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BIBLIOMETRIC STUDY ON 20 YEARS OF THE EVALUATION OF ECO-EFFICIENCY IN MANAGING PUBLIC WORKS, BASED ON THE LIFE CYCLE MANAGEMENT

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ARTICLE INFO	ABSTRACT
	Eco-efficiency has stood out as an important innovative practice, linked to sustainable development, already practiced in the private sector and with a deep need for application in the public sector. Based on this context, the objective of this study is to map, by means of a bibliometric methodology, the eco-efficiency assessment theme in public works based on the management of the life cycle in the scientific literature, between the years 1996 and October 2017. Research activities indexed by the SCOPUS database and analyzed with the support of VOS viewer software have been collected. We could observe that over the last 20 years of evolution, the subject was initially treated with greater concentration in the environmental sciences segment, however, it is understood that there was a transformation of the topic in scientific research and a greater relevance of the subject for the innovation of technologies, applied to sustainable organizations in an interdisciplinary perspective. We have concluded that there is an important amount of research focused on the development of eco-efficiency evaluation models in works, based on life cycle management, with a wide application in the private sector and perceived insufficient analytical standards that take into account the variables that are unique to the public sector, which can mitigate the possible negative impacts on the sustainability of the buildings.

INTRODUCTION

The past few years have been characterized by significant changes, notably in the development models of capitalist economies, even in emerging countries, with direct impacts on management methodologies that support productive practices in private companies, in the third sector and government institutions (Dos Santos *et al*., October 2017). One may observe that one of the central elements interfering in this transformation process is the organizational sustainability, which is capable of being imposed as a process, which can systematically minimize risks and maximize institutional performance in multiple directions, aiming at the long-term and balanced development (Niero *et al*., 2015, Parisi *et al*., 2015). In the wake of the sustainability theme, from the second half of the twentieth century, there is a marked reverberation

of the concept of sustainable development, structured in the idea that there is a need, through institutions and by means of a management that includes economic, social justice and environmental protection, for the availability of resources produced by the planet to be guaranteed for present and future generations (UNCED, 1992). This view of development has significantly influenced the actions, strategies and practices of public and private organizations in many countries (Munck, *et al*., 2012). In this sense, Deustz (2012) emphasizes that the organizational practices guided by the principles of sustainable development will require new forms of management from institutions, as well as the production of products and services. In this sense, actions contrary to the principles of sustainability need to be revised, without losing competitiveness. Deustz (2012) further emphasizes that it is precisely this necessary renewal movement for the survival of public, private, and third-party organizations in a resource-scarce environment, where pressure for responsible actions is increasing, that there will be a propulsion for innovation in the search for new

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technologies applied to organizations that demand the sustainability of their actions, as a value for their business. In this context, an important element of innovation in the management of sustainable organizations is eco-efficiency, an expression that has gained visibility through publications by the World Business Council for Sustainable Development and the ratification of its importance, received at the United Nations Conference on Environment and Development, held in Rio de Janeiro, in June 1992 (Idowu, 2013; Winter *et al.*, 2014). From this introductory movement, eco-efficiency has been highlighted as an important innovative practice, linked to a sustainable development, already widely practiced in the private sector and with a deep need for application in the public sector (Brent, 2011, Dos Santos, October 2017) and has been gaining significant space in the interdisciplinary scientific production, mainly in the United States, China and Oceania and Western Europe, with Brazil and Latin America at an intermediate level, as shown in Figure 1.

degradation eventually became a result of the process of economic growth of companies and governments (Stephens and Partridge, 2015, Al-Mulali *et al.*, 2015, Cheema *et al.*, 2015). In view of this, for Zou *et al.*, (2015); Vahabzadeh *et al.*, (2015) eco-efficient management models have been developed to be a relevant tool for overcoming unsustainability in productive regimes, based on the conception that the creation of services and goods must occur, by using resource efficiency and minimizing waste. In this sense, it is possible to establish a relationship between the added value of what has been produced and the environmental impacts added to the product or service through a management paradigm oriented towards sustainability, through the balance between economic and environmental efficiency, where the evaluation of eco-efficiency has a key role to play in (Wang *et al.* 2015; Robalino-López, 2015; Giljum, 2006). From a historical perspective, one can note that in the late 1990s, several researchers published important articles on the evaluation of eco-efficiency.
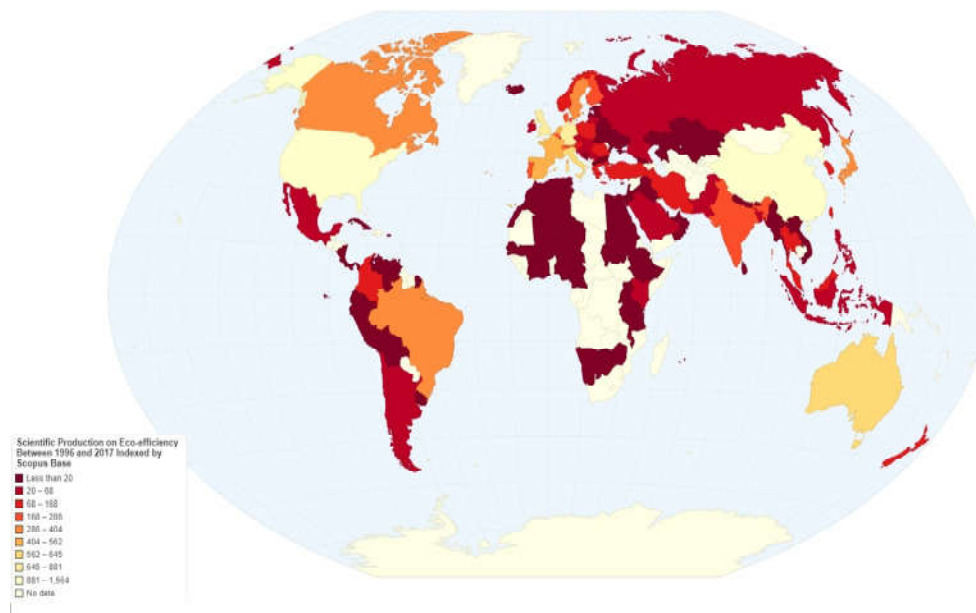

Figure. 1. Scientific production on eco-efficiency in quantity of documents between 1996/2017 indexed by scopus

Specializing the thinking presented in the previous paragraph, we consider the Hall and Purchase (2006) vision, which from his studies on the public sector attitudes towards sustainability in the United Kingdom, in the civil construction segment, had already found that governments have an essential role as instigator of transformations to institute new forms of development that do not ignore the limit of the planet, as the power of the State can stimulate market activities to favor the process of solidification of the consumption versus production ratio, which contribute to sustainable practices, balancing social, environmental and economic aspects from an eco-efficient production perspective. In this context, a management tool emerges as an evaluation tool of the eco-efficiency based on the life cycle management.

Evaluation of eco-efficiency and life cycle management in the scientific literature

Considering the role of the public sector as an agent for guaranteeing eco-efficiency and its evaluation process in public works of civil construction, one can observe that, in the wake of the profusion of neo-industrialization systems that occurred throughout the twentieth century, environmental

It is possible to highlight the work of Friend (1998), published in the Environmental Quality Management journal, on the integration of costs and direct and indirect environmental benefits in information management systems. In this study, the author already pointed out the possibility of organizations being interested in controlling the productivity of resources from internal management models, overcoming the idea that the evaluation of eco-efficiency was a mere instrument of financial measurement. This work influenced other researchers, who in the following decade published an important research on performance evaluation, quality and environmental control, eco-efficiency indicators, sustainability planning and a cleaner production (Corbett e Pan, 2002; Tapiero, 2005; Jollands e Patterson, 2004; Jollands, 2006; Hunkeler, 2000). From the 2000s, the eco-efficiency evaluation theme has gained space in important journals, such as the Journal of Cleaner Production and the *Acta Scientiae Circumstantiae*. In this period, one might note that there is a greater frequency of studies from countries like Nepal, China and Thailand (Kharel and Charmondusit, 2008; Charmondusit and Keartpakpraek, 2011; Zhang and Yang, 2007). In this direction, although at the end of the 1990, it is possible to identify researches that seek to establish the interdependence

between sustainability and eco-efficiency, as of the 2000s an intensification of papers is observed, which also seek to establish these relations with the evaluation (Brady *et al.*, 2003), and in order to improve the quality of the product. In this perspective, product lifecycle management can be understood as a strategic business management model focused on innovation, from product design to the end of the life cycle, that is, successive and connected phases of a product system, from the acquisition of inputs or their generation through natural resources, until their final disposal (Dzikuć, 2015). Thus, several works point to the connection and sharing of principles between the life cycle evaluation, which consists of the compilation and evaluation of inputs, outputs and potential environmental impacts of a product system throughout its life cycle; and the evaluation of eco-efficiency, which is a qualitative and quantitative management tool that allows the investigation of the environmental impacts at each stage of the life cycle of a product system (Ravi, 2015; Berre *et al.*, 2015; Sokol, 2015).

Thus, by examining this introductory context, one may observe that many studies were published; however, it was not the object of these papers to present the mapping and progress of science and related research, specifically in the government sector, between product life cycle, public works and eco-efficiency evaluation. Under these contextual circumstances, the central objective of this research, an integral part of a doctoral research in sustainable management systems, was demarcated: filling a research gap mapping the development of the theme "evaluating eco-efficiency in public works based on life cycle management", considering the period from 1996 to October 2017, through the use of bibliometric methodology. This method has been widely accepted for providing, through content analysis and citations, an innovative understanding about the evaluation of the directions of science in relation to a certain subject.

In the scope of this qualitative study, from its central objective; from the key concepts (thematic areas), a transverse framework of keywords has been built, which provided a framework that allowed the exploration of research activities, published in scientific literature and indexed by the SCOPUS database, determined by a set of filters elaborated through Boolean architecture and analyzed through the VOS viewer software. Several characteristics of the related publications are analyzed, including the analysis of bibliometric data, clusters, and authors. This study was structured in four parts: (1) introduction; (2) methods and data; (3) results and discussions; and (4) conclusions.

METHODS AND DATA

Bibliometric method

In order to achieve this kind of methodological perspective, the purpose of the research must be precisely defined, so that the results are aligned, at the end of the study, with the central matter of the research (Raffaghelli *et al.*, 2015, Smith, 2015). Based on the objective of this study, the bibliometric method was considered the most pertinent one. This methodology, as a form of research, has cooperated with the understanding of information, especially in the clarification of events and bibliography phenomena, showing concrete results for scientific research (Zuccala, 2004; kostoff, 2005). The bibliometric method can be portrayed as a knowledge strand

that converges for the analysis of the quantitative measurement of bibliographical data (Fedorowicz, 1982; Lotka, 1926; Bradford, 1934);

Confirmation of the research gap through bibliometrics

In the context of this qualitative study, from the preliminary research theme, the context and the research gap were established. Then, the central question of the study that seeks to understand the interest and the scientific restlessness through the causal relations with the context, in order to justify and explain it (Treinta *et al.*, 2014) was defined. The purpose of the work has been defined. In the sequence, according to the objective, the method made it possible to demarcate thematic areas and the transversal framework of keywords, which are related as the central question of the study, aiming at the orientation of the application of filters, by using Boolean architecture in the search engines. With the purpose of confirming the research gap, in the first round of application of the filters, using Boolean search in the search engines, based on thematic areas and the cross-section of keywords, it was possible to identify a set of national and international databases papers, collected from the databases indexed by SCOPUS, by using the following keywords: eco-efficiency, Bibliometric, eco-efficiency, management, life cycle, public and governmental.

First, the "AND" and "OR" operators were used in conjunction with the "ALL" code, which returns documents as long as the searched word appears in one of the following variables: article title, source title, language, author, affiliation, summary, keywords, references, DOI, ISBN, ISSN, CODEN, subjects, volume fields, year of publication, sequence bank, bank sequence number, number, chemical name, CAS registry number, manufacturer, publisher or conferences. In the subsequent rounds, the use of the "AND" AND "OR" operators was coupled with a more specific search code: (1) TITLE-ABS-KEY, which returns documents as long as the searched word appears in the summary variable or in the title of the article or in the keyword. During the search at the indexing basis, by using Boolean architecture, we could find that as the use of operators with codes form more specific search scripts, such as the TITLE-ABS-KEY code, the amount of return documents linked to the subject areas and searched keywords are decreasing until they reach zero. The cross-section of keywords with Boolean search application, for confirming the research gap and the collection product are presented in Table 1 below. In addition, after reading the cataloged works, once the delimitation of this study had been met, the observation that there is a research gap was corroborated, namely: the absence of works that have sought to map the development of the "evaluation of eco-efficiency in public works based in the life cycle management" in the scientific literature, considering the period from 1996 to October 2017, through the use of the bibliometric methodology, taking data from research activities published and indexed by the SCOPUS database.

Mapping the development of indexed searches in the Scopus database

After the confirmation of the research gap, in the second round of application of the filters using Boolean architecture in the search engines, focused on the central objective of the study, it was possible to identify a total of 857 national and international papers collected from the databases indexed by SCOPUS.

The detailing of the cross-section of keywords with Boolean search application and the collection product are presented below, in the following Table 2. Considering the themes, which are the purpose of this study, for analysis and presentation of the results concerning: (1) the quantitative evolution of the indexed research performed from 1996 to October 2017; (2) the evolution of indexed studies in the five journals that published the most, between 1996 and October 2017; (3) to the ten authors who published the most, between 1996 and October 2017; (4) the ten most published countries between 1996 and October 2017; and (5) the five areas of most adherent scientific knowledge, between 1996 and October 2017, the data were addressed by using Microsoft Excel software, which includes an intuitive interface and calculation and construction tools of figures and tables.

For data analysis and presentation of the clusters of: (1) co-authorship; (2) co-occurrences; and (3) citations, the data collected were entered into the bibliometric data processing software VOS viewer database, available at www.vosviewer.com. The program identifies the examination object in documents in a low-dimensional space, so as the space between any two elements mirrors the equivalence or affinity of the items, as accurately as possible. For each pair of items i and j, VOS viewer requires as input a similar ij (Sij ≥0). It treats the Sij similarities as measurement on a ratio scale. Thus, the utility minimizes a weighted sum of the square distances between all pairs of items. The square of the distance between a pair of articles is calculated by the similarity between the items. In order to avoid common solutions in which all elements have the same position, the restriction

Table 1. Bottleneck chart with keywords to confirm the research gap

Transversal Architecture	Number of Documents
((ALL (bibliometric)) AND (ALL (eco-efficiency)) AND (ALL ("LIFE CYCLE")) AND (ALL (management)) AND (ALL (evaluation))) AND ((ALL (public)) OR (ALL (governmental)))	*14*
((TITLE-ABS-KEY (bibliometric)) AND (ALL (eco-efficiency)) AND (ALL ("LIFE CYCLE")) AND (ALL (management)) AND (ALL (evaluation))) AND ((ALL (public)) OR (ALL (governmental)))	*5*
((TITLE-ABS-KEY (bibliometric)) AND (TITLE-ABS-KEY (eco-efficiency)) AND (ALL ("LIFE CYCLE")) AND (ALL (management)) AND (ALL (evaluation))) AND ((ALL (public)) OR (ALL (governmental)))	*2*
((TITLE-ABS-KEY (bibliometric)) AND (TITLE-ABS-KEY (eco-efficiency)) AND (TITLE-ABS-KEY ("LIFE CYCLE")) AND (ALL (management)) AND (ALL (evaluation))) AND ((ALL (public)) OR (ALL (governmental)))	*0*

Table 2. Keywords chart linked to the central purpose of the study

Transversal Architecture	Number of Documents
((((ALL ("evaluation off eco-efficiency")) OR (ALL ("efficiency analysis"))) AND ((ALL ("construction")) OR (ALL ("building"))) AND (ALL ("management off product life cycle"))) OR ((ALL ("eco-efficiency")) AND (ALL ("management of product life cycle"))) OR ((ALL ("eco-efficiency")) AND (ALL ("management of product life cycle"))) OR (((ALL ("eco-efficiency analysis")) OR (ALL ("evaluation of eco-efficiency"))) AND (ALL ("product life cycle")))) OR ((((ALL (construction)) OR (ALL (building)) OR (ALL (build)) OR (ALL (making)) OR (ALL (erection)) OR (ALL (fabric)) OR (ALL (framing))) AND (ALL (planning)) AND (ALL ("eco-efficiency analysis")) OR ((ALL ("evaluation of eco-efficiency")) AND (ALL ("management of product life cycle"))))) OR (((ALL (construction)) OR (ALL (building)) OR (ALL (build)) OR (ALL (making)) OR (ALL (erection)) OR (ALL (fabric)) OR (ALL (framing))) AND (ALL (utilization)) AND (ALL ("eco-efficiency analysis")) OR ((ALL ("evaluation of eco-efficiency")) AND (ALL ("management of product life cycle")))) OR (((ALL (construction)) OR (ALL (building)) OR (ALL (build)) OR (ALL (making)) OR (ALL (erection)) OR (ALL (fabric)) OR (ALL (framing))) AND (ALL (maintenance)) AND (ALL ("eco-efficiency analysis")) OR ((ALL ("evaluation of eco-efficiency")) AND (ALL ("management of product life cycle")))) OR (((ALL (construction)) OR (ALL (building)) OR (ALL (build)) OR (ALL (making)) OR (ALL (erection)) OR (ALL (fabric)) OR (ALL (framing))) AND (ALL (demolition)) AND (ALL ("eco-efficiency analysis")) OR ((ALL ("evaluation of eco-efficiency")) AND (ALL ("management of product life cycle")))) OR (((ALL (construction)) OR (ALL (building)) OR (ALL (build)) OR (ALL (making)) OR (ALL (erection)) OR (ALL (fabric)) OR (ALL (framing))) AND (ALL (implantation)) AND (ALL ("efficiency analysis")) OR (ALL ("evaluation of efficiency")) AND (ALL ("management off product life cycle"))))) OR (((ALL ("contract management")) AND (ALL ("evaluation off efficiency")) OR (ALL ("efficiency analysis")) AND ((ALL (construction)) OR (ALL (building)) OR (ALL (build)) OR (ALL (making)) OR (ALL (erection)) OR (ALL (fabric)) OR (ALL (framing))) AND (ALL ("public sector")) AND (ALL ("management off product life cycle"))) OR (((ALL ("public sector")) OR (ALL ("government sector")) OR (ALL (governmental)) OR (ALL (government))) AND (ALL ("contract management")) AND (ALL ("compliance")) AND ((ALL (construction)) OR (ALL (building)) OR (ALL (build)) OR (ALL (making)) OR (ALL (erection)) OR (ALL (fabric)) OR (ALL (framing)))) OR (((ALL ("evaluation off eco-efficiency")) OR (ALL ("efficiency analysis"))) AND ((ALL ("construction")) OR (ALL ("building"))) AND (ALL ("life cycle"))) AND (ALL (government)) OR (ALL (governmental)) OR (ALL ("government sector")) OR (ALL ("public sector"))) OR ((((ALL ("evaluation off eco-efficiency")) OR (ALL ("efficiency analysis"))) AND ((ALL ("construction")) OR (ALL ("building"))) AND (ALL ("life cycle"))) AND (ALL (government)) OR (ALL (governmental)) OR (ALL ("government sector")) OR (ALL ("public sector"))) OR (((ALL ("evaluation of eco-efficiency")) OR (ALL ("eco-efficiency analysis"))) AND ((ALL ("construction")) OR (ALL ("building"))) AND (ALL ("life cycle"))) OR (((ALL (construction)) OR (ALL (building)) OR (ALL (build)) OR (ALL (making)) OR (ALL (erection)) OR (ALL (fabric)) OR (ALL (framing))) AND (ALL (planning)) AND (ALL (utilization)) AND (ALL (maintenance)) AND (ALL (demolition)) AND (ALL (implantation))) OR (((ALL (construction)) OR (ALL (building)) OR (ALL (build)) OR (ALL (making)) OR (ALL (erection)) OR (ALL (fabric)) OR (ALL (framing))) AND (ALL (planning)) AND (ALL (utilization)) AND (ALL (maintenance)) AND (ALL (demolition)) AND (ALL (implantation))))	*857*

imposed is that the average distance between two items must equal 1 (Van Eck and Waltman, 2010). Considering the central objective of this study, for each of the 857 documents exported from SCOPUS database, in CSV (Excel) format, for the VOSviewer analysis base, the fields and data types presented in Table 3 below were considered. After export, the application was parameterized to use the "full" counting method in the three types of analysis performed for the generation of clusters maps, based on bibliographic data. Tables 4 and 5 below present the consolidated description of the counting method and the types of analyzes used at this stage of the investigation. The other criteria used in the parameterization of the software are presented in a consolidated form in Table 6 below, which describes the type of analysis, the units of analysis, the minimum number of analysis unit occurrences for the incorporation into the collected data and the respective number of units selected, for the calculation of the total strength of the links. After the data treatment made through the Microsoft Excel and VOSviewer softwares, the analysis of the results and discussions began. A consolidated summary of the method adopted in this work can be visualized in figure 2, where it is possible to observe the methodological relations between the research gap, the objectives of the study and the use of the bibliometric mapping application that supported research.

RESULTS AND DISCUSSION

Quantitative evolution of the themes until October 2017 and performance of the main journals. Figure 3 and 4, respectively, demonstrate the quantitative evolution of the indexed surveys and the performance of the five most published journals between 1996 and October 2017 on the themes of eco-efficiency evaluation, public works, life cycle management and their connections.

There is an accentuation in the number of documents as of the year 2006, with a certain stabilization between the years 2011 and 2015 and a significant recovery in October 2017. Of the 857 papers analyzed, more than 18% were published in the five journals presented in Figure 2: Journal of Cleaner Production, International Journal of Life Cycle Assessment, Sustainability Switzerland, European Journal of Operational Research, and Journal of Environmental Management, publications which own impact factors in the field of interdisciplinary knowledge, thus concluding that the themes, object of this study, over the last two decades, are being approached through channels of dissemination that have, by the scientific community, a perception of credibility.Aspects that may explain the relative concentration and growth in the aforementoned journals are: (1) the fact that journals with a growing impact factor serve as instruments of slight scientific dissemination in contrast to other dissemination tools and (2) the Law of Dispersion or Productivity of Journals, proposed by Bradford (1934). In the early years of the second half of the 1990s, the first articles on the themes, the purpose of this research, were written and submitted to a small group of journals aligned with the subject. Over the years, mainly from 2006 onwards other groups of journals accepted articles on the subject. This movement attracted more articles throughout the development of the theme, causing other journals to begin their approach on the subject as well, especially the Journal of Cleaner Production that concentrates an important amount of articles on life cycle management in works, related with the evaluation of eco-efficiency.

Performance of key authors and countries

Figures 5 and 6 presented, respectively, the top ten authors and the ten countries with the highest frequency of publications on the subject between 1996 and October 2017.

Table 3. Scopus base data and fields considered for migration in the Vosviewer software

Data	Types of fields
Citation information	Author(s), document title, year, EID, source title, volume, issue, pages, citation count, source and document Type, DOI
Bibliographical information	Affiliations,
Abstract and Keyword	Abstract, author keywords, index keywords
References	References

Table 4. Counting methods used in the Vosviewer software.

Counting Method	
Type	Consolidated description
Full	Only the presence or absence of a term in a document is considered.
Fragmented	The weight of a link is fragmented in such a way that each reference, quote, or document makes the same global contribution.

Table 5. Types of analysis used in the vosviewer software.

Type of analysis	
Type	Consolidated description
Co-authorship	the list of items is determined based on the number of documents with co-authorship.
Co-occurrence	the list of items is determined based on the number of documents in which they occur.
Citation	the ratio of items is determined based on the number of times they are cited.

Table 6. Criteria used in the parameterization of the Vosviewer software.

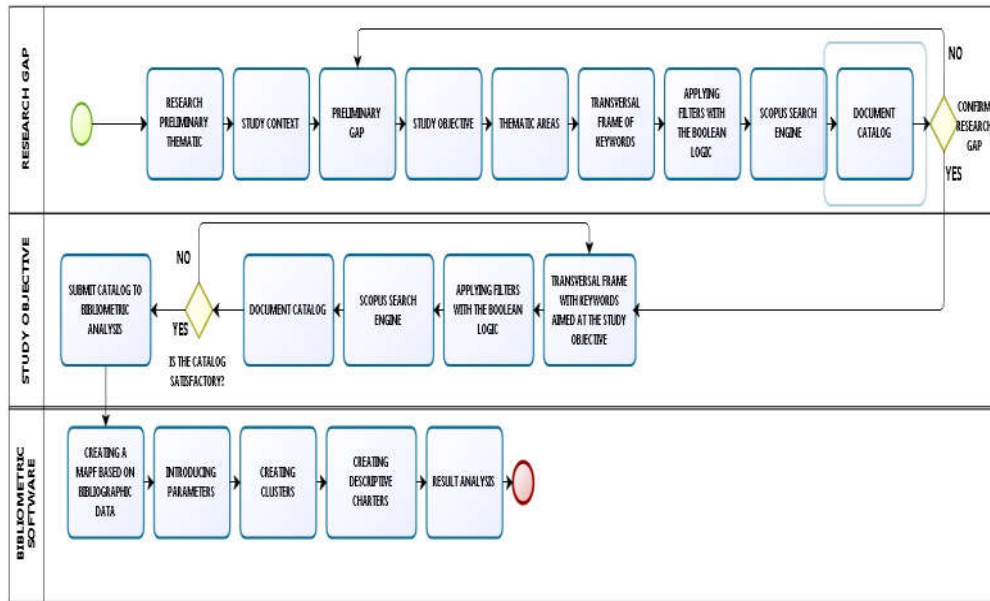| Type of analysis	Analysis unit	Minimum number of analysis units occurrences in the database	Number of analysis units selected for calculation of the total strength of the links
Co-authorship	Authors	1	813
	Countries	1	49
Co-occurrences	keywords	1	2985
Citation	Sources	1	158
	Authors	1	813

Figure 2. Consolidated summary in the methodological process

Highlighted are *Murat é Kucukv*, from Istanbul Sehir University and Gokhan Egilmez, from the University of New Haven. These researchers have developed a relevant work on eco-efficiency evaluation of building materials, eco-efficiency analysis based on life cycle management focusing on issues such as environmental impact, sustainable manufacturing and supply networks.

of Central Florida, where work on solid waste management and eco-efficiency evaluation are carried out by using a methodology involving data analysis; and (3) the *Leuphana Universitat Luneburg*, where studies are carried out on eco-efficiency evaluation, based on tools used in business evaluation.
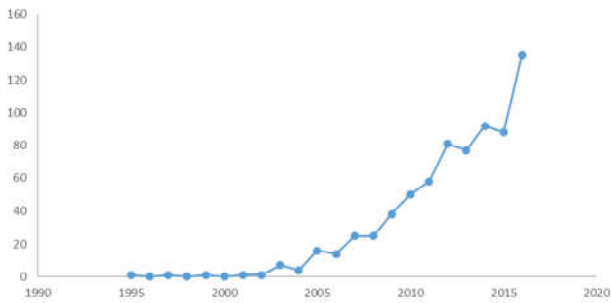

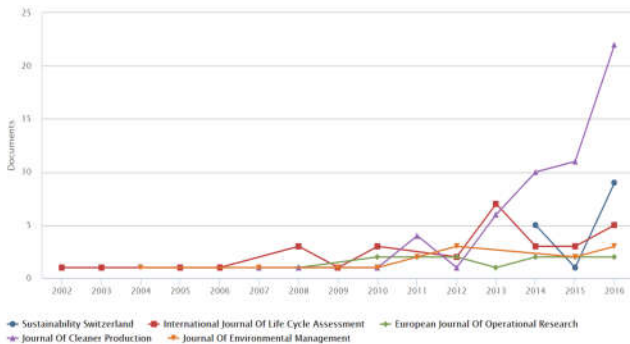**Figure. 3. Quantitative evolution of the themes from 1996 to October 2017**

Fig. 4. Performance of major journals

Figure 5. Performance of key authors

Figure 6. Performance of countries

It is also possible to observe that the United States, China and Germany concentrate approximately 43% of the scientific publications on the subject, highlighting research centers such as: (1) the University of Science and Technology of China, where studies are developed on the use of eco-efficiency as an indicator for sustainable urban development; (2) the University
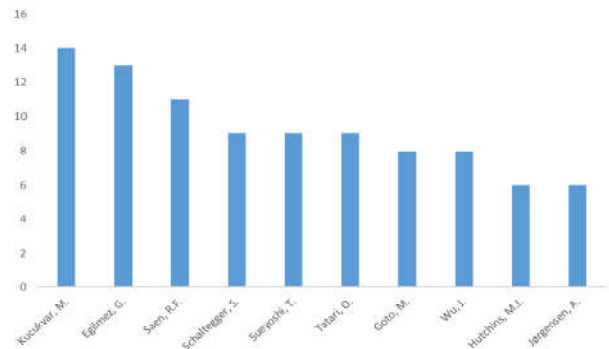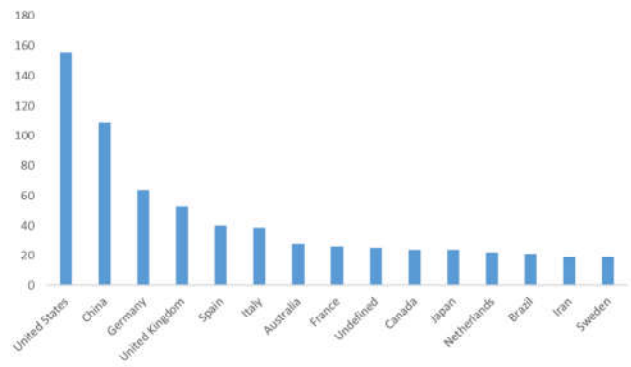
Mapping the area of knowledge of publications

The areas of knowledge that have concentrated publications on evaluating eco-efficiency in public works, based on life cycle management, are presented in figure 7.

One might note that 73% of the disclosures are concentrated in the areas related to the field of environmental sciences, engineering and Administration.
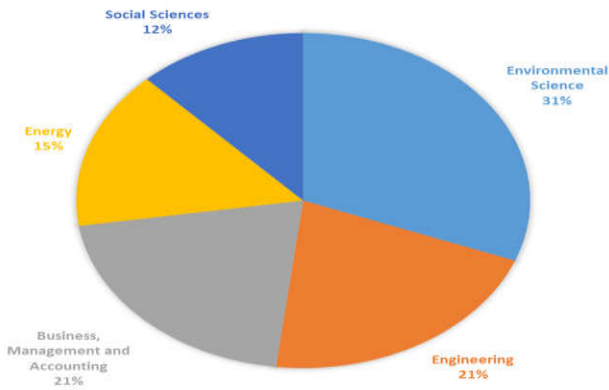

Figure. 7. Mapping the area of knowledge of publications

It is possible to conclude that over the last 20 years, the evaluation of eco-efficiency has been treated with greater concentration in the environmental sciences segment; however, the conjugation of the themes has gained space in other fields of study. This growth can be explained by the need for research and development of eco-efficient practices in several areas of scientific knowledge and in actions that seek to effectively measure processes and their positive interdependence between environmental aspects and other productive dimensions of an organization (Almeida dos Santos *et al*., 2017).

Authors' co-authorship network and between countries

The list of items determined based on the number of documents with co-authorship and the network formed between the groups of authors is shown in Figures 8 and 9. It is possible to observe five large groups where, despite not having in their composition the authors with the largest number of publications, at least one member of a group wrote at least one work with at least one member from another group.

Figure. 8. Authors' co-authorship network

Note that figure 8 is complemented by the figure 9 showing that the network of co-authorship on the themes of eco-efficiency evaluation, public works, life cycle management and their correlations also have a co-authorship network between the countries from a core in China, Germany and the United States formed by a set of research centers. Among the main ones, we could mention the following ones: *(1) University of Science and Technology of China, (2) Research Center for Eco-Environmental Sciences Chinese Academy of Sciences, (3) University of Central Florida, (4) Michigan Technological University, (5) Leuphana Universitat Luneburg,* and *(6) Technische Universitat Berlin*.

The authors and countries co-authorship network demonstrates the consolidation of cooperation and collaboration between the various research centers for the development of science and technology in the interdisciplinary field of sustainability, eco-efficiency and product life-cycle evaluation of public works.
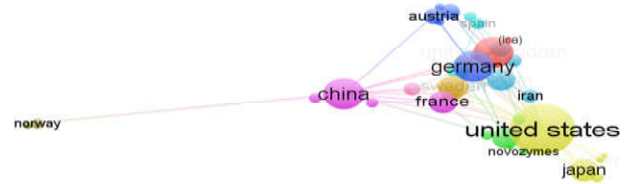

Figure 9. Network of co-authorship between countries

Keyword co-occurrence network

The list of items determined based on the number of documents in which they occur is shown in figure x, which deals with the co-occurrence of keywords. Here, we have a set of clusters where a high frequency of nuclei of terms such as data envelopment analysis, environmental impact and life cycle evaluation is observed. The low connection between expressions such as "public sector", "government", "policy makers" with the core of the keywords related to the research object. It is demonstrated that, even though there are studies seeking to understand the connections between eco-efficiency evaluation, public works and life cycle management, these are still concentrated in the analysis of recycling systems, in the optimization of solid waste, in the environmental impacts of consumption and the reduction of greenhouse gas emissions, from the operations of private organizations. Note the absence of investigations on these connections with the specific and proper actions in the governmental sector, as can be observed in figure 10.

Cluster with the citation of authors and with the citation of the main journals

The ratios determined based of the number of times the documents and journals related to the themes eco-efficiency evaluation, public works and life cycle management are cited are shown in figures 10 and 11. Here is another way of structuring a knowledge center on a set of subjects, which, despite being different from co-authorship, can also show alignment or misalignment of scientific visions and contribute to the mapping of science on a certain proposition, besides being useful to identify thematic knowledge nuclei. Among the authors, the following stand out: (1) Pierre Gallezot with his study on the conversion of biomass into selected chemical products, published in the Chemical Society Reviews in 2012; (2) PAGE Zhou and his work on the use of data envelopment analysis in environmental and energy studies, published in 2008 in the European Journal of Operational Research; and (3) Margot J. Hutchins with a research published in 2008 in the Journal of Cleaner Production, on measures of social sustainability and its application to the decisions of the supply chain. In relation to the journals, figure 12 finds that there are two great nuclei of citation. The first one, led by the Journal of Cleaner Production and the European Journal of Operational Research and the second one, starring the International Journal of Life Cycle Assessment. When we consider these two axes, we can observe that they concentrate a large number of publications on the themes of this investigation.

Figure 10. Network of co-occurrence of the keywords (Source: Scopus base)

Figure 11. Authors citation cluster

Figure. 12. Citation cluster of the main journals

Conclusion

At the end of the 1990s, several researchers published important articles on eco-efficiency evaluation, applied to operations under study in the environmental sciences. Starting in the 2000s, however, there is an intensification of papers that seek to establish the ratio between eco-efficiency evaluation and product life cycle management from a management perspective.This movement attracted more articles throughout the development of the theme, causing some journals to take a more specific approach on the subject, especially the *Journal of Cleaner Production*, which concentrates an important amount of articles on life cycle management in papers related to the evaluation of eco-efficiency as an instrument of management and quality, together with the International *Journal of Life Cycle Assessment.* In recent years, on the themes of this research, we highlight the *University of Science and Technology of China*, where studies are developed to use eco-efficiency as an indicator for sustainable urban development; the *University of Central Florida*, where papers are carried out on solid waste management and eco-efficiency assessment, with the instrument being the data envelopment analysis; and the *Leuphana Universitat Luneburg*, where studies are carried out on eco-efficiency assessment based on tools used in business evaluation.

In this sense, the authors and countries co-authorship network demonstrates the consolidation of cooperation and collaboration between the various research centers for the development of science and technology in the interdisciplinary field of sustainability, eco-efficiency and life cycle evaluation for the building product. The study also concluded that when we consider the product "work" and the evaluation of its eco-efficiency in the approach to the product life cycle management, one may notice that there is a focus of the studies in the phases of planning and use/maintenance of the product cycle to the detriment of the demolition and implementation phases. In addition, it is verified, based on the research gap, that there is an important amount of research aimed at the development of eco-efficiency evaluation models in works, based on life cycle management, with a wide application in the private sector and perceived insufficient analytical standards that take into account the variables exclusive to the public sector, which can mitigate the possible negative impacts on the sustainability of the buildings.

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