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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.

Keywords: Eco-efficiency; Sustainability; Indicators; Sustainable development.

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, Manolas, Pace, 2015](#)). According to [Park et al. \(2015\)](#), concerns about the planet's sustainability have grown

1 after the United Nation's Conference on the Human Environment (a.k.a. Stockholm
2 Conference) in 1972, which initiated the concept of sustainable development as a
3 pathway for improving the quality of life for future generations.

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

10
11 In order to monitor environmental impacts, eco-efficiency indicators emerged,
12 designed to analyse the development of eco-efficiency by measuring economic activity,
13 both in terms of consumption and production, as well as the corresponding impacts. The
14 assessment of these eco-indicators complements the traditional technical and economic
15 evaluations of engineering projects and supports the decision-making process.

16
17 Eco-efficiency indicators can also be used to measure the eco-efficiency of different
18 sectors within a country; to compare eco-efficiency within the same industry in different
19 countries; and to identify possible areas of in which ecological efficiency can be
20 improved. This is reflected through a number of studies that have considered the
21 relationship and investigated the impact of eco-efficiency initiatives on the economic
22 and environmental performance of organisations disregarding the social dimension
23 (Charmondusit et al., 2013) - despite its importance in order to reach the goals of
24 sustainable development (Mickwitz et al., 2006; de Almeida Guimarães and Leal
25 Junior, 2017). However, despite these studies, a comprehensive review of published
26 scientific articles on eco-efficiency practices and indicators seeking the sustainable
27 development in industries, firms, projects and processes is currently lacking.

28
29 Besides that, the academic literature and research lines exploring the impact of eco-
30 efficiency indicators on sustainability performance (Zhang et al. 2008; Rashidi and
31 Farzipoor Saen, 2015) and synergies of eco-efficiency and sustainable development
32 initiatives (Hoffren and Apajalahti, 2009) still remain in early stages. Additionally, it
33 lacks of a clear and structured research definition that may result in difficulties to
34 advance this promising research area. Moreover, still there is a research gap on the
35 literature on a holistic framework used to assess the eco-efficiency of products and
36 services and reach the economic, environmental and social dimensions - TBL (triple
37 bottom line) proposed by Elkington (1998) - in an integrated way, as highlighted by
38 Hart and Milstein (2003) and Abreu et al. (2017).

39
40 Attending to the above mentioned motivation, this paper aims to map Sustainable
41 Development from the perspective of eco-efficiency in main Electronic Databases
42 (EDs). This was to be done through a method of systematic literature review, with the
43 implementation of the adaptation of the Knowledge Development Process intervention
44 instrument - constructivist (ProKnow-C). With this in mind, the following specific
45 objectives were outlined: (i) to select a Bibliographic Portfolio that is aligned with the
46 perception of the researchers on the theme of sustainable development, from the
47 perspective of eco-efficiency; (ii) perform a bibliometric analysis of the selected
48 Bibliographic Portfolio; (iii) perform a thematic synthesis; (iv) find the integration of
49 eco-efficiency and sustainable development with other approaches; (v) propose an
50 integrative framework to implement sustainability through the eco-indicators; and (vi)
51 find paths for further research.

1 Furthermore, this research intends to contribute to the scientific community on the
2 theme studied, since it presents a representative selection of international research in an
3 interdisciplinary area. It is a relevant issue in which there is a significant dialogue of
4 environmental, chemistry and industrial engineering, enabling the researchers to
5 contribute with relevant research. The new contributions of the present paper are: 1)
6 expand the literature review; 2) highlight the synergies and barriers between eco-
7 efficiency and sustainable development; and 3) compare and analyse them, by showing
8 its relevant features.
9

10 **2. Background and terminology**

11 *1. Eco-efficiency*

12 The World Business Council for Sustainable Development (WBCSD) defined eco-
13 efficiency as: “The delivery of competitively priced goods and services that satisfy
14 human needs and bring quality of life, while progressively reducing ecological impacts
15 and resource intensity throughout the life-cycle to a level at least in line with the Earth’s
16 estimated carrying capacity” (WBCSD, 1992). This concept was introduced by
17 WBCSD in the 1990s and is also an instrument for sustainability analysis (Zhang et al.,
18 2008), indicating an empirical relation in economic activities between environmental
19 cost or value and environmental impacts (Hupples and Ishikawa, 2005).
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23 According to Maxime et al. (2006), eco-efficiency is a way to evaluate the
24 parameters of sustainable development, in order to reduce the consumption of resources,
25 as well as the impact on nature, while maintaining or enhancing the value of the
26 manufactured product. Eco-efficiency has emerged as a management response to waste
27 issues associated with current production processes (Jollands et al., 2004) and is one of
28 the most analytical and quantitative approaches for business enterprises interested in
29 practical ways to obtain sustainable development (Willison and Côte, 2009).
30
31

32 The development of eco-indicators is a key strategy for monitoring the eco-efficiency
33 in a simple, systematic and consistent manner (Van Caneghem et al., 2010a), in order
34 to better understand the problem, thus enabling decision-making processes to improve
35 the quality of life and preserve natural resources.
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37

38 Several analyses in the scientific literature also corroborate the beneficial results
39 among companies and industries from different kinds of activities that adopted eco-
40 efficient practices. Eco-efficiency can be applied at different sectors, such as industrial
41 processes, businesses or even to a specific product. Eco-efficiency analyses have been
42 applied, for example, to compare two alternative routes to convert residual biomass into
43 energy or chemicals (Lozano and Lozano, 2017). The study highlights that eco-
44 efficiency can be used as a decision-making tool to choose between transformation
45 processes by combining scientific and technical issues with economic ones.
46
47

48 Eco-efficiency increases small and medium enterprises’ (SME) sustainability
49 independently from their activity, economic situation and size. According to Alves and
50 Dumke de Medeiros (2015), eco-efficiency is a competitive and organizational tool for
51 SMEs in developing countries. Côté et al. (2006) conducted a survey on 25 small and
52 medium-sized enterprises (SMEs) in Nova Scotia, Canada, in order to measure eco-
53 efficiency levels. The research has found that low levels of eco-efficiency were
54 demonstrated in all businesses and suggested that there is much room for improvement
55 and further that economic and environmental benefit through eco-efficiency.
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58 Eco-efficiency analysis can also be applied at a regional or global level, where each
59 sector created its eco-efficiency concept and applied to a particular system. Huang et al.
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1 (2014) developed a study based on the regional eco-efficiency of 30 provinces in China
2 from 2000 to 2010. The research concluded that to promote eco-efficiency at
3 undeveloped regions they should focus on improving management capability and
4 efficiency awareness in addition to accelerating their technological progress.

5 WBCSD (1996) defined some ways to improve eco-efficiency as reducing material
6 and energy intensity, reducing toxic dispersion, enhancing recyclability, maximizing the
7 sustainable use of renewable resources, extending product durability and increasing
8 service intensity.
9

10 In 1996, BASF Corporation developed an eco-efficiency methodology to assess both
11 the economic and environmental impacts of chemicals, processes, and products in their
12 lifecycle (Saling et al., 2002). The methodology created by BASF has since been further
13 developed and follows the ISO 14040 and ISO 14044 standards for lifecycle assessment
14 (LCA) (Uhlman and Saling, 2010) and also ISO 14045 for Eco-Efficiency assessment
15 (Bradlee et al., 2009). BASF's methodology can be used for sustainable decision-
16 making at all levels, from industrial to consumer (Wall-Markowski et al., 2005).
17
18

19 One advantage of the eco-efficiency assessment compared to other methodologies
20 such as Cleaner Production, for example, is that the former provides an explicit and
21 effective criterion of evaluation (Lozano and Lozano, 2017). Moreover eco-efficiency
22 analysis is based on Life Cycle Assessment.
23
24

25 The growing concern with discussing and studying issues as eco-efficiency is very
26 important as it is a major means of achieving sustainability. Increasing the
27 environmental performance of a company or industry is an essential criterion in creating
28 sustainable economy.
29

30 2. *Achieving sustainable development through eco-efficiency*

31 Historically, the concept of sustainable development emerged in the 1987 report
32 from the UN World Commission on Environment and Development, in a document
33 entitled "Our Common Future". It requires development to be achieved "which meets
34 the needs of the present generation without compromising the ability of future
35 generations to meet their needs" (WCED, 1987). Within this context, the eco-efficiency
36 acts as a trend indicator towards the transition to sustainable development (Hoffren and
37 Apajalahti 2009) and might provide a route to it (Zhang et al., 2008).
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41 The eco-efficiency analysis harmonizes two of the three pillars that a company must
42 measure in order to manage and quantify sustainability, it can make strategic decision-
43 making along the entire value chain easier and it helps firms to drive innovative product
44 development toward bringing more sustainable products to the marketplace (Uhlman
45 and Saling, 2010).
46

47 On the other hand, Zhang et al. (2008) states that it is necessary eco-efficiency be
48 coupled with other indicators and tools (e.g. social and cultural indicators) in order to
49 become a useful indicator for sustainable development. From this, the social dimension
50 is needed for a complete measurement of sustainable development and so, Kolsch et al.
51 (2008), integrates social metrics into the eco-efficiency, through a method known as
52 SEEBALANCE, a comparative life-cycle assessment tool that consists of costs,
53 environmental impact and social effects of different product or process alternatives.
54 Also, those socio-eco-efficient solutions combine a relatively good environmental
55 performance with high social benefit and at the same time low costs for the end
56 customer (Kolsch et al., 2008).
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1 Furthermore, [Charmondusit et al. \(2013\)](#) proposed a socio-eco-efficiency ratio in
2 order to measure the improvement of the firm concerning social indicators and the
3 study' results showed that the company has acquired a socially supportive management
4 system at the company, community and social levels, the firms must operate aligned
5 with corporate social responsibility (CSR) in order to provide benefits to people and
6 society and the social indicators enable optimal company stability and ensure greater
7 competitive and business sustainability.
8

9 In addition, eco-efficiency indicators are designed in order to measure the
10 environmental impacts of businesses and to subsequently manage the companies better
11 ([Van Caneghem et al., 2010](#)). Although the eco-efficiency concept doesn't consider the
12 third pillar of sustainability – the social dimension – its efforts could provide better
13 financial, environmental, and social performance ([Alves and Dumke De Medeiros,
14 2015](#)), addressing the social question in a implicitly way.
15

16 As [Hoffren and Apajalahti \(2009\)](#), eco-efficiency seeks to combine economic and
17 material efficiency of production with the aim of sustainable development and the
18 notion of social justice. They mention that although the eco-efficiency intends to reduce
19 environmental degradation to a level that is sustainable, eco-efficiency indicators only
20 give a rough picture of an urgent issue, serving better towards general sustainability of
21 activity. Thus, [Hoffren and Apajalahti \(2009\)](#) also highlight the importance of the
22 operationalization and developing of eco-efficiency, in a standard way, as part of daily
23 activities of industries and organizations in order to achieve its targets.
24

25 Besides that, eco-efficiency reflects trade-offs between the economic and the
26 environmental business performance and can be used to promote improvements along
27 value chain and the sustainability of products, processes and services ([Carvalho et al.,
28 2017](#)). Moreover, eco-efficiency approach can assist governmental agencies and
29 organizations, as SMEs, implementing their sustainable development strategies and
30 improving businesses ([Côté et al., 2006](#)).
31

32 As essential as eco-efficiency is the adoption of a management philosophy that seeks
33 to both environmental improvements and profitability, by incorporating environment
34 concerns efficiently into the firm's strategic planning, by applying lean production
35 techniques ([Carvalho et al., 2017](#)) or by adopting an environmental management system
36 (EMS) - which is focused on the general environmental performance of the company
37 ([Van Gerven et al., 2007](#)) - to improve firm value ([Sinkin et al., 2008](#)). [Reith and
38 Guidry \(2003\)](#) state that eco-efficiency works as an aspect in an EMS such as prescribed
39 by ISO 14000, by monitoring and managing resource efficiency.
40

41 **3. Methodology**

42 In this paper we conduct a systematic review in order to locate the relevant existing
43 studies based on previously formulated research questions, in order to evaluate and
44 synthesize their respective contributions. Systematic reviews are characterized by a
45 clearly defined, explicit question; a comprehensive and systematic search for studies; an
46 explicit, reproducible strategy for screening and including studies; an explicit,
47 reproducible data extraction (coding); an appropriate analysis and reporting of results;
48 interpretations supported by data; and implications for future research, and, if relevant,
49 for policy or practice ([Ravindran and Shankar, 2015](#)). The steps for the construction of
50 knowledge are an adaptation of the ProKnow-C method, which is a systematic approach
51 to organize knowledge from a literature review and comprises: elaboration of
52 bibliographic portfolio; bibliometric analysis, and systemic analysis ([Viegas et al.,
53 2015](#)).
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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.

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.

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. 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.

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 |

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 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.

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 |

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

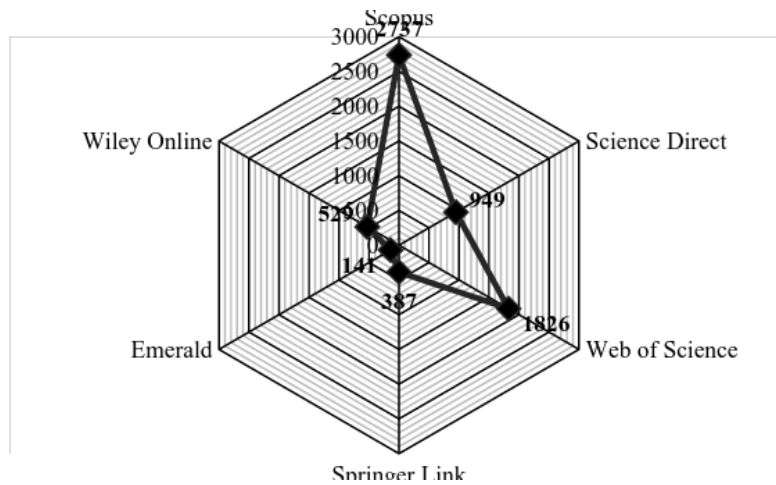


Fig. 1. Quantity of articles found in each database.

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.

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.

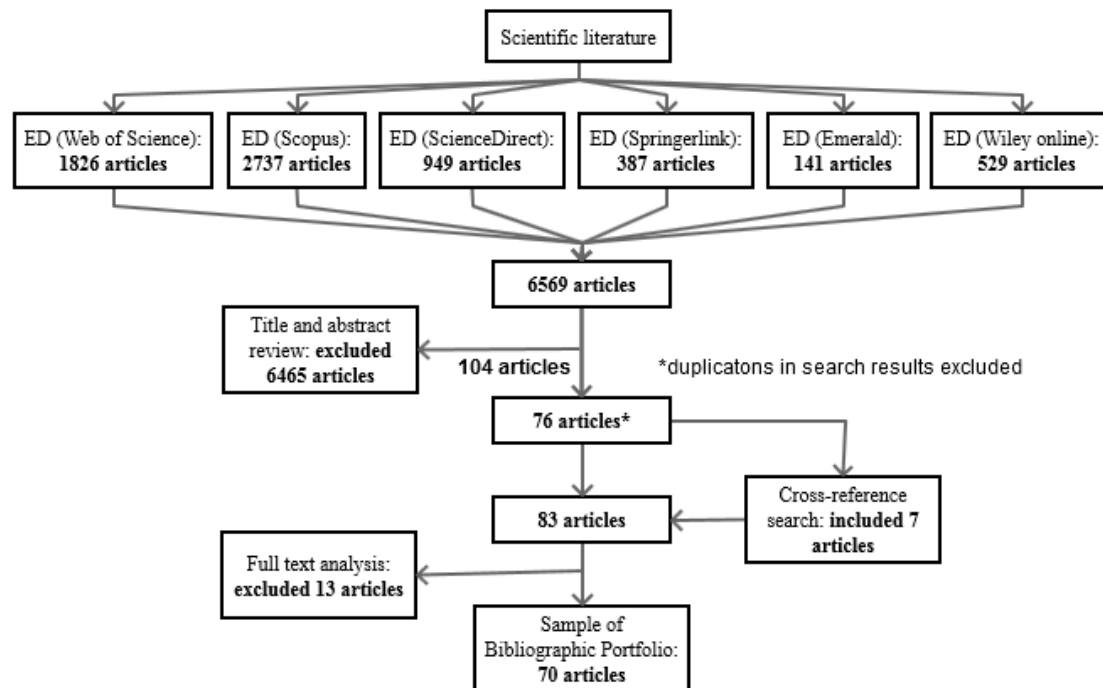


Fig. 2. Mapping the scientific literature search.

Source: adapted from Schulze et al., (2015).

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

1. Bibliometric Analysis

Bibliometric methods are used to examine the characteristics of 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.

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.

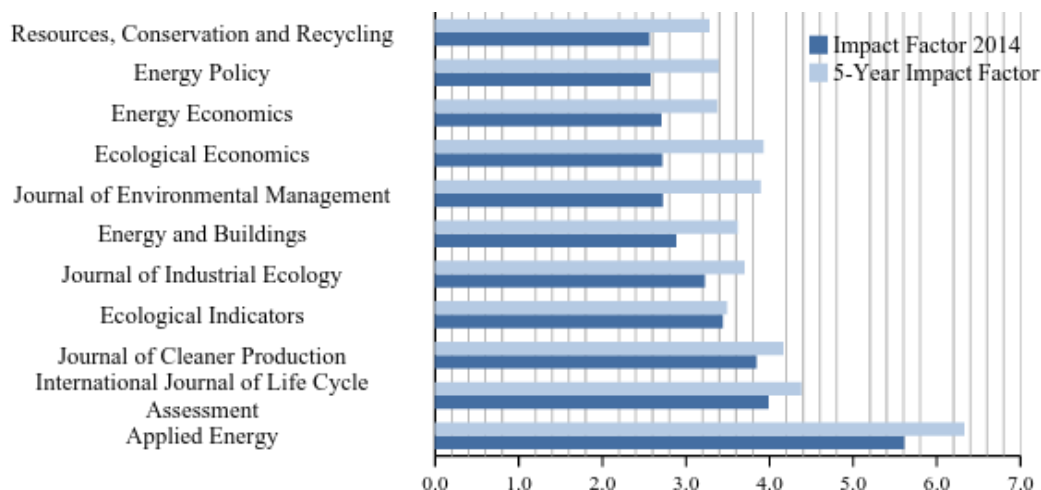


Fig. 3. The impact factors of the main journals.

The prominent journal when it comes to the impact factor in the academic community is Applied Energy, with a JCR of 5,613 in 2014 and an average in the last five years of 6,330.

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.

2. Descriptive analysis of BP

1. Year of publication

Figure 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.

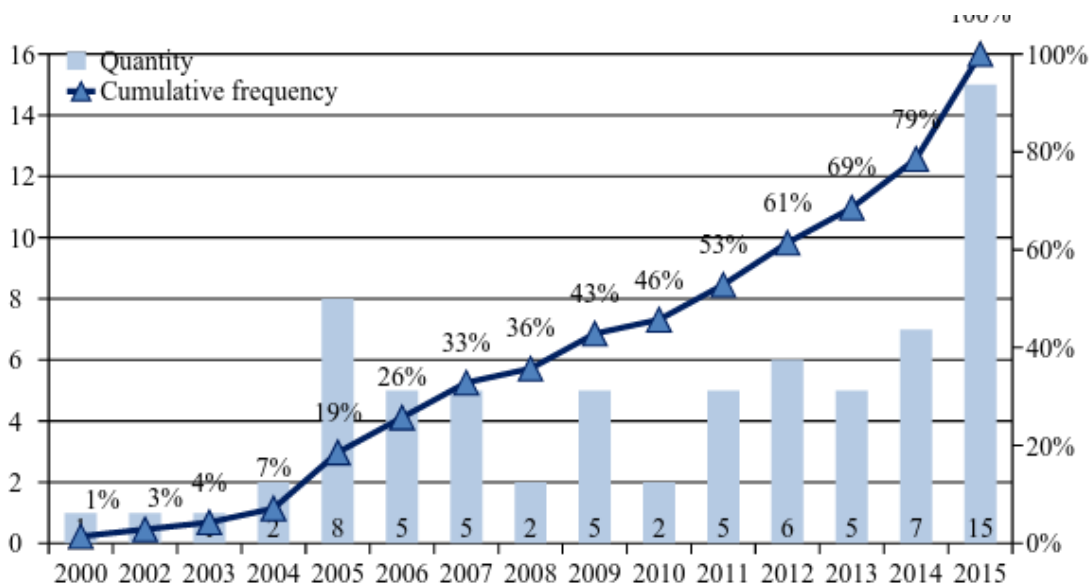


Fig. 4. The number and percentage of publications

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.

2. Journals of publications

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

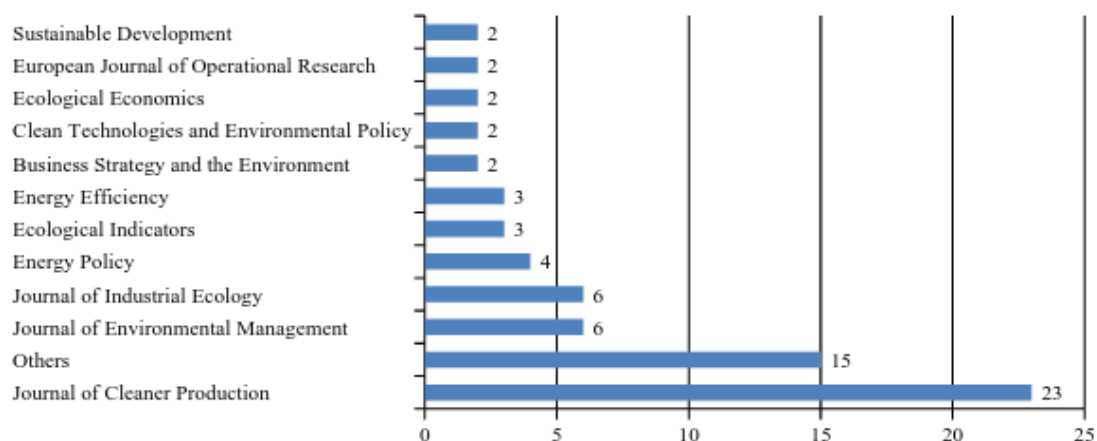


Fig. 5. Number of publications per journal

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).

3. Geographical focus

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

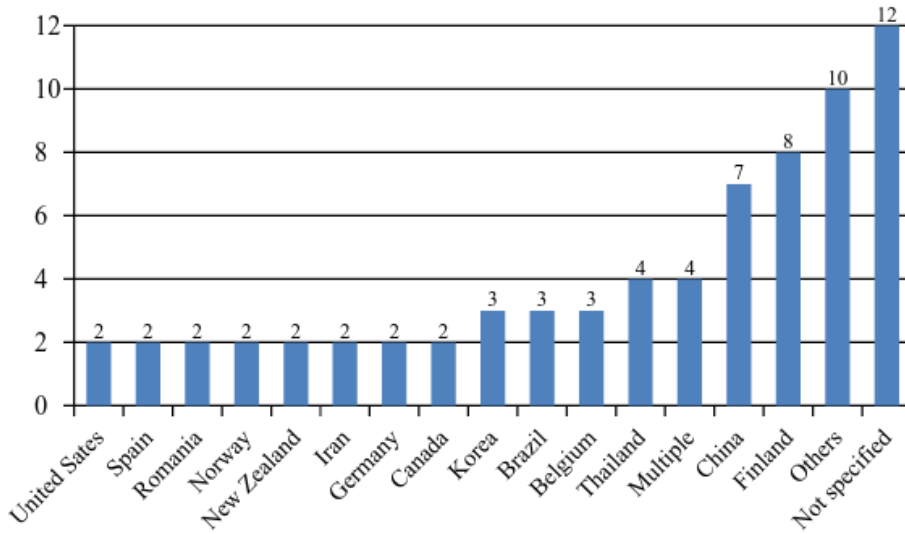


Fig. 6. Geographical distribution of analysis

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 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. Study methodologies

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

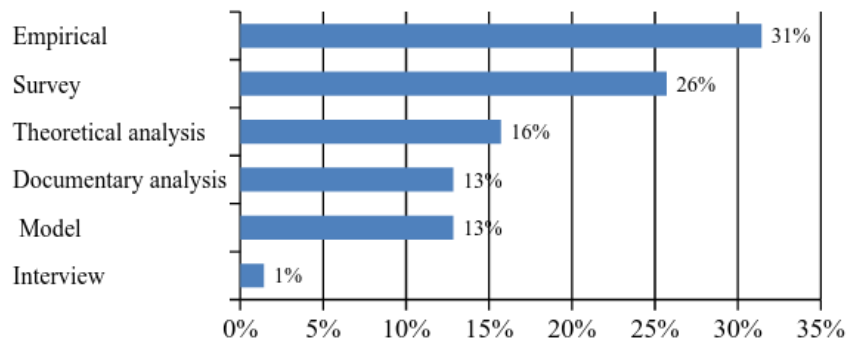


Fig. 7. Percentage of study methodology in the BP

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.

5. Industrial sector focus

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

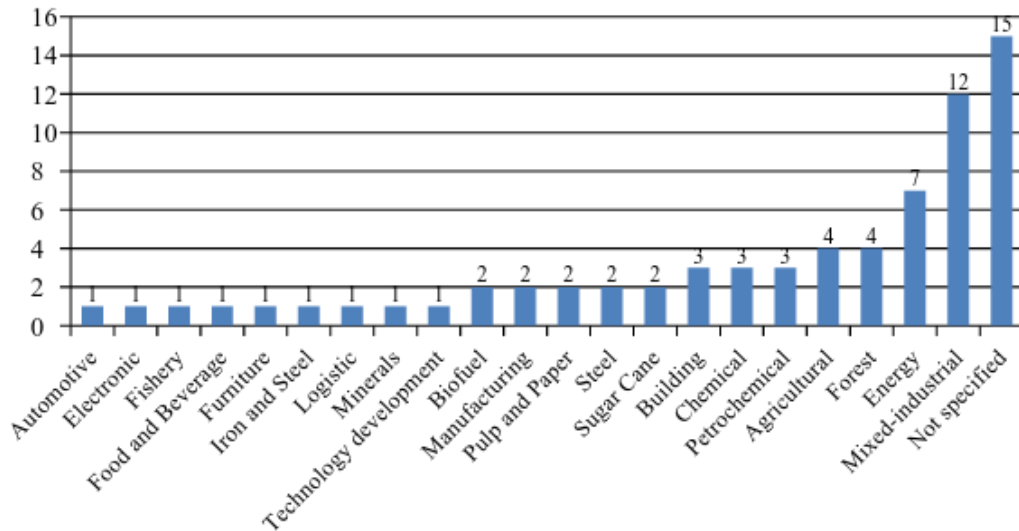


Fig. 8. Distribution of industry sectors in the BP

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.

2. 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.

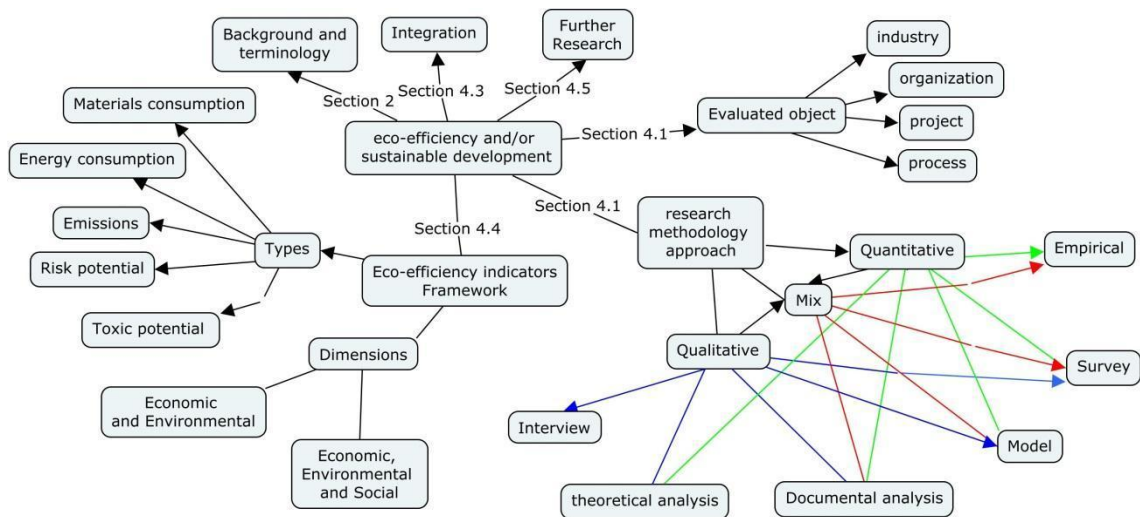


Fig. 9. Concept map of the sustainable development and eco-efficiency review.

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.

3. 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, 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.

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 competitiveness; 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 | Côté et al. (2006); Caetano et al. (2012); Park et al. (2015); |

responsibility;

| 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). |

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. 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.

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

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

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

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

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

30 Fig. 10 presents the conceptual framework towards sustainable development.
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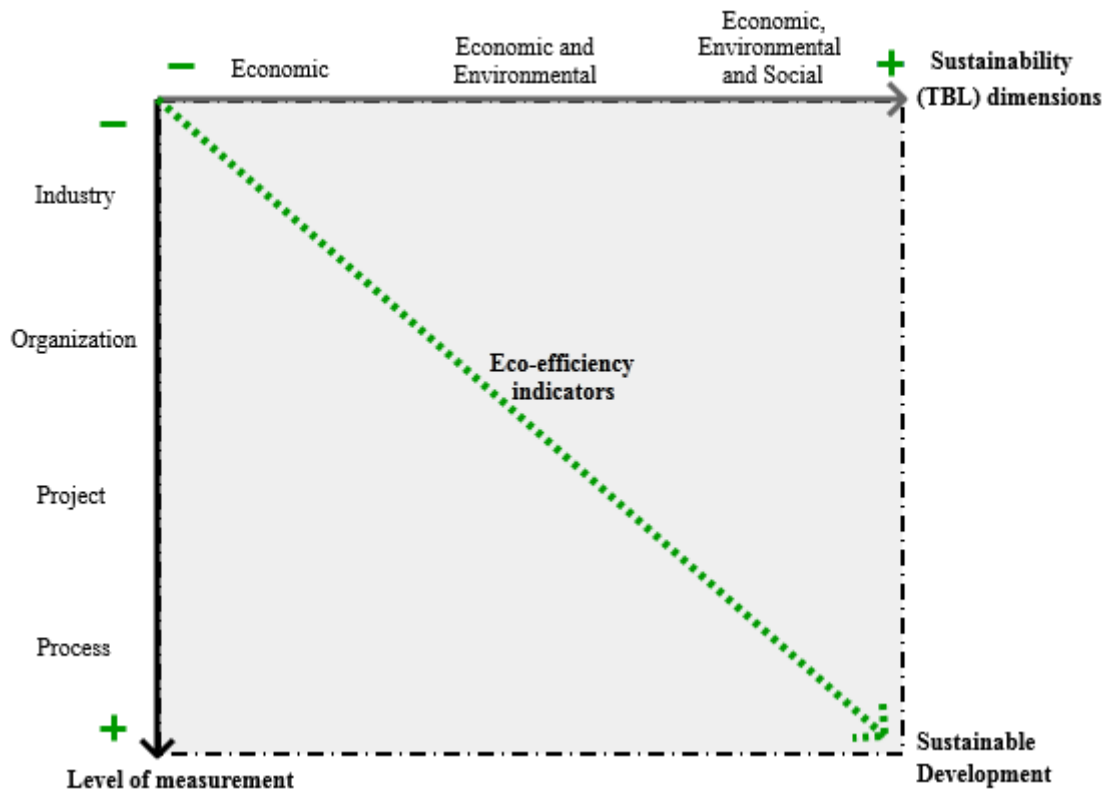


Fig. 10. Innovative conceptual framework towards sustainable development.

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 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, waterpower, 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 Sailing 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.

Table 4 - Contributions from reviewed articles to proposed framework.

| Contributions from Bibliographic Portfolio | Evaluated Object and BASF Indicators | | | | | | | | | | | | | | | | | | | |
|--|--------------------------------------|---|---|---|---|--------------|---|---|---|---|---------|---|---|---|---------|---|---|---|---|---|
| | Industry | | | | | Organization | | | | | Project | | | | Process | | | | | |
| | D | M | C | E | P | M | C | E | P | R | M | C | E | P | R | M | C | E | P | R |
| 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 |
| Charmondusit and Keartpakpraek (2011) | | | | x | x | | | | | | | | | | | | | | | |
| Charmondusit et al. (2013) | | | | x | x | | | | | | | | | | | | | | | |
| Côté et al. (2006) | | | | x | x | | | | | | | | | | | | | | | |
| Ehrenfeld (2005) | | | | x | x | | | | | | | | | | | | | | | |
| Erkko et al. (2005) | | | | | | | | | | | | x | x | | x | | | | | |
| Fortuna et al. (2012) | | | | | | | | | | | | | | | | | | x | x | x |
| Fujii and Managi (2013) | | | | x | x | | | | | | | | | | | | | | | |
| Geng et al. (2012) | | | | x | x | | | | | | | | | | | | | | | |

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

6 Eco-efficiency practices should be encourage in other industries, as in cases with
7 rapidly growing sectors in which energy consumption is increasing and could result in
8 higher emissions in medium and long terms. Further researches should examine trends
9 in energy and CO₂ emissions for example, in specific sectors and use indicators to
10 determine how economic and other factors could influence the results of energy
11 efficiency and decrease CO₂ emissions ([Martínez and Silveira, 2013](#)).

12 It has also been verified the importance to study regional resource availability
13 conditions as well different weights to the sustainability criteria ([Hadian and Madani,
14 2015](#)). Moreover a further study should be conducted to determine how different factors
15 influence regional eco-efficiency when considering spatial interactions ([Huang et al.,
16 2014](#); [Kielenniva et al., 2012](#); [Mickwitz et al., 2006](#)).

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

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

28 **5. Conclusions**

29 The objective of this research was to map Electronic Databases (EDs) through a
30 systematic literature review in order to answer the research question: what is the state of
31 international scientific literature from 2000 to 2015, on the theme of sustainable
32 development from the perspective of eco-efficiency?
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34 The objective was entirely reached with the use of an adaptation of the ProKnow-C,
35 instrument, which allowed the selection of a PB composed of 70 articles. After the
36 verification of the PB through a bibliometric analysis of the theme, the knowledge
37 domain of the researchers involved was established. The key points of the bibliometric
38 analysis of the portfolio of articles were as follows: the year that has the larger number
39 of articles published about the theme was 2015, with 15 articles; the most relevant
40 journal in the PB is Journal of Cleaner Production, with 23 articles published; the most
41 prominent journals of the PB, according to JCR, are Applied Energy and International
42 Journal of Life Cycle Assessment; the countries upon which most of the articles focused
43 were Finland and China, with eight and seven articles, respectively; the preferred
44 methodology within the analysed studies was quantitative, specially empirical or survey
45 studies; most articles address industry-driven indicators and only a third of PB
46 addresses the three pillars of sustainability.
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48 This research makes multiple contributions to the body of sustainable development
49 and eco-efficiency. This is the first attempt to review a large sample size of papers
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1 which increases the reliability of our findings. In addition, many issues are addressed
2 which have not been covered properly in the past such as synergies and barriers,
3 benefits and challenges of this integration. It is hoped that the study will inspire further
4 research and exploration in the area of sustainability and eco-efficiency.

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

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

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

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

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

43 Appendix

44 Articles included in the systematic review (bibliographic portfolio).

| 45 Article 46 No. | 47 Title | 48 Journal | 49 Year |
|----------------------|----------|------------|---------|
|----------------------|----------|------------|---------|

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| 1 | 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 | 2 | Eco-efficiency Analysis by BASF: The Method | International Journal of Life Cycle Assessment | 2002 |
| 3 | 3 | Eco-efficiency analysis of an agricultural research complex | Journal of Environmental Management | 2003 |
| 4 | 4 | Aggregate eco-efficiency indices for New Zealand - a principal components analysis | Journal of Environmental Management | 2004 |
| 5 | 5 | Measurement of green productivity and its improvement | Journal of Cleaner Production | 2004 |
| 6 | 6 | A Framework for Quantified Eco-efficiency Analysis | Journal of Industrial Ecology | 2005 |
| 7 | 7 | Eco-efficiency in the Finnish EMAS reports a buzz word? | Journal of Cleaner Production | 2005 |
| 8 | 8 | Eco-efficiency: inside BASF and beyond | Management of Environmental Quality: An International Journal | 2005 |
| 9 | 9 | How Can the Eco-efficiency of a Region be Measured and Monitored? | Journal of Industrial Ecology | 2005 |
| 10 | 10 | Indicators for sustainable energy development in Thailand | Natural Resources Forum | 2005 |
| 11 | 11 | Measurement and Analysis of Eco-efficiency | Journal of Industrial Ecology | 2005 |
| 12 | 12 | Assessing the Eco-efficiency of End-of-Pipe Technologies with the Environmental Cost Efficiency Indicator | Journal of Industrial Ecology | 2005 |
| 13 | 13 | Eco-efficiency philosophy, theory and tools | Journal of Industrial Ecology | 2005 |
| 14 | 14 | Development of eco-efficiency indicators for the Canadian food and beverage industry | Journal of Cleaner Production | 2006 |
| 15 | 15 | Eco-efficiency and SMEs in Nova Scotia, Canada | Journal of Cleaner Production | 2006 |
| 16 | 16 | Eco-efficiency in extended supply chains: A case study of furniture production | Journal of Environmental Management | 2006 |
| 17 | 17 | Environmental management accounting applications and eco-efficiency: case studies from Japan | Journal of Cleaner Production | 2006 |
| 18 | 18 | Regional eco-efficiency indicators e a participatory approach | Journal of Cleaner Production | 2006 |
| 19 | 19 | Eco-efficiency and ecodesign in electrical and electronic products | Journal of Cleaner Production | 2007 |
| 20 | 20 | Eco-efficiency in the Australian minerals processing sector | Journal of Cleaner Production | 2007 |
| 21 | 21 | Environmental response indicators for the industrial and energy sector in Flanders | Journal of Cleaner Production | 2007 |
| 22 | 22 | Exergy Sustainability Indicators as a Tool in Industrial Ecology | Journal of Industrial Ecology | 2007 |
| 23 | 23 | Energy indicators for tracking sustainability in developing countries | Energy Policy | 2007 |
| 24 | 24 | Eco-efficiency and firm value | Journal of Accounting and Public Policy | 2008 |
| 25 | 25 | Eco-efficiency analysis of industrial system in China: A data envelopment analysis approach | Ecological Economics | 2008 |
| 26 | 26 | A methodology for assessing eco-efficiency in logistics networks | European Journal of Operational Research | 2009 |
| 27 | 27 | Counting biodiversity waste in industrial eco-efficiency: fisheries case study | Journal of Cleaner Production | 2009 |
| 28 | 28 | Emergent Eco-Efficiency Paradigm in Corporate Environment Management | Sustainable Development | 2009 |
| 29 | 29 | Environmental indicators for communication of life cycle | Journal of Environmental | 2009 |

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| | | impact assessment results and their applications | Management | |
| 1 | 30 | Water and wastewater eco-efficiency indicators for the sugar cane industry | Journal of Cleaner Production | 2009 |
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| 3 | 31 | Eco-efficiency trends of the Flemish industry: decoupling of environmental impact from economic growth | Journal of Cleaner Production | 2010 |
| 4 | | | | |
| 5 | 32 | Improving eco-efficiency in the steel industry: The ArcelorMittal Gent case | Journal of Cleaner Production | 2010 |
| 6 | | | | |
| 7 | 33 | An emergy analysis-based methodology for eco-efficiency evaluation of building manufacturing | Ecological Indicators | 2011 |
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| 9 | 34 | Assessing farming eco-efficiency: A Data Envelopment Analysis approach | Journal of Environmental Management | 2011 |
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| 11 | 35 | Defining and Monitoring Meaningful Ecoefficiency Indicators for Tracking Business Performance | Journal of Environmental Protection and Ecology | 2011 |
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| 13 | 36 | Eco-efficiency evaluation of the petroleum and petrochemical group in the map Ta Phut Industrial Estate, Thailand | Journal of Cleaner Production | 2011 |
| 14 | | | | |
| 15 | 37 | Economic–environmental monitoring indicators for European countries: A disaggregated sector-based approach for monitoring eco-efficiency | Ecological Economics | 2011 |
| 16 | | | | |
| 17 | 38 | A Framework for the Application of Eco-efficiency to the Technology Development Process | Journal of Technology Management & Innovation | 2012 |
| 18 | | | | |
| 19 | 39 | Analysis and management of specific progress from environmental engineering and protection based on sustainability indicators | Environmental Engineering and Management Journal | 2012 |
| 20 | | | | |
| 21 | 40 | Assessing eco-efficiency with directional distance functions | European Journal of Operational Research | 2012 |
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| 23 | 41 | Defining Eco-efficiency: A Case Study on the Finnish Forest Industry | Business Strategy and the Environment | 2012 |
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| 25 | 42 | Measuring eco-efficiency of contaminated soil management at the regional level | Journal of Environmental Management | 2012 |
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| 27 | 43 | Towards a national circular economy indicator system in China: an evaluation and critical analysis | Journal of Cleaner Production | 2012 |
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| 29 | 44 | Determinants of eco-efficiency in the Chinese industrial sector | Journal of Environmental Sciences | 2013 |
| 30 | | | | |
| 31 | 45 | Eco-Efficiency Model for Green Building Material in a Subtropical Climate | Environmental Engineering Science | 2013 |
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| 33 | 46 | Eco-efficiency trends in China, 1978–2010: Decoupling environmental pressure from economic growth | Ecological Indicators | 2013 |
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| 35 | 47 | Energy efficiency and CO2 emissions in Swedish manufacturing industries | Energy Efficiency | 2013 |
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| 37 | 48 | Energy efficiency complexities: A technical and managerial investigation | Management Accounting Research | 2013 |
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| 39 | 49 | A comprehensive eco-efficiency model and dynamics of regional eco-efficiency in China | Journal of Cleaner Production | 2014 |
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| 41 | 50 | A framework to characterize energy efficiency measures | Applied Energy | 2014 |
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| 43 | 51 | Evaluation of energy efficiency measures sustainability by decision tree method | Energy and Buildings | 2014 |
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| 45 | 52 | Methodological aspects of applying eco-efficiency indicators to industrial symbiosis networks | Journal of Cleaner Production | 2014 |
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| 47 | 53 | Power industry restructuring and eco-efficiency changes: A new slacks-based model in Malmquist–Luenberger Index measurement | Energy Policy | 2014 |
| 48 | | | | |
| 49 | 54 | The quantitative eco-efficiency measurement for small and medium enterprise: a case study of wooden toy industry | Clean Techn Environ Policy | 2014 |
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| 51 | 55 | Life cycle sustainability assessment of UK electricity scenarios to 2070 | Energy for Sustainable Development | 2014 |
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| 53 | 56 | A combined sustainability index for electricity efficiency | Energy Policy | 2015 |
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| | measures | | |
| 1 | A Novel Life Cycle-based Principal Component Analysis | Journal of Cleaner | |
| 2 | 57 Framework for Eco-efficiency Analysis: Case of the United | Production | 2015 |
| 3 | States Manufacturing and Transportation Nexus | | |
| 4 | 58 A simulation-based decision support for eco-efficiency | Journal of Cleaner | |
| 5 | improvements in production systems | Production | 2015 |
| 6 | 59 A system of systems approach to energy sustainability | Ecological Indicators | |
| 7 | assessment: Are all renewables really green? | | 2015 |
| 8 | 8 An analysis of the cost-effectiveness of energy efficiency | Energy Efficiency | |
| 9 | 60 measures and factors affecting their implementation: a case | | 2015 |
| 10 | study of Thai sugar industry | | |
| 11 | 61 Analysis of energy efficiency and carbon dioxide reduction | Energy Policy | |
| 12 | in the Chinese pulp and paper industry | | 2015 |
| 13 | 62 Counting project savings—an alternative way to monitor | Energy Efficiency | |
| 14 | the results of a voluntary agreement on industrial energy | | 2015 |
| 15 | savings | | |
| 16 | 63 Drivers and Barriers to Energy Efficiency Management | Sustainable Development | |
| 17 | for Sustainable Development | | 2015 |
| 18 | 64 Eco-efficiency as a sustainability measure for kiwifruit | Journal of Cleaner | |
| 19 | production in New Zealand | Production | 2015 |
| 20 | 21 Eco-efficiency change in power plants: using a slacks-based | Journal of Cleaner | |
| 22 | 65 measure for the meta-frontier MalmquisteLuenberger | Production | 2015 |
| 23 | productivity index | | |
| 24 | 66 Eco-efficiency in micro-enterprises and small firms: a case | Journal of Cleaner | |
| 25 | study in the automotive services sector | Production | 2015 |
| 26 | 67 Environmental and energy analysis of biodiesel production | Clean Techn Environ | |
| 27 | in Rio Grande do Sul, Brazil | Policy | 2015 |
| 28 | 68 Measuring eco-efficiency based on green indicators and | Energy Economics | |
| 29 | potentials in energy saving and undesirable output abatement | | 2015 |
| 30 | 69 Measuring eco-efficiency in the Finnish forest industry using | Journal of Cleaner | |
| 31 | public data | Production | 2015 |
| 32 | 70 Toward a systematized framework for resource efficiency | Resources, Conservation | |
| 33 | indicators | and Recycling | 2015 |

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