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Review

Sustainability and Innovation in the Automotive Sector: A Structured Content Analysis

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Abstract: This study aims to analyse the scientific literature on sustainability and innovation in the automotive sector in the last 13 years. The research is classified as descriptive and exploratory. The process presented 31 articles in line with the research topic in the Scopus database. The bibliometric analysis identified the most relevant articles, authors, keywords, countries, research centers and journals for the subject from 2004 to 2016 in the Industrial Engineering domain. We concluded, through the systemic analysis, that the automotive sector is well structured on the issue of sustainability and process innovation. Innovations in the sector are of the incremental process type, due to the lower risk, lower costs and less complexity. However, the literature also points out that radical innovations are needed in order to fit the prevailing environmental standards. The selected studies show that environmental practices employed in the automotive sector are: the minimization of greenhouse gas emissions, life-cycle assessment, cleaner production, reverse logistics and eco-innovation. Thus, it displays the need for empirical studies in automotive companies on the environmental practices employed and how these practices impact innovation.

Keywords: innovation; sustainability; automotive industry

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1. Introduction

Sustainable measures require investments in research and development of technical and managerial skills by the innovative agent, and require a significant period of time until they can be adopted as a new paradigm of production. The effort of a company to be sustainable generates costs that it hopes to recover through the benefits resulting from its adoption [1,2].

Due to the pre-disposition to sustainability in big companies, the inclusion of environmental issues in the innovation process becomes relatively easier, considering the existence of a technical and managerial structure capable of incorporating changes in the production process pushed by the technological development itself of the activity [3].

The design, implementation and diffusion of environmental technologies in the automotive industry, says Christensen [4], are largely dependent on the current configuration of the productive system. Because car manufacturers are important for the environmental, social development of the world, in the context of sustainability.

The automotive sector is considered one of the most important for a country's economy and trade—it shapes the industry, the cities, communal and individual life, ever since Henry Ford was able to produce vehicles on a large scale and banks created specific loans to finance their acquisition. The strength of the automotive sector leverages other sectors of the economy. The sector is the second largest market for the steel industry, consuming approximately 15% of total production of this material, second only to the construction sector. Other major businesses relating to the automotive industry are the aluminum sector (5%), petrochemicals (especially plastics, 7%) and glass [5].

The automotive industry is relevant in terms of its impact on the economy as well as on technology. As stated by Humphrey and Memedovic [6], the automotive sector is global and is characterized as a capital-intensive industry with vertical integration and economies of scale [7]. It has been responsible for the development of technological innovation and management, and the original major change on the industrial production processes [8,9].

Since the mid 1980s, the automotive industry has been going through a transition, in which domestic industries are adapting to an integrated global market [10]. According to the authors, this integration took place mainly in the buyer-supplier relationship, especially among automakers and their suppliers. In the early 21st century, the automotive industry, which had already achieved a level of maturity and high structure, has to be pressed by globalization, government regulations—concerning energy consumption, emissions and safety—and technological advances in electronics, communication and design [7].

Bastin [11], explains that governments in various parts of the world have been implementing measures to increase this importance, such as Brazil, where the Brazilian vehicle registration program was created to improve the energy efficiency of new light vehicles. In the US, with emission control legislation (HC, CO, NOx) [12]. In China, where the National High Technology Research and Development Program (the so-called 863 Program) was created [13]. Moreover, in some European countries, with the implementation of the European Union End-of-Life Vehicle Directive (ELV), which aims to increase the recovery of end-of-life vehicles and thus, reduce waste and improve environmental performance [14].

In the world economy, the automotive industry generates more than $2.5 trillion in revenue per year and corresponds, in general, to roughly 10% of the Gross Domestic Product (GDP) of developed countries [8,15]. According to annual data from the National Association of Vehicle Manufacturers [15], in 2008, China surpassed the United States in the production of auto vehicles. During this period, China produced 9,299,000 units against 8,695,000 units in the US. In 2012, China produced 19.272 million units and the United States ranked second with 10.329 million units, followed by Japan, Germany and South Korea, with 9943, 5649 and 4,558,000 units, respectively. Brazil was in seventh place with a total of 3.403 million units.

From this context, this article aims to analyze the scientific literature on sustainability and innovation in the automotive sector in the last 13 years, in order to identify how this sector—of greater incidence in the world—is treating and minimizing its environmental impacts and at the same time bringing innovations in its products.

The article is divided into six sections, the first one comprises this introduction. The second presents the theoretical framework of sustainability, innovation and automotive sector issues. The third establishes the methodology used in this research. The fourth section reports on the results. The fifth section presents the discussions. Finally, we present the conclusions.

2. Sustainability, Innovation and Automotive Sector

Business sustainability can be understood, in a conventional way, as the ability to generate funds to remunerate the factors of production, replenish the used assets and invest to continue competing. In such a way, there is nothing new about innovations being the product of technology and service and process being the management and business model. These are longstanding understandings and stem from the idea that an organization must have continuity that extends indefinitely, as suggested by their social contracts. However, if business sustainability is understood as an effective contribution to sustainable development, then current innovations present additional assessment criteria in relation to the conventional ones. There is no other reason for this issue to be part of the core of the concept of sustainable development. Even the origins of the sustainable development movement were severely criticized for certain successful innovations, as did Rachel Carson in regards to the DDT (dichloro-diphenyl-trichloro-ethane) [16].

According to this movement's concepts of sustainability, innovation should generate economic results and, simultaneously, a social and positive environment, which is not easily attained given the uncertainties that innovations bring about, especially when novelty is extreme or high in relation to the state of the art. The economic effects are relatively easy to predict, for there is an enormous quantity of tools developed for that purpose and innovative companies that know how to use them. Social and environmental effects are more difficult to assess beforehand, as they encompass more variables, uncertainties and interactions. So, the most frequently observed is the continuity of the conventional understanding accompanied by a discourse that incorporates the theme of sustainable development which boils down to merely good intentions, if not a means to appropriate an idea that is gaining momentum with the population and opinion leaders. Sustainable development demands a combination of technical and social changes, since these are all closely related [17].

Innovation, according to the Oslo Manual (Oslo Manual—Guidelines Proposal for Data Collection and Interpretation on Technological Innovation, which aims to guide and standardize concepts, methodologies and construction of R & D research statistics and indicators of industrialized countries, published in 1990 by the Organization for Cooperation And Economic Development (OECD)), is the implementation of a new or significantly improved product, good or service, or a process, or a new marketing method, or a new organizational method in business practices, in local organizations' work or external relations [18] (p. 55). Based on this definition, [19] defined "eco-innovation" as "the production, assimilation or exploration of a product, production process, service or method of management or business that is new to the organization (developing or adopting it) which results, throughout their life cycle, in the reduction of environmental risk, pollution and other negative impacts of the use of resources, including energy, in comparison to relevant alternatives" [19] (p. 7).

Note that "eco-innovation" refers to "eco-efficiency", procedures resulting from the intersection of two dimensions of sustainability, namely the economic and social. Eco-efficiency is a practice that rests between the economic and environmental pillars. This entails developing goods and services that satisfy human needs at competitive prices and that can progressively reduce environmental impacts to a next level supportable by Earth [20] (p. 82). Eco-efficient innovations, for example, reduce the amount of materials and energy per unit produced, eliminate toxic substances and increase the lifecycle of the product. However, they can generate unemployment, extinguishing skills, harming communities or groups of society, and other social problems. Therefore, the social dimension must be accounted for in eco-efficient innovation so that is also sustainable innovation.

The term "eco-innovation" has been increasingly used in environmental management policies of companies and governments, although in diverse contexts and situations and with varied connotations that resulted in the reduction of their practical value [21,22]. In this way, an important question is to know how eco-innovation are classified in order to better understand its characteristics and turn them into successful features for the sustainable industry [22].

For the purpose of characterizing innovation, including eco-innovation, Christensen [4] presents the distinction between radical and incremental changes, which are: (i) Incremental changes refer to gradual and continuous improvement of competencies and modifications that preserve existing systems and maintain existing networks, creating value to the existing system in which innovations are rooted; (ii) Radical changes, on the other hand, are substitutes for competencies, are discontinuous changes that seek to replace existing components and systems and/or the creation of new networks.

Therefore, this distinction between radical and incremental innovation may also be related to environmental functions [23]. It is increasingly understood that a focus on incremental innovation along established pathways is not enough to meet demanding environmental sustainability goals. The need for radical technological change or even innovation at the system level has been pointed out as the solution [24–26]. However, systemic changes generally incorporate greater potential benefits than radical modification [18]. Sustainable integrated production initiatives, such as closed-loop supply chains, can produce better environmental results in the mid and long term, with simple modifications in processes and products.

Pujari [27] points out that eco-innovation can be a relevant tool for the success of the innovation system. It can help in the renewal of the system in general, considering local, social, cultural, ecological and economic aspects [28]. The long-term survival of the economic system depends on its ability to create and maintain sustainable economic processes, which do not involve, in the short term, value creation over long-term wealth [27]. Thus, they become an essential tool for industrial activity, throughout its supply chain and logistics to the final consumer [29].

The automotive industry is constantly under pressure to make a continuous restructuring of communications systems to more agile, flexible and secure systems. As a result, the competitiveness of automakers increasingly depends on their ability to lead, with agility and efficiency, the network of specialized suppliers and distributors [30].

In the 21st century, due to the need to launch products with agility into the market, companies are applying the simultaneous development of the product, with several departments working in an integrated way, saving time and producing a positive effect by the commission of some stages of development [31].

The greater integration of suppliers and assemblers into product development activities has made it possible to reduce the complexity of the design, shorten the development time and the engineering hours required, and to renew more frequently both the product and the technology used, with lower costs and shared responsibilities and with sustainable practices [32].

The specialization of suppliers allows sustainable innovations that generate speed and releases the company to specialize in what its core business is [33], that is, the design and assembly of the vehicle, not its specific parts through sustainable strategies.

The concept of sustainability, most vehicle and auto parts manufacturers have planned actions to reduce the impact on the nature of both their products and their manufacturing processes. Although initiatives in this sense already exist for some decades, it was in the year 2000, and more markedly after 2005, that they began to be part of the daily routine of companies [34]. The study of all the companies that make this industrial complex up (automakers and the whole supply chain) revealed that actions which aimed at environmental management and social responsibility are generally treated in isolation. They are not integrated into the corporate strategy. Most companies are still at an early stage when compared to world-class standards. On the other hand, we observe, in the implementation of new operating units, automakers are already trying to align production processes with the requirements of cleaner production and eco-efficiency, with actions aimed to material and energy savings and emphasizing the aspects of recycling.

The diffusion of sustainability practices throughout the manufacturing chain is at an early stage for the vast majority of companies. Some automakers require ISO 14001 certification (Environmental Management) and impose a ban on the use of child labor in their operations and suppliers. However, the concern that still drives the main players in the production chain falls preponderantly on the threat of manufacturers in other emerging countries, such as China, India and Mexico. What is not yet clear is that sustainability is a condition for competition at the global level [34].

3. Method

This research is characterized as theoretical in nature. As for its technical procedures, it corresponds to a bibliographic study, as we address data and verifications stemming directly from previous literature on the subject. The perspective's objectives are classified as exploratory and descriptive, since they seek for specific information and characteristics of what is being studied [35].

A structured review of the literature, by means of a bibliometric analysis was made according to the ProKnow-C (Knowledge Process Development—Constructivist) method proposed by Ensslin et al. [36].

The ProKnow-C intervention method proposed by Ensslin et al. [36] for selecting a bibliographic portfolio (Figure 1) consists of a four-step process:

(i) Selection of database of raw articles, which, in turn, comprehends: selecting keywords, selecting databases, searching for articles and verifying the adherence of keywords;

(ii) Filtering the raw articles database, which entails filtering the raw articles of the database by redundancy and filtering the raw articles of the database that are not repeated by the alignment with the title;
(iii) Filtering the article database, pertaining to: determining the scientific recognition of articles, author identification;
(iv) Filtering by alignment to the full article, concerning the full text of the articles.

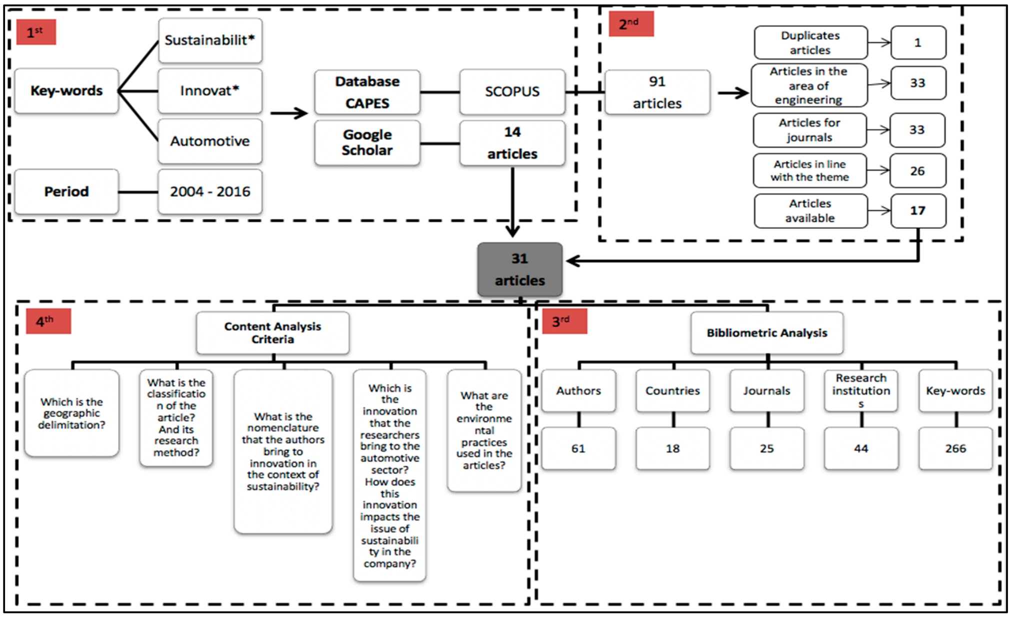

Figure 1. Bibliographic portfolio.

Initially, we defined the keywords "Sustainability *", "Innovation *" and "Automotive", in August 2016. We selected the Scopus database, since it is multidisciplinary and indexes only the most cited journals in their respective fields. It indexes over 15,000 periodicals, approximately 265 million web pages, 18 million patents, among other documents.

The search resulted in 91 articles related to the topic in the last 13 years. These were divided by research fields: 36% stemmed from engineering, 11% environmental science, 10% from business and management, 9% from computer science and 7% from materials science. However, our study focused on the Engineering area, by the fact that it presents the larger amount of articles and that it is research field of the authors, as shown in Figure 2.

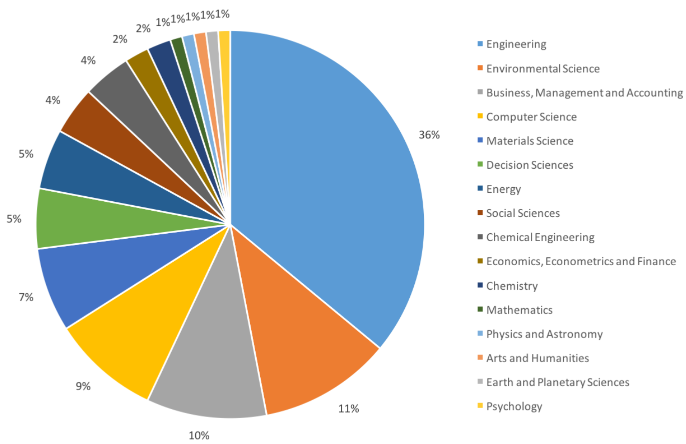

Figure 2. Areas of the articles found in Scopus database.

The total of 91 articles went through successive filters until obtaining a more adherent result to the objectives of our research. These filters have the function of eliminating undesirable articles and also of improving the research process, so non unnecessary time is devoted to the full-text reading of articles that do not add value to the purpose of our study.

For the filtering procedure, some aspects were considered: (i) presence of duplicates/duplicate articles (total of 1 article); (ii) alignment with the engineering field (33 articles); (iii) articles published in journals (33 articles); (iv) alignment of the titles/abstracts of the articles with the theme (26 articles); and (v) availability of articles in full-text (17 articles).

At this stage, an exploratory search in Google Scholar was done with the keywords to add additional studies on the topic. 14 articles were found that were not indexed in the SCOPUS database.

Thus, 31 articles were chosen to compose the Bibliographic Portfolio (PB) of our review. Appendix A presents the list of the 31 articles aligned with the theme of "Sustainability AND Innovation AND Automotive Sector", which will be reviewed through bibliometric and content analyses.

The bibliometric analysis is a technique for mapping the main authors, journals and keywords on a particular theme. Uriona Maldonado, Silva Santos and Santos [37] argue that these techniques are tools that rely on a scientifically recognized methodological theoretical basis, which allows the use of statistical and mathematical methods to map information from bibliographic records of the documents stored in the data in databases.

The content analysis was according to the criteria established by Bardin [38]. In order to organize the analysis, encode the data, categorize, create inference and do the treatment and results of research gaps on the subject of Sustainability and Innovation in the Automotive Sector. For this, some criteria were established by the researchers, as shown in Figure 1.

For the management and tabulation of the collected data, two software were used: (i) EndNote and (ii) VosViewer.

The EndNote software [39] was used to manage and treat the references collected. The Endnote software is a reference manager created by Thomson Scientific, which works in integration with Web of Science. It facilitates research work and the writing of scientific work, gathering references from online databases, importing their metadata and grouping them in different ways. Used in this research to accomplis quantification analyzes of authors, keywords, journals, research centers, quotations and countries.

VosViewer is a software used to build bibliometric networks based on data downloaded from bibliographic databases such as Web of Science and Scopus. The software allows the user to choose between the use of the total and the fractional counting method [40]. Used in this research to do author co-authorship analysis and co-occurrence of keywords.

4. Results

The literature review is the first step for the researcher, to develop a study and to build knowledge in a given context. It also allows an introductory perspective in the development of a research project and summarizes the cumulative scientific knowledge on the subject [41]. It also makes the researcher more familiar with the subject, allowing new constructs and definitions.

Creswell [42] corroborates, remarking that the literature review fulfills several purposes, one of which is to share with the reader the results of other studies that are directly related to what is being done and/or researched. This measure enables greater dialogue around the study, contributing to the literature, filling gaps and extending prior studies.

Lacerda [43] states that with the evolution of information systems, the use of databases (indexed systems) facilitates searches for references and the construction of theoretical platforms for future research.

The 31 articles were written by 61 authors and coauthors, published in 25 journals in the period of 13 years, with 861 references cited, 266 keywords produced by 18 countries (most notably the United

States, Japan, France, Italy and The Netherlands) in 44 institutions/research centers (most notably Caldiff University and Deltf University of Technology).

Figure 3 shows the chronological distribution of the 31 articles. We can identify the first published articles on this subject in the year 2004, they were:

1. Future challenges in automotive emission control, by Jobson, E. [44]: The article deals with the global perspective on emissions by automotive vehicles, in future scenarios of energy production and consumption, the growing population and trade. Addressing, thus, the main technological and scientific challenges to NOx reduction.
2. Institutional change in the automotive industry: Or how fuel cell technology is being institutionalized, by Van den Hoed, R. and Vergragt, P.J. [45]: The article addresses the need for change in the automotive industries, in order to attain sustainability, in relation to fuel cells. It tries to answer the following questions: Why is the industry adopting such technology? How is fuel cell technology in regards to the process of becoming institutionalized?

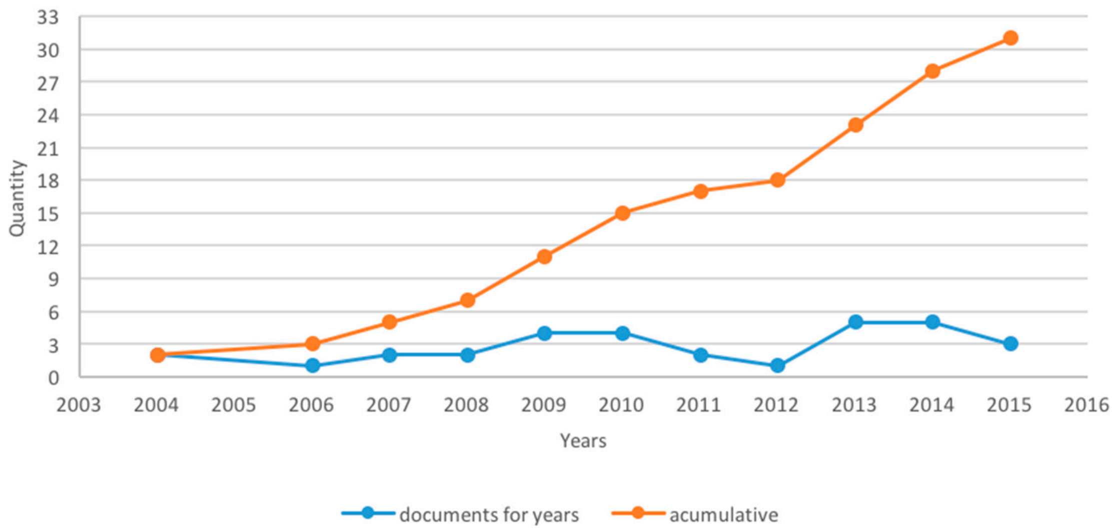

Figure 3. Periodicity and accumulative of publications.

Regarding the most relevant authors, we identified 61 authors and co-authors (Appendix B) in the 31 articles. The most prolific authors were Yamada T. [46,47], Williams, A. [48,49], Van den Hoed, R. [45,50], Inoue M. [46,47] and Bracke S. [46,47], with two articles each.

Figure 4 shows the author co-autorship network, of 61 items that formed 28 clusters with 51 links. The figure shows that the authors of our subject 'Sustainability and Innovation for the Automotive Sector' work in isolation and with only a few partnerships.

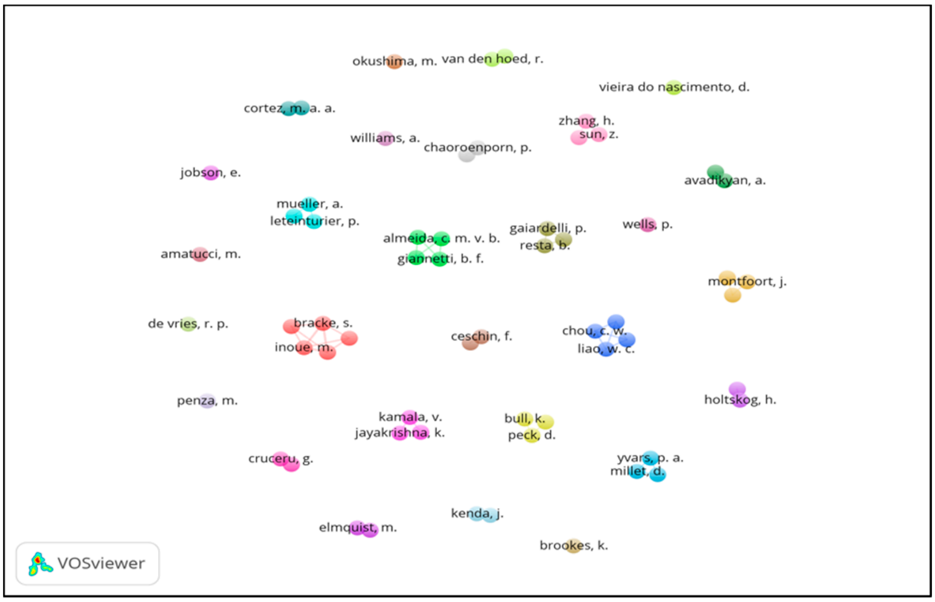

Figure 4. Author Co-autorship.

Figure 4 shows 19 clusters of authors who work together in research studies. The largest clusters (composed by more than 4 authors) are: red, green and blue (presented in detail in Table 1).

Table 1. Authors Relation, Country and Research Institutions.

Clusters	Author	Research Institutions	Country	Research Area
Red	Michalski, J.	University Wuppertal	Germany	Risk Management Quality methods Reliability
	Bracke, S.	University Wuppertal	Germany	Risk Management Quality methods Reliability
	Inoue, M.	Meiji University	Japan	Product development Sustainability System engineering Design support system
	Ulutas, B.	Eskisehir Osmangazi University	Turkey	Industrial Engineering Manufacturing Heuristics
	Yamada, T.	University of Electro-Communications	Japan	Closed-loop Low-carbon supply chains Remanufacturing
Green	Almeida, C.M.V.B.	Universidade Paulista	Brazil	Sustainable Cleaner Production Environmental Accounting
	Bonilla, S.F.	Universidade Paulista	Brazil	Sustainable Development
	Giannetti, B.F.	Universidade Paulista	Brazil	Susteinable Indicator Cleaner Production Eco-Technology
	Huisingh, D.	Institute for a Secure and Sustainable Environment University of Tennesse	U.S.A	Sustainable Societies
Blue	Wee, H.M	Chung Yuan Christian University	Taiwan	Production Engineering management
	Chou, C.W.	National Taiwan University of Science and Technology	Taiwan	Production Engineering management
	Liau, W.C.	National Taiwan University of Science and Technology	Taiwan	Production Engineering management
	Wu, S.	Vigor Management Technology Group	China	System analysis

As it can be seen in Table 1, the authors enter into partnerships with other researchers from different countries and institutions. These include Germany, Japan and Turkey; Brazil and the United States, and Taiwan with China.

Pertaining to journals, we identified 25 Journals (Appendix C) in which the authors published their articles. The Journal of Cleaner Production—transdisciplinary journal focusing on Cleaner Production, Environmental, and Sustainability research and practice. Through our published articles, we aim at helping societies become more sustainable. 'Cleaner Production' is a concept that aims at preventing the production of waste, while increasing efficiencies in the uses of energy, water, resources, and human capital—stood out with five articles, with one publication in 2006, two in 2007, one in 2010 and one in 2014, respectively.

The International Journal of Automotive Technology and Management—effectively positioned as a multi-disciplinary journal, focusing on the context of industrial organization and business management rather than pure engineering topics—stood out with three articles, with one publication in 2009, one in 2010 and one in 2015, respectively.

In Figure 5, we illustrate the co-occurrence of 266 keywords with at least 2 occurrences, 27 items were presented that formed 2 clusters with 218 links. It is noticed that there are two themes (presented by the clusters) when using the keywords "Sustainabilit *", "Innovat *" and "Automotive": the first 'Apllication Performance' and the second 'Innovation Technology'.

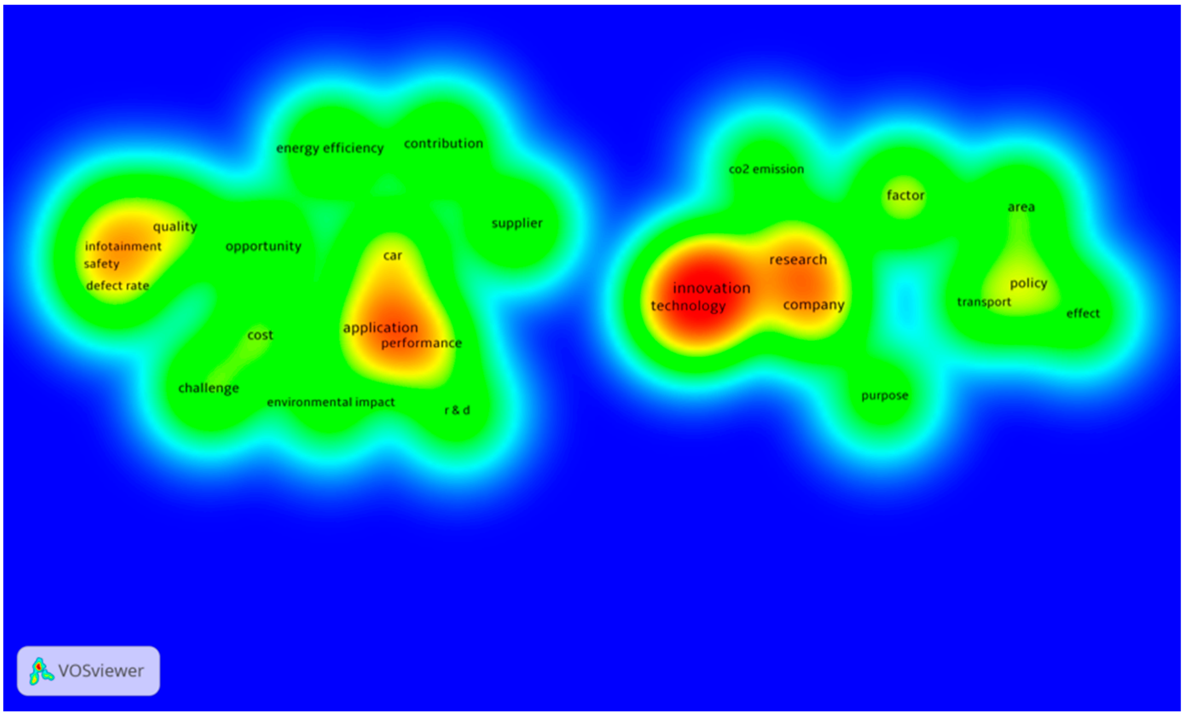

Figure 5. Co-occurrence the keywords.

Out of the 31 articles selected, 27 papers were found with at least one citation (Appendix A) in Google Scholar (Citation is the identification of the number of times the article was used by other scientific articles. Mingers and Loet [51] explain that there are two ways of verifying citations: the first is by the Web of Science (ISI) database and the second is by Google Scholar. In this article, the authors opted for Google Scholar, since it is more easily accessible and of free access.). Figure 6 presents articles with more than 30 quotes.

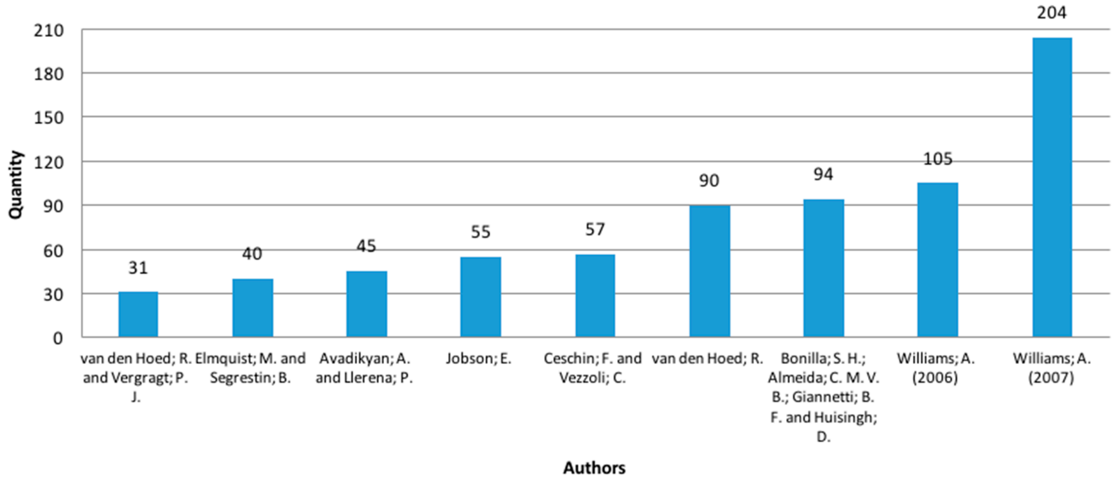

Figure 6. Most cited articles.

Van den Hoed and Vergragt [45] study from 2004 presents 31 citations. The article is about the popularity of fuel cell technology in the automotive industry. It complements itself with the work developed in 2007 from Van den Hoed [50] (90 citations), which explores the way in which radical innovations that offer qualitatively better performance in terms of sustainability may or may not come to pass within a large industry. In this study, the authors conceptualize fuel cell technology as radical technology.

Elmquist and Segrestin [52], obtained 40 citations. The article was based on a collaborative research study with a European car manufacturer, and examined the application of the Concept-Knowledge (C-K) design theory to explore how cars could be both environmental and cost effective.

Avadikyan and Llerena [53] obtained 45 citations. The authors develop a theoretical framework to better account for the technological and market uncertainties and irreversibility that impact the investment and innovation decisions of automotive firms supporting the development of more sustainable vehicle technologies. They investigate the case of hybrid vehicles in a transitional perspective by insisting on their potential to influence the dynamic shaping of investment decisions of firms in the car industry.

Jobson [44] presented 55 citations. The article deals with simulations of future scenarios, using legislators (energy production, energy consumption, population growth and trade) for the emissions of gases (NOx, CO_2) caused by vehicles.

Bonilla, Almeida, Giannetti and Huisingh [54] presented 94 citations. The work provides insights from research designed to holistically integrate Cleaner Production to help society make effective progress to sustainability in automotive sector.

Finally, the two works developed by Williams [48,49] complement each other. The first article of 2006 (105 citations) suggests that the adoption of micro-factory retailing ideas offer a means of introducing such a system-level change in the automotive industry. It allows the adoption of a full scale Product-Service System (PSS) at local levels. The second study of 2007 (204 citations) investigates the actual and potential contribution that product service systems can make in moving beyond incremental technological improvements towards a focus on behavioural changes and system innovation in the automobile industry. The latter inspired the work by Ceschin and Vezzoli [55] with 57 citations. The article brings a discussion about the potential contribution that policy measures can have in fostering the automotive sector in innovating in the PSS.

5. Discussion

We verified that out of the 31 selected articles, 87% are of theoretical nature and 13%, empirical, and that the publications were between 2004 and 2015. Although the search in the articles database is done until August of the year 2016, our research did not find articles in line with the subject, for 2016. Figure 7 presents the articles annual distribution by theoretical-empirical nature.

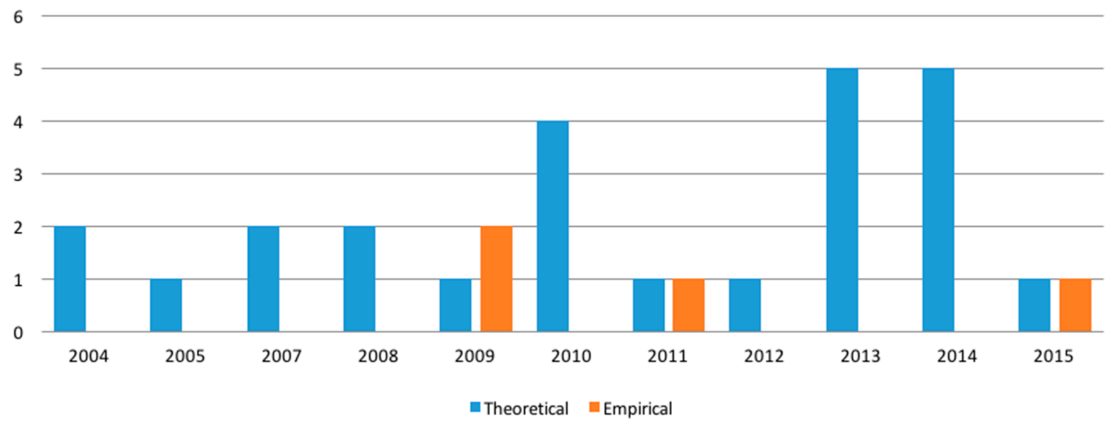

Figure 7. Articles' classification and publication period.

Figure 8 displays the research methods utilized in the 31 articles. We can assert that 31% of the articles are of empirical nature such as the research conducted by Chou et al. [56] in Taiwanese automotive companies and Jobson [44], who reports on Great Britain and Europe. 23% of the studies are literature reviews and 23% multiple case studies, already described in literature, as presented data from the companies Nissan, Ford, Toyota, among others. 15% were conducted based on legislation and environmental guidelines. Finally, 8% of the articles were developed on automotive patents, such as the work by Van Den Hoed [50].

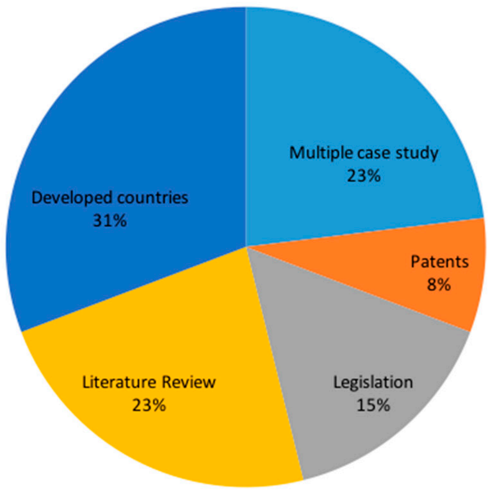

Figure 8. Research Methods.

Environmental practices were related to issues of gas emissions in 37% of the cases, eco-innovation in 27%, life-cycle assessment in 18%, cleaner production in 9% and reverse logistics in 9%, as shown in Figure 9.

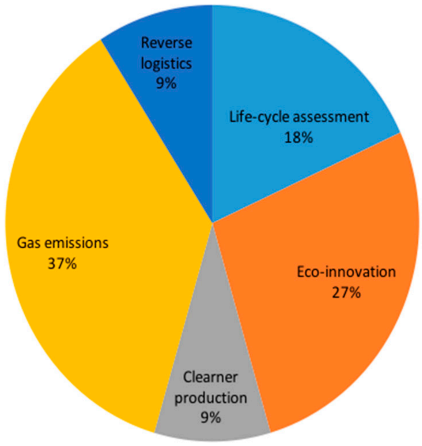

Figure 9. Environmental Practices.

Articles related to gas emissions, addressed how to minimize the carbon dioxide and hydrocarbon gases. Car exhaust fumes are approximately 30% of total atmospheric global emissions and 17% of CO_2 emissions, one of the main contributors to climate change, and brings about varied negative outcomes such as mortality, non-allergic respiratory disease, allergic diseases and symptoms, as well as various forms of cancer [57].

Van Den Hoed [50] explains that a central component of the unsustainability of cars nowadays is the internal combustion engine (ICE), associated to the emissions, the use of fossil fuel and noise. The transition to battery electric vehicles (BEV) requires radical and expensive changes in automotive operations and cannot, therefore, be expected. However, in the last few years, significant amount of resources were spent in developing fuel cell vehicles (FCV), in which the fuel cell substitutes the combustion engine.

Resta, Gaiardelli and Pezzotta [57] show that the applications of life-cycle assessment in automotive industry has focused mainly on technological product innovation and manufacturing processes. On the other hand, the authors explain that automotive companies have not concentrated their efforts on promoting sustainable actions on service activities although the application of sustainability in this context may represent a new way to reach competitiveness. The authors argue that in order to reduce the environmental impacts associated to production processes, car manufacturers have focused their efforts in input use, improving energy efficiency, using renewable energy sources and promoting the efficient use of water, generating outputs, working on waste management and reducing the use of hazardous substances, as well as intelligent mobility solutions (for example, the promotion of green travel plans).

The introduction of reverse logistics solutions, that deal with how products are collected from the end user and returned to a facility, can support a company to comply with the legislation and, at the same time, lead to economical and environmental benefits [57,58].

Bonilla et al. [54] emphasize that biofuels reflect the global concern and urgency on the use and development of renewable fuels and improved energy technologies. The public perception of the central importance of bioenergy has led many researchers to focus only on the positive side of biofuels thus avoiding their inherent limitations. Its real contribution towards a more sustainable world can only be assessed through a carefully executed approach, as in the practice of cleaner production, which allows investigators to identify weaknesses and implement improvements in the process in order to avoid and minimize the negative impacts of the production and use of bioenergy.

The practice of eco-innovation is present in 27% of the articles found in the reviewed papers, as improvements in the car manufacturing process which minimizes the negative impact on the environment, be it through emissions, reutilization of car bodies in the manufacturing process, change in the fuel process, among other that facilitate innovation.

In recent years, innovation has become necessary for survival in the automotive industry. Due to structural changes in the marketplace, more intense competition, stricter regulation, growing fragmentation and shorter product life cycles, manufacturers are required to continuously incorporate new technologies, designs and features in the product development process [52]. Figure 10 shows the types of innovation found in the reviewed articles. Hence, 97% of the articles address incremental innovation in their studies, whilst only 3% present radical innovation.

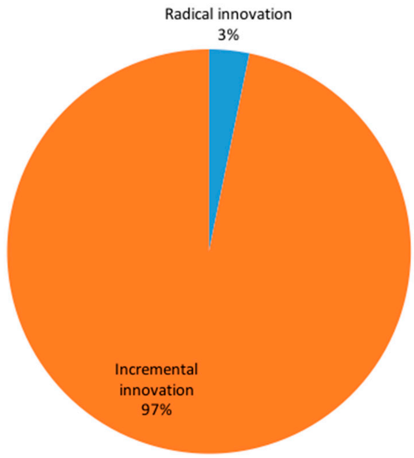

Figure 10. Innovation Types.

Resta, Gaiardelli and Pezzotta [57] highlight that manufacturers have also made great strides in improving vehicle fuel efficiency and safety and reducing emissions, to lower the environmental burden associated with the use phase, through incremental innovations. For instance, the development of hybrid petrol-electric power vehicles, as well as the introduction of new service solutions as car-sharing, whose diffusion can reduce the number of cars by about 40% and distances driven up to 60%, and supporting the End of Life Vehicle (ELV) take-back initiatives, for example, Design for Disassembly, Design for Dismantling and Design for Recycling methodologies, have been introduced to simplify and manage efficiently the disassembling and recovery activities in European companies.

However, Van Den Hoed [50] explains that the auto industry is not always associated with radical innovation, since complex operations, low margins and high risks tend to favor the process of incremental innovations. The author also stresses that the adoption of radical technology is rare because it requires major changes in skills and automotive operations. However, the radical change in the automotive industry may be required to meet the most stringent environmental standards worldwide. As in the case of the adoption of fuel cell technology (FCV—fuel cell vehicles) that has not materialized yet, HR technology provides an interesting case to study the sources of radical technological change in an established industry [50,59].

Radical innovation is known in the automotive sector as radical technology. This technology is defined as a set of different engineering principles that provides substitutes for established technology and overrides current industry competencies [60,61].

The author Van Den Hoed [50] (p. 1015) presents five factors that influence radical innovation in the automotive sector:

1. New entrants: New entrants such as entrepreneurs are less constrained by vested interests and developed routines, and are likely candidates to propose new practices. Apart from entrepreneurs, also powerful stakeholders from a different sector may take an interest in a radical technology; an example may be the investments of utilities in electric vehicle technology as part of their strategy to better utilize their installed capacity. New entries of entrepreneurs and other stakeholders not inhibited by typical constraints of established technologies are likely sources of radical practices.

2. External shocks or crises: Shocks can be conceptualized as 'occasional events' that interrupt relative long periods of stability. Shocks are important mechanisms to lead to instability of the current practice. Shocks provide the occasion at which established practices are reflected upon, they provide uncertainty leading to unorthodox experiments, and create urgency for companies or sectors to develop (radical) alternatives.
3. Performance of the new technology: The performance characteristics and learning curves of the technology itself, vis á vis the technology it replaces, form a third source of radical change. Although most radical technologies are costlier and may be more complex than the established technology, radical technology may demonstrate steep learning curves that feed expectations concerning long term benefits over established technologies. Radical technologies are more likely adopted if they provide superior performance characteristics over the established technology. Where radical technology is frequently treated as a black box in the innovation literature, it is argued here that performance characteristics form an essential element in the treatment of radical technological development.
4. Market changes: Changing market demands may lead current practices or technologies to be challenged if performance limits are reached. Market changes may occur as a result of new options provided by new technologies (technology-induced), or can be a result of progressing demands for performance improvement. The former case stresses technology push mechanisms; the latter pulls, in which changes in market demand may induce experimenting with new, radical technologies, which in time may overturn the established technologies.
5. Industry competition: Competition between/among members in an industrial sector may also be a key factor for radical change. Radical technologies may provide the opportunity to gain a competitive advantage; first movers may see a window of opportunity to increase their market share. Although this typically is the case for more incremental innovation, industry competition may also be a change factor in more radical innovations in order to gain benefits as a first mover.

Since the late 1960s, the automotive industry has faced increasingly stringent standards, especially related to local gas emissions (NOx, CO, VOC1), the use of fossil fuels and in more recent years, greenhouse gases (CO_2). Most of the standards set by governments could be met with improved versions of the ICE (internal combustion engine) or other measures such as developing lightweight constructions or integrate catalyst technologies. In 1990, when the California Air Resources Board (CARB) issued the so-called Zero Emission Vehicles Regulation (ZEV). In the early 1990s the automotive sector increased its investment in alternative propulsion technologies, most notably the BEV (battery electric vehicles) and, to a lesser extent, the hybrid electric vehicle (HEV). Fuel cell vehicles were not considered at the time, and only became relevant in the second half of the 1990s [45].

As to how innovation impacts on business sustainability, Williams [48] explains that there is a wide range of environmental problems associated with the automotive industry, including those linked to high levels of resource use in vehicle production and waste materials when the cars reach the end of their useful life. Cars represent the largest source of pollution of the global air, accounting for approximately 30% of emissions from industrialized countries and 17% of CO_2 emissions. In the environmental arena it has been suggested that, although the efficiency gains obtained as a result of cleaner technologies have reduced emissions, they have been offset by increased consumption and more intensive use. It is precisely this kind of "rebound effect" that led many observers to suggest that, for the industry in general, to advance towards long-term sustainability, the change must be facilitated beyond the product or process level innovation and, instead, be conducted on level of the system.

However, many of the initiatives that are currently or have recently been undertaken by actors within the automotive industry have continued to stress the role of technology itself, rather than facing the greatest challenges of behavioral change or system level. The concept of product-service systems (PSS) offers an interesting opportunity. This approach suggests that focus of economic activity should be moved from manufacturing and sale to the provision of a whole range of products and services designed to deliver a specific function [49].

Therefore, Williams [48] suggests that companies can achieve profitable new business opportunities, while simultaneously improving their environmental performance. There are five main environmental impacts of the life cycle associated with manufacturing, use and disposal of vehicles: (i) automotive production processes are associated with high levels of resource utilization, sometimes non-renewable; (ii) there are impacts associated with the use of water and energy in manufacturing and the emissions resulting from energy production; (iii) some elements of vehicle assembly and manufacturing, especially during metal painting and finishing, result in the emission of pollutants into the air, water and soil; (iv) the wide geographic range of the industry means that it must be supported through global logistics and distribution systems, increasing the mileage of transport and emissions; (v) at the end of life stage, vehicles also represent a large waste stream.

In terms of reducing the environmental impact associated with the production, the industry has focused on outsourcing renewable and recycled materials, as well as implementing clean technology and environmental management systems in individual manufacturing sites and throughout the supply chain. Companies have also made efforts to reduce material inputs, changing manufacturing processes to reuse byproducts and, where possible, alternative, less toxic materials. By addressing the environmental problems associated with emissions, some vehicle manufacturers have been motivated to seek technological alternatives to the internal combustion engine (ICE). Initiatives such as the development of fuel cell powered engines, as well as continued research on the use of electric vehicles represent attempts to find alternatives to the current power train technologies. In addition, some companies have developed the hybrid engine technology in an effort to perceive some environmental benefits while continuing to provide consumers with the security of an IC engine. To the extent that the environmental field is concerned, it has been observed that incremental improvements in environmental performance of vehicles are often negatively offset by increases in overall consumption patterns or more intensive use. In this respect, the current economic strategy based on maximizing unit sales and consumption has a direct impact on the overall environmental impact of the industry. Gains in eco-efficiency are more than offset by the fact that more cars are in use [49].

6. Conclusions

This article has identified specialized literature on the subject of sustainability and innovation in the automotive sector, between the years 2004 to 2016, in the Scopus and Google Scholar databases.

The Proknow-C method was used to review the literature, which was divided into bibliometrics and content analysis.

In the bibliometrics analysis, it was possible to identify that the journal with the largest number of published papers on subject is the Journal of Cleaner Production. The most prominent authors were Yamada, T.; Williams; Van den Hoed, R.; Inoue, M. and Bracke, S. The authors partnered with other researchers from different countries and institutions, as found in 19 clusters of co-authorship the authors. These include, mainly, Germany, Japan and Turkey; Brazil and the United States, and Taiwan with China. When using the keywords "Sustainability *", "Innovate *" and "Automotive" it was possible to identify the occurrence of two thematic clusters: the first 'Application Performance' and the second 'Innovation Technology'. Within the 31 articles selected, 27 papers were found to have at least one citation in Google Scholar.

Through content analysis, it was verified that the automotive sector is well structured in the issue of sustainability and process innovation. The innovations in the sector are mostly of processes and incremental, since they are less expensive and less complex. However, some authors explain that radical innovations are necessary and contribute to comply with the current environmental standards in the world.

The selected studies show that the environmental practices used in the automotive sector are: emissions reductions, life cycle analysis, cleaner production, reverse logistics and eco-innovation.

The sustainable innovations in the automobile manufacturing processes found in the reviewed articles were the transition from internal combustion engines to the fuel cells (FCV), within the environmental practice of emissions reductions. Within the life cycle practice, the sustainable innovations were the technological innovations of products and processes in manufacturing. Also, the development of hybrid cars fits into this practice as well, that is, a car that has an internal combustion engine, usually gasoline, and an electric motor that reduces the effort of the combustion engine and thus reduces consumption and emissions. The practice of cleaner production and reverse logistics appear in the reuse of materials in the process. The practice of eco-innovation brings improvements in the car manufacturing process that minimizes the negative impact on the environment.

The limitations of this study were: (i) the definition of the sample field, since this research used only one database; (ii) use of international studies only; (iii) use of articles published in journals, excluding theses, dissertations, monographies, conferences and books.

Finally, the recommendation for future research is: To analyze how these innovations are being inserted (fuel cells, hybrids cars, electric car, flex motor) in the automotive sector in the Brazilian context. Brazil has led large sustainable innovations, such as the use of biodiesel (oil plants such as castor bean, soybeans, among others) and ethanol produced not only from sugarcane. In 2010, the number of light vehicles produced with a flex-fuel engine has already reached 86% of the total volume produced. However, we must also consider the emergence of electric motor vehicles and hybrids, which are entering the Brazilian Market very slowly due to lack of infrastructure and business models for these technologies.

However, in the automotive sector, ethanol, produced from sugar cane, has a relevant participation, driven mainly by the implementation of the National Alcohol Program (ProÁlcool), one of the main pillars of the Brazilian government in self-sufficiency without damaging the environment. [62] This program showed the feasibility of large-scale ethanol extraction from sugarcane for its use as a fossil fuel, and was a Brazilian response to the oil crises of 1975 and 1979, as a way for the country to seek its energy independence.

After going through a period of decay in its commercialization, due to the drop in oil prices, alcohol is becoming economically attractive again and, with the development of new flex fuel technology, which allows the car engines to run both gasoline and alcohol, the market for fuel alcohol opens up to new perspectives [63].

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

Appendix A

Table A1. List of articles aligned with the theme and citation.

Reference	Author	Year	Title	Citation
[45]	van den Hoed, R. and Vergragt, P.J.	2004	Institutional change in the automotive industry: Or how fuel cell technology is being institutionalised	31
[44]	Jobson, E.	2004	Future challenges in automotive emission control	55
[49]	Williams, A.	2006	Product-service systems in the automotive industry: The case of micro-factory retailing	105
[48]	Williams, A.	2007	Product service systems in the automobile industry: Contribution to system innovation?	204

Table A1. *Cont.*

Reference	Author	Year	Title	Citation
[50]	van den Hoed, R.	2007	Sources of radical technological innovation: the emergence of fuel cell technology in the automotive industry	90
[64]	Ploss, R.; Mueller, A. and Leteinturier, P.	2008	Solving automotive challenges with electronics	9
[65]	De Vries, R.P.	2008	IC innovations in automotive	1
[57]	Resta, B.; Gaiardelli, P. and Pezzotta, G.	2009	Sustainability in the auto repair industry: A life cycle assessment application	3
[52]	Elmquist, M. and Segrestin, B.	2009	Sustainable development through innovative design: Lessons from the KCP method experimented with an automotive firm	40
[66]	Bull, K.; Hull, N. and Peck, D.	2009	Broadening industry perspectives of vehicle telematics application through virtual learning environments: EADIS: European automotive digital interaction studio	0
[67]	Ros, J.; Nagelhout, D. and Montfoort, J.	2009	New environmental policy for system innovation: Casus alternatives for fossil motor fuels	19
[68]	Cruceru, G. and Micuda, D.	2010	The european auto market under the impact of the financial crisis: Lessons to be learned	0
[55]	Ceschin, F. and Vezzoli, C.	2010	The role of public policy in stimulating radical environmental impact reduction in the automotive sector: The need to focus on product-service system innovation	57
[54]	Bonilla, S.H.; Almeida, C.M.V.B.; Giannetti, B.F. and Huisingh, D.	2010	The roles of cleaner production in the sustainable development of modern societies: An introduction to this special issue	94
[53]	Avadikyan, A. and Llerena, P.	2010	A real options reasoning approach to hybrid vehicle investments	45
[69]	Brookes, K.	2011	Unique values win PM design awards	0
[70]	Cortez, M.A.A. and Cudia, C.P.	2011	The virtuous cycles between environmental innovations and financial performance: Case study of japanese automotive and electronics companies	9
[71]	Millet, D.; Yvars, P.A. and Tonnelier, P.	2012	A method for identifying the worst recycling case: Application on a range of vehicles in the automotive sector	20
[72]	Wang; Y.; Zhang; H. and Sun; Z.	2013	Optimal control of the transient emissions and the fuel efficiency of a diesel hybrid electric vehicle	10
[73]	Holtskog, H. and Ringen, G.	2013	Opportunities in the wake of crisis	5
[47]	Bracke, S.; Michalski, J.; Inoue, M. and Yamada, T.	2013	CDMF-RELSUS concept: Reliable products are sustainable products—Influences on product design; manufacturing and use phase	4
[74]	Wells, P.	2013	Sustainable business models and the automotive industry: A commentary	27
[75]	Intarakumnerd, P. and Chaoroenporn, P.	2013	The roles of intermediaries and the development of their capabilities in sectoral innovation systems: A case study of Thailand	9
[76]	Vieira do Nascimento, D.M.	2014	The Brazilian experience of flex-fuel vehicles technology: Towards low carbon mobility	0
[77]	Pusavec, F. and Kenda, J.	2014	The transition to a clean; dry; and energy efficient polishing process: An innovative upgrade of abrasive flow machining for simultaneous generation of micro-geometry and polishing in the tooling industry	16

Table A1. *Cont.*

Reference	Author	Year	Title	Citation
[78]	Penza, M.	2014	COST Action TD1105: New sensing technologies for environmental sustainability in smart cities	5
[46]	Bracke, S.; Inoue, M.; Ulutas, B. and Yamada, T.	2014	CDMF-RELSUS concept: Reliable and Sustainable products—Influences on design; manufacturing; layout integration and use phase	4
[79]	Vinodh, S.; Kamala, V. and Jayakrishna, K.	2014	Integration of ECQFD; TRIZ; and AHP for innovative and sustainable product development	21
[80]	Okushima, M.	2015	Simulating social influences on sustainable mobility shifts for heterogeneous agents	3
[56]	Chou, C.W.; Liao, W.C.; Wu, S. and Wee, H.M.	2015	The role of technical innovation and sustainability on energy consumption: A case study on the Taiwanese automobile industry	1
[81]	Amatucci, M.	2015	The world that chose the machine: An evolutionary view of the technological race in the history of the automobile	7

Appendix B

Table A2. Authors relationship.

Author	Quantity	Author	Quantity
Yamada, T.	2	Montfoort, J.	1
Williams, A.	2	Millet, D.	1
van den Hoed, R.	2	Micuda, D.	1
Inoue, M.	2	Michalski, J.	1
Bracke, S.	2	Llerena, P.	1
Zhang, H.	1	Liao, W.C.	1
Yvars, P. A.	1	Leteinturier, P.	1
Wu, S.	1	Kenda, J.	1
Wells, P.	1	Kamala, V.	1
Wee, H. M.	1	Jobson, E.	1
Wang, Y.	1	Jayakrishna, K.	1
Vinodh, S.	1	Intarakumnerd, P.	1
Vieira do Nascimento, D.M.	1	Hull, N.	1
Vezzoli, C.	1	Huisingh, D.	1
Vergragt, P.J.	1	Holtskog, H.	1
Ulutas, B.	1	Giannetti, B.F.	1
Tonnelier, P.	1	Gaiardelli, P.	1
Sun, Z.	1	Elmquist, M.	1
Segrestin, B.	1	De Vries, R.P.	1
Ros, J.	1	Cudia, C.P.	1
Ringen, G.	1	Cruceru, G.	1
Resta, B.	1	Cortez, M.A.A.	1
Pusavec, F.	1	Chou, C.W.	1
Ploss, R.	1	Chaoroenporn, P.	1
Pezzotta, G.	1	Ceschin, F.	1
Penza, M.	1	Bull, K.	1
Peck, D.	1	Brookes, K.	1
Okushima, M.	1	Bonilla, S.H.	1
Nagelhout, D.	1	Avadikyan, A.	1
Mueller, A.	1	Amatucci, M.	1
		Almeida, C.M.V.B.	1

Appendix C

Table A3. Journals relationship.

Journals	Quantity of Articles
Journal of Cleaner Production	5
International Journal of Automotive Technology and Management	3
Transportation	1
Topics in Catalysis	1
Technological Forecasting and Social Change	1
Resources, Conservation and Recycling	1
Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering	1
Procedia CIRP	1
Metal Powder Report	1
International Journal of Sustainable Manufacturing	1
International Journal of Product Lifecycle Management	1
International Conference on Risk Management, Assessment and Mitigation, RIMA '10	1
IIMB Management Review	1
Greener Management International	1
Energies	1
Asian Journal of Technology Innovation	1
Applied Mathematical Modelling	1
Applied Energy	1
Academy of Accounting and Financial Studies Journal	1
46th CIRP Conference on Manufacturing Systems, CIRP CMS 2013	1
20th International Conference on Urban Transport and the Environment, UT 2014	1
2008 International Symposium on VLSI Technology, Systems and Applications, VLSITSA	1
2008 9th International Conference on SolidState and IntegratedCircuit Technology, ICSICT 2008	1
16th World Congress on Intelligent Transport Systems and Services, ITS 2009	1
13th IEEE SENSORS Conference, SENSORS 2014	1

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