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Review

Towards sustainable development through the perspective of eco-efficiency - A systematic literature review

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ABSTRACT

Sustainability concerns have increasingly gained importance among organizations and their stakeholders around the world. In this context, eco-efficiency has become a consistent tool towards the transition to sustainable development and the efforts of eco-efficiency indicators have been used for comparative studies and decision-making tasks, providing better financial, environmental, and social performance. The aim of this paper is to provide a systematic literature review on the theme of sustainable development from the perspective of eco-efficiency, with the adaptation of the Knowledge Development Process intervention instrument - constructivist (ProKnow-C). The paper identifies and structures the state-of-the-art between Eco-Efficiency and Sustainable Development with a view to: (i) selecting a Bibliographic Portfolio (BP) that is aligned with the perception of the researchers on the theme; (ii) performing a bibliometric analysis of the selected BP; (iii) performing a thematic synthesis; (iv) finding the integration of eco-efficiency and sustainable development with other approaches; (v) proposing an innovative framework to achieve sustainable development through eco-efficiency indicators; and (vi) finding paths for further research. This research makes multiple new contributions, providing both academics and practitioners a better panorama to achieve sustainable development through eco-efficiency by expanding the literature review, highlighting the synergies and barriers between eco-efficiency and sustainable development and by comparing and analysing them, showing its relevant features. In addition, we synthesized the contributions of the BP according to the BASF indicators, sustainable dimensions and four measurement levels: industry, organization, project and process to better describe the current academic scenario on the subject.

Contents

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1. Introduction

Sustainability concerns have increasingly gained importance in practice and in academic discussions over the last several decades, and more recently with the UN publication "The Future We Want" one of the outcomes of the World Conference on Sustainable Development (Rio+20) held in 2012 (Leal Filho et al., 2015). According to Park et al. (2015), concerns about the planet's sustainability have grown after the United Nation's Conference on the Human Environment (a.k.a. Stockholm Conference) in 1972, which initiated the concept of sustainable development as a pathway for improving the quality of life for future generations.

Nowadays, the majority of organizations are seeking to achieve sustainable development with respect to "green" concepts and one of the main criteria for assessing green performance is eco-efficiency (Rashidi and Farzipoor Saen, 2015). Eco-efficiency is an improved measure of sustainability because it links environmental impacts directly with some kind of economic performance (Müller et al., 2014) and it works as a valuable tool towards sustainable development (Charmondusit et al., 2013).

In order to monitor environmental impacts, eco-efficiency indicators emerged, designed to analyse the development of eco-efficiency by measuring economic activity, both in terms of consumption and production, as well as the corresponding impacts. The assessment of these eco-indicators complements the traditional technical and economic evaluations of engineering projects and supports the decision-making process.

Eco-efficiency indicators can also be used to measure the eco-efficiency of different sectors within a country; to compare eco-efficiency within the same industry in different countries; and to identify possible areas of in which ecological efficiency can be improved. This is reflected through a number of studies that have considered the relationship and investigated the impact of eco-efficiency initiatives on the economic and environmental performance of organizations disregarding the social dimension (Charmondusit et al., 2013) - despite its importance in order to reach the goals of sustainable development (Mickwitz et al., 2006; de Almeida Guimarães and Leal Junior, 2017). However, despite these studies, a comprehensive review of published scientific articles on eco-efficiency practices and indicators seeking the sustainable development in industries, firms, projects and processes is currently lacking.

Besides that, the academic literature and research lines exploring the impact of eco-efficiency indicators on sustainability performance (Zhang et al., 2008; Rashidi and Farzipoor Saen, 2015) and synergies of eco-efficiency and sustainable development initiatives (Hoffren and Apajalahti, 2009) still remain in early stages. Additionally, it lacks of a clear and structured research definition that may result in difficulties to advance this promising research area. Moreover, still there is a research gap on the literature on a holistic framework used to assess the eco-efficiency of products and services and reach the economic, environmental and social dimensions - TBL (triple bottom line) proposed by Elkington (1998) - in an integrated way, as highlighted by Hart and Milstein (2003) and Abreu et al. (2017).

Attending to the above mentioned motivation, this paper aims to map Sustainable Development from the perspective of eco-efficiency in main Electronic Databases (EDs). This was to be done through a method of systematic literature review, with the implementation of the adaptation of the Knowledge Development Process intervention instrument - constructivist (ProKnow-C). With this in mind, the following specific objectives were outlined: (i) to select a Bibliographic Portfolio that is aligned with the perception of the researchers on the theme of sustainable development, from the perspective of eco-efficiency; (ii) perform a bibliometric analysis of the selected Bibliographic Portfolio; (iii) perform a thematic synthesis; (iv) find the integration of eco-efficiency and sustainable development with other approaches; (v) propose an integrative framework to implement sustainability through the eco-indicators; and (vi) find paths for further research.

Furthermore, this research intends to contribute to the scientific community on the theme studied, since it presents a representative selection of international research in an interdisciplinary area. It is a relevant issue in which there is a significant dialogue of environmental, chemistry and industrial engineering, enabling the researchers to contribute with relevant research. The new contributions of the present paper are: 1) expand the literature review; 2) highlight the synergies and barriers between eco-efficiency and sustainable development; and 3) compare and analyse them, by showing its relevant features.

2. Background and terminology

2.1. Eco-efficiency

The World Business Council for Sustainable Development (WBCSD) defined eco-efficiency as: "The delivery of competitively priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life-cycle to a level at least in line with the Earth's estimated carrying capacity" (WBCSD, 1992). This concept was introduced by WBCSD in the 1990s and is also an instrument for sustainability analysis (Zhang et al., 2008), indicating an empirical relation in economic activities between environmental cost or value and environmental impacts (Huppes and Ishikawa, 2005).

According to Maxime et al. (2006), eco-efficiency is a way to evaluate the parameters of sustainable development, in order to reduce the consumption of resources, as well as the impact on nature, while maintaining or enhancing the value of the manufactured product. Eco-efficiency has emerged as a management response to waste issues associated with current production processes (Jollands et al., 2004) and is one of the most analytical and quantitative approaches for business enterprises interested in practical ways to obtain sustainable development (Willison and Côte, 2009).

The development of eco-indicators is a key strategy for monitoring the eco-efficiency in a simple, systematic and consistent manner (Van Caneghem et al., 2010a), in order to better understand the problem, thus enabling decision-making processes to improve the quality of life and preserve natural resources.

Several analyses in the scientific literature also corroborate the beneficial results among companies and industries from different kinds of activities that adopted eco-efficient practices. Eco-efficiency can be applied at different sectors, such as industrial processes, businesses or even to a specific product. Eco-efficiency analyses have been applied, for example, to compare two alternative routes to convert residual biomass into energy or chemicals (Lozano and Lozano, 2017). The study highlights that eco-efficiency can be used as a decision-making tool to choose between transformation processes by combining scientific and technical issues with economic ones.

Eco-efficiency increases small and medium enterprises' (SME) sustainability independently from their activity, economic situation and size. According to Alves and Dumke de Medeiros (2015), eco-efficiency is a competitive and organizational tool for SMEs in developing countries. Côté et al. (2006) conducted a survey on 25 small and medium-sized enterprises (SMEs) in Nova Scotia, Canada, in order to measure eco-efficiency levels. The research has found that low levels of eco-efficiency were demonstrated in all businesses and suggested that there is much room for improvement and further that economic and environmental benefit through eco-efficiency.

Eco-efficiency analysis can also be applied at a regional or global level, where each sector created its eco-efficiency concept and applied to a particular system. Huang et al. (2014) developed a study based on the regional eco-efficiency of 30 provinces in China from 2000 to 2010. The research concluded that to promote eco-efficiency at undeveloped regions they should focus on improving management capability and efficiency awareness in addition to accelerating their technological progress.

WBCSD (1996) defined some ways to improve eco-efficiency as reducing material and energy intensity, reducing toxic dispersion, enhancing recyclability, maximizing the sustainable use of renewable resources, extending product durability and increasing service intensity.

In 1996, BASF Corporation developed an eco-efficiency methodology to assess both the economic and environmental impacts of chemicals, processes, and products in their lifecycle (Saling et al., 2002). The methodology created by BASF has since been further developed and follows the ISO 14040 and ISO 14044 standards for lifecycle assessment (LCA) (Uhlman and Saling, 2010) and also ISO 14045 for Eco-Efficiency assessment (Bradlee et al., 2009). BASF's methodology can be used for sustainable decision-making at all levels, from industrial to consumer (Wall-Markowski et al., 2005).

One advantage of the eco-efficiency assessment compared to other methodologies such as Cleaner Production, for example, is that the former provides an explicit and effective criterion of evaluation (Lozano and Lozano, 2017). Moreover eco-efficiency analysis is based on Life Cycle Assessment.

The growing concern with discussing and studying issues as eco-efficiency is very important as it is a major means of achieving sustainability. Increasing the environmental performance of a company or industry is an essential criterion in creating sustainable economy.

2.2. Achieving sustainable development through eco-efficiency

Historically, the concept of sustainable development emerged in the 1987 report from the UN World Commission on Environment and Development, in a document entitled "Our Common Future". It requires development to be achieved "which meets the needs of the present generation without compromising the ability of future generations to meet their needs" (WCED, 1987). Within this context, the eco-efficiency acts as a trend indicator towards the transition to sustainable development (Hoffren and Apajalahti, 2009) and might provide a route to it (Zhang et al., 2008).

The eco-efficiency analysis harmonizes two of the three pillars that a company must measure in order to manage and quantify sustainability, it can make strategic decision-making along the entire value chain easier and it helps firms to drive innovative product development toward bringing more sustainable products to the marketplace (Uhlman and Saling, 2010).

On the other hand, Zhang et al. (2008) states that it is necessary eco-efficiency be coupled with other indicators and tools (e.g. social and cultural indicators) in order to become a useful indicator for sustainable development. From this, the social dimension is needed for a complete measurement of sustainable development and so, Kolsch et al. (2008), integrates social metrics into the eco-efficiency, through a method known as SEEBALANCE, a comparative life-cycle assessment tool that consists of costs, environmental impact and social effects of different product or process alternatives. Also, those socio-eco-efficient solutions combine a relatively good environmental performance with high social benefit and at the same time low costs for the end customer (Kolsch et al., 2008).

Furthermore, Charmondusit et al. (2013) proposed a socio-eco-efficiency ratio in order to measure the improvement of the firm concerning social indicators and the study' results showed that the company has acquired a socially supportive management system at the company, community and social levels, the firms must operate aligned with corporate social responsibility (CSR) in order to provide benefits to people and society and the social indicators enable optimal company stability and ensure greater competitive and business sustainability.

In addition, eco-efficiency indicators are designed in order to measure the environmental impacts of businesses and to subsequently manage the companies better (Van Caneghem et al., 2010a,b). Although the eco-efficiency concept doesn't consider the third pillar of sustainability – the social dimension – its efforts could provide better financial, environmental, and social performance (Alves and Dumke De Medeiros, 2015), addressing the social question in an implicitly way.

As Hoffren and Apajalahti (2009), eco-efficiency seeks to combine economic and material efficiency of production with the aim of sustainable development and the notion of social justice. They mention that although the eco-efficiency intends to reduce environmental degradation to a level that is sustainable, eco-efficiency indicators only give a rough picture of an urgent issue, serving better towards general sustainability of activity. Thus, Hoffren and Apajalahti (2009) also highlight the importance of the operationalization and developing of eco-efficiency, in a standard way, as part of daily activities of industries and organizations in order to achieve its targets.

Besides that, eco-efficiency reflects trade-offs between the economic and the environmental business performance and can be used to promote improvements along value chain and the sustainability of products, processes and services (Carvalho et al., 2017). Moreover, eco-efficiency approach can assist governmental agencies and organizations, as SMEs, implementing their sustainable development strategies and improving businesses (Côté et al., 2006).

As essential as eco-efficiency is the adoption of a management philosophy that seeks to both environmental improvements and profitability, by incorporating environment concerns efficiently into the firm's strategic planning, by applying lean production techniques (Carvalho et al., 2017) or by adopting an environmental management system (EMS) - which is focused on the general environmental performance of the company (Van Gerven et al., 2007) - to improve firm value (Sinkin et al., 2008). Reith and Guidry (2003) state that eco-efficiency works as an aspect in an EMS such as prescribed by ISO 14000, by monitoring and managing resource efficiency.

3. Methodology

In this paper we conduct a systematic review in order to locate the relevant existing studies based on previously formulated research questions, in order to evaluate and synthesize their respective contributions. Systematic reviews are characterized by a clearly defined, explicit question; a comprehensive and systematic search for studies; an explicit, reproducible strategy for screening and including studies; an explicit, reproducible data extraction (coding); an appropriate analysis and reporting of results; interpretations supported by data; and implications for future research, and, if relevant, for policy or practice (Ravindran and Shankar, 2015). The steps for the construction of knowledge are an adaptation of the ProKnow-C method, which is a systematic approach to organize knowledge from a literature review and comprises: elaboration of bibliographic portfolio; bibliometric analysis, and systemic analysis (Viegas et al., 2016). This allows for the development of knowledge in research, and also allows for the perceptions and limitations of the subject to be studied (Da Rosa et al., 2015).

Therefore, in order to develop knowledge about the theme discussed, the authors of this study outlined their research question as: what is the state of international scientific literature on the theme of sustainable development from the perspective of eco-efficiency? The overall question of the research was divided into three guiding questions:

- Question 1: How does eco-efficiency contribute to sustainable development?
- Question 2: What are the barriers and synergies between sustainable development and eco-efficiency?
- Question 3: Based on these above questions, how can this knowledge be synthesized in an integrative conceptual framework of sustainability and eco-indicators?

Moreover, this section presents: (i) the methodological framework of the research; (ii) the limitations of the research; (iii) an explanation of the collection process of articles for the formation of the Bibliographic Portfolio (BP); and (iv) the brute database filtering.

3.1. Methodological framework

These goals of this research are exploratory and descriptive, and involved data collection from primary and secondary sources, as well as a qualitative approach. The results found are a type of applied research, using the literature for descriptive and thematic synthesis analysis in order to map the main areas of research as technical procedures.

3.2. Delimitations of the research

From a constructivist perspective, and from the perspective of the authors, this research is delimited to only seek for scientific articles. Books, contributions to edited volumes, conference papers, periodicals, and working papers were not included in our review, as such research usually goes through a less rigorous peer-review process, and they are less readily available (Podsakoff et al., 2005).

The research was temporally limited, so it includes articles published from 2000 until the completion of the BP selection in November 2015. There was a limitation on the databases used, as it was kept to the following 6 databases: Springer (springerlink.com), Scopus (scopus.com), Emerald (emeraldinsight.com), Elsevier (sciencedirect.com), Wiley (onlinelibrary.wiley.com) and ISI Web of Science (wokinfo.com).

3.3. Procedure for the selection of bibliographic portfolio (BP)

For the bibliographic portfolio selection process it was essential for the researchers to come to a decision on which theme they wanted to build knowledge. In this research, the theme to be deepened is sustainable development through the perspective of eco-efficiency, and therefore these are the two axes of the research (Table 1). Sequentially, the keywords have been defined through the C-I-M-O (context-intervention-mechanism-outcome) (Briner and Denyer, 2012; Garza-Reyes, 2015) framework in order to determine the inclusion/exclusion criteria of search strings.

These keywords were combined in order to form all possible combinations for the collection of articles that were searched. The words highlighted above can form 36 combinations, with the Boolean expression “AND”. The search for articles was performed using combinations of keywords in the titles, abstracts and keywords of articles from the selected databases. We aimed for a generalizability of our findings by applying an extensive keyword search using the major databases as described above and chosen them as Viegas et al. (2016), after reading more than a hundred articles related to sustainable development and eco-efficiency falling within the scope of this research. This allowed this review to avoid ambiguity and to cover the field exhaustively. Our criteria for determining which studies need to be considered from the scientific literature are detailed in Table 2. Besides the general criteria of language, full-text availability, research discipline, sector, and date of publication, the content of the article was of particular importance when it came to the relevance of the article to the study. We have focused the scope of our research on energy eco-efficiency on a micro level (processes, organizations, projects) as

Table 1
Keywords of research.

Eco-Efficiency	Sustainable Development
Eco-efficient	Sustainable
Eco-efficiency indicator	Sustainability
Efficiency measurement	Sustainable management
Energy efficiency	Sustainable performance
Industrial ecology	Sustainable indicator

Table 2
Selection criteria of the systematic review.

Sequence	Criterion	Inclusion	Exclusion
1	Time period	2000 to November 2015* *Remark: The search was initially performed in August 2015 and finally checked/complemented in November 2015.	Any study published before 2000
2	Subject Area	Physical Sciences or Social Sciences & Humanities	Any other research area
3	Knowledge Area	Environmental Science, Energy, Engineering, Business, Management and Accounting and Chemical Engineering	Any other knowledge area
4	Research discipline	Management/Business Administration or Engineering or Energy Technology or Sustainable Development or Environmental or Ecology	Any other research discipline
5	Publication type	Peer-reviewed academic journal (Articles)	Any other publication type (e.g. books, contributions to edited volumes, conference papers, periodicals, working papers)
6	Language	English, Spanish or Portuguese *Remark: Only keywords in English were used, since all selected databases had abstracts in this language	Any other language
7	Availability	Available online as full text	Not available online as full text* *Remark: This was sometimes the case for older articles. We did not use a document delivery service to receive scanned copies of those articles

well as on a macro level (industrial sectors, economies), since energy efficiency measurement and management is usually based on the use of indicators, being regarded as a strategic choice and a very important indicator in the eco-efficiency assessment of many companies and industries.

After performing a search of the scientific articles in the mentioned databases, the following quantity of articles were seen, as shown in Fig. 1.

It is observed in Fig. 1 that the total number of articles located in the databases was 6569, and that they are stored in the bibliographic management software Mendeley. The database with the highest return in searches was Scopus, with 2737 articles, and the one that generated the lowest return was Emerald, with 141 articles.

3.4. Brute database filtering

This step consists of deleting the articles that were not in accordance with the interests of the research, but that were still somehow included in the 6569 brute database articles. As well as Viegas et al. (2016) the filtering of articles took place using the following process: (i) elimination of redundant articles; (ii) alignment of the titles of the remaining articles with the theme; (iii) alignment of the article abstracts with the theme; (iv) availability of full text articles in the databases. To ensure complete coverage, we also identified additional academic studies through manual screening of cross-referencing. The entire process of our search is illustrated in Fig. 2. Ultimately, 70 scientific articles were considered to be eligible for our systematic review.

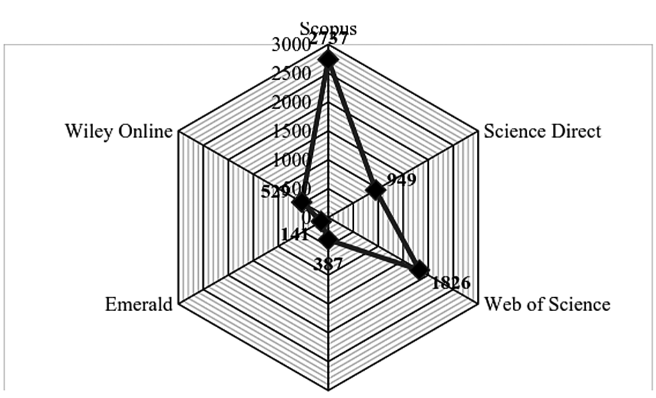

Fig. 1. Quantity of articles found in each database.

Originally, we started out with a database of 6569 articles which was first reduced on an analysis of the title (6312 excluded) and the abstract (153 excluded). Based on the filtering criteria, 104 articles were chosen. From the selected articles, 28 were excluded as duplications and 7 academic studies were included through a process of manual screening and cross-referencing to ensure complete coverage.

These 83 articles were analysed in-depth (full text analysis) in an iterative process and generated the sample of a Bibliographic Portfolio (70 articles).

After identifying the relevant articles, a data extraction form was constructed and the data was extracted into a Microsoft Excel worksheet. Articles were coded according to the bibliographic characteristics of the source, type of study, and other contextual dimensions such as geographical focus, evaluated object and industry sector focus (see the sample of bibliographic portfolio articles in the Appendix).

The Bibliographic Portfolio represents the perception and delimitations of the authors as well as the representativeness of the articles.

4. Analysis and discussion of results

4.1. Bibliometric analysis

Bibliometric methods are used to examine the characteristics of

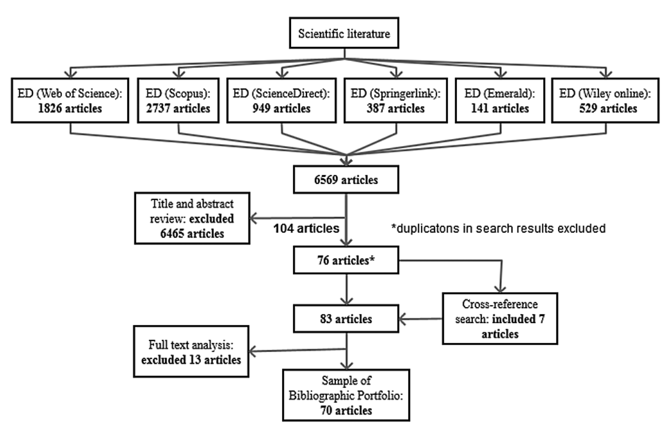

Fig. 2. Mapping the scientific literature search.
Source: adapted from Schulze et al. (2015).

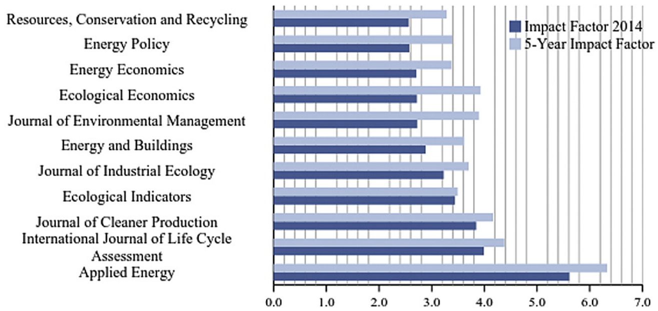

Fig. 3. The impact factors of the main journals.

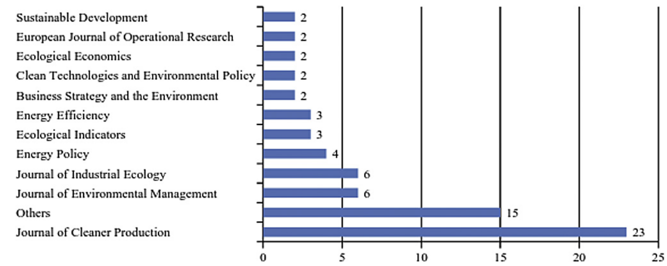

Fig. 5. Number of publications per journal.

publications including countries, research organizations, journals, research fields, citation habits and content analysis (specifically, words in paper titles, author keywords, and keywords plus). In addition, this section demonstrates: (i) the impact factor of the journals and (ii) a descriptive analysis of the bibliographic portfolio.

4.1.1. *Impact factor of the journals*

The articles that form the Bibliographic Portfolio are spread amongst twenty six different journals. The relevance of the articles according to the impact factor of the journals can be measured by the Journal Citations Report (JCR) that is published annually by Thomson Reuters. This is a parameter that is used worldwide in order to assess the relevance of scientific production. For a regular BP, we have listed the greatest impact in 2014, the latest year available, as well as an average of the last five years, as shown in Fig. 3.

The prominent journal when it comes to the impact factor in the academic community is Applied Energy, with a JCR of 5613 in 2014 and an average in the last five years of 6330.

Regarding the index databases, 80% of BP's items are in the databases Science-Direct, Scopus and Web of Science. The remaining portion is found in the databases Springer, Wiley and Emerald. This result demonstrates what databases are more aligned with the research subject, and helps other researchers in seeking relevant research materials with a similar theme to this research.

4.2. *Descriptive analysis of BP*

4.2.1. *Year of publication*

Fig. 4 presents the proportion of the publication sources in relation to the number and percentage of publications per year. We analysed and identified in the BP the evolutionary development of the field between 2000 and 2015.

Within the analysed time period, we can see in 2005 a great number of publications (8 in total) that can perhaps be explained by the "First International Conference on Quantified Eco-efficiency" that happened in 2004. The focus of this conference was on identifying operational methods for quantified eco-efficiency analysis and it encouraged authors to write about the theme. From 2011 until 2015 the number of relevant publications on the subject has grown, illustrating the relevance of the topic in the current context.

4.3. *Journals of publications*

Other interesting analysis is the amount of publications per journal that is presented in Fig. 5.

As indicated by Fig. 5, The Journal of Cleaner Production (33%), The Journal of Industrial Ecology (9%) and The Journal of Environmental Management (9%) represent half of all publications. They contributed significantly to the bibliographic portfolio and have a good impact factor in the last five years, especially The Journal of Cleaner Production (4.167) and The Journal of Industrial Ecology (3.7).

4.4. *Geographical focus*

Fig. 6 illustrates the geographical distribution of the analysed studies.

Fig. 6 illustrates the geographical distribution of the analysed studies. The distribution demonstrates the global interest in the topic, although the majority of studies had a single-country focus on a developed economy. The countries upon which most of the articles focused were Finland (11%), China (10%) and Thailand (6%). Only four studies applied a multiple country focus, ranging from cross-country case studies (e.g. Kemmler and Spreng, 2007) to surveys across continents (e.g. Ingaramo et al., 2009). A large proportion of the analysed studies did not specify a geographical

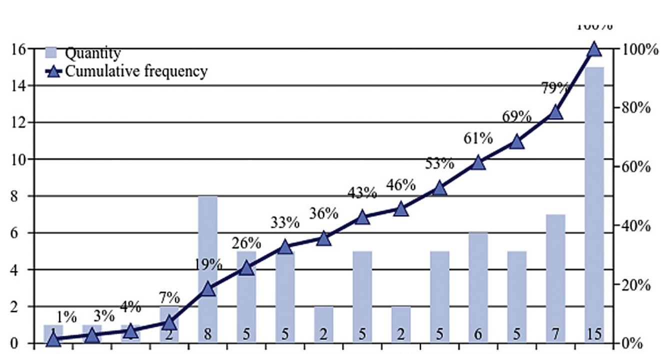

Fig. 4. The number and percentage of publications.

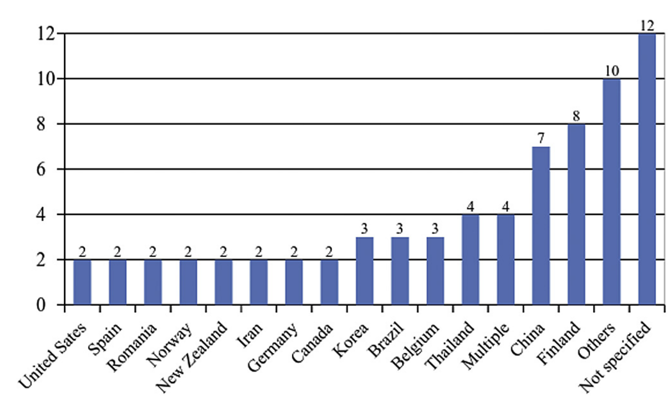

Fig. 6. Geographical distribution of analysis.

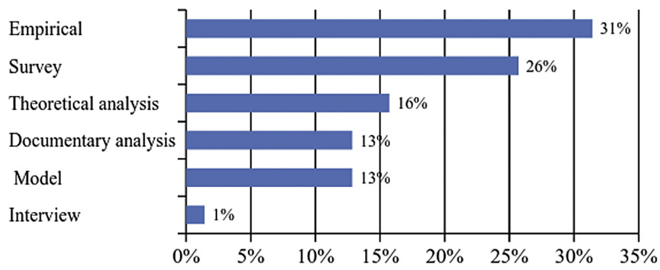

Fig. 7. Percentage of study methodology in the BP.

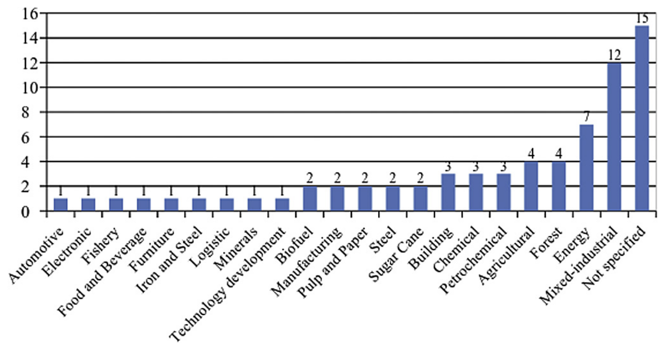

Fig. 8. Distribution of industry sectors in the BP.

focus (12 articles). It is important to note that the OECD countries have low representation in the BP, which can be explained by a lower awareness of the social and environmental impacts in detriment of profit.

4.5. Study methodologies

As Fig. 7 illustrates the percentage of each methodology utilized in the BP.

The preferred methodology within the analysed studies was quantitative, either based on surveys (26%) or empirical (31%). The third largest proportion of studies were those which applied a qualitative research methodology (18 articles), those that had a conceptual or theoretical design (11 articles), and were mostly using a level of theoretical analysis. Mixed method approaches, which combine qualitative and quantitative research methods with documentary analysis, model, empirical and survey studies, constituted 15 articles.

4.6. Industrial sector focus

Fig. 8 illustrates the distribution of industry sectors in the analysed studies.

The largest proportion of the BP did not select a specific industry to analyse (15 in total), and it can be observed that the predominance of theoretical studies were generalizations that could be applied to any industry sector. The mixed-industrial studies – which include a wide range of different industry sectors – represent 12 articles (17%). Single-sector studies mainly focused on the energy industry (7 articles), the forest or agricultural industry (4 articles each). These in particular represent high green-energy sectors in which some countries have been using forest biomass for energy. Finland, for example, has the highest percentage of forest area and has been practicing sustainable forestry in a systematic developed way since the end of World War II.

4.7. Thematic synthesis

The individual articles were coded for content and then analysed in relation to one another, therefore enabling us to detect higher-order themes within the literature (Strauss and Corbin, 1990; Schulze et al., 2015).

While all the articles included in the literature review referred to eco-efficiency and sustainable development, the thematic analysis and categorization presented in Fig. 9 indicated that they had different focuses.

As Garza-Reyes (2015) suggested, a conceptual map is created inductively in order to categorize, organize, visualize and structure the discussions and main findings of this systematic literature review. The articles were 'attached' to every one of the concept map's categories (research streams) according to their thematic focus/content and the categorization structure of the map.

Fig. 9 presents the concept map with eco-efficiency and sustainable development situated in the center, from which six research streams emanate. The research streams include (1) background and terminology, (2) integration, (3) evaluated object, (4) research methodology approach, (5) eco-indicators framework and (6) further research. These were defined based on the thematic content of the articles.

4.8. .Integration of eco-efficiency and sustainable development

In recent years, eco-efficiency indicators, a basic prerequisite for sustainable development, were created, particularly designed in order to face numerous different challenges towards sustainability,

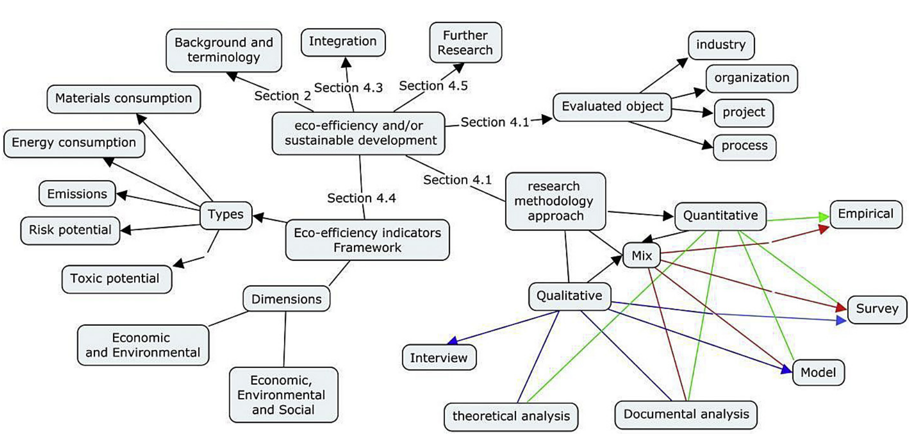

Fig. 9. Concept map of the sustainable development and eco-efficiency review.

which typically include: assessment of economic impacts; assessment of environmental impacts throughout the life cycle of a product; discounting of impacts that occur in the future and aggregation of different environmental impacts into a single environmental damage index (Kuosmanen, 2005).

Through the analysis of the BP we can highlight some points of synergy between sustainable development and eco-efficiency and some barriers that prevent the adoption of a more efficient environmental management system. These points can be found in several areas, as shown in Table 3.

Barriers differ depending on regional and sectoral conditions (Sorrell et al., 2004), indicating a need for specific regional and sectoral studies to observe these barriers.

Eco-efficiency is a key concept of proper indicators which can help a company to achieve more sustainable development (Charmondusit et al., 2013). Nowadays, there is a need for organizations to not only improve their economic and environmental efficiency, but also their social efficiency.

Therefore, increasing eco-efficiency is not a guarantee for a change toward sustainable development. The indicators will only be beneficial if they promote global sustainable development, as sustainable regions in an unsustainable world would not be possible. It is essential, therefore, that the actual use of eco-indicators is critically evaluated from the perspective of sustainable development.

On the other hand, as Mickwitz et al. (2006) suggest, there is a need for an ongoing dialogue among researchers and policy-makers on the diverse theories of sustainable development and the actual practices of utilizing eco-efficiency indicators and the eco-efficiency concept.

4.9. .An integrative eco-efficiency indicators framework towards sustainable development

Uhlman and Saling (2010) emphasize that eco-efficiency analysis is an effective communication tool that can measure the impacts on a system level and include a comprehensive, science-based approach to environmental impact assessment which can protect against potential false conclusions as considering only single metrics. To that end, a systematic evaluation of environmental, economic and social indicators should be established, overcoming challenges such as the provision of credible information on the status of a system to decision-makers, the lack of direct social indicators (Geng et al., 2012) and the need of inclusion of social aspects at the regional level (Mickwitz et al., 2006). In this way, we gathered similar themes into overarching levels that make up the basis of an innovative conceptual framework (Fig. 10). The four levels of the analytical framework include research objects from the BP, where the effects of eco-efficiency indicators on sustainable performance and competitiveness were investigated.

Indicators can be established at different levels of aggregation (micro or macro level) and typically, the lower the level of aggregation, the more data is needed along with a greater understanding of the problem (Abeelen et al., 2015).

To reduce energy consumption and emissions in industry level for example it is important to better understand the factors that influence these indicators in the various industrial sectors. To perform these analyses sometimes it is necessary detailed data at various levels of aggregation and the application of models or methods that can generate reliable and consistent information to support the development of sustainable policies. Many industries are global, so local analysis needs to be complemented with an overall analysis of the global trends within each specific industry (Martínez and Silveira, 2013) so that industrial eco-efficiency improvements can be pursued globally with time.

At the organizational level, firms which adopt eco-efficient business strategies, and as a consequence, achieve reduced costs and increased profits have consistently higher market values than similar firms that do not adopt eco-efficient business strategies. A study aiming to understand the interaction between organizations and the environments in which they operate was conducted by Lee (2015). The results provided some important findings for researchers as the main drivers and barriers for energy efficiency within organizations.

In addition, the chosen level of aggregation is usually guided by data availability. Abeelen et al. (2015) suggested a different method to calculate the effect of an efficiency program is an approach that is based on the number of projects that have been implemented. The sum of the total savings per project can provide the total saving.

Several articles in the bibliographic portfolio also carried out

Table 3
Relationships identified through the bibliographic analysis.

Synergies	Descriptions	Researches
Economic	Increase quality of product and services with more efficient methods; Improving process technology; Encouraging innovation and competiveness; Cost saving.	Sailing et al. (2002); Côté et al. (2006); Van Berkel (2007); Park et al. (2015); Picazo-Tadeo et al. (2011); Caetano et al. (2012); Park and Behera (2014); Alves and Dumke De Medeiros (2015);
Environmental	Preserve resources for future generations; Reduce solid wastes and emissions; Reduce toxic potential and risk potential.	Sailing et al. (2002); Côté et al. (2006); Van Berkel (2007); Park et al. (2015); Caetano et al. (2012); Park and Behera (2014); Picazo-Tadeo et al. (2011);
Social	Improve life quality and well-fare; Increases employee's motivation; Increasing personal responsibility;	Côté et al. (2006); Caetano et al. (2012); Park et al. (2015);
Barriers	**Descriptions**	**Researches**
Policy	Lack of environmental regulations; Lack of economic incentives and inadequate industrial self-regulation policies;	Geng et al. (2012); Lee (2015); Sathitbun-anan et al. (2015)
Market	Lack of demand for eco-efficiency; Low pressure and public awareness;	Lee (2015); Sathitbun-anan et al. (2015).
Economic	High initial capital cost; Difficulty access to finance and short term economic outlook	Côté et al. (2006); Trianni et al. (2014); Lee (2015); Peng et al. (2015).
Information and techniques	Limited training and expertise; Limited information and additional infrastructure	Côté et al. (2006); Trianni et al. (2014); Sathitbun-anan et al. (2015); Lee (2015).
Organizational	Priority on increasing production; concerns about competitiveness; Resistance of managers and inadequate management skills.	Virtanen et al. (2013); Lee (2015).

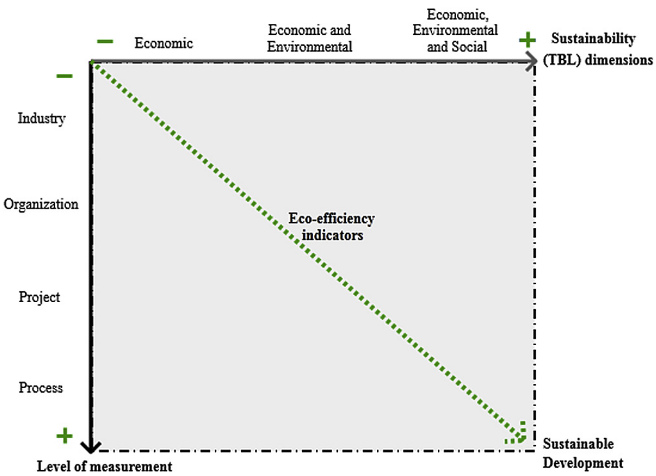

Fig. 10. Innovative conceptual framework towards sustainable development.

eco-efficiency analyses at the process level, such as Fortuna et al. (2012). This study was devoted to a methodology for analysis and evaluation of the sustainability of specific processes from environmental engineering and protection as pollution phenomena, decontamination processes/remediation, reactive and proactive advances, evaluated by applying a set of sustainable development indicators, able to evaluate and develop a set of methods which will make process analysis solid.

Fig. 10 presents the conceptual framework towards sustainable development.

The conceptual framework illustrates that sustainable development is increasing. It is possible to 'measure' the dimensions of sustainability in the form of indicators, from the more general level (industry) to the more micro level (process). With this in mind, sustainability can be measured cumulatively with indicators that reach the micro level, the process in which it would be possible, for example, to verify the eco-efficiency of industry, organization, projects, and even the technologies that were used in the process.

Therefore, the development of eco-indicators to evaluate the three dimensions (economic, environmental and social), and the four levels of measurement (industry, organization, project and process) shows that as the use of sustainable indicators grows to the operational level, this has a greater effect on long-term sustainable strategy. Ideally, there would be three-dimensional indicators of industry, organization, projects and processes combined together.

Additionally, Table 4 considers as reference the indicators used

Table 4
- Contributions from reviewed articles to proposed framework. (Abeelen et al. (2015), Alves and Dumke de Medeiros (2015), Aoe (2007), Arabi et al. (2014), Brondani et al. (2015), Burritt and Saka (2006), Caetano et al. (2012), Charmondusit and Keartpakpraek (2011), Charmondusit et al. (2013), Côté et al. (2006), Ehrenfeld (2005), Erkko et al. (2005), Fortuna et al. (2012), Fujii and Managi (2013), Geng et al. (2012), Goldrath et al. (2015), Hadian and Madani (2015), Hellweg et al. (2005), Helminen (2000), Hoffren and Apajalahti (2009), Hsieh et al. (2013), Huang et al. (2014), Huppes and Ishikawa (2005), Hur et al. (2004), Huysman et al. (2015), Ingaramo et al. (2009), Jollands et al. (2004), Kemmler and Spreng (2007), Kielenniva et al. (2012), Koskela (2014), Koskela and Vehmas (2012), Kuosmanen (2005), Lee (2015), Li et al. (2011), Lim and Park (2009), Martínez and Silveira (2013), Maxime et al. (2006), Michelsen et al. (2006), Mickwitz et al. (2006), Mikučionienė et al. (2014), Müller et al. (2014), Munisamy and Arabi (2015), Park and Behera (2014), Park et al. (2015), Peng et al. (2015), Picazo-Tadeo et al. (2011), Picazo-Tadeo et al. (2012), Quariguasi Frota Neto et al. (2009), Rashidi and Farzipoor Saen (2015), Reith and Guidry (2003), Saling et al. (2002), Sathitbun-anan et al. (2015), Seppälä et al. (2005), Sinkin et al. (2008), Sproedt et al. (2015), Stamford andAzapagic (2014), Teodorescu et al. (2011), Todoc et al. (2005), Trianni et al. (2014), Van Berkel (2007), Van Caneghem et al. (2010a), Van Caneghem et al. (2010b), Van Gerven et al. (2007), Virtanen et al. (2013), Wall-Markowskiet al. (2005), Willison and Côté (2009), Wursthorn et al. (2011), Yu et al. (2013), Zhang et al. (2008), Zvolinschi et al. (2007)).

Contributions from Bibliographic Portfolio	Evaluated Object and BASF Indicators																				
		Industry					Organization					Project					Process				
	D	MC	EC	E	TP	RP	MC	EC	E	TP	RP	MC	EC	E	TP	RP	MC	EC	E	TP	RP
Abeelen et al. (2015)													x								
Alves and Dumke de Medeiros (2015)								x													
Aoe (2007)												x	x	x							
Arabi et al. (2014)			x	x																	
Brondani et al. (2014)																	x	x			
Burritt and Saka (2006)																	x		x		
Caetano et al. (2012)																	x	x	x	x	x
Charmondusit and Keartpakpraek (2011)		x	x	x																	
Charmondusit et al. (2013)		x	x																		
Côté et al. (2006)		x	x	x	x	x															
Ehrenfeld (2005)		x	x	x	x	x															
Erkko et al. (2005)							x	x		x											
Fortuna et al. (2012)																		x	x	x	
Fujii and Managi (2013)		x	x	x																	
Geng et al. (2012)		x	x	x																	

Goldrath et al. (2015)												x	x							
Hadian and Madani (2015)																	x	x		
Hellweg et al. (2005)																x	x	x	x	
Helminen (2000)																x	x	x		
Hoffren and Apajalahti (2009)	x		x																	
Hsieh et al. (2013)																x	x	x		
Huang et al. (2014)	x	x																		
Huppes and Ishikawa (2005)						x	x	x	x	x										
Hur et al. (2004)																x	x	x		
Huysman et al. (2015)	x	x	x	x																
Ingaramo et al. (2009)	x			x																
Jollands et al. (2004)						x	x	x												
Kemmler and Spreng (2007)							x	x												
Kielenniva et al. (2012)	x	x	x	x																
Koskela (2014)			x																	
Koskela and Vehmas (2012)	x	x	x	x																
Kuosmanen (2005)						x	x	x	x	x										
Lee (2015)						x	x		x											
Li et al. (2011)		x	x																	
Lim and Park (2009)	x	x	x	x	x															
Martínez and Silveira (2013)		x	x																	
Maxime et al. (2006)	x	x																		
Michelsen et al. (2006)	x	x	x	x																
Mickwitz et al. (2006)	x	x	x																	
Mikučionienė et al. (2014)		x	x																	
Müller et al. (2014)			x																	
Munisamy and Arabi (2015)		x	x																	
Park and Behera (2014)	x	x	x																	
Park et al. (2015)		x	x																	
Peng et al. (2015)		x	x																	
Picazo-Tadeo et al. (2011)	x	x	x																	
Picazo-Tadeo et al. (2012)																	x	x	x	x
Quariguasi Frota Neto et al. (2009)						x	x													
Rashidi and Farzipoor Saen (2015)		x	x																	
Reith and Guidry (2003)		x																		
Saling et al. (2002)	x	x	x	x	x															
Sathitbun-anan et al. (2015)	x	x	x																	
Seppälä et al. (2005)						x	x	x	x	x										
Sinkin et al. (2008)						x	x	x	x	x										
Sproedt et al. (2015)	x	x	x																	
Stamford and Azapagic (2014)		x	x	x																

Teodorescu et al. (2011)		x	x																		
Todoc et al. (2005)								x	x												
Trianni et al. (2014)			x	x																	
Van Berkel (2007)																	x	x	x	x	
Van Caneghem et al. (2010a)					x	x															
Van Caneghem et al. (2010b)		x	x	x	x	x															
Van Gerven et al. (2007)		x	x	x																	
Virtanen et al. (2013)																		x	x		
Wall-Markowski et al. (2005)																	x	x	x		
Willison and Côté (2009)		x	x	x		x															
Wursthorn et al. (2011)				x	x																
Yu et al. (2013)		x	x	x																	
Zhang et al. (2008)		x	x	x																	
Zvolinschi et al. (2007)			x	x																	

*MC: Material Consumption; EC: Energy Consumption; E: Emissions; TP: Toxic Potential; RP: Risk Potential.
**D: Dimension: Economic and Environmental dimensions - green color;
Economic, Environmental and Social dimensions - yellow color.

in the BASF's methodology (Saling et al., 2002) and also studied by Wall-Markowski et al. (2005). These indicators are material consumption, energy consumption, emissions, toxicity potential and risk potential. They are one of the main indicators used for eco-efficiency calculation in the industry (Saling et al., 2002), due to its high significance until today.

Materials consumption is the total weight of all materials that a company purchases or obtains from other sources (Park and Behera, 2014). Through eco-efficient practices it is possible to create goods and services that optimize the use of resources. The objective is to reduce the amount of resources needed while increasing the productivity. This ensures that more products will be obtained from fewer raw materials by reducing material consumption.

Energy is an essential input to ensure the process operation and to produce heat and power applications. The energy source considered could be coal, oil, gas, lignite, nuclear energy, water-power, biomasses and others (Sailing et al., 2002). Energy consumption can be quantified by the energy consumed per year, per product or by the energy saved by improvement programs.

Emissions can be quantified by quantity of specific emissions per year or per unit of product. Emissions values can be calculated separately as air, water and soil emissions (waste). The calculation includes values from electricity, steam production and transport, and also values directly resulting from the processes (Saling et al., 2002). Emissions of greenhouse gasses such as O2, SF6, N2O and CH4 need to be taken into consideration for their respective Global Warming Potentials (GWP) in order to account for the total emission of CO2-equivalents (Van Caneghem et al., 2010b).

The toxicity potential can be quantified by the amount of toxic waste controlled by permits or toxic waste eliminated by substitution of material (Caetano et al., 2012). The toxicity potential should be calculated using the classifications for hazardous materials of each country. For the calculation of the impact on human toxicity the yearly emissions of organic and inorganic toxic components (e.g. PAHs, PCDD/Fs, particulate matter (PM), SO2, heavy metals such as cadmium and Arsenic) are multiplied by the respective Human Toxicity Potential (Van Caneghem et al., 2010a).

The risk potential reflects the dangers of accidents in the manufacture, use and recycling of the product. The risk is assessed using comparative evaluations. According Saling et al. (2002) could be considered potential risks: abuse risks, dye handling, disposal upsets, filling/packing upsets, warehouse accidents, system upsets harming the environment, transportation accidents, and others.

Finally, Table 6 shows the contribution of the BP articles to the framework through an analysis of the levels (assessed study subjects) in relation to the three dimensions of sustainability (social, economic and environment) and BASF indicators.

Fig. 11 shows the indicators displayed in a graphic in order to better visualize which indicators are more utilized by authors. As we can see, energy consumption (EC), emissions (E), and material consumption (MC) listed inside the category of industry are the main indicators that were investigated by the researchers.

4.10. Paths for further research

Based on the findings and limitations of the bibliographic portfolio research it was found that there are some gaps in the literature, resulting in possible implications that serve as the basis for future researches.

According Virtanen et al. (2013), future research in sustainability accounting need to develop more pragmatic tools, integrating sustainability targets with performance management. Moreover future searches should explore more deeply which phases of the decision-making need the involvement of different actors, and how drivers could better improve their involvement (Trianni et al., 2014).

Eco-efficiency practices should be encourage in other industries, as in cases with rapidly growing sectors in which energy consumption is increasing and could result in higher emissions in

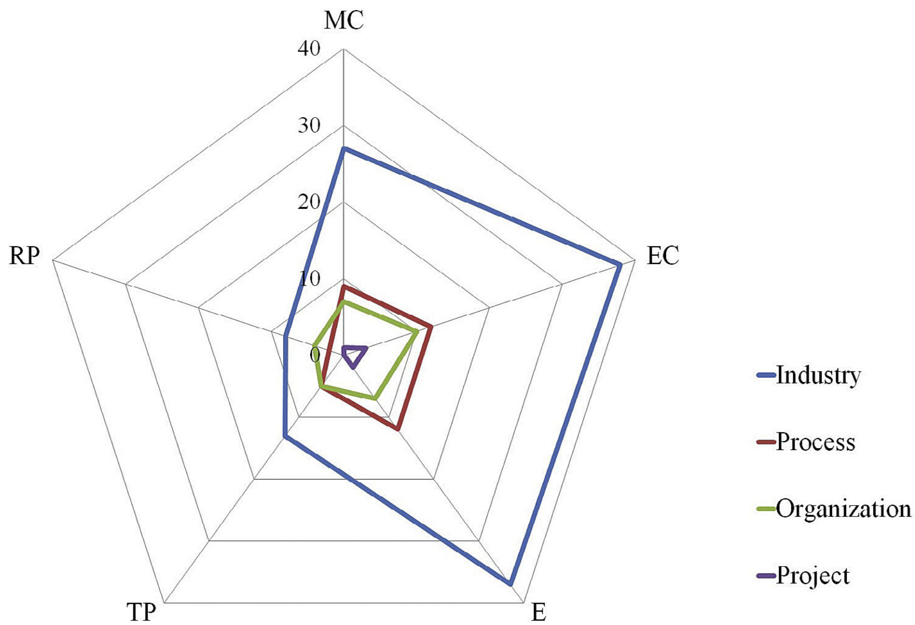

Fig. 11. Indicators analysed in the framework by category.

medium and long terms. Further researches should examine trends in energy and CO_2 emissions for example, in specific sectors and use indicators to determine how economic and other factors could influence the results of energy efficiency and decrease CO_2 emissions (Martínez and Silveira, 2013).

It has also been verified the importance to study regional resource availability conditions as well different weights to the sustainability criteria (Hadian and Madani, 2015). Moreover a further study should be conducted to determine how different factors influence regional eco-efficiency when considering spatial interactions (Huang et al., 2014; Kielenniva et al., 2012; Mickwitz et al., 2006).

Social aspects should also be taken into consideration (Müller et al., 2014). In order to direct progress toward the sustainable development, the social dimension should be included in future researches (Kemmler and Spreng, 2007). Economic and environmental indicators should be in line with social issues such as job creation or enhanced community image (Park and Behera, 2014).

Other studies considered the importance and functionality of the simulation-base approach including optimization algorithms as a decision support for eco-efficiency improvements (Sproedt et al., 2015). Furthermore it is necessary to examine the influence of technological progress with real data on eco-efficiency and is interesting that future studies provide mathematical proofs (Huang et al., 2014) or statistical methodologies (Park et al., 2015).

5. Conclusions

The objective of this research was to map Electronic Databases (EDs) through a systematic literature review in order to answer the research question: what is the state of international scientific literature from 2000 to 2015, on the theme of sustainable development from the perspective of eco-efficiency?

The objective was entirely reached with the use of an adaptation of the ProKnow-C, instrument, which allowed the selection of a PB composed of 70 articles. After the verification of the PB through a bibliometric analysis of the theme, the knowledge domain of the researchers involved was established. The key points of the bibliometric analysis of the portfolio of articles were as follows: the year that has the larger number of articles published about the theme was 2015, with 15 articles; the most relevant journal in the PB is Journal of Cleaner Production, with 23 articles published; the most prominent journals of the PB, according to JCR, are Applied Energy and International Journal of Life Cycle Assessment; the countries upon which most of the articles focused were Finland and China, with eight and seven articles, respectively; the preferred methodology within the analysed studies was quantitative, specially empirical or survey studies; most articles address industry-driven indicators and only a third of PB addresses the three pillars of sustainability.

This research makes multiple contributions to the body of sustainable development and eco-efficiency. This is the first attempt to review a large sample size of papers which increases the reliability of our findings. In addition, many issues are addressed which have not been covered properly in the past such as synergies and barriers, benefits and challenges of this integration. It is hoped that the study will inspire further research and exploration in the area of sustainability and eco-efficiency.

In particular, we would like to emphasize the lack of a specific integrated framework to achieve sustainable development through eco-efficiency indicators. We have tried to fill this gap through our proposed innovative conceptual framework, in Fig. 10, which is based on the pillars of sustainability and four levels of measurement: industry, organization, project and process, specific theoretical elements extracted from papers during our literature review. In addition, we synthesized the contributions of the bibliographic portfolio according to BASF indicators, TBL or DBL (just environmental and economic) dimensions and the four measurement levels. This classification and differentiation of research has enabled us to determine the gaps and limitations that may serve as paths for further research.

As in all studies, this research also faced some limitations. Firstly, there is a limitation in time, because the data is collected on a certain date. If there have been new authors and new articles since, they will naturally not be a part of the portfolio. Secondly, opinions of the researchers who developed the research are inherently limited. The decision regarding whether or not an article aligns with the theme or not was sometimes made by the researchers, and is therefore limited. Also, with our focus on academic journal papers in English, we are aware of the risk of excluding relevant papers in other languages as well as other types of publications. Lastly, due to the keyword-based identification of publications, it is possible that publications matching the research focus have not been found, because they do not contain the required keywords in the title or abstract of their paper.

This research provide both academics and practitioners a better panorama to understand the contributions of eco-efficiency towards sustainable development and these analyses serve as benchmarking for future corporate sustainability operations and strategies. The results offer some managerial implications for professionals who want to start measuring eco-efficiency and continuously improve the sustainable performance of their organizations.

From a political point of view, to achieve a better corporate sustainable performance in products and services, government policies should determine rules and restrictions to put the eco-efficiency aligned with social responsibilities in a higher priority and incentive policies may encourage the organizations to invest more in sustainable improvement, which could facilitate the adaptation of strategies to sustainable management systems and the financing through the private sector.

Finally, this paper also can be used as a guide for building knowledge in a systematic way and has fulfilled the gap in the literature by providing an aggregated overview of the research agenda developed from 2000 until 2015, pointing out eco-efficiency approaches, considering a glimpse of the current situation of indicators related to sustainable development and indicating fertile areas for further academic inquiry.

Appendix

Articles included in the systematic review (bibliographic portfolio).

Article No.	Title	Journal	Year
1	Developing tangible measures for eco-efficiency: the case of the finnish and swedish pulp and paper industry	Business Strategy and the Environment	2000
2	Eco-efficiency Analysis by BASF: The Method	International Journal of Life Cycle Assessment	2002
3	Eco-efficiency analysis of an agricultural research complex	Journal of Environmental Management	2003
4	Aggregate eco-efficiency indices for New Zealand - a principal components analysis	Journal of Environmental Management	2004
5	Measurement of green productivity and its improvement	Journal of Cleaner Production	2004
6	A Framework for Quantified Eco-efficiency Analysis	Journal of Industrial Ecology	2005
7	Eco-efficiency in the Finnish EMAS reports a buzz word?	Journal of Cleaner Production	2005
8	Eco-efficiency: inside BASF and beyond	Management of Environmental Quality: An International Journal	2005
9	How Can the Eco-efficiency of a Region be Measured and Monitored?	Journal of Industrial Ecology	2005
10	Indicators for sustainable energy development in Thailand	Natural Resources Forum	2005
11	Measurement and Analysis of Eco-efficiency	Journal of Industrial Ecology	2005
12	Assessing the Eco-efficiency of End-of-Pipe Technologieswith the Environmental Cost Efficiency Indicator	Journal of Industrial Ecology	2005
13	Eco-efficiency philosophy, theory and tools	Journal of Industrial Ecology	2005
14	Development of eco-efficiency indicators for theCanadian food and beverage industry	Journal of Cleaner Production	2006
15	Eco-efficiency and SMEs in Nova Scotia, Canada	Journal of Cleaner Production	2006
16	Eco-efficiency in extended supply chains: A case studyof furniture production	Journal of Environmental Management	2006
17	Environmental management accounting applicationsand eco-efficiency: case studies from Japan	Journal of Cleaner Production	2006
18	Regional eco-efficiency indicators e a participatory approach	Journal of Cleaner Production	2006
19	Eco-efficiency and ecodesign in electrical and electronic products	Journal of Cleaner Production	2007
20	Eco-efficiency in the Australian minerals processing sector	Journal of Cleaner Production	2007
21	Environmental response indicators for the industrial andenergy sector in Flanders	Journal of Cleaner Production	2007
22	Exergy Sustainability Indicators as a Tool in Industrial Ecology	Journal of Industrial Ecology	2007
23	Energy indicators for tracking sustainability in developing countries	Energy Policy	2007
24	Eco-efficiency and firm value	Journal of Accounting and Public Policy	2008
25	Eco-efficiency analysis of industrial system in China: A data envelopment analysis approach	Ecological Economics	2008
26	A methodology for assessing eco-efficiency in logistics networks	European Journal of Operational Research	2009
27	Counting biodiversity waste in industrial eco-efficiency: fisheries case study	Journal of Cleaner Production	2009
28	Emergent Eco-Efficiency Paradigm in CorporateEnvironment Management	Sustainable Development	2009
29	Environmental indicators for communication of life cycle impact assessment results and their applications	Journal of Environmental Management	2009
30	Water and wastewater eco-efficiency indicators for the sugar cane industry	Journal of Cleaner Production	2009
31	Eco-efficiency trends of the Flemish industry: decoupling of environmental impact from economic growth	Journal of Cleaner Production	2010
32	Improving eco-efficiency in the steel industry: The ArcelorMittal Gent case	Journal of Cleaner Production	2010
33	An emergy analysis-based methodology for eco-efficiency evaluation of building manufacturing	Ecological Indicators	2011
34	Assessing farming eco-efficiency: A Data Envelopment Analysis approach	Journal of Environmental Management	2011
35	Defining and Monitoring Meaningful EcoefficiencyIndicators for Tracking Business Performance	Journal of Environmental Protection and Ecology	2011
36	Eco-efficiency evaluation of the petroleum and petrochemical group in the map Ta Phut Industrial Estate, Thailand	Journal of Cleaner Production	2011
37	Economic–environmental monitoring indicators for European countries: A disaggregated sector-based approach for monitoring eco-efficiency	Ecological Economics	2011
38	A Framework for the Application of Eco-efficiency to the Technology Development Process	Journal of Technology Management & Innovation	2012
39	Analysis and management of specific progress from environmental engineering and protection based on sustainability indicators	Environmental Engineering and Management Journal	2012
40	Assessing eco-efficiency with directional distance functions	European Journal of Operational Research	2012
41	Defining Eco-efficiency: A Case Study on the FinnishForest Industry	Business Strategy and the Environment	2012
42	Measuring eco-efficiency of contaminated soil management at the regional level	Journal of Environmental Management	2012

(*continued*)

Article No.	Title	Journal	Year
43	Towards a national circular economy indicator system in China: an evaluation and critical analysis	Journal of Cleaner Production	2012
44	Determinants of eco-efficiency in the Chinese industrial sector	Journal of Environmental Sciences	2013
45	Eco-Efficiency Model for Green Building Material in a Subtropical Climate	Environmental Engineering Science	2013
46	Eco-efficiency trends in China, 1978–2010: Decoupling environmental pressure from economic growth	Ecological Indicators	2013
47	Energy efficiency and CO2 emissions in Swedishmanufacturing industries	Energy Efficiency	2013
48	Energy efficiency complexities: A technical and managerialinvestigation	Management Accounting Research	2013
49	A comprehensive eco-efficiency model and dynamics of regional eco-efficiency in China	Journal of Cleaner Production	2014
50	A framework to characterize energy efficiency measures	Applied Energy	2014
51	Evaluation of energy efficiency measures sustainability by decision tree method	Energy and Buildings	2014
52	Methodological aspects of applying eco-efficiency indicators to industrial symbiosis networks	Journal of Cleaner Production	2014
53	Power industry restructuring and eco-efficiency changes: A new slacks-based model in Malmquist –Luenberger Index measurement	Energy Policy	2014
54	The quantitative eco-efficiency measurement for smalland medium enterprise: a case study of wooden toy industry	Clean Techn Environ Policy	2014
55	Life cycle sustainability assessment of UK electricity scenarios to 2070	Energy for Sustainable Development	2014
56	A combined sustainability index for electricity efficiency measures	Energy Policy	2015
57	A Novel Life Cycle-based Principal Component Analysis Framework for Eco-efficiency Analysis: Case of the United States Manufacturing and Transportation Nexus	Journal of Cleaner Production	2015
58	A simulation-based decision support for eco-efficiency improvements in production systems	Journal of Cleaner Production	2015
59	A system of systems approach to energy sustainability assessment: Are all renewables really green?	Ecological Indicators	2015
60	An analysis of the cost-effectiveness of energy efficiencymeasures and factors affecting their implementation: a case study of Thai sugar industry	Energy Efficiency	2015
61	Analysis of energy efficiency and carbon dioxide reduction in the Chinese pulp and paper industry	Energy Policy	2015
62	Counting project savings—an alternative way to monitorthe results of a voluntary agreement on industrial energysavings	Energy Efficiency	2015
63	Drivers and Barriers to Energy Efficiency Managementfor Sustainable Development	Sustainable Development	2015
64	Eco-efficiency as a sustainability measure for kiwifruit production in New Zealand	Journal of Cleaner Production	2015
65	Eco-efficiency change in power plants: using a slacks-based measure for the meta-frontier MalmquisteLuenberger productivity index	Journal of Cleaner Production	2015
66	Eco-efficiency in micro-enterprises and small firms: a case study in the automotive services sector	Journal of Cleaner Production	2015
67	Environmental and energy analysis of biodiesel production in Rio Grande do Sul, Brazil	Clean Techn Environ Policy	2015
68	Measuring eco-efficiency based on green indicators and potentials in energy saving and undesirable output abatement	Energy Economics	2015
69	Measuring eco-efficiency in the Finnish forest industry using public data	Journal of Cleaner Production	2015
70	Toward a systematized framework for resource efficiency indicators	Resources, Conservation and Recycling	2015

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