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Review

Sustainability indicators for the assessment of eco-industrial parks: classification and criteria for selection

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A B S T R A C T

A variety of indicators is available for assessing the economic, environmental, and social aspects of an Eco-industrial park (EIP). The managers of a sustainability assessment over these parks should overcome an important task at the beginning of the study: to select indicators.

To support this activity, the challenge is to list and classify a large set of sustainability indicators. Consequently, the main achievements of this article are a wide search and classification of sustainability indicators, and the development of four criteria to filter indicators when assessing an EIP. A literature search in ISI Web of Science's database is presented to explore feasible indicators. The definition of 249 indicators is provided in an annotated list.

An important difficulty to use these indicators is to select a proper subset. To deal with this selection, this work proposes four criteria constructed to be functional, clear, and adaptable to the application context. The proposed criteria are: *understanding*, *pragmatism*, *relevance*, and *partial representation of sustainability*. The 249 indicators have been filtered using the four criteria, and have been classified according to three dimensions of sustainability (social, environmental, and economic dimensions).

The four criteria provide a formal way to filter a large set of possible indicators, improving the mechanism for their selection. In order to illustrate their application to select suitable indicators for the assessment of EIPs, a hypothetical case is constructed on the basis of an industrial park in Kalundborg. The selected indicators meet the four criteria and the evaluation goal.

Focusing on sustainability dimensions, many of the integrated indicators are related to the economic and environmental dimensions. Nevertheless, few of them are related to social dimension. Therefore, to cover the main aspects of each dimension of sustainability, a combination of single and integrated indicators should be included in this assessment.

Finally, four recommendations are made to select proper indicators during the sustainability assessment of an EIP: start with a large set of possible indicators, as those presented herein, preselect those indicators linked to the objectives of the assessment, apply the four criteria for indicators choice, and prefer comparative indicators.

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1. Introduction

Industrial Ecology (IE) is a field of study focused on the stages of the production processes of goods and services from a point of view of nature, trying to mimic a natural system by conserving and reusing resources (Chertow, 2008). It studies the interaction of industrial development with environmental, social, and industrial system of different scales and aims at increasing business success, preserving environment and taking into account the life of local community (Chertow, 2007; Frosch and Gallopoulos, 1989). A specific area of this field is the Industrial Symbiosis (IS), which “engages traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water, and by-products. The keys to industrial symbiosis are collaboration and the synergistic possibilities offered by geographic proximity” (Chertow, 2000). The main conception of the IS is to transform the wastes or by-products from the activity of a firm, into inputs of another by means of connections between them.

An industrial park can be classified as an Eco-Industrial Park (EIP) if the community of businesses cooperate with each other, sharing resources (PCSD, 1997). This type of industrial parks can receive their denomination of EIP because of different reasons, related with sharing materials, energy, or infrastructure. It's also possible to develop green infrastructure or foster scavenger companies in the park, so Industrial Symbiosis is one possible aspect of EIPs. The most accepted definition of an EIP (Lowe, 2001) proposes a community of businesses located together on a common property. These businesses seek enhanced environmental, economic, and social performance through collaboration in managing environmental and resource issues.

A precursor to EIPs is the regional industrial symbiosis at Kalundborg, Denmark, uncovered in 1990 and then described in the international press (Knight, 1990). The participants share water, wastewater facilities, steam, fuel, by-products and waste products, that become feedstock in other processes (Chertow, 2008). The benefits of the symbiosis for this industrial park and the surrounding community are (National Research Council, 1997):

- The significant reduction in energy consumption and coal, oil, and water use.
- The reduction in sulfur dioxide (SO_2) and carbon dioxide (CO_2) emissions and improved quality of effluent water.
- The transformation of traditional waste products such as fly ash, sulfur, and biological sludge, into raw materials for production.

On the other hand, many authors have measured the benefits of applying IS to different sustainability projects about enterprise management and city design, in order to reduce the carbon emissions. For example, in the work of Yu et al. (2015), the authors make a quantitative evaluation of the effects of IS performance on carbon emission reduction in Xinfa Group, a comprehensive large enterprise group in China. They compare a scenario with IS and other without IS, and obtain that the first one exhibits a decrease of the carbon emission by 11% compared with the second one. Other example is the application of IS to cities presented in Dong et al. (2014b). In this work, the authors study the CO_2 emissions reduction potential in IS projects in two cities of China, Jinan and Liuzhau. They design new scenarios to apply in the both real project, including energy network, waste plastics recycling, and others. They obtain that the total reduction potential amounts to 4000 thousands tCO_2/year and 2300 thousands tCO_2/year in Jinan and Liuzhau respectively. Based on the results, the authors propose several policies to promote IS model in China. Both examples mentioned above show that IS is an important tool to reduce the environmental impact and to achieve the sustainability. This behavior may be extended to other aspects (as social), to promote the sustainability further than environmental or economic dimension.

Benefits of applying IS to an industrial park are related to economic, environmental and social aspects (Azapagic and Perdan, 2000; Harlem, 1987), and they are focused on (i) to improve the profits and resilience of the companies, (ii) to reduce environmental impact, and (iii) to care about the life of people in local communities. Some of them are mentioned in the works of Dunn and Steinemann (1998) and Gibbs (2008). Economic benefits are reducing of waste disposal costs and decreasing of purchase of raw materials. The environmental achievements are a reduction of waste production and of exploitation rate of new resource inputs (Dunn and Steinemann, 1998). The social consequences of IS are not obvious, since increased company profitability will produce a trickle-down effect on local spending and on jobs to the benefit of the wider local population (Gibbs, 2008). Other social effects are related to life style and health in the surroundings of the EIP. While the effects of economic and environmental benefits are easy to measure because they are often assessed in an industrial context, the social effects require a suitably evaluation because they are difficult to quantify and are not usually assessed. Therefore, all the sustainability dimensions must be properly assessed in order to quantify the total effect of applying IS to an industrial park.

To choose the best EIP configuration, a measurement of sustainability is required to facilitate the comparison of different alternatives. An optimal EIP minimizes the negative impacts and maximizes the positives ones as a result of the activity of the park. However, how the social, environmental, and economic aspects of sustainability in an industrial park could be measured?

The answer comes from the quantitative sustainability indicators. Using this indicators it is possible to assess the effectiveness of an industrial park in terms of dimensions of sustainability development. This quantitative sustainability assessment of an EIP is necessary to ease the comparison between different configurations and to support decisions on its design. Some examples of these indicators are *Value Added* (economic), *Ozone Depletion* (environmental), and *Income Distribution* (social) (Azapagic and Perdan, 2000). There are also integrated indicators grouping two or more of these single indicators. For instance, Eco-efficiency includes one economic indicator and three environmental indicators (raw material consumption, energy consumption, and CO_2 emissions) (Park and Behera, 2014).

Other tools used to analyze and to assess the sustainability level of industry are Life Cycle Analysis (LCA) and Material Flow Analysis (MFA). LCA is an analytical tool for a systematic evaluation of the environmental impact of a product (or services) on its completely life cycle (Chertow, 2008; Curran, 1996). It offers a quantitative comparison between different alternatives of product design in order to analyze each of them and to select the best one. MFA is similar tool to LCA, and is based on methodically organized accounts in physical units and the principle of mass balancing (OECD, 2008; Sendra et al., 2007). The use of this tool can provide an integrated view of the economy and the environment; capture flows that are not used and produce a relevant impact; and reveal how flows of material shift among countries and within countries. It can analyze various scales of the industry (as shown in Fig. 1) with different instruments depending on the issue of concern and the goal of the assessment. Both tools are widely used in the assessment of industrial parks and EIPs (Chen et al., 2013; Dong et al., 2013; Sendra et al., 2007; Wen and Meng, 2015; Yang et al., 2012; Zhang et al., 2016) and use indicators to measure the activity of the actors.

On the other hand, there are many articles about IS and the dynamic organization of an EIP (Boons et al., 2011; Chertow, 2000, 2007, 2008, 2012) where the authors explain the bases and propose models of IS. There are also many examples about EIP projects, which mimic the development of the regional industrial symbiosis in Kalundborg (Baas, 2011; Behera et al., 2012; Côté and Cohen-Rosenthal, 1998; Geng et al., 2010a; Sokka et al., 2011; van Beers et al., 2007; Zhang et al., 2010). There are works related to the

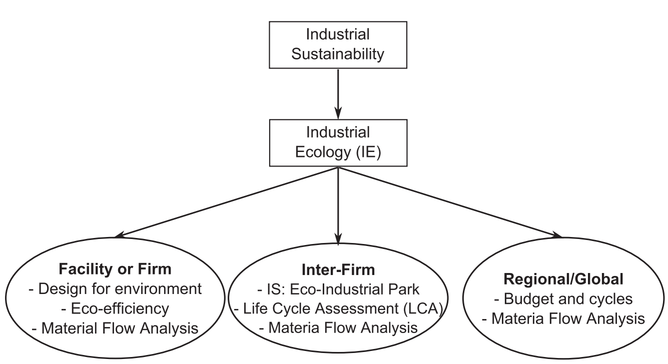

Fig. 1. Conceptual model of the Industrial Ecology level. IS transforms the wastes or by-products from a firm into inputs of another by means of connections between them. Information taken and modified from Chertow (2000).

design of EIPs where the authors optimize economic, environmental, and social aspects of each park (recently Boix et al. (2015) wrote a complete review on this topic). However, to our knowledge there is no article focused on a wide repository of EIP indicators and their applicability to a quantitative assessment on the EIP sustainability. Besides other non-quantitative indicators could be useful to assess an EIP, this work covers quantitative indicators because of their wide application in sustainability assessment, and the suitability of this type of indicators to compare different EIP configurations or their progression in time (Azapagic and Perdan, 2000; Zhu et al., 2010).

An important difficulty to use indicators when assessing an EIP is to select a proper set among all possible indicators. To overcome this difficulty, the goals of this article are to develop criteria in order to construct suitable indicators, to build a database of single and integrated indicators, and to classify them focusing on the assessment of EIPs. An important challenge is to cover a wide set of indicators. Accordingly, the keywords for this search have to be wide. After finding these indicators, a set of filters are presented herein for their classification aiming at sustainability. Therefore, a broad search and the respective classification of sustainability indicators are presented as results to the readers.

First, we present the indicators that can be found in the literature and propose criteria to select or construct suitable indicators to assess an EIP. We also present two classifications of these indicators: the compliance with the criteria proposed herein and the covering of the three dimensions of sustainability. For studying the applicability of the four criteria to select suitable indicators, a hypothetical case is presented. After a critical analysis, the last section summarizes the desirable features for an indicator to assess an EIP.

Instead of using these four criteria, the managers could select the indicators for the assessment of an EIP based on their own experience. Nevertheless, the four criteria presented herein provide a formal way to filter a large set of possible indicators, improving the mechanism to select proper indicators.

Naturally, this is not the only strategy to filter variables. Is possible to perform a multiple criteria data envelopment analysis (MCDEA) (Zhao et al., 2006), addressing qualitative and quantitative criteria. MCDEA is used to rank the alternatives through the consideration of the relative membership degree of qualitative factors in quantitative data. However, this type of analysis requires data. The criteria developed in the present work assume a scenario where the data is not yet provided.

2. Methods for searching indicators

Sustainable indicators are essential to assess the effectiveness of an EIP regarding the axes of sustainable development (economic, environmental, and social dimensions) (Azapagic and Perdan, 2000; Harlem, 1987). These indicators have to capture the main characteristics of an EIP: to compare with other contexts and to support decisions concerning its configuration. The comparison of an EIP can be done with: (i) its historical performance, (ii) a new configuration of the same park, (iii) or other parks.

For a complete sustainability assessment, the indicators must quantify all impacts (internal, external, positives, and negatives) produced by the geographical location of firms and their connections through an industrial network.

This repository of indicators is based on publications registered in the ISI Web of Science (ISI-WoS). The keywords used in the search are subject to the following logic sentence: (indicator OR quantitative assessment) AND ("industrial park" OR "industrial symbiosis"). The search was performed over the abstract, title, and keywords of all publications in the database with the ISI-WoS searching engine. Through this search we found 51 articles published between 2000 and 2014.

The keywords used in the search are generic because we propose a wide search considering all the indicators used in assessments. The resulting indicators could include indicators with no relation to sustainability. However, the resulting indicators also include those sustainability indicators not presented as sustainability indicators in bibliography. Therefore, after processing the results, we classify the resulting indicators in the respective dimension of sustainability and the adjustment to the criteria for selection.

In order to achieve the goals of this article, these publications were filtered by document type, publication year, and topic. The works passing this filter are related to industrial assessment and provide a set of indicators. Thus, we exclude publications about dynamic organization of EIP, studies of diseases caused by proximity to an EIP, and other specific evaluations.

Finally, we consider 32 articles published between 2000 and 2014 in which industrial assessment is the main topic and which includes a set of indicators.

To propose criteria for indicators choice, is necessary to cover the context of the sustainability assessment. A review of criteria proposed in literature is performed in order to take into account previous efforts to guide the indicators selection. These criteria, proposed for a wide industrial context, will be adapted to the assessment of an EIP. This adaptation mainly considers the applicability of the criteria and their suitability to an industrial analysis of sustainability.

3. Results: indicators for eco-industrial parks: selecting criteria, sustainability dimension, and classification

3.1. Criteria for selecting indicators on EIPs

Sustainability indicators allow to assess economic, environmental and social aspects of a process, a company, the development of a product, a city, an industrial park, and others. When applied to an industrial park, those indicators must capture the main characteristics of a process from a specific angle of the sustainability assessment. They must reflect the negative and positive impacts resulting from the activity of an EIP, focusing on a specific dimension of evaluation.

To reflect those characteristics of an EIP, indicators must achieve minimum requirements because they are often oversimplified, they include only some important characteristics, or some of them are difficult to quantify or understand (Azapagic and Perdan, 2000). As a general framework, other authors (Azapagic and Perdan, 2000) have presented a standardization of industrial indicators for their application to companies and included the following characteristics for them:

- Simple and informative.
- Relevant to the three dimensions of sustainability.
- Generic for all industry and sector.
- Normalized by a certain value depending on the goal of the assessment.

To achieve the goal of the evaluation and to assess different scales of companies, the authors Azapagic and Perdan (2000) define three types of analysis: product-, process-, and company-oriented analyses. These analyses normalize indicators by a certain value or functional unit. The first one is related to products sharing the same function but made by different competitors. The second one refers to the operation and production of a plant. The last one is focused on the performance of a company or of its parts. Each analysis informs the levels of sustainability (Azapagic and Perdan, 2000).

Other alternatives are the risk analysis (Tixier et al., 2002) and exergy analysis (Dewulf and Van Langenhove, 2002) among other types of analysis. As the classification based on scale is related with the sustainability assessment of an EIP, this type of analysis will be adopted. Specifically, the process-oriented analysis allows to identify aspects to overcome within a set of connected processes.

Even though it's possible to avoid the scale classification, this logic allows to properly separate these analyses developed for different types of assessment, most of them oriented to single entities: single companies, single processes, or single products. An alternative analysis could have a systemic view based on the integration of processes or companies. However, this type of analysis could also be classified in the former scale-based categories because an integrated process is still a process, and the integration of companies can be considered a new entity with the characteristics of a larger company. In general, the scale-based classification of analyses is well adapted to the sustainability assessment in an industrial context.

Most of the articles referenced in this work can be classified as process-oriented analyses. The goal in this classification is to separate the attention points of the variety of feasible analyses, looking at the outputs, operations, or corporations. Regarding an EIP, the most important factors are the chemical/physical operations and the energy and mass input/output flows. Therefore, we considered a process-oriented analysis, since the performance of an EIP is mainly related with their operations and connections.

Ten years later, Zhu et al. (2010) reported four characteristics of EIP indicators to evaluate the incorporation of candidate companies to an EIP. They adopted the following criteria for selecting indicators (Zhu et al., 2010):

- Comprehensive: In choosing scale indicators, the indicators must consider various factors including capacity of an EIP to incorporate a new enterprise and the characteristics of an enterprise, e.g., resource use and pollutant production.
- Available: Indicators must be measurable and based on existing (easy to obtain) information.
- Relevant: Indicators must be relevant to the EIP development goal and to the long term strategy of participating companies.
- Practical: The measurement and monitoring of the indicators are practical and reliable given the available resources in the park and in companies. The value of the indicators must also be easy to obtain.

Taking the aforementioned criteria presented by Zhu et al. (2010), the *Availability* criterion can be discussed. Since the creation of an inventory is a complex and expensive work, the indicators with less complexity and less cost have an advantage. Nonetheless, is it important to have existing information? Existing information tend to be inaccurate and questionable, so industries measure their behavior with a specific scope. To our understanding, the key point in this criterion is the advantage of *easy-to-obtain* information, not the availability of existing information. Using the *Availability* criterion proposed by Zhu et al. (2010) with focus on existing information could impose a bias when selecting sustainability indicators, preferring those based on existing information instead of other *easy-to-obtain* options adjusted to the purpose of the study.

Most of the criteria proposed by Zhu et al. (2010) for selecting indicators for an EIP assessment are similar to the characteristics for industrial indicators presented by Azapagic and Perdan (2000). The main difference is the evaluation goal because the first one is based on product-, process-, and company-oriented analyses (generic case for industry), while the second one is only based on a process-oriented analysis (specific case for an EIP). Another difference is the selected criteria for defining proper indicators.

Since the criteria presented by Azapagic cover the generic case of an industrial analysis (product-, process- and company-oriented analyses) and the criteria reported by Zhu are process-oriented, we define new criteria more similar to the last ones. It is important to observe that the criteria by Zhu cannot be used directly in our scenario because they are only oriented towards the admissions of new members in an EIP.

The proposed new criteria are focused on selecting indicators to assess the EIP behavior. This new set is proposed combining the former criteria described by Azapagic and Zhu, and modifying some of them. This new reference to select indicators is constructed as follows.

We put forward three modifications on this base:

The first one (i) is to join *available* and *practical* features together, because both address calculation. This criterion will be called *pragmatism* and will comprise all the features of the aforementioned criteria.

Another modification (ii) concerns the feature *comprehensive*. We propose a modification to reflect the simplicity of the indicators as exposed by Azapagic and Perdan (2000). Accordingly, the meaning of the *understanding* criterion aims to simplicity instead of variety as the former *comprehensiveness* criterion by Zhu et al. (2010). The new criterion does not aim to wideness. It aims to previous formation of the personnel and the tuning of the indicator with this training. The original idea proposed by Zhu can now be represented in the combination of the concept *relevant*. Therefore, EIP indicators must present the following criteria: *understanding*, *pragmatism*, and *relevance*. An EIP indicator exhibits the criterion *understanding* if it is easy to understand (simple). It shows *pragmatism* if the characteristics are measurable by input–output flow data or surveys, and if its value is easy to obtain. The availability of information before the assessment is helpful but not critical, so its existence is not included in this criterion. An indicator shows *relevance* if it is engaged with the goals of both the EIP and firms.

The last modification to basic criteria (iii) is the addition of a new criterion, *partial representation of sustainability*, to state the proper representation of a dimension of sustainability by an indicator. All these definitions are shown in Table 1.

In Section 4 we focus the discussion on the performance of the indicators showed in Section 3.2 using the selected criteria as a filter.

3.2. Classification of EIP indicators

3.2.1. Classification by criteria for indicators choice

Several indicators have been used to evaluate the impact of an industrial park. For instance, in Lu et al. (2012), the authors assess the emissions of an EIP using a metabolic model and defining suitable indicators for this purpose. Other authors define considering energy performance (emergy and exergy) (Geng et al., 2010b; Jiang et al., 2010) or using Life Cycle Analysis (LCA) or hybrid-LCA strategies (Azapagic and Perdan, 2000; Chen et al., 2011).

At the beginning of a sustainability assessment, managers have to select indicators among all possible options. Different authors use a variety of indicators to evaluate the goals of EIPs or of companies. To ease the selection of indicators, a repository has been constructed through the search described in Section 2. Table 2 presents all the indicators used in these articles, including their definitions. Table 2 also presents an evaluation of the criteria defined in Section 3.1 for each indicator. Fig. 2 shows a histogram for each selection criterion, as a synthesis of the classification in Table 2. The green bars reflect the number of indicators meeting each criterion separately, and the red bars show the number of indicators classified according to each sustainability dimension. Additionally, single and integrated indicators are presented separately in order to analyze each category.

On the other hand, each indicator can also be classified according to its dimensions of sustainability (social, environmental or economic one). The following section is focused on this issue.

3.2.2. Classification by dimensions of sustainability

Sustainability dimensions are economic, environmental, and social. Indicators in Table 2 assess these dimensions and therefore they can be classified in these categories. Column *Dimen. of Sust.* in Table 2 shows this classification.

For assigning a category to an indicator we consider its main objective. Thus, if the main aspect assessed by the indicator is the use of resource, water, energy, by-product, and waste, it will be classified as environmental, even if this main aspect has also an economic or social impact. Recycling and reusing of material or energy will be also classified as environmental. An indicator will be considered as economic if it is related to the economic performance and capacities, or measures production efficiency. An indicator will be social if it is related to impacts on local community or workers of an EIP.

Some indicators, like ratios, assess more than one dimension. Examples of them are the *Chemical Oxygen Demand (COD) production per unit Industrial Value Added (IVA)* or the *ratio of industrial*

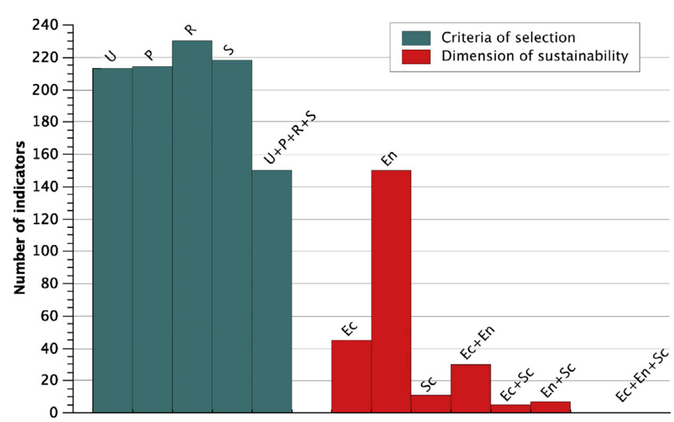

Fig. 2. Histogram of indicators by criteria of selection and sustainability dimension. U: Understanding; P: Pragmatism; R: Relevance; S: Partial Representation of Sustainability; Ec: Economic; En: Environmental; Sc: Social.

Table 1
Criteria for indicators choice and their description.

Criterion	Description
Understanding	An indicator must be easy to understand.
Pragmatism	An indicator must be measurable, its value has to be easy to obtain.
Relevance	An indicator must be relevant to the goal of EIP development and to enterprises' future.
Partial representation of sustainability	An indicator must properly represent one or more sustainability dimensions, allowing to compare configurations or historical progression of an EIP.

waste water utilization (Bai et al., 2014; Zhu et al., 2010). In these cases, we consider all the dimensions evaluated by the indicator.

Accordingly, an indicator can evaluate one or more dimensions of sustainability. The classification of an indicator as *single* or *integrated* refers to this issue. In both cases, the sustainability dimensions addressed in the assessment are informed in Table 2 including the number of dimensions in the corresponding column. In the case of integrated indicators, the dimensions included are separated by the character /. An indicator will be single if it evaluates only one dimension. Namely acidification potential (AP), which measures the contribution of SO_2, nitrogen oxides (NOx), hydrogen chloride (HCl), ammonia (NH_3), and hydrogen fluoride (HF) to potential acid deposition (Azapagic and Perdan, 2000), in essence it is an environmental indicator. On the other hand, if the indicator assesses two or more dimensions, it will be considered as an integrated indicator. An example is emergy-LCA index, which is a ratio of economic to environmental aspects (Brown and Ulgiati, 1997; Song et al., 2013; Yang et al., 2003). Fig. 2 shows a histogram for each sustainability dimension and their combination in integrated indicators. It is important to remark the counting in this histogram, because single and integrated indicators assessing environmental aspects have been counted separately in their respective bars: En, for single indicators; and Ec + En, En + Sc, for integrated indicators. The same separation is valid for the other sustainability dimensions.

4. Discussions

The total number of indicators studied on this article is 249. They have been classified using the four criteria selected in Section 3.1 and the dimensions of sustainability. The assessment managers should take into account the context of their application. This context could make a difference in the classification of indicators in our proposed categories. For instance, the availability of information or the formation of personnel could justify a change in *pragmatism* and *understanding* of an indicator, respectively.

As can be observed in Fig. 2, many indicators meet one of the four criteria, and only 150 meet all of them. Thus, some indicators are not suitable for assessing the activity of an EIP. Most of the rejected indicators need reserved information from companies, which is not easy to obtain. Other indicators were rejected because they were not directly understandable in an industrial context and demands a higher level of training for process managers than normal indicators.

Regarding the assessed dimension, the economic and environmental aspects have the largest number of single indicators (45 and 150 respectively), and only 11 are related to the social aspect. Integrated indicators have presented a similar distribution. There are many indicators evaluating the economic and environmental dimensions (30 indicators), and only a few of them are related to social aspects (5 economic-social and 7 environmental-social). On the other hand, there are no integrated economic-environmental-social indicators. The aforementioned distributions reflect the lack of indicators covering the social aspects and the need of constructing such indicators for the sustainability assessment of EIPs.

In the following sections the applicability of the four criteria over the indicators of Table 2 are analyzed in order to understand what indicators are included or excluded under each of them. A hypothetical case related to an EIP in Kalundborg is also presented for selecting sustainability indicators using these four criteria. After that, the classification using the sustainability dimensions over the set of indicators is studied and discussed. Finally, a general discussion related to the main characteristics of suitable indicators for the EIP sustainability assessment is presented.

4.1. Applying the criteria for indicators choice over 249 indicators

The proposed criteria for classifying the performance of EIP indicators are: *understanding*, *pragmatism*, *relevance*, and *partial representation of sustainability*. Indicators in Table 2 were filtered using these four criteria in order to simplify their further selection. The application of the four criteria is analyzed highlighting the attributes of the rejected indicators in each category. It is important to remark the flexibility of this filter. Each context of application could change the classification of indicators in three categories, because the *understanding*, *pragmatism*, and *relevance* depend on the context, because of the preparation of the personnel, availability of data, or measurement feasibility. These criteria also depend on the purpose, taking into account the goal of the assessment and the projected comparison after the analysis.

4.1.1. Understanding

In general terms, an indicator has been excluded from this category if its definition is hard to understand in an industrial context. Some indicators study the industrial interactions using a rationality based on metabolic pathways, as in biological networks. Thus, they were excluded according to the criterion of *understanding*. For instance, in Lu et al. (2012), the authors define a *mutualism index* to reflect the ratio of positive to negative mutualism relationships between entities. These type of indicators were excluded from this category, because it is necessary to manage the concept of mutualism in an industrial context for their application. Emergy is referred to the energy required to provide a given product or flow (Odum, 1996). All emergy-based indicators were excluded from this category because the use of emergy concept is not easy to understand in an industrial environment. An example is *Absolute emergy saving* (Geng et al., 2014) that uses the emergy concept to measure savings concerning, for instance, nonrenewable resources and purchased resources, resulting from sharing by-products between companies.

It is important to highlight the hypothesis sustaining this filter: It has been supposed the use of these indicators by process managers. Naturally, if the assessment is executed by professionals with environmental, economic, and social formation, the *understanding* criterion impose a less restrictive filter. The knowledge about indicators can be modified at any context with information available in measurement manuals (OECD, 2008).

4.1.2. Pragmatism

Some indicators are not easily measurable because they need a deep knowledge about the companies in the park. For instance *long term vision*, which needs information about projections and strategy of each company (Phillips et al., 2006). Since this information is not always available, all indicators exhibiting these characteristics were excluded under the criterion of *pragmatism*.

Among detailed analyses, LCA is probably the most important tool. It requires detailed data from companies participating in the production process, inside and outside the industrial park. The quality of information has to be guaranteed to support the analysis, so companies conduct audits. However, within a context, this information could be available or not. The necessary information to back up an LCA can already exist or its measurement can be possible. In both cases the related sustainability indicators are pragmatic. Nevertheless, the necessary information could be nonexistent or impossible to be measured because of technical or economic reasons, turning the involved indicators in non-pragmatic. Consequently, the availability of information or its feasibility of measurement justify the classification of an indicator as pragmatic or not.

We supposed no detailed information is available when performing the assessment, so footprint-like indicators have been filtered because of the *pragmatism*. Is important to remark this classification is flexible and the *pragmatism* filter can change with the availability of information.

For instance, there are indicators using the carbon footprint to quantify the emissions. Although there are methodologies for measuring the carbon footprint, there is no warranty about the behavior of the companies in this area. Applying a carbon footprint with an LCA approach requires detailed information about companies and their providers from outside the park. This is a highly valuable approach. Nonetheless, its application is hard within the boundaries of an EIP. Since these indicators were proposed in a complete LCA approach, this class of indicators was excluded under the criterion of *pragmatism*. However, indicators applied under a Hybrid-LCA approach (Azapagic and Perdan, 2000) were accepted and, in this case, such indicators are considered pragmatic.

Other indicators reflect the presence or absence of specific institutions in the park. Even though this information is easy to obtain, it is not measurable using a continuous variable (continuous numerical space). Therefore, they were excluded under the criterion of *pragmatism* because they are only measurable with a binary variable (1 = presence; 0 = absence), and this class of variables were not fully integrable with other indicators during the sustainability assessment.

4.1.3. Relevance

The main units in the sustainability assessment of an EIP are firms and the EIP itself. A firm is the basic unit of an EIP and its activity causes economic, environmental, and social impacts on the whole park. Some indicators for sustainability work as black boxes instead of gray boxes over the EIP. A black box work as a simple input/output model of the whole park, while a gray box model includes information about partial steps (processes or firms). The representation of the complete activity of firms is impossible, and disregarding their existence is an oversimplification. As an example, we can analyze the indicator *output rate of land*, which measures the value generated in the EIP per unit of used land (Su et al., 2013). This sustainability indicator only takes into account a sustainability assessment of the whole EIP without focus on each participating company.

Another group of indicators is focused on products, without paying attention to firms or EIP performance. As an example, the indicator *product durability* reflects the durability of a product and is oriented to consumers. All these indicators were excluded under the criterion of *relevance*, because they do not aim to assess an EIP as proposed in Section 1. Relevant indicators allow to give feedback to companies in the EIP.

4.1.4. Partial representation of sustainability

Some of the indicators can be used to make a comparison between enterprises or products. However, some of them do not afford a comparison between the EIP and its history, or between different configurations of the park. Even though they make a suitable assessment for any sustainability dimension, these indicators do not achieve the second objective of the *partial representation of sustainability* criterion. For instance, the indicator *percent-added of park energy productivity*, can only be used to compare different firms incorporated in a park (Zhu et al., 2010).

Another set of indicators use characteristics of an industrial plant, when placed on different location. Therefore, this set of indicators was excluded from the *partial representation of sustainability* category because the comparison between firms in a park is not supported.

On the other hand, it is noteworthy that all indicators in Table 2 assess some dimension of sustainability, and thus they meet the first part of the definition of *partial representation of sustainability*.

4.2. Applying the criteria for indicators choice to an EIP in Kalundborg: hypothetical case

The formation of the regional industrial symbiosis in Kalundborg, Denmark, is attributed to an evolutionary progress of exchanges between firms, into a complex network of symbiosis interactions (Jacobsen, 2006). The main facilities in this regional integration are an oil refinery, a power station, a gypsum board facility, and a pharmaceutical company. Other firms have been located around these companies. The goal is to share ground water, surface water and wastewater, steam, fuel, and others by-products used as feedstock in other process (Chertow, 2000, 2008).

In order to evaluate the effectiveness of the criteria presented herein to select suitable indicators for the sustainability assessment of EIPs, we propose a set of indicators from Table 2 to assess the example from a subset of companies in Kalundborg. A hypothetical example is constructed, assuming the availability of some data and the goal of the EIP composed by:

- Novo Nordisk.
- Novozymes.
- Novo Nordisk & Novozymes Land Owner's Association.
- Novozymes Wastewater & Biogas.

These entities share energy (steam, warm condensate, and district heating), water (surface water, cleaned surface water, and waste water), and materials (ethanol waste and biomass) (Kalundborg-Symbiosis, 2015).

We remark the demonstrative purpose of this example. While the real case from Kalundborg is far more complex, the instance will be simplified to illustrate the applicability of the criteria presented in this work.

4.2.1. Defining the hypothetical case

Kalundborg is a regional industrial symbiosis where many companies share water, steam, by-products, or other resource, in order to increase the level of sustainability. Let's assume the following ideas to illustrate the application of the criteria for indicators choice, in the context of the aforementioned EIP composed by four participants:

- The main goals of this park are to reduce the main gases emissions (CO_2, NOx, and SO_2) and to increase the economic returns for each firms in the EIP.
- In this context, the achievement of the goals will be measured by a technical assistant from a Government department.
- This assistant has a basic academic training on process and environmental subjects.
- The available information to assess this EIP is a list of input/output flows of each industrial plant in the park.
- The goal of the assessment is to measure the main economic and environmental aspects of the park.

Now, based on the information and the four criteria previously identified, we propose a set of indicators to be checked by the assistant.

4.2.2. Applying the criteria for indicators choice

- **Understanding**: This criterion depends on who is assessing the EIP. In the example, the applicant has a basic academic training on process and environmental subjects. As the supposed applicants in the definition of the *understanding* criterion are professionals with analogous formation as the hypothetical applicant in the example, all the indicators classified as *understanding* on Table 2 may be used to assess this EIP in Kalundborg. For example, *CO_2 emission indicator*, *COD generation intensity*, *SO_2 emissions per added industrial value*, and *Net economic benefit*. In this case, the set of indicators has been reduced from 249 to 209.

- **Pragmatism**: This criterion depends on specific information, which reflects if the indicators are based on available or easy to obtain information. In the example, the available information is the input/output data of each firm in the park, therefore, only those indicators that measure characteristics using the input or output flow data are included. For instance, *Acidification*, *Air pollution*, *Direct Material Input*, and *Industrial value-added per capita*. The set of indicators has been reduced from 209 to 175.
- **Relevance**: This criterion considers the focus on the assessment and the goal of the evaluated park and firms. In the example, the goal of the EIP in Kalundborg considers the reduction of main emissions (CO_2, NOx, and SO_2) and the increase of economic return for all firms in the EIP. In this sense, the indicators as *Industrial value-added per capita*, *Increase company competitiveness*, *Park SO_2 emission change rate %*, *CO_2 emission indicator*, or *Eco-efficiency* may be used to assess these goals. The set of indicators has been reduced from 175 to 162.
- **Partial Representation of Sustainability**: This criterion considers the assessment of a sustainability dimension and the possibility of performing a comparison with the history of the EIP or with other feasible configurations. In the example, the indicators classified as environmental (En), economic (Ec), and those integrating both dimensions (En/Ec) are suitable for the assessment. The selected indicators have also allowed a comparison of the EIP performance with that of other feasible configurations or with its own performance in time. The set of indicators has been reduced from 162 to 131.

The application of the four criteria formalizes the indicators choice to assess the EIP. Despite the variety of economic and environmental indicators achieving the four criteria, they could be redundant. Thus, we selected the most representatives of each class to use them in the evaluation of the illustrative EIP in Kalundborg (see Fig. 3).

In Jacobsen (2006), the author uses a similar set of indicators to study the progress of the IS in the regional integration in Kalundborg: saving cost by substitutions; reduction of carbon dioxide, sulfur dioxide, and nitrogen dioxide emissions; and, heat saving and water consumption. In this work, Jacobsen also selects heat saving and water consumption as indicator, because he has specific information about the power plant in Kalundborg, and the goal of the assessment is to evaluate the symbiotic exchange between companies. In our case, we have only input/output flow data and the goals are to measure the main economic and environmental aspects of the park.

4.3. Sustainability dimensions

If the purpose is to optimize an EIP, then the problem grows rapidly in size with the number of indicators or objectives (Copado-Méndez et al., 2014; Díaz-Alvarado, 2015). In this context is preferable to have more dimensions of sustainability integrated in less indicators. This approach involves an oversimplification risk. Since this issue depends on the objective of the sustainability assessment, it was not considered in the criteria detailed in Section 3.1. The oversimplification risk has to be considered during the selection of indicators for the assessment.

The oversimplification risk comes from the selection of an integrated indicator instead of a set of single indicators. The integrated indicators could avoid details when compared with a set of single indicators. Other possible impact is the sensitivity difference between integrated or single indicators when describing real cases. For instance, assume we change the configuration of a park and a single indicator changes its value by 50%. Is this difference also represented by an integrated indicator? Is the reality well-captured by the single or the integrated indicator? Is important to remark the higher sensitivity of single indicators when compared to integrated indicators.

The desirable flexibility of single indicators to represent reality has a trade off with the increase of complexity. The level of detail is the cause of both. A proper set of indicators has to be pragmatic in

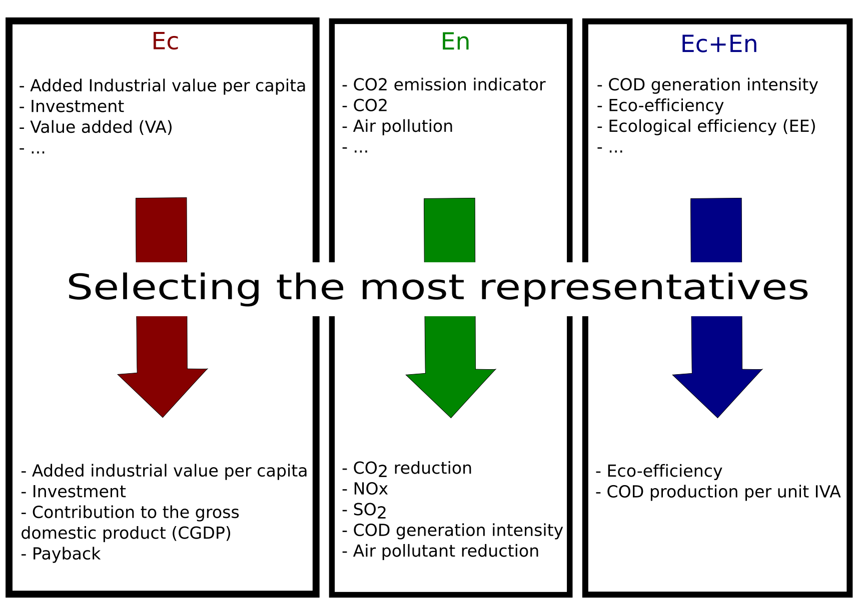

Fig. 3. Set of indicators proposed to assess the illustrative EIP in Kalundborg.

the sense of an approachable complexity, not sacrificing its relevance in terms of the flexibility to represent the reality.

Even though we found indicators meeting the four criteria, no indicator considers the three dimensions of sustainability. However, we found some indicators which covered two dimensions. For instance the ratio indicators measure the emission of certain pollutant divided by the added industrial value in products. In general, this type of integrated indicator takes into account an environmental characteristic of a system divided by an economic feature generated by the system. The most common environmental characteristics are resource consumption, generated emissions, reuse of by-product, water use or reuse, and amount of waste generated. The added industrial value is the most common economic characteristic. On the other hand, some indicators consider both economic and environmental characteristics as a measure of the energy required to provide a product or flow. An example is *emergy economic efficiency index*. It reflects the amount of local resource exploited compared to the amount of emergy investment (Brown and Ulgiati, 1997; Song et al., 2013; Yang et al., 2003). When used these indicators are not easy to classify into sustainability dimensions, because some of them commonly do not meet the criterion of *understanding*. The use of emergy concept is mainly associated with the energy. Then it should be considered as environmental, and its classification depends on the aim of the evaluation.

There are also integrated indicators known as Eco-efficiency indicators, which assess economic and environmental aspects as the ratio indicators. In general, they use the added industrial value divided by the sum of some characteristics measured by LCA.

The integrated indicators assess mainly economic and environmental aspects, and a few of them take into account the social dimension. There are two social integrated indicators applicable on EIPs: environmental-social and economic-social. The first one considers the specific emissions affecting the local community and the environment. For example, *health* indicator measures the air and water pollutant that could promote diseases as well as waste discharged by factories on the surrounding area (Chen et al., 2012a). The second one reflects an economic flow from companies to the local community or workers in the park. For instance, the indicator *expenditure on health and safety (EHS)* indicates the budget invested by an enterprise (an economic flow) in health and safety (social aspects) for its workers (Azapagic and Perdan, 2000).

Even though these integrated indicators meet the four criteria and assess two dimensions of sustainability, they do not cover all the factors related to a suitable social assessment. For instance, they do not evaluate the level of satisfaction of the surrounding population, the employment contribution of the enterprises, etc. In order to solve this lack of integrated indicators, single indicators may be considered. However, the use of these indicators must be aligned with the goal of the assessment and simplify the comparison between feasible configurations.

As integrated indicators do not cover the social dimension properly, single indicators included in Table 2 should be used in order to couple this topic in the analysis.

4.4. Final considerations

Many indicators classified in this article assess the sustainability dimensions and meet the four criteria. Even though there are plenty of them, the assessment coordinator must wonder if all these indicators are necessary to assess a park. The use of the indicators will depend on the park under evaluation. Not all of these indicators show a significant change when comparing different feasible configurations of a park. Another possibility for potential reduction is revealed if the Pareto dominance structure of different parks is preserved when certain indicator is absent (Brockhoff and Zitzler, 2006; Díaz-Alvarado, 2015). Thus, the selected indicators must be significant for the assessed parks to represent the change in their characteristics. The selection of significant indicators can be addressed with the Pareto dominance analysis (Brockhoff and Zitzler, 2006; Díaz-Alvarado, 2015), artificial neural networks (ANN) or genetic programming (GP) (Muttil and Chau, 2007).

On the other hand, the four criteria allow to select suitable indicators to evaluate EIPs but these indicators do not necessary assess the three sustainability dimensions (economic, environmental, and social). In Jacobsen (2006), the authors focused on a quantitative analysis of the economic and environmental performance of regional industrial symbiosis in Kalundborg. In order to measure these aspects, they used a set of economic and environmental indicators: saving cost by substitutions; reducing carbon dioxide, sulfur dioxide, and nitrogen dioxide emissions; and heat saving and water consumption. In this case, all these indicators pass the four criteria and therefore, they are suitable to evaluate the progress of the IS in the industrial park. Now, if we change the goal of the assessment and add a social analysis, the selected set of indicators would not be enough. In this case, this set will pass the four criteria. Nevertheless, they will not cover all the important aspects of social dimension, like investment of firms on near community and the job creations. Thus, to select a suitable set of indicators to assess EIPs, they should cover all the main aspects of the sustainability assessment and to achieve the four proposed criteria.

Finally, to select a suitable set of indicators during the sustainability assessment of an EIP, four recommendations are made: start with a large set of possible indicators, as those presented herein, preselect those indicators linked to the objectives of the assessment, apply the four criteria for indicators choice, and prefer comparative indicators.

5. Conclusions

In this work, we list a significant set of sustainability indicators in order to select a suitable subset to evaluate an EIP. Accordingly, four criteria were proposed to classify them all: *understanding*, *pragmatism*, *relevance*, and *partial representation of sustainability*. Under this classification, the excluded indicators use definitions difficult to understand in an industrial context, need a deep knowledge about companies in the park, only consider the EIP scale excluding the performance of the firms, or do not allow a comparison between feasible configurations of a park.

It is important to highlight the flexibility of the filter imposed by the criteria for indicators choice. Each context of application could change the classification of indicators in three of the four categories, because the *understanding*, *pragmatism*, and *relevance* depend on the context. From this point of view, the classification of indicators performed in this article can vary with the context. Future directions could report the most used indicators in the sustainability assessments of EIPs as an orientation to managers. This improvement should be translated to the *understanding* criterion, because the most applied indicators are also the most understood. We also suggest to develop a pathway of the historical progression of an EIP following the change in the value of some indicators. This pathway could be a reference to new successful cases of Eco-industrial parks.

Under a hypothetical case, a set of suitable indicators were selected to assess an illustrative EIP in Kalundborg. These indicators were: *added industrial value per capita*, *investment*, *contribution to the gross domestic product*, *payback*, *CO_2 reduction*, *NOx*, *SO_2*, *COD generation intensity*, *air pollutant reduction*, *Eco-efficiency*, and *COD production per unit of IVA*. They were selected by using the four criteria and choosing the most representative ones from this resulting set of indicators. All of them achieved the four criteria and met the goal of the evaluation.

On the other hand, indicators were also classified under the assessed dimension of sustainability: *single* for one dimension, and *integrated* for two or more dimensions. This classification showed an abundance of integrated indicators assessing economic and environmental dimensions, and a few of them are related to the social dimension. To solve this problem, single indicators may be considered.

In order to optimize an EIP, the integrated indicators are useful to reduce the number of indicators during the assessment. Classified indicators assess two dimensions of sustainability: economic-environmental, environmental-social, or economic-social. Single indicators should also been included because the integrated indicators related to the social dimension do not cover all the main aspects.

Finally, to construct or select suitable indicators for the sustainability assessment of EIPs, they have to meet the four criteria presented herein, cover the main goal of the assessment, be significant in comparing historical or feasible configurations, and take the complexity vs sensitivity trade-off into account.

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Appendix. Indicators

Table 2
Indicators obtained though the research, and their dimension and criteria classification. Ec: economic – En: environmental – Sc: social; U; understanding – P: pragmatism – R: relevance – S: partial representation of sustainability.

Indicator name	Definition	Dimen. of sust.	U	P	R	S	Ref.
Industrial chain extension	It measures the role of the candidate enterprise in improving existing EIP member businesses linkage through supplies or demands.	Ec	✓		✓		Zhu et al. (2010)
Industrial chain coupling	It measures the level of coupling difficulty of the exchange of product, by-product and waste, water and energy, of the candidate enterprise.	Ec	✓	✓	✓		Zhu et al. (2010)
Industrial chain adjustability	It measures by how much the candidate enterprise will improve the industrial chain adjustability.	Ec	✓	✓	✓		Zhu et al. (2010)
Land carrying capacity	It measures whether an EIP can accommodate the demand of the candidate enterprise.	Ec	✓	✓	✓	✓	Zhu et al. (2010)
Water carrying capacity	It measures the possibility of meeting the water demand of the candidate enterprise in an EIP.	En	✓	✓	✓	✓	Zhu et al. (2010)
Energy carrying capacity	It measures the possibility of meeting the energy demand of the candidate enterprise in an EIP.	En	✓	✓	✓	✓	Zhu et al. (2010)
Wastewater collection and treatment capacity	It measures whether the wastewater volume from the candidate firm exceeds the maximal treatment load of the existing plant.	En	✓	✓	✓	✓	Zhu et al. (2010)
Wastes collection and central treatment capacity permit	It evaluates whether the park has enough capacity for wastes collection and central treatment to accept the wastes from the new member enterprise.	En	✓	✓	✓	✓	Zhu et al. (2010)
COD environmental capacity	It evaluates whether the *COD* capacity of the park is enough to accommodate a new member firm.	En	✓	✓	✓	✓	Zhu et al. (2010)
SO_2 environmental capacity	It measures the amount of SO_2 added to the park by a new firm and evaluates if the park SO_2 environmental capacity is enough.	En	✓	✓	✓	✓	Zhu et al. (2010)
Park *COD* emission change rate %	It measures the contribution of new business to the total emission of *COD* in the park after the introduction of this.	En	✓	✓	✓		Zhu et al. (2010)
Park SO_2 emission change rate %	It measures the contribution of new business to the total emission of SO_2 after the introduction of the new business.	En	✓	✓	✓		Zhu et al. (2010)
Percent-added of park water productivity	It measures the growth rate of water production in the park after the introduction of the new business.	En	✓	✓	✓		Zhu et al. (2010)
Percent-added of park energy productivity	It measures the growth rate of energy production in the park after the introduction of the new business.	En	✓	✓	✓		Zhu et al. (2010)
Sustainable architecture design	It evaluates the sustainable construction design of the candidate enterprise through three aspect including sustainable energy, sustainable building materials and building placement.	En	✓	✓	✓		Zhu et al. (2010)
Product eco-design	It evaluates the design for disassembly and recovery, and product data management, of the candidate enterprise.	En	✓		✓		Zhu et al. (2010)
Green packing	It measures the level of green packaging of the candidate enterprise in both environmentally friendly packaging materials and green packaging design.	En	✓		✓		Zhu et al. (2010)
Green transportation design	It evaluates the environment-oriented transportation facilities, mode and scheme, of the new member firm.	En	✓		✓		Zhu et al. (2010)
Industrial value-added per unit area	It measures the economic value created by the candidate enterprise per unit of area.	Ec	✓	✓	✓		Zhu et al. (2010)
Industrial value-added *per capita*	It measures the annual industrial value-added of enterprises and employees in total.	Ec	✓	✓	✓	✓	Zhu et al. (2010)
Energy consumption per unit	It measures the energy efficiency of the candidate enterprise by calculating of all the energy and converting to the number of standard coal using means conversion coefficients.	En	✓	✓	✓		Zhu et al. (2010)
Fresh water consumption per unit	It measures the efficiency of water use in production as well as the level of technology and equipment of the new member firm.	En	✓	✓	✓		Zhu et al. (2010)
Recycling rate of industrial water	It evaluates the proportion of water recycled in the new member enterprise.	En	✓	✓	✓		Zhu et al. (2010)
Recycling rate of industrial solid waste	It measures the level of material re-used and recycled in the new firm.	En	✓	✓	✓		Zhu et al. (2010)

Table 2 (*continued*)

Indicator name	Definition	Dimen. of sust.	U	P	R	S	Ref.
Wastewater production per unit IVA	It measures the efficiency of production management of the candidate enterprise. It also evaluates water utilization efficiency.	En/Ec	✓	✓	✓	✓	Zhu et al. (2010)
COD production per unit IVA	It measures the quality of wastewater and material utilization efficiency through the total annual production of *COD* per unit IVA.	En/Ec	✓	✓	✓	✓	Zhu et al. (2010)
Wastes production per unit IVA	It measures the solid waste production in the candidate enterprise.	En/Ec	✓	✓	✓	✓	Zhu et al. (2010)
Output rate of main material resources	It refers to the amount of production value in EIP generated from one unit of material.	Ec	✓	✓		✓	Su et al. (2013)
Output rate of land	It refers to the amount of production value in EIP generated from one unit of land.	Ec/En	✓	✓		✓	Su et al. (2013)
Output rate of energy	It refers to the amount of production value in EIP generated from one unit of energy.	Ec/En	✓	✓		✓	Su et al. (2013)
Output rate of water	It refers to the amount of production value in EIP generated from one unit of water.	Ec/En	✓	✓		✓	Su et al. (2013)
Energy consumption per unit of production value	It measures the efficient use of energy in a firm.	En	✓	✓	✓	✓	Su et al. (2013), Geng et al. (2012), Geng et al. (2009b)
Energy consumption per unit of production in the key industrial sector.	It measures the efficient use of energy in an the key industrial sector.	En	✓	✓		✓	Su et al. (2013)
Water consumption per unit of production value	It measures the efficient use of water in a firm.	En	✓	✓	✓	✓	Su et al. (2013)
Water consumption per unit of production in the key industrial sector	It measures the efficient use of water in an the key industrial sector.	En	✓	✓		✓	Su et al. (2013)
Utilization rate of industrial solid waste	It measures the ratio of amount of recycled industrial solid waste to total amount of industrial solid waste generated.	En	✓	✓	✓	✓	Su et al. (2013)
Reuse ratio of industrial water	It measures the amount of total reused wastewater for industrial purpose. It includes both recycled water reuse and cascaded water reuse	En	✓	✓	✓	✓	Su et al. (2013)
Recycling rate of industrial wastewater	It measures the amount of total recycled industrial wastewater for industrial propose. It includes both treated domestic wastewater and industrial wastewater.	En	✓	✓	✓	✓	Su et al. (2013)
Decreasing rate of industrial solid-waste generation	It measures the total amount of industrial solid waste for final disposal.	En	✓	✓	✓	✓	Su et al. (2013)
Decreasing rate of industrial wastewater generation	It measures the total amount of industrial wastewater for final disposal.	En	✓	✓	✓	✓	Su et al. (2013)
Education and training in waste minimization methodology	It measure the amount of employees trained per annum.	Sc	✓	✓	✓	✓	Phillips et al. (2006)
Resource acquisition	It measures obtaining external funds to from local clubs	Ec	✓	✓	✓	✓	Phillips et al. (2006)
Forming local and regional partnerships	It measures networking through clubs with all key local and regional organizations.	Ec	✓	✓	✓	✓	Phillips et al. (2006)
Geographical distribution of clubs	It measures clubs in each district and borough, especially those with high deprivation	Sc	✓	✓			Phillips et al. (2006)
Long term vision	It measures exit strategies from projects in place so as to continue with new club development	Ec	✓		✓		Phillips et al. (2006)
Environmental reporting	It measures success of club activities included in local and regional media as well as journals.	En	✓				Phillips et al. (2006)
Companies adopting waste minimization	It measures the increase in number of trained companies (in waste treatment) per annum.	En	✓	✓		✓	Phillips et al. (2006)
Resource efficiency	It measures reduction in resource use per unit of production, the increase in recycling, and re-use.	En	✓	✓	✓	✓	Phillips et al. (2006)
Reduction in effluent and special waste	It measures the reduction in effluent and special waste produced.	En	✓	✓	✓	✓	Phillips et al. (2006)
Increase company competitiveness	It measures the companies saving.	Ec	✓	✓	✓	✓	Phillips et al. (2006)
Cost effective waste minimization clubs	It measure the cost saving of waste ratio of clubs	Ec	✓	✓	✓	✓	Phillips et al. (2006)
Job creation	It measures new job created per annum by partnership.	Sc	✓	✓	✓	✓	Phillips et al. (2006)
Direct energy consumption carbon footprint	It refers to emission from direct combustion of fossil fuels within the administrative boundary.	En	✓		✓	✓	Dong et al. (2014a), Dong et al. (2013)
Industrial process carbon footprint	It refers to emissions from chemical and physical reactions in the production process.	En	✓		✓	✓	Dong et al. (2014a)
Material carbon footprint	It refers to the indirect carbon footprint embodied in the input materials.	En	✓		✓	✓	Dong et al. (2014a)
Depreciation carbon footprint	It refers to the indirect carbon footprint embodied in the annual depreciation of fixed assets that support the production in the industrial park.	En	✓		✓	✓	Dong et al. (2014a)
Electricity and heat carbon footprint	It refers to the indirect carbon footprint embodied in the purchased electricity and heat out of the park.	En	✓		✓	✓	Dong et al. (2014a)
waste treatment carbon footprint	It refers to emissions caused during the treatment process of the wastes generated within the park.	En	✓			✓	Dong et al. (2014a)
Added industrial value *per capita*	It measures the annual added industrial production value per total employees at the end of the year.	Ec	✓	✓	✓	✓	Geng et al. (2009a), Geng et al. (2008)
Growth rate of added industrial value	it measures the relative difference of added industrial value between two years.	Ec	✓	✓	✓	✓	Geng et al. (2009a)
Energy consumption per added industrial value	It measures the energy consumption including coal, electricity, oil, and energy consumption for both heating and cooling.	En/Ec	✓	✓	✓	✓	Geng et al. (2009a)
Fresh water consumption per added industrial value	It measures the industrial fresh water used for production and living within the enterprises, including the tap water and self-provided water (if the domestic	En/Sc	✓	✓	✓	✓	Geng et al. (2009a)

(*continued on next page*)

Table 2 (*continued*)

Indicator name	Definition	Dimen. of sust.	U	P	R	S	Ref.
	wastewater is not blended with the industrial wastewater, then water consumption for living should no be included).						
Industrial wastewater generation per added industrial value	It measures the industrial wastewater generation, not including water obtained from cascading and domestic wastewater from resident living in the park	En/Ec	✓	✓	✓	✓	Geng et al. (2009a)
Solid waste generation per added industrial value	It measures solid, semisolid, and high-density liquid waste, including smelt residues, fly ash, bottom ash, gangue, dangerous waste, gangue, and radioactive wastes.	En/Ec	✓	✓	✓	✓	Geng et al. (2009a)
Industrial water reuse ratio	It measures the industrial reuse water, including water that is recycled or cascaded.	En	✓	✓	✓	✓	Geng et al. (2009a)
Solid waste reuse ratio	It measures the industrial solid waste, including all kinds of non domestic, non dangerous solid wastes generated by industries.	En	✓	✓	✓	✓	Geng et al. (2009a)
Middle water reuse ratio	It measures the recycled treated wastewater from wastewater treatment plants.	En	✓	✓	✓	✓	Geng et al. (2009a)
COD loading per added industrial value	It measures the amount of *COD* loading, including *COD* loading both from companies and wastewater treatment plant.	En/Ec	✓	✓	✓	✓	Geng et al. (2009a)
SO_2 emission per added industrial value	It measures the amount of SO_2 emissions.	En/Ec	✓	✓	✓	✓	Geng et al. (2009a)
Disposal rate of dangerous solid waste	It measures the dangerous industrial wastes, including those toxic and hazardous wastes ad defined by the environmental standards.	En	✓	✓	✓	✓	Geng et al. (2009a)
Centrally provided treatment rate of domestic wastewater	It refers to the ratio of total amount of treated domestic wastewater to amount of domestic wastewater generation.	En	✓	✓	✓	✓	Geng et al. (2009a)
Safe treatment rate of domestic rubbish	It refers to the ratio of total amount of safely treated domestic rubbish to total amount of domestic rubbish.	En	✓	✓	✓	✓	Geng et al. (2009a)
Waste collection system	It refers to the existence of a waste collection system	En	✓		✓	✓	Geng et al. (2009a)
Centrally provided facilities for waste treatment and disposal	It refers to the existence of a environmental management system.	En	✓		✓	✓	Geng et al. (2009a)
Environmental management systems	It refers whether the park management should pass ISO 14001 certification and have an emergency response plan.	En	✓			✓	Geng et al. (2009a)
Extent of establishment of information platform	It indicates whether the park has established a comprehensive information platform.	En	✓			✓	Geng et al. (2009a)
Environmental report release	It refers to the existence of an environmental report release.	En	✓		✓	✓	Geng et al. (2009a)
Extent of public satisfaction with local environmental quality	It measures the degree satisfaction of the population of the whole park with local environmental quality.	Sc	✓	✓	✓	✓	Geng et al. (2009a)
Extent of public awareness degree with eco-industrial development	It measures the public awareness of the population park about eco-industrial development.	Sc	✓		✓	✓	Geng et al. (2009a)
Energy intensity	It measures the energy consumption efficiency. It relates the consumption to the output of the sector in monetary values	En	✓	✓	✓	✓	Tolmasquim et al. (2001)
Emission intensity	It assess the ratio between CO_2 emissions of the industrial sector and its output value.	En	✓	✓	✓	✓	Tolmasquim et al. (2001)
The specific emission	It relates the total CO_2 emissions to the energy consumption	En	✓	✓	✓	✓	Tolmasquim et al. (2001)
Nodes	It measures the quantity of metabolic compartments, and also the size of network.	Ec		✓		✓	Lu et al. (2012)
Links	It measures the quantity of metabolic direct flows or arcs.	Ec		✓	✓	✓	Lu et al. (2012)
Link density	It measures the metabolic linking degree.	Ec		✓	✓	✓	Lu et al. (2012)
Connectance	It measures the metabolic connectivity, also the proportion or realized direct pathways	Ec		✓	✓	✓	Lu et al. (2012)
Mutualism index (MI_x)	It reflects the ratio of the number of positive and negative signs regard to mutualism relationships between components of a system.	Ec		✓	✓	✓	Lu et al. (2012)
Synergism index (SI_x)	It quantifies the total magnitude of the positive and negative utilities, which assess the mutualism condition of a system in slightly different angles.	Ec		✓	✓	✓	Lu et al. (2012)
Control index (CI)	It indicates the control utility and organization capability of the whole system. It can be employed to index the self-regulation of system metabolism.	Ec		✓	✓	✓	Lu et al. (2012)
R/U	It indicates the ratio of renewable inputs to total used emergy.	Ec/En		✓	✓	✓	Geng et al. (2014)
N/U	It indicates the ratio of nonrenewable inputs to total used emergy.	Ec/En		✓	✓	✓	Geng et al. (2014)
I/U	It indicates the ratio of imported resources to total used emergy.	Ec/En		✓	✓	✓	Geng et al. (2014)
Emergy yield ratio	It reflects the net economic benefit.	Ec		✓	✓	✓	Geng et al. (2014)
Environmental loading ratio	It reflects the pressure of industrial activities on the local ecosystem.	En		✓	✓	✓	Geng et al. (2014)
Emergy sustainability indicator	It reflects the sustainable level of on industrial park.	Ec/En		✓	✓	✓	Geng et al. (2014)
Absolute emergy savings	It is the absolute emergy savings of nonrenewable resource, purchased resources, services associated with imported resource, and emergy of the total energy used due to the use of by-products among different firms within the same park.	Ec/En		✓	✓	✓	Geng et al. (2014)
Relatives emergy savings	It is the ratio of avoided inputs through all the industrial symbiosis activities to total emergy inputs without related industrial symbiosis activities.	En		✓	✓	✓	Geng et al. (2014)
Emdollar values of total savings	It represents the economic benefits of industrial symbiosis.	Ec		✓	✓	✓	Geng et al. (2014)
Per capita industrial value added	It refers to industrial value added created by one employee of the industry park in one year.	Ec	✓	✓	✓	✓	Bai et al. (2014)
Per land use industrial value added	It refers to land use of production facilities, warehouse and affiliated facilities in enterprises such as railways, ports and land for roads, not including land for open pit mine.	En/Ec	✓	✓	✓	✓	Bai et al. (2014)
Total energy consumption intensity	It refers to energy such coal, electricity, oil and other energy consumption (including the production of heating and cooling energy) used for production and operations of the enterprise.	En	✓	✓	✓	✓	Bai et al. (2014)
Fresh water consumption intensity	It refers to tap water and selfprepared water used for production and operations of the enterprises.	En	✓	✓	✓	✓	Bai et al. (2014)

Table 2 (*continued*)

Indicator name	Definition	Dimen. of sust.	U	P	R	S	Ref.
Ratio of industrial waste water utilization	It refers to the ratio reuse of water including recycling, multiple use and cascade use of water (including the reuse of disposed waste water) in the production of enterprises and to water used for production and operation of the enterprises.	En	✓	✓	✓	✓	Bai et al. (2014)
Ratio of industrial solid waste utilization	It refers to the ratio of recycled, processed, circulated or exchanged solid waste from solid waste generated by industrial enterprises.	En	✓	✓	✓	✓	Bai et al. (2014)
Waste water generation intensity	It refers to industrial value added created by the total amount of waste water by industrial enterprises in a year.	Ec/En	✓	✓	✓	✓	Bai et al. (2014)
Solid waste generation intensity	It refers to industrial value added created by the total amount of solid waste generated by industrial enterprises in a year.	Ec/En	✓	✓	✓	✓	Bai et al. (2014)
COD generation intensity	It refers to industrial value added created by the total amount of solid *COD* by industrial enterprises in a year.	Ec/En	✓	✓	✓	✓	Bai et al. (2014)
SO_2 emission intensity	It refers to industrial value added created by the total amount of SO_2 by industrial enterprises in a year.	Ec/En	✓	✓	✓	✓	Bai et al. (2014)
Direct Material Input (DMI)	It measures the direct input of materials for use in the economy, i.e. All materials which are of economic value and are used in production and consumption activities.	En	✓	✓	✓	✓	Eurostat (2001)
Total Material Input (TMI)	It measures the materials that are moved by economic activities but that do not serve as input for production or consumption activities.	En	✓	✓	✓	✓	Eurostat (2001)
Total Material Requirement (TMR)	It measures the total “material base” of an economy. It includes, in addition to TMI, the material flows that are associated to imports but that take place in other countries.	En	✓	✓	✓		Eurostat (2001)
Domestic Total Material Requirement (domestic TMR)	It measures the total of material flows originating from the national territory.	En	✓	✓	✓		Eurostat (2001)
Domestic Material Consumption (DMC)	It measures the total amount of material directly used in an economy.	En	✓	✓	✓	✓	Eurostat (2001)
Total Material Consumption (TMC)	It measures the total material use associated with domestic production and consumption activities, including indirect flows imported but less exports and associated indirect flows of exports.	En	✓	✓	✓	✓	Eurostat (2001)
Net Additions to Stock (NAS)	It measures the quantity of new construction materials used in buildings and other Infrastructure, and materials incorporated into new durable goods such as cars, industrial machinery, and household appliances.	En	✓		✓	✓	Eurostat (2001)
Physical Trade Balance (PTB)	It measure the physical trade surplus or deficit of an economy.	Ec	✓	✓	✓	✓	Eurostat (2001)
Domestic Processed Output (DPO)	It refers to the total weight of materials, extracted from the domestic environment or imported, which have been used in the “domestic economy”, before flowing to the environment.	En		✓	✓	✓	Eurostat (2001)
Total Domestic Output (TDO)	It represents the total quantity of material output to the environment caused by economic activity.	En	✓	✓	✓	✓	Eurostat (2001)
Direct Material Output (DMO)	It represents the total quantity of material leaving the economy after use either towards the environment or towards the rest of the world.	En	✓	✓	✓	✓	Eurostat (2001)
Total Material Output (TMO)	It measures the total of material that leaves the economy.	En	✓	✓	✓	✓	Eurostat (2001)
DMI	It measures the amount of materials entering the system to be used and/or processed.	En	✓	✓	✓	✓	Sendra et al. (2007)
TMR	It measures the total material requirement.	En	✓	✓	✓	✓	Sendra et al. (2007)
DMIw	It measures the DMI per number of workers.	En	✓	✓	✓	✓	Sendra et al. (2007)
TMRw	It measures the TMR per number of workers	En	✓	✓	✓	✓	Sendra et al. (2007)
TWG	It measures the total waste generated by the system.	En	✓	✓	✓	✓	Sendra et al. (2007)
TWGw	It measures the TWG per number of workers.	En	✓	✓	✓	✓	Sendra et al. (2007)
Wp	It measure the production of the system per number of workers, i.e., the worker productivity.	Ec	✓	✓	✓	✓	Sendra et al. (2007)
Eco-Ef	It is the percentage of DMI converted into product.	En	✓	✓	✓	✓	Sendra et al. (2007)
Eco-In	It measures the tonnes of material input required to manufacture a tonne of product or the amount of raw material equivalent to a product.	En	✓	✓	✓	✓	Sendra et al. (2007)
M-Inef	It is the amount of output to nature per unit of material processed.	En	✓	✓	✓	✓	Sendra et al. (2007)
TWI	It measures the amount of water consumed by the system from own sources (domestic) and imported from supply system, shafts and rivers.	En	✓	✓	✓	✓	Sendra et al. (2007)
TWWG	It measures the amount of wastewater generated by the system.	En	✓	✓	✓	✓	Sendra et al. (2007)
TWIw	It is used to analyze the difference with the average of water consumption per inhabitant	En	✓	✓	✓	✓	Sendra et al. (2007)
TEI	It is the amount of energy consumed by the system and subsystem, distinguished between energy generated domestically and imported energy.	En	✓	✓	✓	✓	Sendra et al. (2007)
TEIw	It measures the TEI per number of workers.	En	✓	✓	✓	✓	Sendra et al. (2007)
E-In	It is used to make different-sized system comparable.	En	✓	✓	✓	✓	Sendra et al. (2007)
Net economic benefit (net value added)	It measures the annual added industrial production value.	Ec	✓	✓	✓	✓	Park and Behera (2014)
Raw material consumption indicator	It refers to the total weight of all materials that the company purchases or obtains from other sources including raw materials for conversion, other process materials, and pre-or semi-manufactures goods and parts.	Ec	✓	✓	✓	✓	Park and Behera (2014)
Energy consumption indicator	It measures the total energy consumption of a park.	En	✓	✓	✓	✓	Park and Behera (2014)
CO_2 emission indicator	It measure the GHG emissions resulting from fuel combustion, process reactions, and treatment processes.	En	✓	✓	✓	✓	Park and Behera (2014)
Eco-efficiency	It is a combination of economic and ecological performance, where it indicates the ratio of the net economic benefit to three environmental indicators.	Ec/En	✓	✓	✓	✓	Park and Behera (2014)
Air pollution		En	✓	✓	✓	✓	Chen et al. (2012a)

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Table 2 (*continued*)

Indicator name	Definition	Dimen. of sust.	U	P	R	S	Ref.
	It includes particulate matter, volatile organic compounds, sulfur oxides, and nitrogen oxides.						
Water and solid waste pollution	In considers biochemical oxygen demand, chemical oxygen demand, and suspended solids,	En	✓	✓	✓	✓	Chen et al. (2012a)
Resource use	It considers the tree major resources, water, land, and energy	En	✓	✓	✓	✓	Chen et al. (2012a)
Health	It measures the quantities of air pollutants, water pollutants, and waste discharged by manufactories into the surrounding area.	En/Sc	✓	✓	✓	✓	Chen et al. (2012a)
Quality of life	It measures the number of manufactories and traffic generated by them.	Ec/Sc	✓	✓	✓	✓	Chen et al. (2012a)
Recycling of metals	It reflects reduced input of scarce materials from nature	En	✓	✓	✓	✓	Pakarinen et al. (2010)
Waste and by-product utilization	It measures waste and by-product utilization as raw material in paper production.	En	✓	✓	✓	✓	Pakarinen et al. (2010)
Fuel use	It measures the amount of total fuel used in the park.	En	✓	✓	✓	✓	Pakarinen et al. (2010)
Restricting emissions of chemicals to nature by the recovery of process chemicals	It measures the amount of by-products reused to avoid emissions of certain substances.	En	✓	✓	✓	✓	Pakarinen et al. (2010)
Decrease in hazardous substance emissions to the water	It measures the amount of chlorine, mercury, and others hazardous compounds emissions released to the water.	En	✓	✓	✓	✓	Pakarinen et al. (2010)
Other emissions to the water	It measures the amount of suspended solids in the water, biological oxygen demand, and phosphorus and nitrogen load.	En	✓	✓	✓	✓	Pakarinen et al. (2010)
Emissions to the air	It measures the amount of atmospheric emissions (CO_2, mercury, etc.).	En	✓	✓	✓	✓	Pakarinen et al. (2010)
Recycling and waste treatment	It indicates whether exists a property waste management.	En	✓		✓	✓	Pakarinen et al. (2010)
Extraction of wood and other resources	It measures the consumption of natural resources.	En	✓	✓	✓	✓	Pakarinen et al. (2010)
Other area-consuming activities	It measures the amount of resources imported to industrial area.	En	✓	✓	✓	✓	Pakarinen et al. (2010)
Health risks of the pollution	It describes the pollution level of the resources used by the humans like water.	En/Sc	✓	✓	✓	✓	Pakarinen et al. (2010)
Renewable resources input (R)	It is the total energy and material driving a process that is derived from renewable sources.	En		✓	✓	✓	Song et al. (2013)
Non-renewable inputs (N)	It is a resource that their use rate exceeds replacement rate.	En		✓	✓	✓	Song et al. (2013)
Input from the economy (F)	It considers mainly energy resources, raw material, transportation costs, labor costs, management costs, maintenance costs, and depreciation.	Ec/En		✓	✓	✓	Song et al. (2013)
Waste emergy (E_w)	It reflects the emergy of the service of disposing waste.	En		✓	✓	✓	Song et al. (2013)
Recycled resource emergy (E_r)	It reflects the recovery emergy from waste.	En		✓	✓	✓	Song et al. (2013)
E-waste emergy (E_e)	It reflects the emergy of the service of disposing waste.	En		✓	✓	✓	Song et al. (2013)
Output emergy (E_0)	It reflects the emergy of all the products.	Ec/En		✓	✓	✓	Song et al. (2013)
Yield of industrial process (Y)	It measures the amount of local resources exploited.	En		✓	✓	✓	Song et al. (2013)
Emergy economic efficiency index (EYR)	It measures the net benefit to the economy from an waste processing activity-that is, the amount of local resources exploited compared to the amount of emergy investment. It measures the capability of industrial processes to exploit local resources.	Ec/En		✓	✓	✓	Song et al. (2013)
Emergy environmental efficiency index (ELR)	It is an indicator of the pressure of the process on the local ecosystem and can be considered a measure of the ecosystem stress due to production activity.	En		✓	✓	✓	Song et al. (2013)
Emergy sustainability index (ESI)	It reflects the ability of a system to provide desired products or services with a minimum of environmental stress and a maximum profit.	En			✓	✓	Song et al. (2013)
Emergy recovery ratio (ERR)	It measures the ability of a system to recover energy and materials from waste.	En		✓	✓	✓	Song et al. (2013)
Quotes for emergy recyclability (QER)	It measures the quotes for emergy recyclability, i.e., the total emergy recyclability available from waste.	En		✓	✓	✓	Song et al. (2013)
Emergy-LCA index	It assesses the ratio of the economic emergy (emergy used to evaluate the economic situation) and the total environmental performance expressed in LCA results (the unit environmental impacts multiplied by the total quantity of e-waste).	Ec/En		✓	✓	✓	Song et al. (2013), Brown and Ulgiati (1997), Yang et al. (2003)
Virgin Material Savings (VMS)	It assess the environmental benefits, measuring the amount of reuse or recycle wastes in place of virgin material use.	En	✓	✓	✓	✓	Chen et al. (2012b)
Operation Rate (OR)	It is the ratio of the amount of wastes treated in practice to the planned amount of treatment. It assess the operational performance of an eco-town.	En	✓	✓	✓	✓	Chen et al. (2012b)
Symbiosis degree ($gamma_{ij}$)	It expresses the change rate of the main essential parameter of a symbiosis unit corresponding to the change rate of the main essential parameter of other unit. It indicates which unit has more influence on the other.	En/Ec		✓	✓		Wang et al. (2014)
Symbiosis degree of individual element ($gamma_{si}$)	It expresses the change rate of the main essential parameter of a unit corresponding to the change rate of the main essential parameter of the symbiosis system. It provides a simple way to analyze the stability of a symbiosis system.	En/Ec		✓	✓	✓	Wang et al. (2014)
Symbiosis degree of total element ($gamma_s$)	It indicates the correlation degree of the symbiosis units and the system.	Ec		✓	✓	✓	Wang et al. (2014)
Symbiosis profit (E)	It measures the net profit from the symbiosis process of a system.	Ec		✓	✓	✓	Wang et al. (2014)
Symbiotic consumption	It is the cost of perform the symbiosis and gain symbiosis profit.	Ec		✓	✓	✓	Wang et al. (2014)
Ecological efficiency (EE)	It measures the overall efficacy of the production system regarding to environmental support and resources input.	Ec/En	✓	✓	✓	✓	Jiang et al. (2010)
Resource use efficiency (RUE)	It is based on the overall resources including energy sources.	En	✓	✓	✓	✓	Jiang et al. (2010)
Environmental emission intensity (EEI)	It indicates the waste emissions per unit of yield. This ratio is focused on the direct impacts from waste emissions.	En	✓	✓	✓	✓	Jiang et al. (2010)
Environmental loading ratio (ELR)	It represents the ratio of purchased and non-renewable emergy to locally free environmental emergy. It measures ecosystem stress due to excess exploitation of local non-renewable resources or investment from outside, compared with locally available renewable resources.	Ec/En		✓	✓	✓	Geng et al. (2010b)

Table 2 (*continued*)

Indicator name	Definition	Dimen. of sust.	U	P	R	S	Ref.
Emergy yield ratio (EYR)	It represents the ratio of total emergy used and exploited by the process to the emergy invested from outside the system. It measures the net benefit to the economy, namely the amount of local resources exploited derived from the investment amount. It measures the capability of industrial processes to exploit local resources.	Ec/En		✓	✓	✓	Geng et al. (2010b)
RWCP	It refers to the ratio of waste collection within the prefecture.	En	✓	✓	✓	✓	Ohnishi et al. (2012)
RPDP	It is the ratio of product delivery within the prefecture.	Ec	✓	✓	✓	✓	Ohnishi et al. (2012)
PCF	It is the processing capacity of the facility.	Ec	✓	✓	✓	✓	Ohnishi et al. (2012)
INWST	It measures the amount of industrial waste generated in the prefecture where the facility is located.	En/Sc	✓	✓			Ohnishi et al. (2012)
HHWST	It measures the amount of household waste generated in the city where the facility is located.	En/Sc	✓	✓			Ohnishi et al. (2012)
CPRI	It represents the capacity of steel, non-ferrous, and cement industries in the prefecture where the facility is located.	Ec	✓	✓			Ohnishi et al. (2012)
DMAG	It indicates whether exists an agglomeration type.	En	✓		✓	✓	Ohnishi et al. (2012)
DMCPL	It indicates whether exists a container/packaging recycling law.	En	✓		✓	✓	Ohnishi et al. (2012)
DMHAL	It indicates whether exists a home appliance recycling law.	En	✓		✓	✓	Ohnishi et al. (2012)
DMAML	It indicates whether exists a automobile recycling law.	En	✓		✓	✓	Ohnishi et al. (2012)
DMFDL	It indicates whether exists a food recycling law.	En	✓		✓	✓	Ohnishi et al. (2012)
RSET	It refers to the ratio of subsidies from the government.	Ec	✓	✓	✓	✓	Ohnishi et al. (2012)
DMPRS	It indicates whether exists a waste collection support.	En	✓		✓	✓	Ohnishi et al. (2012)
DMFS	It indicates whether exists a financial support from the municipality.	Ec	✓		✓	✓	Ohnishi et al. (2012)
DMGP	It indicates whether exists a green purchase from the municipality.	Ec	✓		✓	✓	Ohnishi et al. (2012)
DMWE	It indicates whether exists a waste exchange.	En	✓		✓	✓	Ohnishi et al. (2012)
DMCOS	It indicates whether exists a Eco-Town committee.	Sc/En	✓				Ohnishi et al. (2012)
RRCL	It measures the recycling rate in certain year in the city where the facility is located.	En/Sc	✓	✓	✓	✓	Ohnishi et al. (2012)
Investment	It measures the amount of millions USD invested in a project.	Ec	✓	✓	✓	✓	Behera et al. (2012)
Profit	It measures the amount of millions USD of benefit of both supplier and recipient.	Ec	✓	✓	✓	✓	Behera et al. (2012)
Payback	It indicates the period of time required for a project to recover the money invested.	Ec	✓	✓	✓	✓	Behera et al. (2012)
CO_2 reduction	It reflect the amount of CO_2 emissions that the project reduces.	En	✓	✓	✓	✓	Behera et al. (2012)
Air pollutant reduction	It reflect the amount of SOx, NO_x and CO emissions that the project reduces.	En	✓	✓	✓	✓	Behera et al. (2012)
Primary energy	It reflects the contribution of a material of a process to the primary energy.	En		✓	✓	✓	Eckelman and Chertow (2013)
Greenhouse gas	It reflects the contribution of a process to greenhouse gas emissions.	En	✓	✓	✓	✓	Eckelman and Chertow (2013)
Acidification	It reflects the contribution of a process to acidification of the environment.	En	✓	✓	✓	✓	Eckelman and Chertow (2013)
Eutrophication	It reflects the contribution of a process to eutrophication of the environment.	En	✓	✓	✓	✓	Eckelman and Chertow (2013)
Global warming potential (GWP)	It is the amount of greenhouse gas that a project produces.	En	✓	✓	✓	✓	Chen et al. (2011)
Fossil fuel savings	It is the amount of fossil fuel replaced by other obtained as a by-product in a process.	En	✓	✓	✓	✓	Chen et al. (2011)
Water consumption	It measures the amount of ground water, surface water, cooling/waste water of a process or an industrial park.	En	✓	✓	✓	✓	Jacobsen (2006)
CO_2	It measures the amount of CO_2 emissions saved by an industrial park.	En	✓	✓	✓	✓	Jacobsen (2006)
SO_2	It measures the amount of SO_2 emissions saved by an industrial park.	En	✓	✓	✓	✓	Jacobsen (2006)
NO_x	It measures the amount of NO_x emissions saved by an industrial park.	En	✓	✓	✓	✓	Jacobsen (2006)
Abiotic resource depletion (resource use)	it reflects the depletion of nonrenewable resource.	En	✓	✓	✓	✓	Azapagic and Perdan (2000)
Biotic resource depletion (resource use)	it is related to the use of species threatened with extinction.	En	✓	✓	✓	✓	Azapagic and Perdan (2000)
Land use (resource use)	It represents the total land area used in different stage of the life cycle.	En	✓	✓	✓	✓	Azapagic and Perdan (2000)
Global warming potential (GWP)	It represents total emissions of the greenhouse gases expressed relative to the global warming potential of CO_2.	En	✓	✓	✓	✓	Azapagic and Perdan (2000)
Ozone depletion potential (ODP)	It indicates the potential of emissions of chlorofluorohydrocarbons (CFCs) and chlorinated (HCs) for depleting the ozone layer.	En	✓	✓	✓	✓	Azapagic and Perdan (2000)
Acidification potential (AP)	It reflects the contributions of SO_2, NO_x, HCl, NH3, and HF to potential acid deposition.	En	✓	✓	✓	✓	Azapagic and Perdan (2000)
Eutrophication potential (EP)	It is defined as the potential to cause over-fertilization of water and soil, which can result in increased growth of biomass.	En	✓	✓	✓	✓	Azapagic and Perdan (2000)
Photochemical smog (PS)	It represents total emissions of different contributory species, primarily VOCs.	En	✓	✓	✓	✓	Azapagic and Perdan (2000)
Human toxicity potential (HTTP)	It measures the human toxic releases to the three different media, i.e., air, water, and soil.	En	✓	✓	✓	✓	Azapagic and Perdan (2000)
Ecotoxicity potential (ETP)	It measures toxic substances in water and soil.	En	✓	✓	✓	✓	Azapagic and Perdan (2000)
Solid waste (SW)	It measures the amount of solid waste generated in the life cycle of a system.	En	✓	✓	✓	✓	Azapagic and Perdan (2000)
Material intensity (MI)	It represents the sum of all materials used in the system.	En	✓	✓	✓	✓	Azapagic and Perdan (2000)
Energy intensity (EN)	It represents the sum of the total amount of energy.	En	✓	✓	✓	✓	Azapagic and Perdan (2000)
Material recyclability (MR)	It shows a potential for the product to be recycled, either in the same or a different life cycle. It can be expressed as a percentage of the material that can potentially be recycled relative to the total amount of the material.	En	✓	✓			Azapagic and Perdan (2000)
Product durability (PD)	It represent the durability (period of time) of a product in relation with life cycle.	Ec	✓	✓			Azapagic and Perdan (2000)

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Table 2 (*continued*)

Indicator name	Definition	Dimen. of sust.	U	P	R	S	Ref.
Service intensity (SI)	it measures the degree to which the company has closed the loop in providing the service as opposed to only selling the product.	En		✓	✓	✓	Azapagic and Perdan (2000)
Environmental Management Systems (EMS)	It is a qualitative indicator which indicates whether in the company exists an environmental management system.	En	✓		✓	✓	Azapagic and Perdan (2000)
Environmental improvements above the compliance levels (ICL)	it expresses an average percentage decrease in environmental burdens for either prescribed substances, or substances that are of general environmental concern but are not legislated.	En	✓		✓		Azapagic and Perdan (2000)
Assessment of suppliers (AS)	It is a qualitative indicator which indicates whether the suppliers to have certain environmental features.	En	✓		✓	✓	Azapagic and Perdan (2000)
Value added (VA)	It is expressed as net operating profit of the company.	Ec	✓	✓	✓	✓	Azapagic and Perdan (2000)
Contribution to the gross domestic product (CGDP)	GDP is an aggregate measure of production equal to the sum of the gross values added of all participant in the industry. CGDP is expressed in terms of value added per functional unit.	Ec	✓	✓	✓	✓	Azapagic and Perdan (2000)
Expenditure on environmental protection (EEP)	It represents an investment in the protection of the environment.	Ec	✓	✓	✓	✓	Azapagic and Perdan (2000)
Environmental liability (EL)	It expresses the costs that a company may have to pay if it is found liable for causing an environmental hazard.	Ec	✓	✓	✓	✓	Azapagic and Perdan (2000)
Ethical investments (ETI)	It represents assets invested in business activities that are considered to be ethical.	Ec/Sc	✓	✓	✓	✓	Azapagic and Perdan (2000)
Employment contribution (EM)	It represents the ratio of the number of employees per functional unit over an average number of people employed in the countries involved in the life cycle of an activity. Also it represents the number of employees per functional unit.	Sc	✓	✓	✓		Azapagic and Perdan (2000)
Staff turnover (ST)	It expresses the ratio of new employees to workforce made redundant by a company in a certain life cycle stage.	Sc	✓	✓	✓	✓	Azapagic and Perdan (2000)
Expenditure on health and safety (EHS)	It expresses the total expenditure on health and safety over the total number of employees, to give an investment in health and safety per employee.	Ec/Sc	✓	✓	✓	✓	Azapagic and Perdan (2000)
Investment in staff development (ISD)	It expresses the investment in training and continuing professional and personal development per employee.	Ec/Sc	✓	✓	✓	✓	Azapagic and Perdan (2000)
Stakeholder inclusion	It indicates whether the activities and performance of an organization have an impact in the local community, suppliers and business partners, civil society, natural environment, future generation and their defenders in to pressure groups.	Sc	✓		✓	✓	Azapagic and Perdan (2000)
Involvement in community projects	It is related to satisfaction of social needs. It shows the level of partnership that an organization develops with the community in which it operates.	Sc	✓	✓	✓	✓	Azapagic and Perdan (2000)
Income distribution (ID)	It shows an average distribution of wealth and could be expressed in term of income of the top 10% of employees per income of the bottom 10%.	Sc	✓	✓	✓	✓	Azapagic and Perdan (2000)
Work satisfaction (WS)	It represents the number of sick days or number of people "happy" with their job per employee.	Sc	✓	✓	✓	✓	Azapagic and Perdan (2000)
Satisfaction of social needs (SN)	It can be expressed as both quantitative and qualitative indicators. It is measured in terms of financial contributions of business to satisfying social needs. Contributions that cannot be measured in monetary terms can be included as a statement which describes the activity that contributed to satisfying a particular need and puts it in the context of the society to which the contribution has been made.	Ec/Sc	✓	✓	✓	✓	Azapagic and Perdan (2000)

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