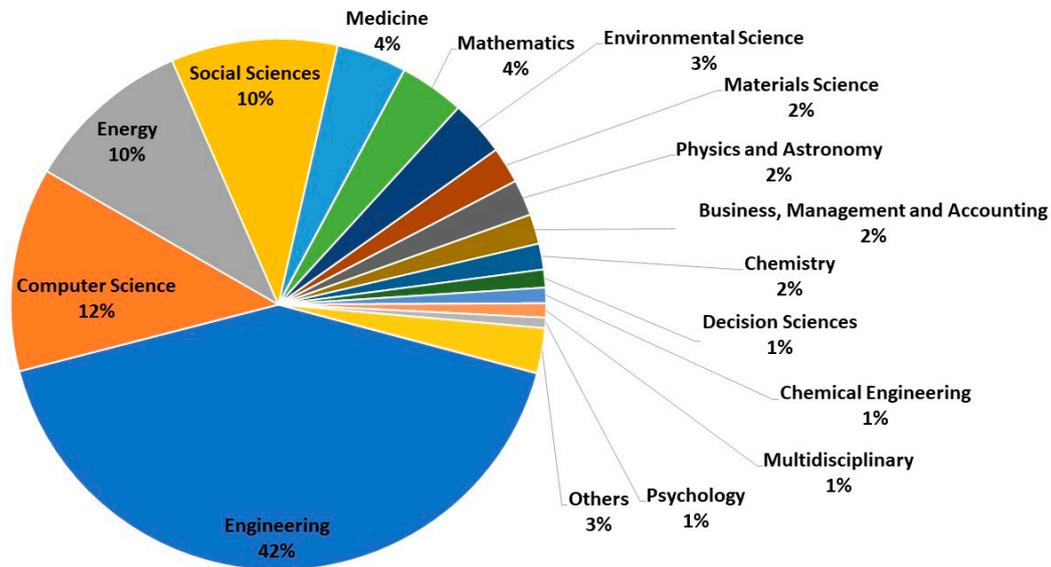


Figure 4. Distribution by thematic category of scientific production in relation to electric bicycles.

#### 4.3. Distribution of Publications by Countries and Institutions

Figure 5 shows the geographical distribution of the countries with publications in this field. The top ten countries concerned about this issue, as reflected in their scientific production, are, by order: China, United States, Taiwan, Italy, Germany, Japan, South Korea, Australia, Malaysia, and Canada.

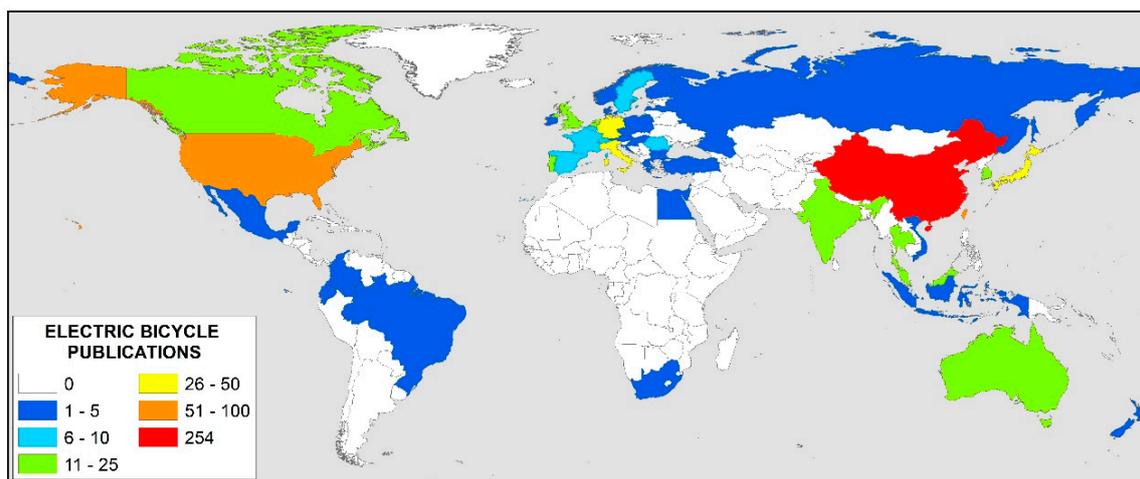


Figure 5. Geographic distribution by countries of scientific production in relation to electric bicycles.

Table 1 shows that the institutions with more than 8 publications, of the 16 represented, 10 are from China: Southeast University, Tongji University, Tsinghua University, Zhejiang University, Southwest Jiaotong University, Beijing Jiaotong Daxue, Chang’an University, Jilin University, Chinese Academy of Sciences, and Nanjing University of Aeronautics and Astronautics. 2 are from the USA: University of Tennessee, Knoxville and UC Berkeley, while a number of countries produce one publication and

include Italy (Politecnico di Milano), Australia (Monash University), Taiwan (Kao Yuan University Taiwan), and Portugal (Universidade de Lisboa). If the total citations (TC) in these publications are observed, the Tsinghua University leads, followed by the University of Tennessee. However, when it comes to average appointments for published work (TC/N), it is the other way around.

**Table 1.** Main institutions with research on electric bicycle and their main bibliometric indicators.

Institution	Country	Number of Publications (N)	Total Citations (TC)	Citations Per Document (TC/N)	Rank (by N)
Southeast University	China	36	145	4.0	1
Tongji University	China	17	133	7.8	2
Tsinghua University	China	15	363	24.2	3
University of Tennessee, Knoxville	USA	14	350	25.0	4
UC Berkeley	USA	14	242	17.3	4
Kao Yuan University Taiwan	Taiwan	14	25	1.8	4
Zhejiang University	China	13	69	5.3	7
Politecnico di Milano	Italy	12	43	3.6	8
Southwest Jiaotong University	China	10	30	3.0	9
Monash University	Australia	10	131	13.1	9
Beijing Jiaotong Daxue	China	10	17	1.7	9
Chang'an University	China	10	21	2.1	9
Universidade de Lisboa	Portugal	8	33	4.1	10
Jilin University	China	8	37	4.6	10
Chinese Academy of Sciences	China	8	125	15.6	10
Nanjing University of Aeronautics and Astronautics	China	8	33	4.1	10

#### 4.4. Keyword Analysis

The analysis of the keywords identifies or summarizes the work of the researchers [29]. This section analyses the keywords obtained from the main query described in the methodology section. In the overall articles obtained from the query, the frequency of appearance of each keyword has been obtained. In Figure 6, a word cloud has been represented where size and centrality show the importance of that keyword within the total publications, defined by the highest frequency of occurrence or the number of times it is repeated. If the main query is filtered by each of the major countries by number of publications, the main keywords of these countries are obtained. Therefore, Table 2 shows the three main keywords of the top ten countries. The keywords of the countries that least resemble the rest are those of Japan and Australia, and both have a gender component that is very much present in their studies.

On the other hand, if the main search is limited to a particular keyword, the frequency of occurrence of this keyword for each year can be obtained. Figure 7 shows the evolution over time of the top three keywords. Note that the search is limited to the last ten years, from 2007 to 2017. This is due to the small difference existing in earlier years (note that in 2007 two of these keywords had no values). The keywords “Electric Vehicle” were almost always above the others but they have emerged mainly since 2015. The other two keywords, “Sporting Goods” and “Transportation”, were in the same rank until 2012. Since then, sporting goods began to distance itself upwards. In this part of the analysis, it is worth noting that the electric bicycle is no longer just an alternative for transportation, but a means of daily sports practice to improve health. Indeed, the electric bicycle is considered a vehicle. It is important to highlight this fact, because for many countries it is proposed as a solution to the problem of personal transport. On the other hand, in the US, “sporting goods” refers to items that are purchased for recreational purposes.



#### 4.5. Analysis of the Interconnection Between Keywords: Community Detection

Considering a community as a system composed by multiple interdependent elements, with a very wide range of relationships that are variable and dependent, we could accept, conceptually, that communities are made up of a highly cohesive central core and peripheral spheres with unions increasingly weaker compared to the center. The central core would be structured by the most significant elements of the community, in terms of granting a definable individuality, evinced by the links between its constituents who share the strongest and most significant connections within the entire community complex. Communities or clusters are usually groups that are more likely to relate to each other than with members of other groups [30]. Identifying communities is an interesting problem in our case because it will guide us around which way the main topics of the publications are grouped. For this specific analysis, we downloaded the keywords of each publication separately, generating a file line with up to six keywords used in each publication; this file was entered into a network analysis software that detected the main communities.

Clusters with different colors have been shown (Figure 8) and they are represented in the form of neural network. Each node is a keyword, and the thickness of the link between nodes is the frequency of that relationship. In the analysis of the publication of the electric bicycle, six communities have been detected using a community detection algorithm, and Table 3 shows their main keywords. To identify each cluster a proposed name is offered in the last column of the table. By order of importance they are: Transportation–Environment, Electrical engineering, Safety, Batteries, Sporting goods–Urban planning, and Mechanical engineering. Transport and environment is the first in order of importance, highlighting this cluster within world research, and above all the concern for air pollution in cities. As was expected, electrical engineering supports this technology, and it is quite logical that it ranks second. The risk factors for accidents have increased greatly with the increase in the number of electric bicycles, so the issue of safety appears as the third most important issue. Batteries rank fourth among the clusters, highlighting the improvement of batteries, especially in charging systems and the increase in their autonomy.

As mentioned above, it is surprising that the electric bicycle is part of the concept of sport, but its daily use undoubtedly promotes individual sport, and this can be a health-enhancing sports routine. The mechanical approach is therefore the last of the categories.

**Table 3.** Main keywords used by the communities detected in the topic electric bicycle.

Cluster	Color	Main Keywords	Topic	%
1°	Blue	Age factors–traffic accidents–risk factors	Safety	25.2
2°	Green	Electric motors–dc motors–voltage control–electric machine control	Electrical engineering	21.4
3°	Yellow	Electric batteries–charging batteries–Energy transfer–Fuel cells–Lithium ion batteries–Energy storage	Batteries	19.5
4°	Pink	Roads and streets–civil engineering–speed–Highway accidents–pedestrian safety	Roads and streets	14.6
5°	Red	Urban transportation–urban planning–Air pollution–Carbon dioxide–Carbon emission	Transportation–Environment	11.9
6°	Sky-blue	Torque control–human power–pendulums–systems stability	Mechanical engineering	7.3

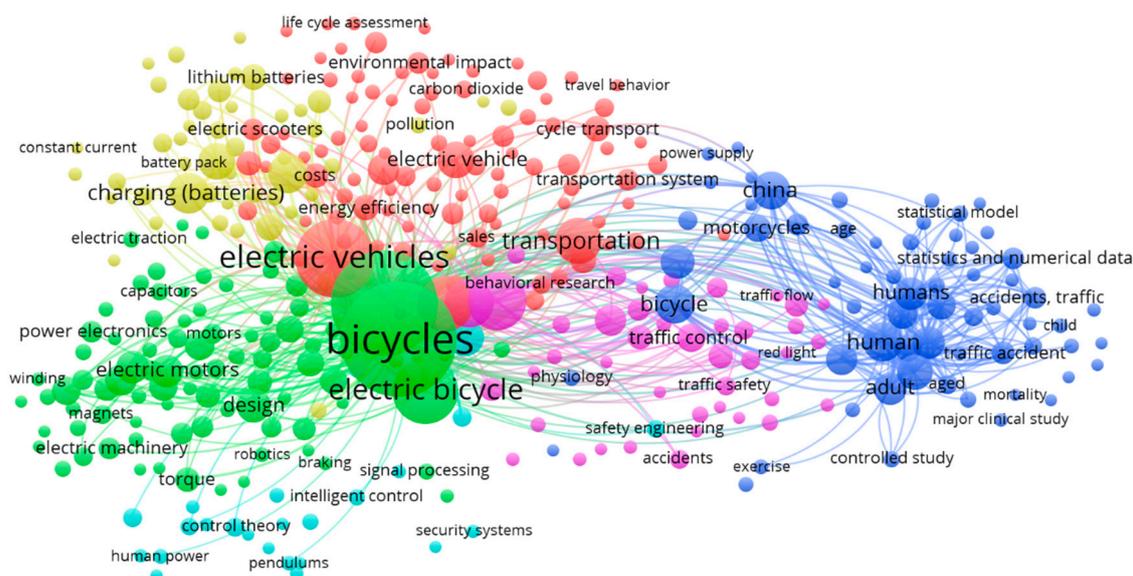


Figure 8. Electric bicycle Keywords network and their community detection.

## 5. Discussion

Regarding the language, these publications are mostly written in English more than 90% of the time, but it is not surprising that the Chinese language appears for 7.5% of the total, which is due to the fact this country is the one that has the most electric bicycles in the world. In Figure 1, two major milestones for the electric bicycle are highlighted: the year 2005 with the appearance of the lithium ion battery and the year 2012, when 40,000,000 million electric bicycles were sold worldwide.

As expected, the field of engineering leads the research, since it covers facets such as transport [31], the development and manufacturing of a product [32], innovation in materials to lighten bicycles [33], and electrical issues related to batteries [34]. Computer science deals mainly with the design [35], distribution of energy to the charging batteries [36], issues related to safety [37], behavior [38], and Medicine to Accident Analysis and Prevention [39–42].

About the analysis of the countries that most publish on this subject, they can be classified into three types of countries. First, the countries with high environmental awareness [43,44]. Second, those which have a large population and where the electric bicycle is a sustainable form of mobility. And third, countries with a long tradition of the bicycle as a means of transport, such as Taiwan or China [45]. The other block of countries with scientific interest in the electric bicycle is composed of 20 countries. Their number of publications in order are Portugal, the United Kingdom, India, the Netherlands, Thailand, Belgium, Spain, Singapore, Switzerland, and Romania. The same trend is observable for the top ten, who share great bicycle traditions, such as Belgium or the Netherlands [44], and countries with environmental concerns. For instance, the number of cities that offer a bike sharing program has enlarged quickly, and currently more than 800 exist from just a few in the late 1990s [45]. The future trend includes the integration of e-bikes to share and the project BiciMAD, introduced in Madrid (Spain) in June 2014, includes 2028 electric bicycles distributed among 165 stations. Therefore, bike-sharing is also an emerging topic of urban transport and sustainable mobility related research [46]. This e-bike mobility will also be enhanced by bike lanes implemented in the cities [47]. While e-bikes may mainly compete with cars in many countries, in the Netherlands it competes with regular bicycles as well, which are an even more sustainable transport mode. Hence, an important question that still needs to be addressed is to what extent the market share of the e-bike draws from all other available alternatives. Other policies are the granting of aid to purchase. For instance, in Spain, to enhance mobility with zero emissions in urban transport, the program PIMA AIRE 2 subsidizes the procurement of e-bikes and direct discounts of 200€ are available [48].

Regarding the main institutions dedicated to the research of this scientific field, as expected of the countries, research is led by Chinese institutions. The institutions are mainly dedicated to the problems of their countries, for example, Southeast University has focused its efforts on Transportation [49] and energy [36].

If one pay attention to the keyword analysis in Figure 6, one can observe how the central theme is electric, followed by battery and motor. From the main keywords by country shown in Table 1, the main keyword, Electric Vehicles, dominates the top five, as expected. And interestingly in China, the second keyword is Sporting Goods and the third Transportation. In the USA, they are more concerned with transport and then battery technology, Taiwan is design, Italy and Malaysia are Fuel Cells, Germany, Australia and Canada are Sporting Goods, Japan with gender concerns, and South Korea with electric and mechanical design. From the evolution of the main keywords shown in Figure 7, it is observed that the consideration of an electric vehicle clearly dominates the trend of the studies, and since 2013 sporting goods is a higher trend topic than transport. Nonetheless, these publications also have a great relationship with the transport issue [42].

The clusters identified by community detection are, by order of importance in Figure 8 and Table 3: Transportation/Environment, Electrical engineering, Safety, Batteries, Roads and streets, and Mechanical engineering. The safety cluster (1) is not surprising given the increasing number of crashes in this type of transport. For example, between 2004 and 2008 in China, mortality and injury rates increased 6.5 times and 3.7 times, respectively [50]. The most studied keywords are: age factors, traffic accidents, and risk factors. Even so, some authors think that one of the major gaps in the safety literature in China is the lack of research attributing fault or causal crash analysis on rising e-bike casualty burden [51].

Cluster 2 is related to Electrical engineering. Thanks to its lighter weight, the electric drive technology has enabled e-bikes to be very energy-efficient. For instance, most e-bikes consume about one-tenth the energy consumption of a small electric car; this means less than 2 kWh/100 km [41].

Battery cluster (3) is focused on the keywords: Electric batteries, charging batteries, Energy transfer, Fuel cells, and Lithium ion batteries. The improvements in battery and motor technology show that there is a trend for e-bike design that more closely resembles traditional bicycles, which probably makes them more attractive to traditional bicycle users. As mentioned earlier, the use of the electric bicycle reduces CO<sub>2</sub> emissions, and is apparently an environmental benefit. But in the e-bike literature, there are still few studies on the future environmental impact of certain types of batteries used in them. It is estimated that 95% of e-bikes in China use lead-acid batteries, though other batteries have been entering the market in recent years [4]. Lithium Ion (Li-ion) batteries can increase vehicle and environmental performance [33]. Therefore, battery technologies will improve the environmental challenges of contamination caused by batteries.

Roads and streets, which is cluster 4, deal with civil engineering for the improvement or adaptation of streets, roads, and even highways for this new transport system. It is clear that e-bikers are likely to increase exposure and risk in relation to traditional cyclists, for example because of speed, and may therefore be more vulnerable on public roads. Research in China and the Netherlands demonstrates that the risk of collision appears to be higher than conventional bicycles.

In cluster 5, Transportation–Environment, these keywords are observed: Air pollution, Carbon dioxide, or Carbon emission, which makes one think of the increase in ecological awareness caused by concern about climate change, and the following keywords are observed: Urban transportation or Urban planning, which relate to the need to reduce traffic in cities where collapse occurs during peak hours. Underlining that, one of the most cited e-bike benefits is the potential for the bike to act as a replacement for the use of a motor vehicle [38]. So, for those using e-bikes predominately for transport purposes, the social positive context (to e-bikes) and environmental beliefs are important determinants [52]. It should be noted that CO<sub>2</sub> emissions are 40 times less than a conventional vehicle travelling the same distance [41].

Mechanical engineering, cluster 6, deals with studies related to Torque control, human power, and pendulums or systems stability. In this area, there is still potential for improvement, particularly in the search for lighter materials. This weight relief would also allow certain types of electric bicycles to be adapted to the regulations of countries whose restrictions are based on the weight of the bicycle.

In this study we have observed that research on electric bicycles has grown in recent years, perhaps in parallel with their sale. It is evident that there is still room for improvement from a technical point of view; i.e., electrical engineering and mechanical engineering, or clusters 2 and 6, respectively, especially in e-bike assistance.

Therefore, research should be focused on three main areas. The first would be the upgrade or adaptation of cities to this new means of transport, especially in terms of safety for pedestrians and cyclists, which can be derived from the overlap of clusters 1, 4, and 5, where there are keywords that could be associated with the same problem; for example, traffic accidents (cluster 1), pedestrian safety (cluster 4), and urban planning (cluster 5). There are some works already in this research line, where it is highlighted that many governments are attempting to improve cycling safety to reduce the number of bicycle crashes and encourage cycling [53].

The second would be the environmental treatment of waste produced by the withdrawal or change of e-bike components. Since the environmental problems studied in this topic seem to be centered for the moment in the atmosphere, especially in the reduction of CO<sub>2</sub> emissions (cluster 5), the share of the electric bicycle in a massive way has been seen to be relatively recent, and the analysis of the life cycle of its components, especially the most sensitive ones, such as batteries (cluster 2), can give rise to environmental problems in other areas, such as the lithosphere or the hydrosphere [54], although more in the long term.

Finally, although the topic of health does not appear as a key word in the analysis carried out, the search is also extended to the abstract of the articles, (TITLE-ABS-KEY (“Electri\* bicycl\*” OR “Electri\* Bik\*” OR “E-bike”)) AND (health), and it does play an important role, appearing in more than 20% of these publications. Its first work was done in 2007 [55], and since then the relationship between health and the electric bicycle has increased significantly. Additionally, it has been observed that these works are widely cited, with more than four average citations per work. Other authors also emphasize the importance of the term “health” in relation to the electric bicycle [4], and especially because of increased physical activity. However, if the search is focused on the “physical activity”, TITLE-ABS-KEY (“Electri\* bicycl\*” OR “Electri\* Bik\*” OR “E-bike”) AND (“physical activity”), results are four times lower than those of health, playing an important role in medical journals; for example, *Medicine and Science in Sports and Exercise* [56]. Some works claim that cycling is in a unique position for its ability to integrate physical activity into everyday living [57]. In this sense, the electric bicycle can increase cycling, since its use is not only traditional as a sport but also as a means of transport.

Other lines of research that have been explored but with little success have been those related to active transport, which obtained only seven published works, and those that related to recreational trips, which obtained only two published works, although these are all very recent, from 2015 onwards. There are very interesting works about active transport, specifically associated to the ages and attitudes of the e-bike users. For example, there is not so much difference in age between these new users and traditional bicycle users, and on the other hand there are differences in the increase in the average distances covered [58]. On the other hand, some authors find that e-bikes are preferred for commuting (home-work) and business (work related) trips rather than for recreational trips [59]. Given the nature of this means of transport, weather influence is a vital area of concern, but it has been found that weather conditions have more influence on recreational trips than on commuting trips [59]. Measures to promote the use of the e-bike should include workplace promotion measures aimed at addressing not only the instrumental but also motivational reasons for the use of the e-bike [58].

These issues should be addressed by researchers as they are the ones that can attract users to this type of transport. In general, it would be necessary to establish legal regulations for their use, although this goes against existing commercial policies at the moment, which considers them, in most

cases, as bicycles or as sporting goods (Figure 7). The latter goes against the real performance of this means of transport, especially its speed and autonomy, which allows them to circulate not only on city streets but also on roads between towns or even motorways; so there is currently no guarantee that the e-biker knows the basic rules of the road. As we have seen, the main line of research is related to safety (Age factors–traffic accidents–risk factors).

## 6. Conclusions

After completing the scientometric analysis, it is observed that the top ten countries concerned about this issue, as reflected in their scientific production are, by order: China, United States, Taiwan, Italy, Germany, Japan, South Korea, Australia, Malaysia, and Canada. It can be deduced that there are these main trends: countries with a large number of inhabitants are interested in electric bicycles because they are a sustainable form of mobility due to their long tradition as a means of transport, and countries with high environmental awareness. Regarding the main institutions six are from China (Southeast University, Tongji University, Tsinghua University, Zhejiang University, Southwest Jiaotong University and Beijing Jiaotong Daxue), two are from the USA (University of Tennessee, Knoxville and UC Berkeley), one from: Italy (Politecnico di Milano), Australia (Monash University), and Taiwan (Kao Yuan University Taiwan). Thus, the main languages of these publications are English, as was expected as a scientific language; however, Chinese stands out in a high percentage. Our analysis also shows that the electric bicycle as a research issue is not very consolidated, as the type of publication corresponds mostly to conference papers.

The data analyzed related to the electric bicycle shows an increase in scientific and technological interest in this subject. The countries through their research centers or universities have devoted a good part of their efforts to develop an efficient and high quality electric bicycle model by means of the latest technology. This is reflected mainly from the use of lithium batteries in 2005 and since 2012 by the increase in sales of electric bicycles. This was a phenomenon promoted by the attraction caused by the price, much less than a scooter, and by its speed and lightness in use, in addition to having a simple and inexpensive recharge.

The most important part of this study has focused on finding out what scientific trends are observable in the research and how electric bicycle research is grouped. This has been obtained through the analysis of keywords. Thus, when they are analyzed together one can see that the electrical subject is the one that dominates, using keywords such as electric, motor or batteries. However, they stand out especially in the last ten years. Of the ten, three of them are notable: “Electric Vehicle” almost always occurs above the others but this trend has emerged mainly since 2015, “Sporting Goods” is in second place and “Transportation” arrives in third. It has been noted that the electric bicycle is not only an alternative for transportation, but also a way of practicing daily sports to promote healthy living.

This research is classified into distinct areas: Engineering (42%), Computer Science (12%), Energy (10%), Social Sciences (10%), and Medicine (4%). From the point of view of mechanical engineering it is being investigated in the incorporation of new ultra-light and resistant materials, and from electrical engineering in batteries with more autonomy, and a lighter and faster recharge. Large cities, especially in countries with large populations such as China, or with bicycle transport traditions, such as Holland or Belgium, are betting on this means of transport to make their cities less polluting and for the sake of a healthier way of life. This is reflected in the large number of publications that relate to the electric bicycle as a means of transport and its consideration as a sporting good. Therefore, an increase in the number of electric bicycles in circulation is expected.

Additionally, if the analysis is carried out with the relationship between the keywords of the publications studied, the main clusters can be obtained by means of a community detection algorithm. The obtained clusters were, in order of significance: Transportation/Environment, Electrical engineering, Safety, Batteries, Roads and streets, and Mechanical engineering.

In short, the research in relation to electric bicycles every year incorporates new technologies that make more and more people bet on this alternative means of transport, which makes it compatible

with a healthier lifestyle, is respectful to the environment, and will contribute to energy saving. More research is needed to improve the knowledge base on the use and safety of the e-bicycle, particularly on two key issues: firstly improving road safety and secondly reducing the impact of conventional lead-acid batteries in favor of less environmentally polluting ones.

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