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LITERATURE REVIEW ON ENVIRONMENTAL INDICATORS FOR SUPPLY CHAINS USING "SYSTEMATIC LITERATURE NETWORK ANALYSIS" *

F. Strozzi[**], *C. Colicchia*[***], *A. Sorrenti*[****]

1. Introduction

The need to include environmental criteria in the performance evaluation of supply chains is becoming an issue of great relevance. This is a result of the increasing pressures, both external (e.g. legislative requirements) and internal (e.g. need for a more efficient use of resources), oriented towards the implementation of "green" supply chains. Indeed, the definition of a structured set of environmental indicators can bring a variety of advantages for companies: they can detect potentials for improvement both in terms of sustainability of process and cost reduction; they can better coordinate the supply chain and fulfill the limitation posed by legislation having clear and transparent information about their environmental performances; furthermore, comparing environmental indicators for different companies allows for a benchmark that will guide the development of optimized and environmentally sound products and processes; finally companies can share both the costs and the benefits of environmental initiatives with customers encouraging them to move towards closer collaborations for a more sustainable supply chain (Tsoulfas and Pappis, 2008). In order to face these challenges it's important that companies can rely on well-defined and clear environmental indicators set.

Several approaches are developed for selecting key environmental performance indicators.

The Environmental Performance Evaluation (EPE) is the subject of the international standard ISO 14031. EPE indicates a process to facilitate management decision related to environmental performance helping in selecting indicators, collecting data, reporting and

[*] Keywords: Supply Chain; Environmental indicators; Systematic Literature Network Analysis; Citation Network; ISO 14000.
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communicating the improvement process (Commission Recommendation 2003/532/EC, http://ec.europa.eu/environment/emas/documents/legislative_en.htm). Other approaches are given by: GRI G3 guideline, 2006, (http://www.globalreporting.org/ReportingFramework/) and the UK Reporting Guidelines approach (2006),

http://www.defra.gov.uk/environment/business/envrp/guidelines.htm.

Despite all these approaches and the increase of methodologies, the "actual measurements of sustainability and sustainable development remain an open question" (Cucek *et al*., 2012).

Scientific contributions focusing on the development of new environmental indicators are progressively being submitted to the academic community consideration and several authors have presented overviews of indicators and approaches to measure sustainability (e.g. Michelsen *et al.*, 2006; Tsoulfas and Pappis, 2008). The scientific literature on environmental indicators becomes very rich and varied in the last years, hence the necessity to review it in a structured manner increases. Some authors already performed a systematic literature review. Stechemesser and Guenther (2012) used HistCite software to gather all the existing definitions of carbon accounting concluding that there are no fully shared definitions and many of them are only qualitative. In this paper we have reviewed the scientific literature on environmental sustainability indicators within the context of supply chain using a new methodology-- Systematic Literature Network Analysis (Colicchia and Strozzi, 2012)-- that offers a framework to develop and analyze a literature using its representation as a network. This representation helps to investigate the clusters of papers and to identify the process of knowledge creation, transfer and development. This paper is organized as follows: in Section 2 the SLNA is descripted, in Section 3 SLNA is applied to the context of the environmental indicators in the supply chain. In Section 4 there is a detailed analysis of the connected components of the citation networks and in particular of the MCC in which it is possible to individuate the MP and some clusters. In Section 5 it is shown how a classification of papers using the ISO 14000 emerges from the SLNA and in Section 6 the main conclusions are drawn. In the appendix the theoretical background of ISO 14031 and ISO 14044 is presented.

2. SLNA methodology

The literature analysis carried out in this study is based on the Systematic Literature Network Analysis (SLNA) methodology proposed by Colicchia and Strozzi, 2012 (Figure 1) that combines Systematic Literature Review (SLR) and Citation Network Analysis (CNA).

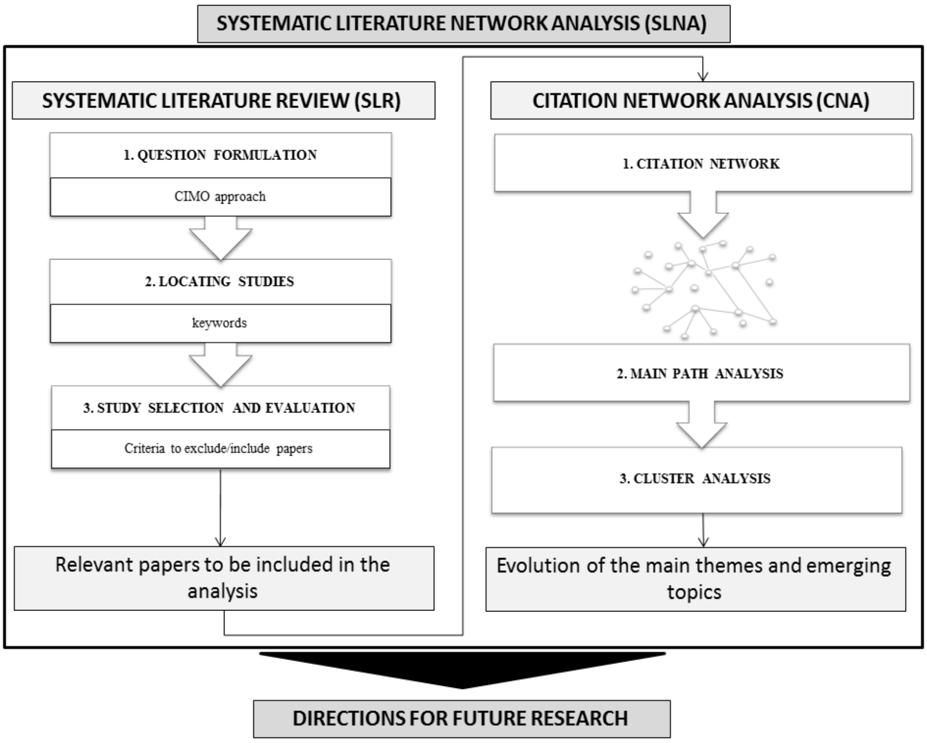

Figure 1. SLNA Research Methodology (adapted from Colicchia and Strozzi, 2012)

The definition of a structured framework is essential for the correct execution of a literature review. SLR satisfies this requirement, offering a tool that allows researchers to conduct a rigorous and systematic selection of the most relevant papers.

According to Colicchia and Strozzi (2012), SLR framework can be structured in three steps:

- Question formulation, which includes the definition of the objectives of the study.
- Locating studies, concerning the clarification of the keywords that will be used in the research.
- Study selection and evaluation that regards the identification of a reliable database for papers selection and the subsequent analysis of the retrieved papers.

CNA "recognizes a backbone in citation network that help us to understand how the body of knowledge has evolved over time" (Colicchia and Strozzi, 2012). This definition highlights the importance of CNA, since it enables a researcher to perform a dynamic interpretation of the "process of knowledge creation, transfer and development".

Authors of papers usually cite each other and researchers that have published works in the same field. From this perspective, citations are valuable source of data that reveal the impacts of articles and their authors on later scientific works.

After having collected the papers for the literature review, it’s conceivable that particular attention should be given to the more cited papers. Citations can hence be used to assess the scientific importance of the retrieved works. It is also likely that linked articles having many citations can be assumed as “milestones” in the analysis of the specific research tradition. Moreover the respective years of publication indicate the temporal evolution of the discipline. Considering these two elements, a researcher can undertake an analysis which should indicate the most important insights to be taken into account for determining how the scientific background has evolved over time.

CNA will be carried out by means of Pajek software. Pajek (http://vlado.fmf.uni-lj.si/pub/networks/pajek/) is one of the best-known and most frequently used packages developed to conduct comprehensive analysis on network data and their visualization (De Nooy et al., 2005).

The steps of CNA are the following:

- Citation Network Analysis, in terms of structure of the network and citation relationships among the retrieved papers.
- Main Path Analysis (MPA). Proposed by Hummon and Doreian (1989), explicitly focuses on the identification of specialties, the evolution of research traditions, and changing paradigms
- Cluster analysis, to detect specific area of research within the examined discipline.

SNLA is thus a well-structured system for conducting a literature review, since it combines the rigour and systematic nature of SLR for the finding of relevant contributions, and the dynamic perspective of CNA, that enables a researcher to keep in evidence the evolution of the theory background.

3. Applying the SLNA to the context of environmental indicators in supply chains

The first phase is represented by the definition of the scope of the study. In accordance with Colicchia and Strozzi, 2012 the CIMO (Context, Intervention, Mechanisms, Outcome) methodology was adopted. CIMO logic is a framework developed by Denyer and Tranfield, 2009 that can be summarized as following: “after having identified the Contexts of interest, it should be possible to define an Intervention type that will produce through determined Mechanisms specific Outcomes”. Hence CIMO is based on these four essential elements: Context, that concerns a clear definition of the field/system that is going to be studied, and whereby Interventions should be analyzed; Intervention, that regards the evaluation of the consequences deriving from specific operations and activities; Mechanisms, concerning the detection and explanation of the linkages between Intervention and Outcome, as well as the conditions that activate these mechanisms; Outcomes, in which the main conclusions about the effects of Interventions are drawn.

Adopting the CIMO logic to the present study requires to explicitly defining the four elements that will constitute the guidance for the present literature review:

Context: in this research the context concerns the evaluation of indicators for assessing the environmental sustainability of supply chains. This aspect is reflected by the increasing number of papers concerning this topic, anyway a clear framework about such measurements is still lacking.

Intervention: the interventions referred to the mentioned context are exposed in terms of indicators and measurement systems, defined for assessing sustainability at the supply chain level.

Mechanisms: the mechanisms to be analyzed concern organizational issues in implementing an effective sustainability measurement system within the supply chain. In particular this aspect is related with suppliers relationships management and, more generally, with all the interested parties.

Outcome: the outcome evaluation is focused on the linkages between sustainability indicators and sustainability performance.

The following phase, i.e. locating studies, is based on the selection of the keywords used to retrieve the papers of interest. Obviously a structured definition of the keywords is fundamental since a shallow execution of this phase can lead to invalid and/or insignificant results. The keywords were combined in order to constitute a series of strings, to be applied in the search on the databases. Considering the purpose of this study three strings of keywords were adopted:

- ((“environmental indicator*” OR “environmental performance indicator*”) AND “supply chain”)
- (“supply chain” AND environmental AND indicator* AND sustainab*)
- ((“supply chain” AND “environmental performance*”) AND indicator*)

Where the OR and AND correspond to the Boolean commands of union and intersection, and the symbols “ “” “and “* “implement the cutting off and exact research functions.

The present research was conducted in 2011 by means of the Web of Science database. Web of Science is a web-based database interfaced with the Institute for Scientific Information (ISI) databases. ISI developed a bibliographic database including various services. Among these services we will focus on the Science Citation Index (SCI), since it covers around 8000 notable and significant journals, across 150 disciplines, from 1900 to the present. As argued by other authors (Newbert, 2007), it was deemed that by limiting the search to peer-reviewed journals, the quality of results can be enhanced due to the process to which articles published in such journals are subject prior to publication. Furthermore, the results retrieved from the ISI Databases can be easily organized and analysed through specific software packages, such as HistCite.

The identified research strings were combined together with the OR command and 15 seed papers were retrieved. Documents on the Web of Science database that cite these seed papers were further included in the analysis.

In order to perform the third step i.e. study selection and evaluation, a series of inclusion and exclusion criteria should be defined. The following criteria, based on the ones proposed by Colicchia and Strozzi (2012) and Seuring (2008), have been considered to include/exclude papers: search for papers published in peer-reviewed scientific journals in English with a management focus; ensure relevance by requiring that selected papers contain at least one keyword in their title or abstract; eliminate irrelevant articles by excluding papers related to very narrow aspects or contexts; ensure relevance by reading all remaining abstracts; further ensure relevance by reading all remaining articles in their entirety.

The collected citation data were organized through the HistCite software package. The citation data were exported to Pajek software package in order to conduct the citation network analysis.

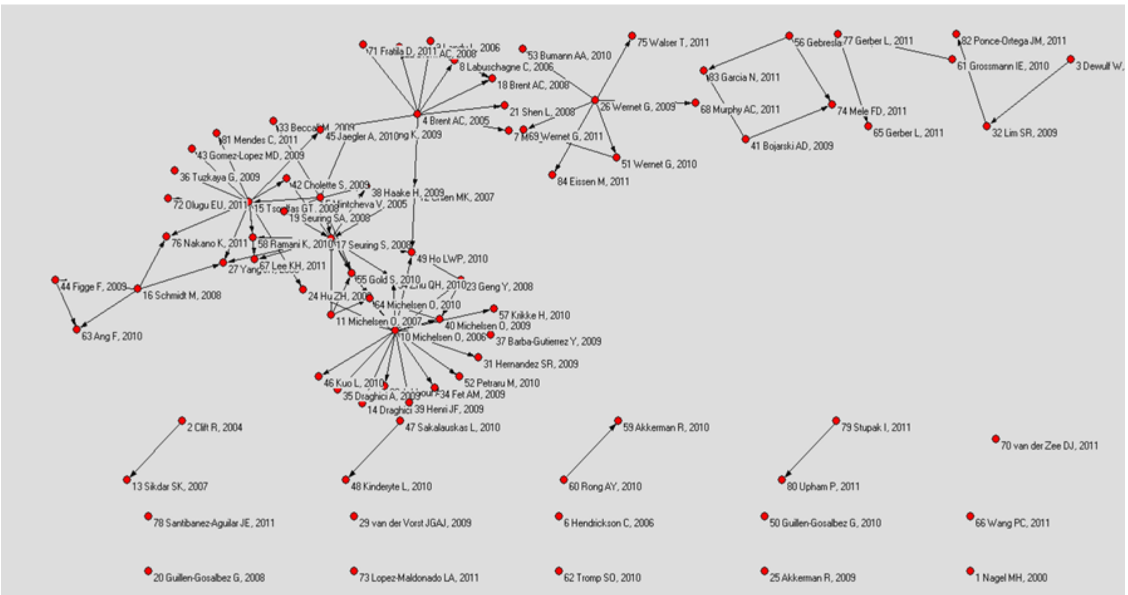

Figure 2. The citation network of 84 papers

The research conducted following the exposed methodology resulted in 84 papers published between 2000 and 2011, represented as a network in Figure 2. It comprises one large connected component and many smaller ones. The Main Connected Component (MCC) represents the largest connected part of the network. Specifically the MCC of the obtained citation network is constituted of 48 papers. The other components are: 11 isolated nodes, 4 components with 2 nodes, 2 with 3 nodes, one with 4 nodes and one with 7 nodes (Figure 3).

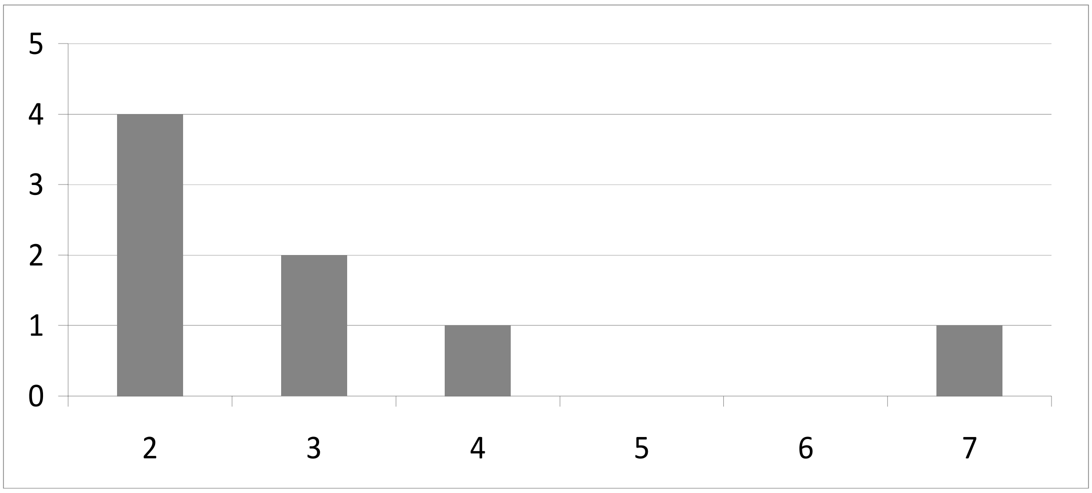

Figure 3. Distribution of connected components (different from MCC) within the network. The horizontal axis represents the number of articles in the connected components and the vertical axis the number of components with that number of nodes.

We started the CNA with a first investigation of the papers outside of the MCC then a deeper analysis was performed on MCC, which is the biggest connected subset were it makes sense to apply techniques such as MPA and Pons and Latapy (2005) clustering methodology.

The MPA is based on the assumption whereby knowledge circulates through citations, hence "the most important cited papers constitute one or more main paths, which are the backbones of a research tradition" (De Nooy *et al.*, 2005). According to this assumption Main Path Analysis tool implements an algorithm that calculates a ranking value for papers and arcs, called the traversal weight of citation, i.e. the extent to which a particular citation is necessary to link articles. The resulting backbone highlights important insights, indicating how the scientific background has evolved over time. Main Path Analysis applied to the obtained MCC produced a backbone composed of 21 papers, whose examination will be exposed in a following section.

Clusters Analysis on the MCC allows identifying clusters of papers, enabling a researcher to detect specific area of research within the examined discipline. This analysis was carried out by means of R software, implementing the Pons and Latapy algorithm (Pons and Latapy, 2005). According to this algorithm, "the approach is to perform random walks in the network and since a random walk on a graph tends to get "trapped" into densely connected parts, the distribution of these connected parts will provide the corresponding communities" (Pons and Latapy, 2005).

4. Analysis of the citation network

The citation network enabled us to study the data from two different perspectives: a static one through the analysis of the citation network topology and a dynamic one by means the Main Path Analysis. Furthermore Cluster Analysis was used in order to better analyse and classify the selected papers.

From a static perspective --considering the printing year-- it is interesting to note that the number of articles is clearly increasing during the period (2000-2011), so the area is under expansion (Figure 4).

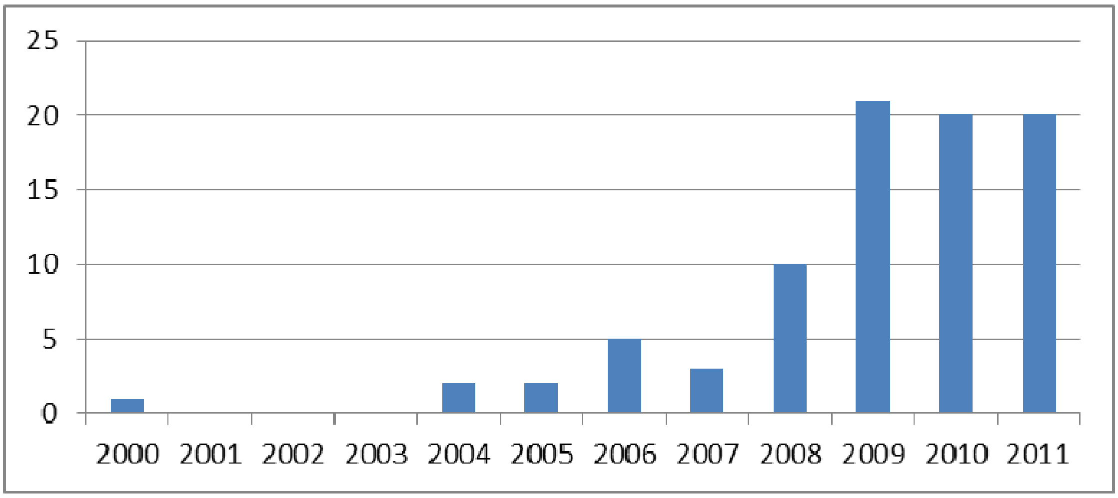

Figure 4. Distribution of scientific articles on supply chain environmental indicators published during the years 2000-2011

The CNA of the selected papers allows us to compute a ranking of articles in terms of number of received citations. The most frequently cited five articles are presented in Table 1.

Table 1 – Most Frequently Cited Five Articles

RANK	TITLE	AUTHORS	JOURNAL / YEAR	LCS	GCS
1	Eco-efficiency in extended supply chains: A case study of furniture production	Michelsen, O., Fet, A.M., Dahlsrud, A.	*Journal of Environmental Management (2006)*	18	19
2	A model for supply chains environmental performance analysis and decision making	Tsoulfas, G.T., Pappis, C.P.	*Journal of Cleaner Production (2008)*	11	11
3	An environmental performance resource impact indicator for life cycle management in the manufacturing industry	Brent, A.C., Visser, J.K.	*Journal of Cleaner Production (2005)*	9	9
4	From a literature review to a conceptual framework for sustainable supply chain management	Seuring, S., Muller, M.	*Journal of Cleaner Production (2008)*	9	62
5	Indicators for environmental policy integration in the food supply chain (the case of the tomato ketchup supply chain and the integrated product policy)	Mintcheva, V.	*Journal of Cleaner Production (2005)*	7	7

LCS = local citation score shows the count of citations to a paper within the collection; GCS= global citation score shows the total number of citations to a paper in the Web of Science

In Table 2 the journals with the most cited papers i.e. the most important nodes in the citation network from the point of view of the flow of knowledge are listed.

Table 2 – Journals with the highest number of citation network articles

JOURNAL	Number of articles
Journal of Cleaner Production	11
Industrial and Engineering Chemistry Research	5
Journal of Environmental Management	5
Clean Technologies and Environmental Policy	3
Computers and Chemical engineering	3

4.1. Connected Component analysis

The analysis conducted in this section follows these phases:

- Examination of isolated nodes.
- Analysis of connected components.
- Drawing of conclusions from the extracted information.

4.1.1 Isolated nodes

Figure 2 shows that the initial framework presents 11 isolated nodes. An investigation of these papers should be interesting for determining how the associated authors tend to explore sustainability indicators within the supply chain, and for drawing some hypothesis on the reasons why these nodes are isolated. Although the nodes haven't any linkages with other nodes, it's possible to find some common elements.

Wang et al., 2011 and Hendrickson et al., 2006 propose respectively a model for evaluating sustainability within detergent supply chain and an evaluation of the different supply chain impacts for six different transportation service sectors. In order to evaluate impacts Wang et al., 2011 undertakes an assessment based on LCA, whereas Hendrickson et al., 2006 focuses on energy, GHGs emissions and toxic emissions indicators, performing an evaluation based on input-output processes associable to OPIs (ISO 14031) framework. Five articles adopt a mathematical programming model for optimizing both the economic and environmental performance. These papers tend to focus on environmental issues rather than on social ones. This aspect is emphasized when dealing with indicators, since it's a hard task to effectively quantify the social dimension (Akkerman, et al., 2009).

For the purpose of this study, it's interesting to observe which framework authors adopted for assessing the environmental impacts and, thus, constructing indicators. Four papers (Santibanez-Aguilar et al., 2009, Guillen-Gosalbez et al. 2008, Lopez-Maldonado, 2011, and Guillen-Gosalbez et al., 2010) make use of Eco-indicator 99 for assessing environmental impacts. Nagel, 2000 adopts the previous version of Eco-indicator 99 that is Eco-indicator 95. This is due to the reason that Nagel published his paper in 2000, around 10 years before the three other articles. Indeed, considering that in 2000 Eco-indicator 99 could be considered a new tool, Nagel has probably decided to adopt the classical framework based on the '95 version. Leaving out considerations on Eco-indicator 99, it should be observed how the authors approach their studies. Nagel, 2000 introduces an original framework for evaluating suppliers. Supplier's relations are considered as a major trigger for achieving sustainability within the supply chain (Seuring et al., 2008). It proposes to evaluate suppliers from both a normalized (relative) and absolute perspective. According to Nagel, 2000 a normalized perspective is associated to a business perspective since "such a performance can be integrated into the supply chain strategy related to eco-supplier development and contracting". This is obtained by normalizing in a single index the environmental data calculated for some crucial aspects (i.e. energy, materials, waste, packaging, emissions). On the other hand the absolute perspective involves the evaluation of the absolute environmental loads associated to suppliers. This is carried out by mean of Eco-indicator 95.

The other four mentioned papers using Eco-indicator 99 (i.e. Santibanez-Aguilar et al., 2011, Guillen-Gosalbez et al. 2008, Lopez-Maldonado, 2011, and Guille-Gosalbez et al, 2010), although dealing with different contexts, undertake a similar approach. Santibanez-Aguilar et al., 2011 focuses on biorefinery (a plant producing energy from biomass) production processes, Guillen-Gosalbez et al. 2008 considers chemical processes, Lopez-Maldonado, 2011 analyzes heat exchanger networks, whereas Guillen-Gosalbez et al., 2010 examines hydrogen supply chain. This diversity in the treated arguments further demonstrates the general applicability feature of LCA. Moreover it's possible to observe that these topics don't concern the whole supply chain, but they can be associated to specific supply chain levels (i.e. manufacturing, warehouse and transportation). This consideration is not true for Guillen-Gosalbez, 2010, that explores hydrogen supply chain for vehicle use. However the provided results refer to a peculiar system that is still under development and, thus, can't be completely interpreted in the current supply chain context. Despite these considerations the papers are valuable for this study, since their purpose is the evaluation of environmental impacts of processes concerning the supply chain. As last observation it must be noted that the LCA performed in these studies is a partial LCA that considers the life of product till the production stage, excluding the usage and reverse logistics phases, i.e. a "cradle-to-gate" LCA.

It's interesting to note that three papers, i.e. (Akkerman et al., 2009, Van der Vorst et al., 2009, and Tromp et al., 2010), focus on food supply chain. This topic is considered even by other papers belonging to the MCC that will be analyzed later on (e.g. Mintcheva, 2005). Considering this, it can be argued that food supply chain is a relevant topic; anyway it's strange to observe that, in this case, papers dealing with a common topic (food supply chain) don't cite each others. This is partially explained by observing the perspective adopted in every study. Akkerman et al., 2009 study aims to improve sustainability in the professionally prepared meal supply chain by introducing super-chilled meal elements, Van der Vorst et al., 2009 focuses on food quality models and environmental impacts, combining these elements in a simulation tool for supply chain redesign, Tromp et al., 2010 evaluates food supply chain considering both sustainability impacts and risks associated to microbial elements, whereas Mintcheva, 2005 introduces a set of environmental indicators to be applied into food supply chain for measuring the integration of integrated product policy requirements. Although there is a common element, i.e. the food supply chain, the authors adopt different approaches for conducting their study, resulting in an absence of citations among papers. However, apart this consideration, it's possible to detect some measurements related to environmental performance that are considered by all the papers. Specifically particular attention is given to distribution time (due to food perishability), storage, energy (especially for maintaining perishable food at low temperature), and packaging. These elements, in particular energy and packaging, are considered crucial for improving the environmental performance.

4.1.2 Bi-connected components

After the exposed examination of isolated nodes, it's necessary to undertake an analysis of the connected components.

By observing the distribution in Figure 3 it emerges that the bi-connected components presents the highest number of appearances (i.e. four). Since bi-connected components include only two papers linked by an arc, it's likely that the arguments studied in both articles are similar. This tendency is respected by the retrieved bi-connected components, showing coherence in terms of citations. In order to proof this argumentation, a brief examination of these components is provided.

Clift, 2004 is cited by Sikdar, 2007. Clift, 2004 deals explicitly with indicators for sustainable supply chains adopting both an environmental and social perspective. The paper is interesting because introduces OBIA index, a useful tool to compare the economic and environmental performance from an eco-efficiency perspective. Eco-efficiency is a concept mentioned by many papers (Michelsen et al., 2006) that have been developed by the World Business Council for Sustainable Development (WBCSD). The peculiarity of eco-efficiency is the simultaneous evaluation of product economic and environmental performance, which follows the paradigm of "creating more goods and services with ever less use of resources, waste and pollution" (WBCSD). With reference to the economic performance, Clift, 2004 proposes to use Value Added (VA), whereas other authors, e.g. Bojarski et al., 2009, suggests other methods such Net Present Value (NPV). On the other hand Clift uses LCA for assessing the environmental performance, confirming a choice adopted by several other papers (Michelsen et al., 2006). Anyway it must be noted that some authors recognizes that LCA requires a use of resources which is prohibitive for many organizations (Schmidt et al., 2008). Following this perspective Clift, 2004 quantifies OBIA for the main supply chain levels, concluding that the first stages (i.e. raw material extraction) present the highest environmental impacts. Moreover he evaluates OBIA in terms of reverse logistics, confirming the results whereby recovery of materials involves high costs.

Another interesting aspect is that Clift, 2004 considers the social sphere of sustainability in terms of satisfaction of human needs, whereby the product should be not only economically and environmentally efficient, but even capable to satisfy a more general social need. Anyway, although considering the social sphere, no indicators are presented, confirming the difficulty suggested by other papers for a structured quantification (Akkerman, et al., 2009). Sikdar, 2007 cites Clift, 2004 for introducing a framework for assessing the sustainability of chemistry processes. The author doesn't develop a MILP model such Guille-Gosalbez et al., 2008, but identify some major issues (i.e. energy, materials, and water) to consider when evaluating the environmental performance. Even this paper considers LCA as the most suitable tool for the established scope and, on this basis, some metrics are presented.

Sakalauskas, 2010 and Kinderyte, 2010 constitute another bi-connected component in which the first paper is cited by the second one. Even these papers deal with sustainability indicators applicable to supply chain context. This observation confirms another time that the research methodology has produced coherent results for the purpose of this study. Sakalauskas, 2010 considers that, due to the huge number of data to be managed, it's necessary to develop a structured framework for assessing the sustainability performance of supply chains, reflecting the observations of other authors (Tsoulfas et al., 2008). For this purpose the paper presents a specific set of indicators. Following this approach Kinderyte, 2010 extends the research stating that "sustainability performance evaluation systems do not assure the efficiency because they are separated from management system". Hence data must be structured in quantitative and qualitative indicators that should be comprehensible and relevant for management decisions. The approach adopted in the papers reflects the ISO 14031 framework, whereby EPIs should be referred to management (MPIs) and operational (OPIs) processes.

The bi-connected component including Akkerman et al., 2010 and Rong et al., 2010 concerns food supply chain. As previously mentioned food supply chain is an argument studied by three isolated papers (i.e. Akkerman et al., 2009, Van der Vorst et al., 2009, and Tromp et al., 2010) that, although the common topic, aren't connected among each other. This tendency is verified even with reference to the bi-connected component. In this case, however, the lack of connection appears stranger than the previous ones. Indeed it's possible to note how the citing author, Akkerman, is the author of an isolated paper, i.e. Akkerman et al., 2009. The lack of connection can be explained considering that Akkerman et al., 2009 is focused on super-chilled prepared meals, whereas Akkerman et al., 2010 doesn't consider such type of meals and adopts a more general approach based on a review of "quantitative operations management approaches to food distribution management". This is not a completely satisfying argumentation, since Akkerman et al., 2010, like Akkerman et al., 2009, explicitly considers food quality, safety, and sustainability, and support a decision framework structured in strategic, tactical and operative levels. Rong et al., 2010, the cited paper in the considered component, also focuses on food supply chain. In this case the authors examines traceability and sustainability issues concerning the production and distribution planning, and present a MILP model for selecting the optimal supply chain configuration.

The last bi-connected component includes Stupak et al., 2011 and Upham et al., 2011. Even in this case there is coherence in terms of analyzed topic; indeed both papers regard forestry biomass. Anyway, although common aspects, the approach is different. Stupak et al., 2011 focuses on indicators for sustainable production and harvesting methods related to forest biomass fuel. Although the papers don't deal explicitly with supply chain, some insights can be extracted. Indeed different production processes present commonalities in terms of indicators of environmental performance. This is confirmed by the paper that considers crucial the adoption of indicators concerning energy consumption, soil and water quality, GHGs emissions, and recovery processes, recognized as fundamental measures by several other papers (e.g. Brent et al., 2005). The citing article, i.e. Upham et al., 2011 examines forestry biomass issues related to risks and uncertainty and adopts a perspective based on the European policy. It's interesting to recall that, among isolated nodes, there was a paper dealing with biomass energy conversion (i.e. Santibanez-Aguilar et al., 2009). In this case the missing linkage is more comprehensible than the previous one (Akkerman, 2010), since the approach adopted in the papers is completely different (Santibanez-Aguilar et al., 2009 develops a MILP model considering environmental impacts by mean of Eco-indicator 99, whereas Stupak et al., 2011presents environmental indicators specific of biomass energy production).

Some conclusions can be drawn from the expose considerations:

- There is a high degree of correlation between topics treated by papers in bi-connected components.
- The identified bi-connected components aren't related among them. Thus, in this case, the absence of linkages is clearly explained.
- Three of the four bi-connected components include only recent papers (published since 2010). This can partially explains why the examined papers present just one linkage. Indeed, considering that these papers are quite novel, it's possible that they haven't received great attention. It must be noted that this is not a complete and valid explanation but a possible perspective of investigation.
- One bi-connected component comprises "mature" papers (published in 2004 and 2007). In this case it's not possible to undertake an interpretation similar to the previous one. We just suppose that the shortage of linkages simply depends on the fact

that these papers hadn't a great impact on the research community. Anyway it's important to underline that this assumption is implicitly adopted in the analysis of all the small components obtained by the performed research.

4.1.3 Three-connected components

By observing the structure of the two three-connected components it emerges that they have a similar disposition. Indeed they are both characterized by a sequence of articles forming an "open" citation chain, whereby the first paper (in terms of year of publication) is just cited by the second one, and the second paper is cited by only the third one. Hence the first and last article can be considered respectively as a "source" and a "sink" node. These relations partially reflect the Main Path logic, in which it's possible to identify a research evolution path by observing citations.

By examining the first three-connected component i.e. Grossmann et al., 2010, Gerber et al., 2011, and Gerber et al, 2011, it's possible to identify Groosmann et al., 2010 as the "source" node. This paper focuses on chemical processes, reflecting a tendency manifested by other papers (e.g. Bojarski et al., 2009). Moreover it's possible to note how one of the author, i.e. Guillen-Gosalbez, has published two papers belonging to isolated nodes. From this perspective it also emerges that the articles reflect some considerations of the isolated papers, since it focuses on chemical processes and provides an example related to hydrogen supply chain. It's thus strange the lack of connections with the mentioned isolated nodes. This can be partially explained considering that the scope of Grossman et al., 2010 is to review the available optimization tools applicable to process synthesis and supply chain management including environmental concerns. The adopted approach fundamentally reflects the one of other papers (e.g. Mele et al., 2011), whereby MILP models are combined with LCA; anyway, in this case, it's adopted a more general view (review of methodologies) compared to the ones undertaken by the other articles (specific methodology).

The second paper, i.e. Gerber et al., 2011 cites Grossmann et al., 2010 and presents a MILP model combined with LCA for an optimal design of biomass energy conversion processes. The citation linkage between the papers is well explained, since Gerber et al., 2011 makes use of a methodology reviewed by Guillen-Gosalbez, 2010. On the other hand the approach is very similar to the one adopted by Santibanez-Aguilar et al., 2011 anyway no connections are present. In this case a possible explanation can be drawn considering that both articles have been published in July 2011 and, thus, due to their simultaneity, no citations were possible.

Finally Gerber et al, 2011, the "sink" node, includes argumentation of both Grossmann et al., 2010 and Gerber et al., 2011 (the author is the same). Specifically it adopts the process synthesis optimization methodology of the first paper and the indicators construction framework, based on Eco-indicator 99, proposed by the second article. The nodes relationships are thus well explained.

The second three-connected component is composed of Dewulf et al, 2004, Lim et al., 2009, and Ponce-Ortega et al., 2011. Dewulf et al., 2004 is the “sink” node and exposes the European rail sectorwide Design for Environment. The approach is interesting because integrates LCA and ISO 14031 frameworks, developing indicators which are mainly focused on energy usage and materials management as crucial triggers. Moreover the paper proposes an evaluation based on eco-efficiency concept that, unlike other papers (Michelsen et al., 2006), monetize environmental impacts through environmental costs in order to adopt a unique dimension for eco-efficiency evaluation (indeed usually eco-efficiency is evaluated by the ratio of the product economic value, expressed by monetary terms, and the environmental impacts, expressed by mean of environmental indicators such LCA category indicators).

The second article, i.e. Lim et al., 2009, is not clearly related with the “source” node. Indeed it adopts the usual approach combining MILP model with LCA for minimizing environmental impacts and maximizing the economic performance. Anyway the article differs from the others since adopts EPS2000 tool for conducting LCIA phase. In this case the focus is on wastewater treatment, a topic faced also by a paper in the MCC (Gomez-Lopez et al., 2009). This lack of connection can be interpreted considering the temporal perspective adopted for explaining the missing linkage between Gerber et al., 2011 and Santibanez-Aguilar et al., 2011. Indeed even in this case both articles have been published in the same year (2009).

Finally the “sink” node, i.e. Ponce-Ortega et al., 2011, is strictly related to Lim et al., 2009, since it performs an evaluation based on MILP model and LCA (in this case the authors use Eco-indicator 99 for the LCIA step) that focuses on wastewater treatment in chemical processes.

It’s possible to conclude that the just examined three-connected component shows a relationship among the included papers, anyway this is clear only with reference to the last two articles (i.e. Lim et al., 2009, and Ponce-Ortega et al., 2011).

Even in this case some observations, concerning the three-connected components, can be exposed:

- Although dealing with different aspects, the approach based on the combination of MILP models and LCA is common to various papers within both the connected components.
- The two three-connected components present different features in terms of publication year of the included papers. Indeed the first three-connected component is characterized by a “source” node published in 2010 and two nodes published in 2011, whereas the second three-connected component presents a “source” node published in

2004, a "connection" node published in 2007 and a "sink" node published in 2011. The second component thus reflects a "slower" research evolution compared to the first one.

4.1.4 Four and Seven connected components

Following the assumptions adopted in this study, they should provide more insights than the previous ones, especially with reference to the seven papers component.

Proceedings in the same way of the previous analysis we first examine the structure of these components. The component composed of four papers presents a quadrangular shape. This shape is explained by considering that there are two "source" nodes and two "sink" nodes, hence the resulting linkages are disposed in a way that can be associated to a quadrangular polygon.

In the component including seven papers it's possible to identify a "fan" disposition along with a triangular relationship. As a consequence it's possible to identify, a "dominant" article (i.e. Wernet et al., 2009).

As previously mentioned the four papers component presents two "source" nodes (i.e. Gebreslassie et al, 2010 and Bojarsky et al. 2009) and two "sink" nodes (i.e. Garcia and Caballero, 2011 and Mele et al., 2011). In order to conduct an investigation of the component it should be useful to precede with an examination of the "source" nodes, and then evaluate their contributions to the "sink" nodes.

The two "source" nodes present, a common aspect in the usage of multi-objective optimization tools combined with LCA for assessing both the economic and environmental performance. Anyway, although this commonality, the two papers deal with different topics. Gebreslassie et al, 2010 focuses on solar assisted absorption cooling system and calculate environmental impacts by mean of Eco-indicator 99. Although this paper doesn't consider supply chain, it provides useful elements for developing a panoramic of the most common environmental indicators. On the other hand Bojarsky et al. 2009 considers explicitly the optimization of supply chain design in terms of facilities location and distribution planning. This work thus incorporates an assessment of the environmental performance within the supply chain, resulting in a much "centered" element for the purpose of the present study. Two particular aspects should be noted in Bojarsky et al. 2009: the authors quantify the economic performance by mean of Net Present Value (NPV), choosing an evaluation method that differs by other papers (e.g. total costs, VA), and calculate the environmental performance in the LCIA phase by mean of IMPACT2002+ tool and Global Warming Potential (GWP). With reference to this last aspect it's possible to observe that, unlike several papers, the authors don't use Eco-indicator 99, trying to adopt a new research framework. An interesting aspect concerning

Gebreslassie et al, 2010 is that, also in this case, Guillen-Gosalbez is present as coauthor. Anyway, with reference to this situation, missing links with the other Guillen-Gosalbez works (see the analysis of the first three-connected component) can be explained considering that solar assisted absorption cooling system is a different topic compared to the previous ones (i.e. chemical processes and hydrogen supply chain) and, moreover, the adopted approach doesn't reflect the author's previous papers.

Now, after having investigated the "source" papers, we perform an analysis of the two "sink" nodes. Both nodes cite the two "source" papers, anyway the presented studies are quite diverse. Mele et al., 2011 analyzes sustainability within bio-fuel (ethanol obtained by sugar cane) supply chains. Here the influence of the "source" nodes is clearly visible, since the authors propose a MILP model combined with a cradle-to-gate LCA. In particular the authors considers NPV for measuring the economic performance (Bojarsky et al. 2009), and adopt both Eco-indicator 99 and GWP for assessing environmental impacts (Gebreslassie et al, 2010 and Bojarsky et al. 2009).

On the other hand the correlation of Garcia et al., 2011 with the two "source" nodes is less evident. Even in this case the authors propose a multi-objective optimization model that combine LCA, anyway it's not possible to identify specific elements belonging to the "source" papers (actually the paper evaluates the environmental performance by mean of Eco-indicator 99 like Gebreslassie et al, 2010, however, as the previous analysis showed, this is a feature common to several other papers). Apart these considerations it's necessary to underline that the study offers some insights. In particular it suggests to optimize process flowsheets for separating acetic acid from water by measuring the economic performance through Economic Potential, a concept similar to VA (Clift, 2004), and Total Annual Costs, that include fixed and variable costs as well as taxes.

Finally we provide an analysis of the component composed of seven papers. From a first investigation of the included papers it emerges that all of them deal with environmental impacts concerning chemical processes, reflecting a tendency showed in other papers (e.g. Grossman et al., 2010). This is explained considering that the dominant (is also a "source") paper, i.e. Wernet et al., 2009, is focused on a model that presents LCIA results for a large variety of chemicals. In particular the reason of this choice depends on author's observation whereby data on chemical products are scarce. The article underlines that such an evaluation should be done in the process planning and design phase, since following improvements would be very expensive. According to this view the authors performs a cradle-to-gate LCA for several products that implements three different LCIA methods, i.e. Cumulative Energy Demand (CED), Global Warming Potential (GWP), Eco-indicator 99. This is an interesting perspective that considers the results obtained by different methodologies, anyway the paper relevance should be attributed to the fact that it provides LCA data for a large set of chemicals. On this basis is possible to examine the connected papers. Murphy, 2011 uses the mentioned data to carry out a LCA focused on biocatalysis and its effects on the reduction of fossil fuel usage, Walser et al, 2011 performs a cradle-to-grave LCA on nanosilver t-shirts concentrating on GWP indicator, whereas Bumann et al., 2010 defines an Energy Index for measuring energy consumption during chemical processes, recognized as the most relevant matter (Wernet et al., 2010, Wernet et al., 2011). This last framework is considered even in Eissen et al., 2011 that, in order to evaluate energy consumption, adopts the methodology proposed by Wernet et al., 2009, i.e. CED.

These last four articles are responsible for the "fan" shape of the connected component, indeed it's possible to observe how their only linkage concerns the citation of Wernet et al., 2009.

On the other hand it could be more interesting to investigate the triangular relationships, since all the included papers (i.e. Wernet et al., 2009, Wernet et al., 2010, Wernet et al., 2011) present Wernet as first author (this suggests the presence of correlation among papers).

Wernet et al., 2010 cites Wernet et al., 2009. This depend on the fact that the paper makes use of data provided by Wernet et al., 2009, performing a cradle-to-gate LCA on pharmaceutical products. Anyway the paper is interesting for the purpose of this study because extends the LCIA phase including further methodologies compared to the cited paper. Specifically, apart CED, GWP and Eco-indicator 99, the authors implement an assessment based on Ecological Scarcity 2006, TRACI (Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts), IMPACT2002+ (see Bojarsky et al., 2009) and ReCiPe.

Wernet et al., 2011 cites both Wernet et al., 2009, and Wernet et al., 2010. Like for the previous observation, the citation of Wernet et al., 2009 is related to the adoption of the provided chemical LCA data (in this case the authors evaluate the environmental impacts of chemical processes considering 99 chemical products). On the other hand Wernet et al., 2011 is connected to Wernet et al., 2010 due to the inclusion of all the proposed LCIA methodologies. Moreover, as Eissen et al., 2011 and Wernet et al., 2010, the authors conclude that the major environmental impacts can be associated to energy consumption.

After these considerations it's hence possible to state that Wernet et al., 2009 is a dominant paper due to its original and useful approach. Indeed the provided set of LCA data is very large (338 chemicals product) and avoids the efforts connected to data gathering, considered by several papers (e.g. Fet et al., 2009) as a major limitation of LCA. Finally it's curious to observe that several papers concerning LCA and chemical processes (e.g. Garcia et al., 2011, Grossmann et al., 2010) don't cite Wernet (2009) and, thus, don't make use of the mentioned data. Obviously there is no a clear explanation for this (it's simply possible that the authors haven't retrieved the paper or that the provided data were not useful for the purpose of their study), anyway it's interesting to note how a research structured in the way we propose allows to detect such kind of possible inconsistencies.

We have provided a detailed analysis of papers included in the initial network, anyway it should be useful to expose some general conclusions:

- The majority of the papers adopt an approach based on the combination of MILP models along with LCA. It's interesting to note that the previously examined papers usually adopt a cradle-to-gate LCA (that excludes the usage and reverse logistics phases), confirming a tendency to focus on impacts till manufacturing processes. For the purpose of the study, it's necessary to underline how the authors perform the LCI and LCIA phase. During the previous examination LCI approach was not mentioned. This depends on the consideration that, in the analyzed papers, LCI can be considered as a standardized operation, whereby the authors tend to evaluate a specific set of input-output flows (i.e. energy, materials, emissions, waste, and water). On the other hand the LCIA phase is generally conducted by mean of Eco-indicator 99, which can thus be considered as the most common tool for performing the mentioned LCA phase. Even Global Warming Potential (GWP) indicator and Cumulative Energy Demand (CED) are quite used, confirming the current emphasis on energy issues and GHGs emissions. Eventually there are a set of alternative methodologies, such IMPACT2002+, ReCiPe, that are proposed by just some authors.
- The ISO 14031 framework isn't adopted by a large number of papers (Hendrickson et al., 2006, Sakalauskas et al., 2010, Kinderyte et al., 2010,), suggesting that, when evaluating environmental impacts, authors tend to prefer LCA (a possible explanation for this observation will be provided later on). Anyway it must be noted that some papers (e.g. Wang et al., 2011, Dewulf et al., 2004) make use of both LCA and ISO 14031 framework. In particular, among these papers, Dewulf et al., 2004 provides a well structured approach for combining the two standards.
- The analysis of the paper confirms the validity of the research, since most of the papers deal with environmental performance. Indeed the adopted keywords were designed to provide results focused on environmental concerns. It should be observed that some authors (e.g. Clift, 2004) try to define a framework for assessing the social performance, embracing thus all the spheres of sustainability; anyway the difficulties concerning the quantification of social aspects make this task quite hard (Akkerman et al., 2010).

- It's possible to observe a large set of papers focuses on chemical processes; this trend is in accordance with Table 1, which shows that two of the five journals including more citations concern chemistry. It should be noted that this specific tendency is not present in the MCC, resulting in the consideration that papers dealing with chemistry don't create large citation connections when talking of sustainability indicators within chemical supply chains (indeed, as we previously observed, papers considering chemical aspects often don't cite each other). Finally it's possible to identify two other themes mentioned frequently, i.e. food supply chain (e.g. Akkermann et al., 2010, Rong et al., 2010) and biomass energy production (e.g. Stupak et al., 2011, Gerber et al., 2011).

Focusing on the contents of the selected paper, an analysis of the initial network (i.e. including all the 84 retrieved papers) was first performed and some conclusions can be provided. Numerous papers adopt an approach based on the combination of optimization models (mainly based on Mixed Integer Linear Programming) and LCA (although Life Cycle Assessment is not included in the search strings of keywords) (e.g. Guillen-Gosalbez *et al.*, 2008; Guillen-Gosalbez *et al.*, 2010; Lopez-Maldonado, 2011). In doing this they usually adopt a cradle-to-gate LCA (that excludes the usage and reverse logistics phases), confirming a tendency to focus on impacts till manufacturing processes. For the purpose of the study, it is necessary to underline how the authors perform the LCI and LCIA phase. LCI can be considered as a standardized operation, whereby the authors tend to evaluate a specific set of input-output flows (i.e. energy, materials, emissions, waste, and water). On the other hand the LCIA phase is generally conducted by mean of Eco-indicator 99, which can thus be considered as the most common tool for performing the mentioned LCA phase (e.g. Santibanez-Aguilar *et al.*, 2009).

Furthermore it's possible to observe a large set of papers focused on chemical processes (e.g. Bojarski *et al.*, 2009). It should be noted that this specific tendency is not present in the MCC, resulting in the consideration that papers dealing with chemistry don't create large citation connections. Finally it's possible to identify two other themes mentioned frequently, i.e. food supply chain (e.g. Akkermann *et al.*, 2010; Rong *et al.*, 2010) and biomass energy production (e.g. Gerber *et al.*, 2011; Stupak *et al.*, 2011).

4.2 MCC analysis

In this section we provide a complete analysis of the MCC, differing from the just exposed examination due to the implementation of the additional MPA and Cluster Analysis methodologies.

Figure 5 shows the Main Path component derived through the Pajek software. It identifies the most relevant papers at different moments of time, i.e. the ones facilitating the flow of information and the progress of knowledge. The obtained Main Path structure is particular, since the research backbone starts from two papers (i.e. Michelsen *et al.*, 2006 and Mintcheva, 2005) and seems to converge in the central part of the network, where there are four papers (i.e. Cholette *et al.*, 2009; Lee *et al.*, 2011; Ramani *et al.*, 2010; Yang, 2009). This convergence is enabled by the presence of three crucial "interconnection" nodes, i.e. Michelsen, 2007, Seuring and Muller, 2008, Tsoulfas and Pappis, 2008. It is also possible to detect two groups of "peripheral" "sink" nodes, related through citations respectively to Tsoulfas and Pappis (2008) and Seuring and Muller (2008). By analyzing the content of the papers constituting the Main Path, the following conclusions can be drawn:

- The two "source" papers, i.e. Michelsen *et al.*, 2006 and Mintcheva, 2005, reflect the dichotomy ISO 14031 and ISO 14044 as reference frameworks for the construction of environmental indicators concerning the supply chain.
- The paths convergence resulted in four papers (Cholette *et al.*, 2009; Lee *et al.*, 2011; Ramani *et al.*, 2010; Yang, 2009), dealing with environmental indicators for supply chains and the need of a structured approach for the assessment of environmental performances. In these papers, however, it is not possible to identify a specific framework (ISO 14031 and ISO 14044) whereby to associate the presented indicators. A possible explanation can be drawn considering that the research convergence has involved the simultaneous integration of elements belonging to both the ISO 14031 and ISO 14044 frameworks.
- The "peripheral" "sink" papers connected to Tsoulfas and Pappis, 2008 face different topics, all of them related to the scope of this study. Indeed two papers (Olugu *et al.*, 2011 and Mendes *et al.*, 2011) are explicitly focused on indicators, whereas four papers (Gomez-Lopez *et al.*, 2009; Hu *et al.*, 2009; Jaegler *et al.*, 2010; Tuzkaya *et al.*, 2009) present decision-making model including environmental indicators.
- Some relevant issues observed in the initial network are not highlighted in the Main Path also. Although ISO 14044 is frequently mentioned, few papers included in the Main Path adopt an approach based on the combination of optimization models (mainly based on Mixed Integer Linear Programming) and LCA. Also Eco-indicator 99 is mentioned by just some papers.

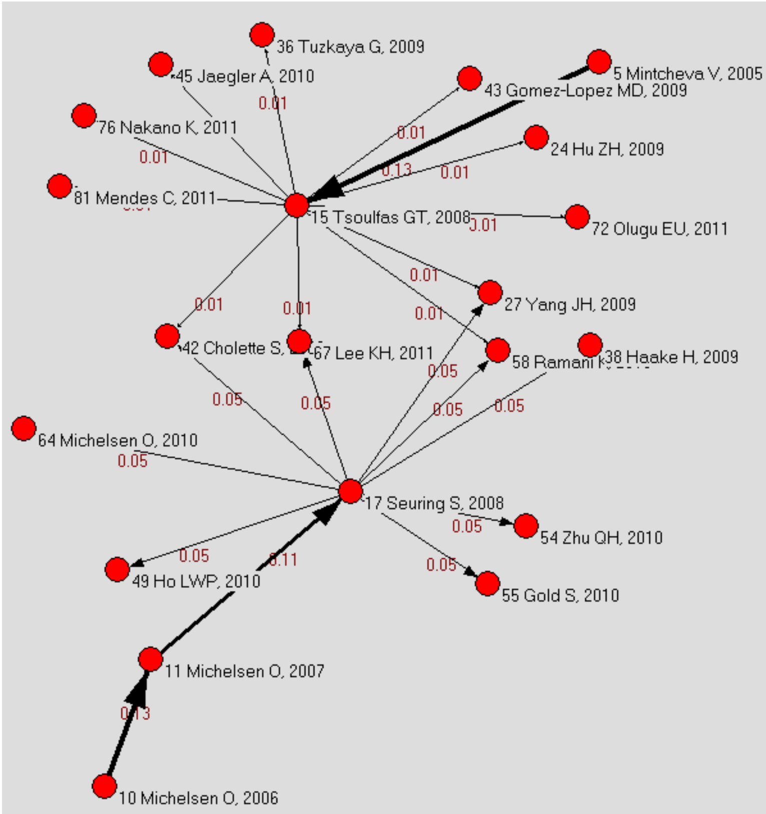

Figure 5. The Main Path (the dimension of arcs is proportional to the traversal weight of citations)

Finally cluster analysis of MCC was performed to identify cluster of papers dealing with specific areas of research within the examined topic. Six clusters were identified within the MCC (Figure 6)).

- The green and red clusters have a similar structure characterized by a dominant paper. They deal respectively with the Environmental Performance Resource Impact Indicator (EPRII) methodology and the eco-efficiency concept. EPRII model can be considered as a new LCIA methodology. Eco-efficiency is the combination of environmental and economic dimensions of sustainability and has been tackled in different ways by the papers belonging to the red cluster. For example Barba-Gutierrez *et al.* (2009) and Kuo *et al.* (2010) combine eco-efficiency in a DEA (Data Envelopment Analysis) model, Henri *et al.* (2009) conducts an empirical analysis focused on the implementation of eco-efficiency practices, Draghici *et al.* (2009) and Draghici *et al.* (2008) consider the importance of the eco-efficiency concept for management training, whereas Jabbour *et al.* (2009) applies eco-efficiency argumentation for supplier evaluation.

- The yellow cluster mainly coincides with the Main Path. Thus the research direction characterizing this cluster can be generally associated to measurement frameworks concerning sustainability within the supply chain and the conclusions derived from the Main Path Analysis can be applied to this cluster.
- The blue cluster is composed of three papers on the methodologies to quantify eco-efficiency.
- The pink and white clusters are constituted of just one paper (respectively Jaegler *et al.*, 2010 and Chien *et al.*, 2007). Jaegler *et al.* (2010) present a supply chain simulation model for evaluating CO_2 emissions. Chien *et al.* (2007) propose an empirical investigation concerning the implementation of green supply chain practices in the Taiwanese electrical and electronic industry.

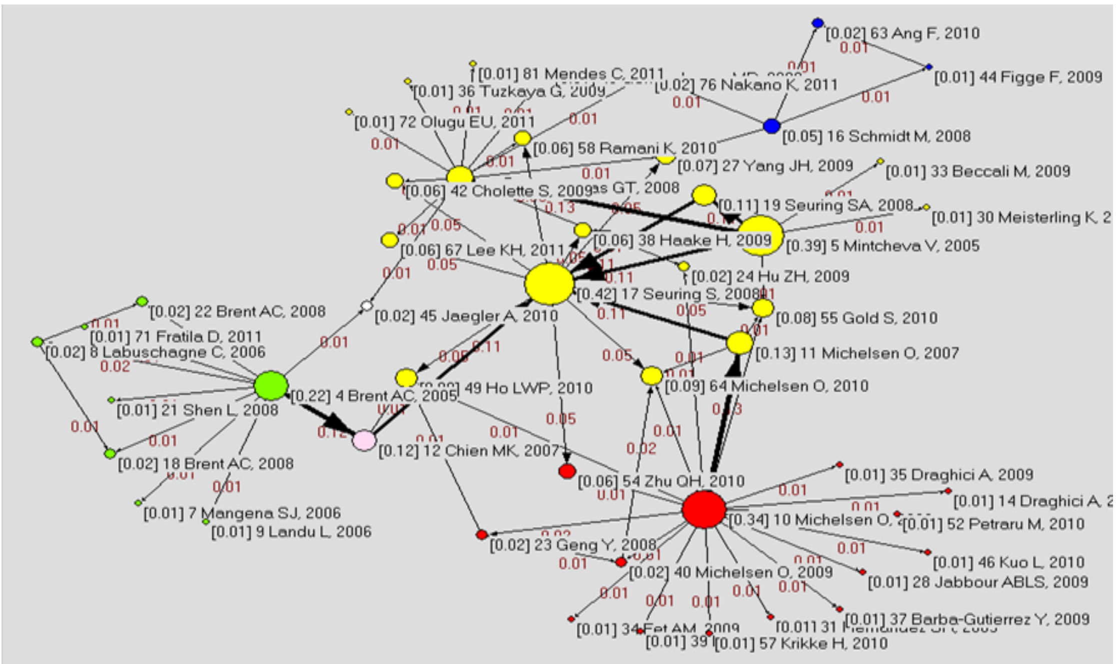

Figure 6. Identified clusters within the MCC

5. Papers classification using ISO 14031 and ISO 14044 frameworks

Two frameworks: ISO 14031 and ISO 14044 emerge from the papers themselves since in the development of environmental indicators the authors refer often to one of the two standards or, sometimes, to both (e.g. Brent et al., 2005)

5.1 Environmental indicators related to ISO 14031

Table 3 includes papers associable to (citing) ISO 14031 and classified according to ISO 14031 classifications, i.e. OPIs, MPIs or ECIs.

Furthermore, building upon classifications proposed by the literature (e.g. Ramani et al., 2010; Tsoulfas and Pappis, 2008; Zhu et al., 2010) they were further classified according to the following categories:

- Product design, when the environmental performances are evaluated considering the criteria adopted for product design.
- Process design, which fundamentally concern the manufacturing phase.
- Transportation, that incorporate indicators related to the environmental impacts caused by freight transportation.
- Warehousing, which includes indicators associable to the environmental impacts of warehousing operations.
- Reverse logistics, including indicators measuring the implementation and efficiency of recovery practices.
- Supplier's management, including indicators measuring supplier's sustainability performance.
- Other management issues

In Table 3 the papers of the MP are highlighted in green; in red the ones of the MCC that are not in the MP and in black the others. In order to examine the following table we make use of an analysis framework based on the categories presented before.

Product design: Product design has a fundamental relevance for the environmental performance improvement. This is confirmed by some authors (e.g. Ramani et al., 2010), that underline how environmentally oriented decisions at early stages, i.e. product design, can avoid the high environmental costs concerned with future modifications. Considering the identified indicators it emerges that the related papers mainly focus on the green composition of the product, as well as recyclability, reusability and biodegradability requirements. It's also possible to note that, although less cited, even indicators concerning the packaging proportion and the inclusion of non-assemblability and standardization specifications can be considered relevant. Within this category indicators related to management decisions regarding the product, such as product greenness and costs associated to the implementation of green practices, have been classified as MPIs.

Process design: Process design corresponds to the manufacturing phase. In this stage the main operational environmental issues are quantified resulting in the following conclusions:

- Energy consumption is considered as the most important issue, confirming that a more efficient utilization of energy sources is a crucial aspect when dealing with sustainability.
- Apart from energy consumption, it's important to note that even materials utilization, emissions, waste produced and water consumptions are fundamental concerns.

These considerations reflect the major aspects associable to the operative input-output scheme characterizing OPIs.

Transportation: Transportation has a significant role for determining the supply chain environmental impacts. This is emphasized by some of the retrieved papers (Hendrickson et al., 2006), that adopt an approach explicitly focused on this category. When dealing with transportation indicators, researchers are mainly focused on energy efficiency and harmful emissions. As for the previous analyzed categories, most of the presented indicators are OPIs since the adopted perspective reflects again the operational input-output approach.

Warehousing: Indicators belonging to the warehousing category fundamentally concern the main issues identified in the transportation category, i.e. energy consumption and emissions. This is explained considering that the collected papers dealing explicitly with the transportation phase (e.g. Cholette et al., 2009) take into account also the warehousing phase. In particular they state that, when measuring energy consumption and emissions, the transportation phase has the highest impacts compared to warehouse operations. Despite this consideration, that could diminish the environmental relevance of warehousing operations, it's important to develop indicators for measuring the environmental impacts of warehouse operations since a supply chain perspective should include this phase. Returning to the discussion of the identified indicators, it's important to note that packaging utilization is a fundamental aspect, in accordance with the argumentation of some of the retrieved papers (Tsoulfas et al., 2008).

Reverse logistics: This phase it's fundamental for the supply chain environmental performance, since it is based on the recovery of materials and products. It's thus clear how, with a well-planned reverse logistics system, it's possible to achieve great improvements in terms of efficient use of resources. By analyzing the table it emerges that the main indicators concerning this phase are the recovery rate (that should be expressed for the main types of recovered materials/products), recycling rate, material recovery time. The area of reverse logistics has been considered for its managerial aspects too such as the availability of standard operating procedure for the collections of end of life products.

Suppliers' management: Suppliers evaluation is considered an essential requisite for improving the supply chain environmental performance (this is emphasized by some of the retrieved papers such as Jabbour et al., 2009). The indicators belonging to this category measure various aspects concerning suppliers' environmental performance. By considering the related papers column it emerges that supplier certification is the most cited aspect for evaluating suppliers' environmental performance. It's also possible to note that all suppliers' indicators can be classified as MPIs. This is reasonable; indeed suppliers' indicators are fundamentally purchasing indicators attaining the sphere of management decisions.

Other management issues: Like for the usage phase category, management issues can't be associated to the operational input-output scheme characterizing OPIs. It's thus clear why all the included indicators are expressed as MPIs that try to evaluate the management commitment in the adoption of environmental practices. The table 1 shows that the identified indicators concern variegated issues such as:

- Labeling/certification
- Motivation of suppliers/customers/employees for the adoption of environmental behaviors
- Costs associated to the implementation of green practices
- Environmental objectives achieved

Finally it's interesting to note how ECIs have been mentioned by only one paper, i.e. Mendes et al., 2011. This result reflects the considerations made in the ISO 14031 framework presentation, whereby an organization should firstly focus on OPIs and MPIs, since ECIs are necessary only when the organization has enough resources and can be considered responsible of relevant and specific environment condition modifications.

Table 3. Environmental indicators related to ISO 14031

ISO classification	Area	Indicators	Related papers*
OPI	Product design	Recyclability	15,36,54,72,3
		Reusability	15,36,54,72,3
		Biodegradability	15,36,54,72,3
		Standardization	15,36
		Disassemblability	15,36,72,3
		Size of the packaging	5,15,36,47
		Proportion of packaging	5,15
		Percentage decrease in product development cycle time	72
	Process design	Materials intensity	5,72,12,21,39,3,4,27,47,48,53,66, 79
		Energy consumption	5,15,24,36,72,81,12,21,28,39,71, 3,4,27,43,47,48,53,66,79
		Consumption of renewable energy sources	15,72,3,27,39,47,48,66
		Water use/reused	15,36,81,21,28,4,53,66
		Emissions per product unit product (e.g.CO2)	36,67,72,12,28,46,16,27,29,47,48,53,66
		Spillage/leakage per product unit	36,72,43
		Percentage of polluted wastewater	36,43
		Production waste	5,15,36,72,12,21,28,4,27,39,47,48,66
		By-products	72,3,15,47,79
		Use of recycled materials, by-products, defected products, packaging	5,15,72,3,48,66,79
		Non-hazardous-hazardous disposed materials	5,15,72,3, 47,48
	Transportation	Fuel consumption for transportation	5,15,24,42,3,6,25,27,45,47,48,53,60
		Average emissions per km	42,67,6,25,27,29,45,47,48,53,60
		Proportion of transportation means with low environmental impacts	42,6,45,60
	Warehousing	Size of the packaging	5,15,36,1,47,48
		Energy consumption for warehouse operations	24,42,67,25,45,47,53,60
		Average emissions per handled item	42,25,29,45,47,60
	Reverse logistics	Recovery of materials	5,15,36,54,72,28,3,6,47,48
		Recycling rate	15, 36,72,28,3,47,48
		Material recovery time	15,72
MPI	Supplier	Suppliers environmental certification	54,72,3,6,27,47,48
		Quality of the supplied components for green products	36,48
		Volume of goods purchased from environmentally certified suppliers	72,48
		Fraction of environmentally assessed suppliers	72
	Product design	Product greenness/harmfulness	43,5,15,36,28,3,47,72
	Reverse logistics	Availability of standard operating procedure for the collection of end of life products	72,15
		Number of collection centers	72,15
	Other management issues	Number of environmental management initiatives	72,54, 55,12,3,27,47
		Number of conducted environmental audits	72,12,3, 27
		Number of company's green certified facilities	15,72
		Number of sites with environmental indicators system	72
		Labeling/certification	49,5,15,54,72,27,47
		Motivation of suppliers	15,54,72,48
		Motivation of customers	15,36,54,72,48
		Level of market share controlled by green products	5,72,12
		Motivation of employees	15,36,72,12,48
		Trainings and programs for green consciousness	36,54,72,12,14,47,48
		Number of employees responsible for environmental performance	8,21
		Costs associated to the implementation of green practices	5,36,54,72,81,27
		Availability of environmental reward systems	72
		Targets for environmental impacts reduction	5,72,81,25,27,47,48
		Number of violations of environmental regulations	72,47
		Amount of imposed environmental penalties	15,54,72,27
		Number of complaints by local communities	72,12,47
		Number of sponsoring activities concerning the company environmental commitment	15,54,72,27
ECI		Concentration for monitoring of a given contaminant in air, at selected sites	81
		Dissolved oxygen in receiving bodies	81

* Papers in green are included in the Main Path, papers in red are included in the Main Connected Component, the other papers of the citation network are in black

After the exposed considerations, and in accordance with the previous analysis, it should be useful to summarize the results and make some further observations:

- When dealing with OPIs along the supply chain researchers tend to focus on the manufacturing phase. This can be explained considering that usually manufacturing is the phase where the organization has the major availability of data, thus indicators construction can result simpler than others.
- Although the other stages are less important than the manufacturing phase, their evaluation is fundamental. This is confirmed by the collected papers, in particular with reference to suppliers (Jabbour et al., 2009), transportation (Hendrickson et al., 2006), and reverse logistics (Krikke, 2010).
- Energy appears as the most important concern when constructing OPIs, anyway even other measurements can be considered relevant (e.g. emissions that actually are an indirect way to express energy consumption, produced waste etc.)
- By observing the related papers column it emerges that three papers are often cited, i.e. Mintcheva, 2005, Tsoulfas and Pappis, 2008, Olugu et al., 2011. This is not surprising since, as previously noted during the MPA, they can be considered the most relevant ISO 14031 indicators frameworks.

5.2 Environmental indicators related to ISO 14044

In accordance with the adopted framework of analysis we present in this section the identified papers related to ISO 14044. As done for Table 3 we firstly make some considerations on the table lines. ISO 14044 classifications indicates the two types of indicators, i.e. LCI data, and LCIA category indicators. It's important to note that LCI data are always defined as input-output flow associated to the product, whereas LCIA indicators requires the execution of some stages for their definition (as for the Eco-indicator 99 methodology). We thus identified 3 categories:

- Process efficiency, concerning the major input and output flows associable to the product (functional unit).
- Resource depletion that is referred to the quantification of the main environmental impacts.
- Economic value of the product, that is associated to the economic assessment of product life cycle.

These categories are completely different from the ones associated to ISO 14031. Indeed while we previously defined categories reflecting the main supply chain stages, in this case we consider implicitly the whole supply chain perspective. This depends on the life cycle nature of

ISO 14044, which include all the stages of product life (and inevitably all the supply chain levels).

Process efficiency: this category includes the main LCI data that fundamentally concern materials, energy and water as inputs, and wastes and emissions as outputs. It's also possible to note how some of the collected papers cite land usage and dust fallout as LCI data, anyway, by observing the related paper columns, it emerges how they have a marginal role compared to the other ones.

Resource depletion: This category contains the main LCIA indicators defined by the most common LCIA methodologies. By observing Table 4 it emerges that most of the LCIA indicators present a high number of citing papers. Moreover it's possible to note that the related papers are almost the same for LCIA indicators. Several papers citing this depends on the consideration whereby these LCIA indicators are associated to the indicators implemented in Eco-indicator 99 methodology that is adopted by several papers. Specifically it should be interesting to provide an examination of the identified LCIA indicators based on Eco-indicator 99 framework. For this purpose we recall that the model evaluate impacts considering three damage categories (endpoints), i.e. Human health, Ecosystem quality and Resources. We also note that for each one of these categories the methodology quantifies impacts on the basis of midpoint indicators. From this perspective we examine the LCIA indicators presented in table 4.

Same of the LCIA indicators of Table 4 associable to the human health category are:

- Global warming potential (GWP).
- Ozone depletion potential.
- Carcinogenic/respiratory effects on human health.
- Human toxicity potential (this LCIA indicator isn't explicitly mentioned by Eco-indicator 99 anyway, due to its focus on human health, we classified the indicator in this category).

Indeed the corresponding indicators exposed within the Eco-indicator 99 methodology are:

- Carcinogenic effects and Respiratory effects. We have included both these aspects in the LCIA indicator "Carcinogenic/respiratory effects on human health" of table 2.
- Climate change. We associated this aspect to GWP, anyway it should be noted that GWP can be considered a standalone LCIA methodology, reflecting the approaches of a relevant number of the collected papers (this also explains why GWP has the highest number of citations). The decision to associate the two indicators derives by the

consideration whereby both measurements quantify the same aspect (i.e. climate change) and "climate change" isn't explicitly cited by the collected papers.

- Radiation. This quantity doesn't appear since it's not mentioned by the collected papers.
- Ozone depletion. Ozone depletion is associated to the LCIA indicator: "Ozone depletion potential".

Some of the LCIA indicators associated to Ecosystem quality are:

- Acidification potential.
- Eutrophication potential.
- Aquatic toxicity potential.
- Occupied land usage.
- Transformed land usage.

On the other hand, the categories mentioned in Eco-indicator 99 methodology are strictly connected with the LCIA indicators of Table 4. Specifically they are:

- Ecotoxicity.
- Acidification.
- Eutrophication.
- Land use and transformation.

As last step we consider LCIA indicators associated to Resources category. In this case Mineral reserves depletion and Energy reserves depletion LCIA of Table 4 have been associated to the indicators mentioned by Eco-indicator 99 framework, i.e. Minerals extraction and fossil fuels extraction.

Eventually we observe that there are four LCIA indicators that weren't associated to Eco-indicator 99 (this is demonstrated by the low number of related papers compared to the ones related to Eco-indicator 99). Specifically they are:

- Ozone Creation Potential.
- Photochemicals Ozone Creation Potential.
- Emissions of heavy metals
- Cumulative Energy Demand (CED)

The first two LCIA indicators could be associated to Eco-indicator 99 (see above); anyway we discard this choice in order to avoid redundancies. Despite this observation these two indicators are cited by some papers and thus were included in Table 4. On the other hand Emissions of heavy metals has a low importance, whereas CED (that can be used as LCIA methodology), as it's possible to observe from the related column, present a relevant number of citations. This is confirmed by the argumentations provided during papers analysis.

Economic value of the product: Here it's included only one indicator, i.e. product value. Actually this is not an indicator belonging to LCA framework, since it has been used by Michelsen et al., 2006 for measuring the economic performance from an eco-efficiency perspective. Anyway, due to its life cycle approach we decided to include the indicator in the table.

Table 4 Environmental indicators related to ISO 14044

ISO classification	Area	Indicators	Related papers*
LCI data	Process efficiency	Energy consumption	10,42,76,7,9,21,30,31,1,3,12,20,24,33,53,56,61,66,75,77,79
		Material consumption	11,10,76,9,21,31,37,1,3,20,51,53,61,65,66,74,75,77,79,84
		Water consumption	10,7,21,33,1,9,53,61,66
		Harmful emissions	42,67,7,16,31,34,46,12,32,41,53,66,74,77,79
		Total waste	10,9,21,31,1,3,12,20,32,51,65,66
		Land in charge	4, 7,21,41,79
		Land fully rehabilitated to agricultural use	4, 7,79
		Dust fallout	7,9
LCIA indicators	Resource depletion	Global warming potential	10,42,64,67,7,9,16,22,30,33,34,37,1,2,4,20,26,41,50,51,61,69,73,74,75,78,82,83
		Cumulative energy demand	11,57,26,50,51,61,69,83,84
		Acidification potential	10,64,7,9,22,37,1,2,4,20,26,41,50,51,61,69,73,74,75,78,82,83
		Photochemical ozone creation potential	64,2,10,41,69
		Emissions of heavy metals	10,64,1
		Ozone creation potential	9,22,2,4
		Ozone depletion potential	10,7,4,9,22,37,1,20,26,41,50,51,61,69,73,74,75,78,82,83
		Eutrophication potential	7,9,22,34,37,1,4,20,26,41,50,51,61,69,73,74,75,78,82,83
		Human toxicity potential	7,9,2,20,26,41,50,51,61,69,73,74,75,78,82,83
		Aquatic toxicity potential	4,7,9,37,2,20,26,41,50,51,61,69,73,74,75,78,82,83
		Mineral reserves depletion	4,7,9,22,37,20,26,41,50,51,61,69,73,74,75,78,82,83
		Energy reserves depletion	4,7,9,22,37,2,20,26,41,50,51,61,69,73,74,75,78,82,83
		Occupied land usage	4,7,9,37,20,26,41,50,51,61,69,73,74,75,78,82,83
		Transformed land usage	7,4,9,37,20,26,41,50,51,61,69,73,74,75,78,82
		Carcinogenic/respiratory effects on human health	37,1,20,26,41,50,51,69,73,74,75,78,83,61,69,82
	Economic value of the product	Product value (1/LCC)	10,4

* Papers in green are included in the Main Path, papers in red are included in the Main Connected Component, the other papers of the citation network are in black

We can summarize the results as follows:

- It emerges that generally papers related to LCA indicators are more numerous than the ones considering ISO 14031 framework. This depends on the fact that papers dealing with LCA tend to adopt the same measurements (this is emphasized by considering that most of the papers make use of eco-indicator99).
- The number of identified LCA indicators is lower than the one corresponding to the ISO 14031 framework. This reflects the previously made considerations (i.e. authors dealing with LCA consider very similar measures) and seems to demonstrate that the adoption of ISO 14031 involve a major discretion in terms of indicators construction. This is explained considering that ISO 14031 explicitly recognizes that there isn't a universal set of indicators, since they should be defined in accordance to the organization context. Thus the standard emphasizes indicators diversity. On the other hand LCA is a more structured methodology that, although recognizing the necessity to consider the context, tends to focus on a specific set of indicators.

After these considerations, and in accordance with the observations made, it's possible to conclude that, although examining similar environmental issues, ISO 14031 and ISO 14044 adopt rather different approaches. Specifically ISO 14044 is a methodology that should be considered when evaluating the environmental load corresponding to the product life cycle, whereas ISO 14031 should be adopted for assessing the organization environmental performance. Despite these differences both frameworks should be considered (anyway as Michelsen et al., 2006 states, ISO 14044 could be prohibitive for small organizations); moreover it could be profitable to integrate complementary aspects of both standards in order to improve the effectiveness of the organization environmental assessment framework.

6. Discussion and conclusions

In the present paper a detailed literature analysis on environmental indicators in supply chains was performed. The application of SLNA methodology allows to identify many relevant issues and in particular a new classification of indicators based on ISO 14000 emerges and in particular on ISO 14031 and ISO 14044. For this reason we have organized our findings according to these frameworks and we have presented the results in Tables 3 and 4. It is to be underlined that ISO framework emerges even if it is not in the keywords. The classification columns of the Tables are as follows: "ISO classification" column that allows the reader to find the correspondence between papers and ISO classification; "Area" column that is intended to group the environmental indicators, according to the main areas of supply chain management and in line with other indicators classifications already proposed by other authors (e.g. Ramani et al., 2010; Tsoulfas and Pappis, 2008; Zhu et al., 2010); "Example of Indicators" column that presents some environmental indicators for supply chains identified through our literature review.

The network analysis of the citation network and in particular of the MCC are included in the Tables 3 and 4 as follows: in "Related papers" column the Main Path papers are highlighted in green, in red the ones of the MCC that are not in the MP, and in black the others papers of the citation network. With this kind of information it is possible to check whether the papers of the MCC or the ones of the MP, that are the most relevant part of the Citation Network, are able to capture all the "areas". It seems that MCC papers (green and red papers) contain environmental indicators related to ISO 14031 and to ISO 14044, thus confirming the effectiveness of the adopted methodology and in particular of the citation network analysis.

An additional outcome is that MP papers seem related mainly with ISO 14031. This can be explained by the fact that the papers containing indicators related to ISO 14031 can be easily cited by the ones related to ISO 14044 which may integrate them in the more complex LCA methodology, thus resulting in the most important papers.

Although ISO 14031 and ISO 14044 adopt rather different approaches (LCA described in ISO 14044 is a methodology that should be considered when evaluating the environmental load corresponding to the product life cycle, whereas ISO 14031 should be adopted for assessing the organization environmental performance) in our analysis it emerges that both frameworks should be considered in order to improve the effectiveness of the company environmental assessment. This is also highlighted by the MPA. In fact the evolution of the research development seems to converge in four papers (Cholette *et al.*, 2009; Lee *et al.*, 2011; Ramani *et al.*, 2010; Yang, 2009) in which it is not possible to identify a specific framework (ISO 14031 and ISO 14044) but the simultaneous integration of elements belonging to both ISO 14031 and ISO 14044 frameworks. This is also confirmed by the presence of the same papers in both Table 3 and Table 4.

The results of our literature review confirmed the effectiveness of the adopted methodology and provide a framework to classify the papers and related environmental indicators with the aim to support companies in finding new environmental performance measurement systems or improving an already existing one having information on the related literature. Furthermore researchers can identify unexplored research areas.

Future research may go towards the deepening of the areas of supply chains that appear less investigated, taking into account the integration of guidelines provided by ISO 14031 and ISO

14044 and the current implementation of environmental indicators and performance measurement systems by companies.

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Appendix: Theoretical background: the ISO 14031 and ISO 14044

ISO 14000 specifies requirements and guidelines for implementing an Environmental Management System (EMS), defined as "that part of the overall management system that includes organizational structure, planning activities, responsibilities, practices, procedures, processes, and resources for developing, implementing, achieving, reviewing, and maintaining environmental policy" (UNI EN ISO 14001, 2004). The adopted approach is based on a "Plan-do-check-act" model whereby the EMS should be considered as an iterative process of continuous improvement. Other important peculiarities are the generality and flexibility (with reference to the environmental performance) requirements, that allow to apply the standard to every organization types.

Within the ISO 14000 series, the ISO 14031 and ISO 14044 standards are explicitly related with the definition of environmental indicators. The two frameworks fundamentally differ for the fact that ISO 14031 focuses on the organization performance whereas ISO 14044 adopts a perspective based on the evaluation of the product (functional unit) performance.

Specifically ISO 14031 has proposed a methodology to measure Environmental Performance in terms of definitions, working structure, and different types of quantitative indicators. According to ISO, Environmental Performance Evaluation (EPE) is defined as "an environmental management process that uses indicators to provide information comparing an organization's past and present performance with its environmental performance criteria" (UNI EN ISO 14031, 1999). ISO 14031 establishes two general categories of environmental indicators:

- Environmental Performance Indicators (EPIs), which provide information about an organization's environmental performance.
- Environmental Condition Indicators (ECIs), that provides information about the local, regional, national, or global condition of the environment.

EPIs are further on classified in two categories:

- Management Performance Indicators (MPIs) that provide information about management efforts to influence the environmental performance of the organization's operations.
- Operational Performance Indicators (OPIs), which provide information about the environmental performance of the organization's operations, following an input-output operational scheme.

On the other hand the ISO 14044 framework deals with Life Cycle Assessment (LCA), an iterative technique (reflecting the focus on continuous improvement that characterizes the "Plan-do-check-act" model) defined as a "compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle" (UNI EN ISO 14044, 2006). Specifically LCA is structured in four steps, i.e. Goal and scope definition, Life Cycle Inventory (LCI), Life Cycle Impact Assessment (LCIA), Interpretation. Anyway, for the scope of this study, particular attention will be given to the LCI and LCIA phases. LCI is defined as "the phase of LCA involving the compilation and quantification of inputs and outputs, for a given product system throughout its life cycle", whereas LCIA, by means of LCI data, is "aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system" through the definition of impact categories, category endpoints and the corresponding category indicators. There are several methodologies for conducting the LCIA phase, in particular Eco-indicator 99, Eco-points, Global Warming Potential (GWP) and Cumulative Energy Demand (CED).

Sommario

La necessità di includere considerazioni ambientali nella valutazione delle prestazioni della supply chain sta guadagnando sempre maggiore attenzione, sia da un punto di vista della ricerca e pratica. Contributi scientifici incentrati su questo tema vengono progressivamente sottoposti al vaglio della comunità accademica. Tenuto conto di questa tendenza verso una proliferazione di documenti, la necessità di rivedere sistematicamente e classificare i contributi esistenti fornisce la motivazione per questo studio. La metodologia adottata consiste nell'applicare la Systematic Literature Network Analysis (SLNA) che combina un approccio di revisione sistematica della letteratura per identificare gli articoli più rilevanti da includere nell'analisi e la Network Analysis delle citazioni al fine di spiegare la dinamica del settore in fase di studio e di identificare i cluster di articoli. Da questa analisi emerge una classificazione di documenti in conformità con la ISO14000.

Questo lavoro contribuisce al crescente dibattito sugli indicatori ambientali più adatti alle supply chain attraverso l'analisi della letteratura scientifica e di fornire una classificazione degli indicatori ambientali stessi.

Abstract

The necessity to include environmental considerations in the assessment of supply chain performance is gaining increasing attention from both a research and practical perspective. Scientific contributions focusing on this topic are progressively being submitted to the academic community consideration. Given this trend towards a proliferation of papers, the need to systematically review and classify the existing contributions provides the motivation for this study. The methodology adopted consists is applying the Systematic Literature Network Analysis (SLNA) that combines a Systematic Literature Review approach to identify the most relevant articles to be included in the analysis and Citation Network Analysis in order to unfold the dynamics of the field under study and to identify clusters of papers. From this analysis a classification of papers emerges in accordance with ISO14000 framework.

This paper contributes to the growing debate on environmental indicators for supply chains, by analyzing the existing body of knowledge on this topic and providing a classification of the environmental indicators.

Nota biografica sugli autori

Dr. Fernanda Strozzi

Fernanda Strozzi si è laureata in Matematica a Pavia ed ha conseguito il dottorato in Ingegneria chimica presso l'università di Twente in Olanda nel 1997. E' ricercatrice presso l'Università Cattaneo-LIUC dove è titolare dei corsi di Simulazione e Gestione di Sistemi Discreti e Metodi Matematici per le Applicazioni Industriali. I suoi principali interessi di ricerca riguardano la teoria dei sistemi non lineari, lo studio delle serie temporali, lo studio del controllo e della stabilità dei sistemi dinamici, l'effetto bullwhip, la teoria delle reti complesse e recentemente ha incominciato ad occuparsi del problema della sostenibilità nelle supply chain. Su questi temi è autrice di circa 100 pubblicazioni di cui 30 su riviste "peer-review" in collaborazione con centri di ricerca nazionali ed internazionali. E' stata coordinatrice per l'Università Cattaneo-LIUC di due progetti Europei, uno sulla sicurezza dei reattori chimici (AWARD, 2002-2005) ed un altro sulla teoria delle reti complesse applicata alle reti artificiali sviluppate dall'uomo come ad esempio le reti elettriche e logistiche (MANMADE, 2007-2009). E' revisore di diverse riviste internazionali tra cui: International Journal of Production Economics, International Journal of Production Research, Decision Support System, Physica A, T-ASE: Transaction on Automation Science and Engineering, International Journal of Systems Science.

Biographical sketch

Dr. Fernanda Strozzi

Fernanda Strozzi was graduated in Mathematics at the University of Pavia, and received her PhD in Chemical Engineering from the University of Twente in the Netherlands in 1997. She is a research fellow at the Cattaneo University-LIUC where she is teaching Management and Simulation of Discrete Systems and Mathematical Methods for Industrial Applications. Her main research interests include the theory of nonlinear systems, time series analysis, control and stability of dynamical systems, bullwhip effect, complex networks theory and recently she has started to work on sustainability of supply chain and bibliographic networks. On these issues she is the author of about 100 publications in collaboration with national and foreign research centres. She was work package leader in two European projects, one on the safety of chemical reactors (AWARD, FP5 2002-2005) and another on the theory of complex networks applied to manmade networks such as power grids and supply chains (MANMADE,FP6, 2007-2009). She is reviewer for several scientific journals, between them: International Journal of Production Economics, International Journal of Production Research, Decision Support System, Physica A, T-ASE: Transaction on Automation Science and Engineering, International Journal of Systems Science.

Nota biografica sugli autori

Dr. Claudia Colicchia

Claudia è attualmente Lecturer in Logistics and Supply Chain Management presso la Hull University Business School nell'ambito del Logistics Institute, dove è responsabile del percorso di studi denominato BSc Supply Chain Management. Claudia è laureata con lode in Ingegneria Gestionale (2007) ed è dottore di ricerca in Gestione Integrata d'Impresa (2010), titoli ottenuti presso l'Università Carlo Cattaneo - LIUC di Castellanza. Nel 2009 ha ottenuto il master in Gestione Strategica degli Acquisti e della Supply Chain del MIP - Politecnico di Milano. A partire da ottobre 2010, ha intrapreso una collaborazione di ricerca con la Cranfield University – School of Management dopo un semestre in qualità di visiting researcher. Dal 2008 è abilitata all'esercizio della professione di Ingegnere Industriale.Ha precedentemente ricoperto il ruolo di assegnista di ricerca presso la Scuola di Ingegneria Industriale dell'Università LIUC, è stata collaboratrice alla didattica presso la medesima Scuola e ricercatrice presso il Centro di Ricerca sulla Logistica della LIUC. Claudia è stata collaboratrice alla docenza presso la Scuola di Ingegneria dei Sistemi del Politecnico di Milano e presso numerosi Istituti di formazione pubblici e privati. La sua attività scientifica si è sviluppata su tre linee di ricerca principali: Gestione del rischio nella Supply Chain, Sostenibilità delle Supply Chain, Progettazione e gestione delle reti logistiche. I risultati dell'attività scientifica hanno consentito la realizzazione di articoli presentati a conferenze internazionali e pubblicati sulle principali testate nazionali del settore e su riviste internazionali referate. Claudia è revisore di numerose prestigiose riviste internazionali.

Biographical sketch

Dr. Claudia Colicchia

Claudia is a Lecturer in Logistics and Supply Chain Management at Hull University Business School within the Logistics Institute, where she is leading the BSc Supply Chain Management programme. Claudia, after having obtained an MSc in Management and Industrial Engineering in 2007 (with full honours) and her Ph.D. in Management and Industrial Engineering in 2010 (with full honours and publication recommended) at LIUC University - Italy, successfully completed an MBA programme in Strategic Supply Chain and Purchasing Management at MIP Politecnico di Milano - Italy. Since 2010, she started a research collaboration with Cranfield University School of Management, after having spent there a semester as a visiting researcher. Since 2008 she is licensed to practice the profession of Industrial Engineer. Prior to this post, Claudia was a lecturer, adjunct lecturer and tutor for undergraduate, graduate and professional level courses within different educational bodies, i.e. LIUC University - Italy, Politecnico di Milano - Italy, public and private business schools and trade union institutes - Italy. She was researcher at the Logistics Research Centre of LIUC University – Italy, contributing to the development of several research and consulting projects. Her scientific activity has been focusing on three main research streams: Supply Chain Risk Management, Supply Chain Sustainability, Logistics networks design and management. The results of the scientific activity allowed producing articles presented at international conferences and published in leading national journals and international peer-reviewed journals. Claudia is reviewer for a number of international peer-reviewed journals.

Nota biografica sugli autori

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Andrea Sorrenti ha una laurea triennale in economia e commercio conseguita presso l'Università degli Studi di Milano Bicocca ed una laurea specialistica in ingegneria gestionale conseguita presso l'università LIUC. Al momento lavora nel dipartimento di project control presso una multinazionale operante a livello mondiale come EPC (Engineering, Procurement, Construction) contractor nella realizzazione di progetti su larga scala (impianti Oil & Gas , impianti industriali, raffinerie, impianti petrolchimici, infrastrutture civili).

Biographical sketch

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Andrea Sorrenti got a bachelor degree in economics at Bicocca University in Milan and a master degree in industrial engineering at LIUC University. Currently is working in the project control department of a multinational corporation operating worldwide as EPC (Engineering, Procurement, Construction) contractor for large-scale projects (Oil & Gas plants, industrial plants, oil refineries and petrochemical plants, civil infrastructures).