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Innovation for Sustainable Development Network

Deliverable D2.2. Green Economy and Eco-Innovation: A review of emerging research themes

WP 2 – Harmonization of concepts of green economy and eco-innovation

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Abstract

The paper reviews the literature, over the last three decades, to map out the existing body of knowledge of the themes associated with the concepts of 'eco-innovation' and 'green economy'. The aim is to better understand the cohesion, integration, inter-relatedness, evolution and exposure in the scientific literature of the concepts. A bibliometric, content and network analysis approach was followed to identify connections between the themes and concepts, through a forward looking analysis, and discusses how eco-innovation can effectively contribute to the green economy and how these concepts may be better aligned to support the sustainable development goals. The paper concludes with a research agenda to improve the uptake and impact of the concepts by various stakeholders.

Keywords

Eco-innovation; Green Economy; Sustainable Development; Bibliometric Analysis; Content Analysis; Network Analysis.

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1. Introduction

Sustainable development and the transitioning to a low-carbon, resilient economy, also referred to as the 'green economy', require a concerted effort from different scientific disciplines. The United Nations Environment Programme (2011) defines a green economy as "*an economy that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities*". Further, to facilitate this sustainable transition, appropriate research and development efforts that are transdisciplinary in nature are necessary (Brent, 2015).

Such research and development efforts will require knowledge co-creation with societal participants that are intrinsically involved with real-world complex problems (Regeer and Bunders, 2009). Also, to find solutions to these complex problems, a preferred mechanism, to a large extent, is innovation. With respect to sustainability challenges the interest in the notion of sustainable innovation, connected to new business models, is rapidly increasing (Boons et al., 2013). Nevertheless, the definition of the term sustainable innovation is limited in academic literature.

A handful of authors have noted that sustainability-oriented innovation is an emerging field for which its theoretical, empirical, and policy base is currently under construction (c.f. Kemp, 2010, Ekins, 2010). In particular, Van den Bergh et al (2011) noted a clear fragmentation of this emerging academic area and a lack of a coherent community or journal devoted to it. Notwithstanding, the growing academic interest in the study of eco-innovation, and its apparent fragmentation, can be illustrated with the results of literature-based innovation output (LBiO) measurement of bibliographic data (Arundel et al., 2007), such as the one presented by the authors of this document.

A review of Carrillo-Hermosilla et al. (2010) lists innovation definitions that focus on ecological sustainability, such as eco-innovation and environmental innovation. They then define the term as: "*innovation that improves sustainability performance*", where such performance includes ecological, economic, and social criteria. However, Boons et al. (2013) note that the criteria will differ as a result of spatial, temporal and cultural embeddedness, and sustainable innovation will then have different meanings and characteristics in different contexts. Because of the different sustainability challenges associated with the context, they argue that a clear distinction can be made between: developed, consumerist economies; emerging economies, such as Brazil, Russia, India China, and South Africa (BRICS); and so-called Base-Of-the-Pyramid economies, which include many countries in Africa and other developing regions (Tukker et al., 2008; Hart and Milstein, 1999). Among European scholars the definition provided by Kemp and Pearson (2008) is widely accepted, as it refers to: *"the production application or exploitation of a good, service, production process, organisational structure, or management or business method that is novel to the firm or user and which results, throughout its life cycle, in a reduction of environmental risk, pollution and the negative impacts of resources use (including energy use) compared to relevant alternatives."* However, as it is noted in this paper, across the world different epistemic communities have used manifold concepts and associated meanings for innovations oriented to sustainable development, including terms such as low carbon innovation, green innovation, environmental technologies, eco-efficient innovation, etc.

With respect to the green economy, the concept of eco-innovation (and associated terms) could represent the evolutionary economic approach to the analysis of the

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greening of industry and the economy (Andersen, 2010). Machiba (2010) then provides a useful classification and framework (see Figure 1) of eco-innovation based on the levels of making differences from the existing state. A similar approach is adopted by Carrillo et al (2010) and Kemp (2011):

Level 1 (incremental): Incremental or small, progressive improvements to existing products.

Level 2 (re-design or 'green limits'): Major re-design of existing products (but limited the level of improvement that is technically feasible).

Level 3 (functional or 'product alternatives'): New product or service concepts to satisfy the same functional need, e.g. teleconferencing as an alternative to travel.

Level 4 (systems): Design for a sustainable society.

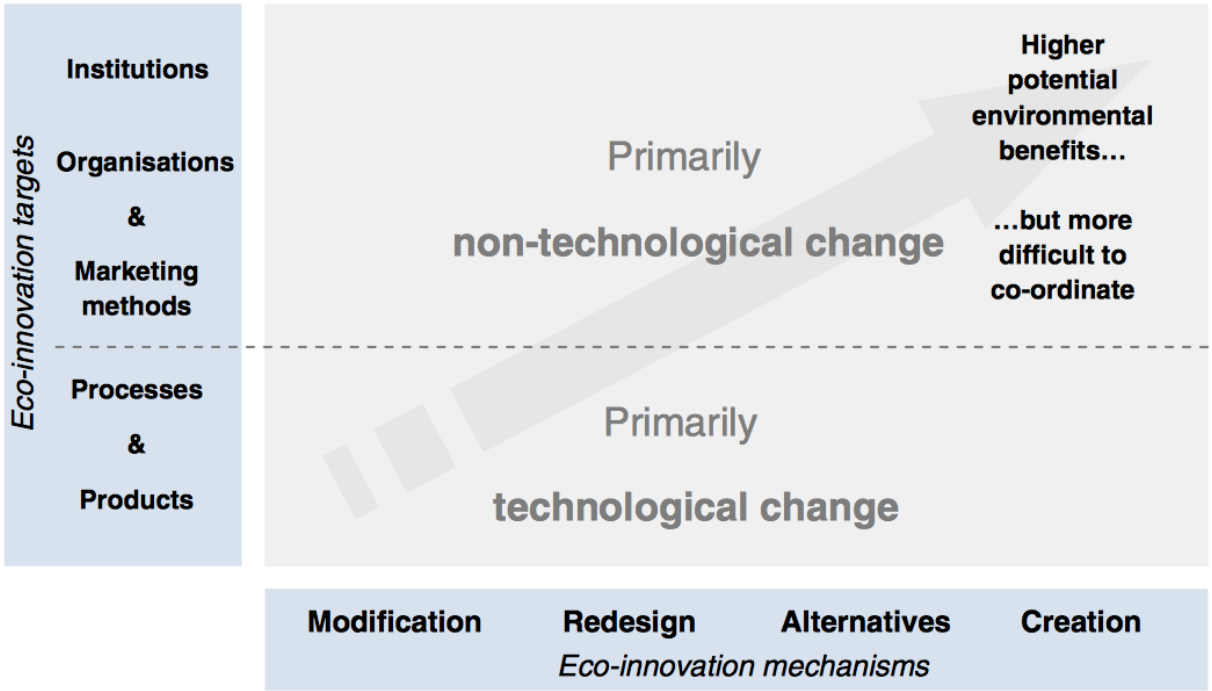

Figure 1: A proposed framework for eco-innovation in the green economy context (adopted form Machiba, 2010)

1.1. Objectives of the paper

The paper addresses the need to understand the research and development efforts that have been undertaken globally pertaining to the green economy and sustainable innovation, specifically eco-innovation. The paper then reviews the literature since the 1980s when sustainable development came to the fore, to map out the research themes associated with the concepts of green economy and eco-innovation, as sub-concepts of sustainable development. The paper aims to establish connections between the themes and concepts, through bibliometric and network analyses, and discusses how eco-innovation can effectively contribute to the green economy, and how these concepts may be better aligned to support the sustainable development goals.

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The paper concludes with a research agenda to improve the uptake and impact of the concepts by various stakeholders.

The paper complements Deliverable 2.1 of the project, which maps the concepts of eco-innovation, green economy, and sustainable development according to how they are defined geographically, and by different stakeholders, namely: the public sector (at different levels), the private sector (at various scales), and by society at large (NGOs). Whereas this paper focuses on the academic literature, Deliverable 2.1 is based on a review of documents that that have been influential in the conceptualization of sustainable development across the globe and by the different stakeholders; and establishes how the different stakeholders have utilised the concepts across the globe; for planning, policy- and decision-making.

1.2. Approach and questions of the paper

The evaluation of scientific work is among the key driving forces behind modern scientific advancements. Evaluative bibliometrics seeks to assess the impact of scientific output in the context of other published science and usually compares the relative scientific contributions of research groups or institutions (Rosas et al., 2011). Bibliometrics involves the quantitative assessment of the occurrence of certain events in the scientific literature, as opposed to the analysis and interpretation of the literature's content. The use of bibliometrics relies on the very structured nature and expectations of the refereed scientific literature.

This bibliometric analysis included the publication output characteristics, as well as country, region and institution contributions to the body of literature associated with the concepts of green economy and eco-innovation. The network analysis was undertaken to highlight existing scientific clusters and research themes, as well as to identify emerging research themes. Content analysis of documents is used as an auxiliary method to identify messages contained in large sets of documents (Stone, Dunphy et al. 1966).

The general approach of the paper was then to address the following five questions:

1. How did the concepts co-evolve?
2. How have the concepts been integrated?
3. What is the structure of the scientific / academic network of the concepts?
4. What are the key research themes in the body of literature concerned?
5. What are the salient factors that are representative of the scholarly community of eco-innovation?

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3. Data sources and methodology

3.1. Sampling and search procedure

To engage with the academic literature for the bibliometric analysis, the Scopus database was selected and searched. Scopus was selected as database because it is deemed to be the largest abstract and citation database of peer-reviewed research literature. Scopus provides a set of metadata that includes article title, authors, abstracts, keywords, citations, institutions and references that could be used to perform the bibliometric analysis.

The search was conducted in September 2015 to collect articles published with the phrases 'green economy' and 'eco-innovation' and related terms. No restrictions were placed on publication date, document type or subject area. The documents were subsequently analysed according to characteristics of publications such as patterns, authorship, citations, and keywords.

The key areas of interest are 'eco-innovation', 'green economy' and 'sustainable development'. However, it is argued that eco-innovation and green economy inherently imply sustainable development, and thus was the term 'sustainable development' not included in the search phrases. However, alternatives for eco-innovation and green economy were selected to ensure that all literature relevant to the primary keywords be included in the bibliometric analysis. The key terms or phrases that were used in the database search are shown in Table 1. The initial search, using only the phrases Green economy and Eco-innovation, produced only two documents. The search phrases were expanded to include related alternatives for the phrases 'eco-innovation' and 'green economy'; the first expanded set produced a total of 8 documents. A second expansion was done on the set of search phrases, and is also shown in Table 1. The outcome from the second expanded set was 46 articles, and these articles were selected to perform further analyses. Keywords directly related to energy were deliberately excluded; in order to let the relevance of green economy and eco-innovation for energy emerge from the analysis.

After the initial analysis of the 46 documents, two were excluded due to one document being a conference review, and the other a book. However, book chapters were not excluded.

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Table 1: Keywords used in the database search

	Scopus Search	# of documents
	(TITLE-ABS-KEY (**{green economy}**) **AND** TITLE-ABS-KEY (**{eco-innovation}**))	2
1st Expanded set	(TITLE-ABS-KEY (**{eco-innovation}**) **OR** TITLE-ABS-KEY (**{environmental innovation}**) **OR** TITLE-ABS-KEY (**{sustainable innovation}**) **AND** TITLE-ABS-KEY (**{green economy}**) **OR** TITLE-ABS-KEY (**{low-carbon development}**) **OR** TITLE-ABS-KEY (**{low-carbon economy}**) **OR** TITLE-ABS-KEY (**{resilient economy}**))	8
2nd Expanded set	(TITLE-ABS-KEY ({**eco-innovation**}) **OR** TITLE-ABS-KEY ({**environmental Innovation**}) **OR** TITLE-ABS-KEY ({**Environmental Technology**}) **OR** TITLE-ABS-KEY ({**Eco-efficiency**}) **OR** TITLE-ABS-KEY ({**Eco-design**}) **OR** TITLE-ABS-KEY ({**Environmental Design**}) **OR** TITLE-ABS-KEY ({**Sustainable Design**}) **OR** TITLE-ABS-KEY ({**Sustainable Innovation**}) **AND** TITLE-ABS-KEY ({**green economy**}) **OR** TITLE-ABS-KEY ({**low carbon development**}) **OR** TITLE-ABS-KEY ({**low carbon economy**}) **OR** TITLE-ABS-KEY ({**resilient economy**}))	46
Refinement search	TITLE-ABS-KEY ({Eco-innovation}) OR TITLE-ABS-KEY ({Environmental Innovation}) OR TITLE-ABS-KEY ({Ecological innovation}) OR TITLE-ABS-KEY ({Low carbon innovation }) OR TITLE-ABS-KEY ({Green innovation }) OR TITLE-ABS-KEY ({Climate change innovation}) OR TITLE-ABS-KEY ({Cleantech}) OR TITLE-ABS-KEY ({Sustainable Innovation})	1369

An additional "refinement" search of eco-innovation documents was performed in October 2015 focusing on peer-reviewed articles within the categories of **eco-innovation, environmental Innovation, or Sustainable Innovation.** To the previous list the research team decided to add 5 additional terms: **Climate change Innovation**, **Ecological Innovation, Cleantech, Low carbon innovation**, and **Green Innovation** (using the Boolean connector **OR**).[1] Using content analysis of documents, a sample of this dataset was subsequently used to further identify messages around 'green economy' and 'sustainable development' possibly contained in academic literature within the Eco-innovation (and related terms) domain. A total of 1369 documents published between the year 1976 and 2015 were identified and a sample of 15% of these documents was further stratified (per year) indexed and coded. A complementary search of reports from publicly funded studies was also performed using the standard function of google search. A total of 270 documents was selected

[1] The reason for including the terms 'green innovation' and additional terms such as "cleantech" appeared to have a relative importance in the results from the search, producing nearly 200 and above 100 documents respectively. Other terms were also include for representativity purposes, albeit their frequency ranged in between 2 to 66 documents in the set but these are terms to be used by scholars in India, China, North America, etc..

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and categorised to be usable in automated content analysis of documents, both academic articles and public reports representing knowledge around these topics produced by academics and consultants, respectively.[2]

3.2. Bibliometric analysis

The bibliometric analysis considered the published articles since the 1980s and stratified the number of publications by journal and year. The initial 46 papers had been published 20 sources (journals and conference proceedings), and identified 109 authors that contributed towards the 46 documents.

A network analysis was then undertaken pertaining to the geographical regions, authors, number of papers, and focus areas. For example, most frequently cited articles were determined from networks of citations, or articles referenced, and co-citations. The co-citation network indicated the degree of similarity among references by showing the papers that have been mentioned together. The network analysis of the keywords of the publications, specifically, revealed the emerging research themes and focus areas in the combined fields of 'green economy' and 'eco-innovation'.

3.3. Content analysis

Automated content analysis of documents using NVIVO® is used to systematically review literature for the analysis a large amount of documents (Welsh 2002). The method employed in this analytical exercise is based on the method proposed by Diaz Lopez and Montalvo (2015a, 2015b) for the study of large data sets of eco-innovation-related documents.

In principle, two broad sets of documents collected during the "refinement" step were analysed using this auxiliary analytical method. The sample of academic articles corresponded to a stratified (by year) non-random selection of around 15% of the articles identified in the dataset of 1369 documents collected from Scopus using the TITLE-ABS-KEY for the terms: Environmental innovation, Eco-innovation, Sustainable Innovation, Green innovation, Cleantech, Climate change innovation, Ecological innovation, and Low carbon innovation (see 2.1).This sample resulted in 193 journal articles published in the period 1976-2015. The second group of documents included 77 scientific and policy reports commissioned by public authorities or multi-national organisations in the period 1983-2015, primarily the OECD, UNEP and the European Commission.

[2] This dataset of reports included a large number of OECD publications - which for the purposes of the analysis of the authors was considered in the category of reports.

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4. Results

An overview of the results is provided in Table 2.

Table 2: Search statistics

Search term	Documents in search	Total citations	Total authors
Green economy (and related terms)	2132		
Eco-innovation (and related broad terms)	14955		
Eco-innovation (and related narrow terms)	1369		
Green economy and eco-innovation (and related terms)	46	76	109

4.1. Publishing trends

The review of publications related to the green economy included the following terms:

(TITLE-ABS-KEY ({**green economy**}) **OR** TITLE-ABS-KEY ({**low carbon development**}) **OR** TITLE-ABS-KEY ({**low carbon economy**}))

Up to September 2015 the total publications numbered 2098, of which 1948 were published until the end of 2014 (see Figure 2). The first publications occurred in the early 2000s, and escalated over the last decade.

Much more has been published on eco-innovation when considering the following broad terms:

(TITLE-ABS-KEY ({**eco-innovation**}) **OR** TITLE-ABS-KEY ({**environmental Innovation**}) **OR** TITLE-ABS-KEY ({**Environmental Technology**}) **OR** TITLE-ABS-KEY ({**Eco-efficiency**}) **OR** TITLE-ABS-KEY ({**Eco-design**}) **OR** TITLE-ABS-KEY ({**Environmental Design**}) **OR** TITLE-ABS-KEY ({**Sustainable Design**}) **OR** TITLE-ABS-KEY ({**Sustainable Innovation**}))

A total of 14748 publications were recorded by September 2015, with 13417 documents by the end of 2014 (see Figure 3).

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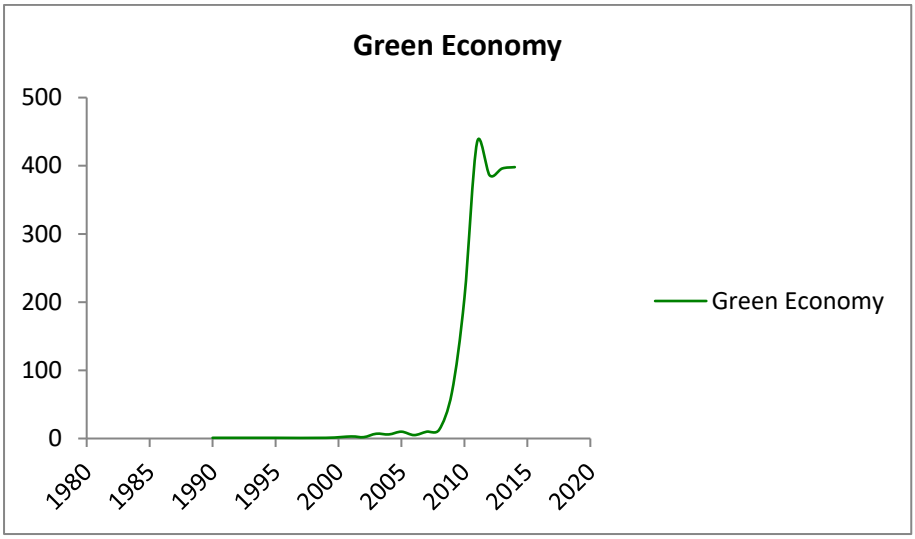

Figure 2: Publications related to the green economy and related terms

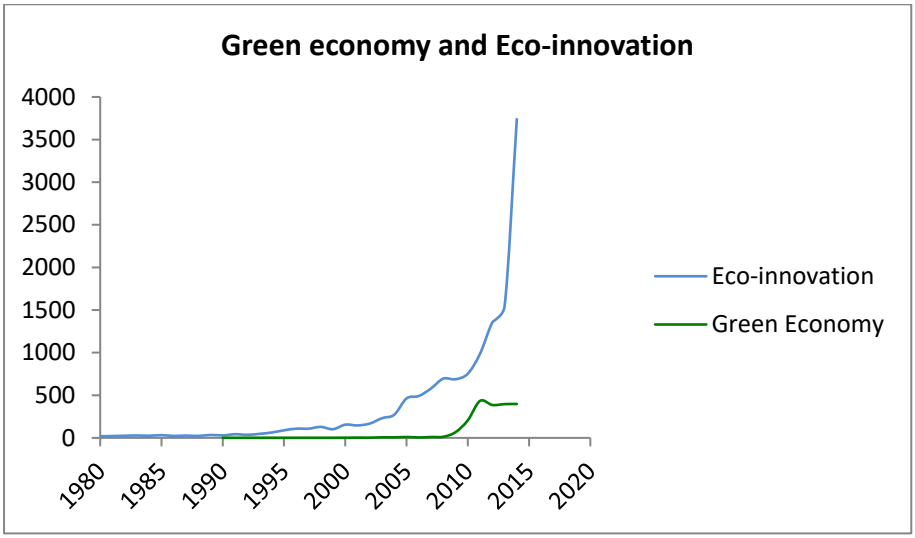

Figure 3: Publications related to eco-innovation and related terms (the outcomes of Figure 1 are also reflected)

Eco-innovation as a broad concept emerged with sustainable development, by the end of the 1980s, whereas the concept of a green economy was only realised a decade later (see Table 3). Notwithstanding, related terms first made their appearance as early as 1950s and seems to have a strong association with the fields of engineering, environmental sciences, energy, social sciences, business management and economics.

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Table 3: Summary of results regarding the first appearance of eco-innovation terms (broad definition), countries that has produced the largest amount of articles and areas of knowledge (subjects) of scholarly publications.

Keyword	First appearance	Country1	Country2	Country3	Subject1	Subject2	Subject3
Environmental technology	1968	China	USA	UK	Engineering	Environmental Sciences	Energy
Environmental design	1955	USA	UK	China	Engineering	Environmental Sciences	Social sciences
Eco-efficiency	1986	China	USA	Germany	Environmental Science	Engineering	Business, Management and Accounting
Sustainable design	1996	USA	UK	China	Engineering	Social sciences	Environmental sciences
Eco-design	1993	France	UK	China	Engineering	Environmental Sciences	Energy
Environmental innovation	1991	USA	Germany	UK	Business, Management and Accounting	Environmental Sciences	Economics, econometrics and finance
Eco-innovation	2000	Spain	France	Italy	Business, Management and Accounting	Engineering	Environmental sciences
Sustainable Innovation	1993	Netherlands	USA	UK	Business, Management and Accounting	Engineering	Social sciences

A subsequent search of a narrower interpretation of the term eco-innovation was performed in October 2015. This exercise allows filtering and refining how much has been exclusively published on innovation-related terms. For analytical purposes, in this refinement exercise it was decided to exclude those terms related to design, efficiency, and technology due to the large amount of documents for each category obtained from previous searches.

TITLE-ABS-KEY ({**Eco-innovation**}) **OR** TITLE-ABS-KEY ({**Environmental Innovation**}) **OR** TITLE-ABS-KEY ({**Ecological innovation**}) **OR** TITLE-ABS-KEY ({**Low carbon innovation** }) **OR** TITLE-ABS-KEY ({**Green innovation** }) **OR** TITLE-ABS-KEY ({**Climate change innovation**}) **OR** TITLE-ABS-KEY ({**Cleantech**}) **OR** TITLE-ABS-KEY ({**Sustainable Innovation**})

A total of 1369 publications were recorded by October 2015 (published in the period 1987-2015) when including the additional terms low carbon innovation, green innovation, climate change innovation, ecological innovation and cleantech, with 1219 documents published by the end of 2014 (see Figure 4). [3]

[3] The search was further performed for all 'technology', 'efficiency' and 'design' related terms. For example, the test of TITLE-ABS-KEY ({**Environmental technology**}) produced over 7303 documents whereas the search TITLE-ABS-KEY ({**Sustainable design**}) produced 2096 documents.

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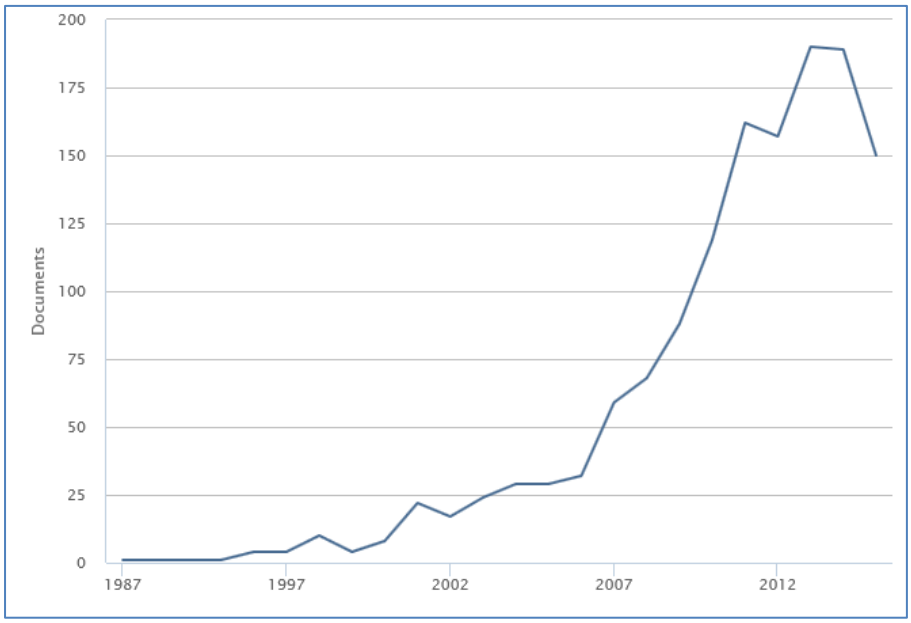

Figure 4: Publications related to eco-innovation in the period 1987-2015 (focusing only on innovation-related terms)

The bibliographic analysis of academic documents also allows the identification of geographical areas and subjects/fields of knowledge where additional terms have been used the most (see Table 4). Such terms seem to have presence in other areas of knowledge, such as agricultural sciences and biochemistry.

Table 4: Summary of results regarding the first appearance of additional eco-innovation terms (narrower definition), countries that has produced the largest amount of articles and areas of knowledge (subjects) of scholarly publications.

Additional term	Year	Country 1	Country 2	Country 3	Subject1	Subject2	Subject3
Ecological innovation	1987	USA	CN	Dk	Agricultural and biological sciences	Biochemistry, genetics and molecular biology	Business, Management and Accounting
Cleantech	1996	USA	DE	UK	Engineering	Business, Management and Accounting	Energy
Low carbon innovation	2003	UK	CA	CN	Energy	Environmental Sciences	Social sciences
Green innovation	2004	TW	CN	UK	Business, Management and Accounting	Engineering	Environmental sciences
Climate change innovation	2009	USA	-	-	Business, Management and Accounting	Energy	Engineering

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Where both concepts were jointly searched for (in September 2015)[4], as described in Table 1, only 46 publications emerged, of which 44 were considered further. Of these, 41 were published by the end of 2014 (see Figure 5 and the supplementary spreadsheet). Only in the last five years did both concepts merge in publications.

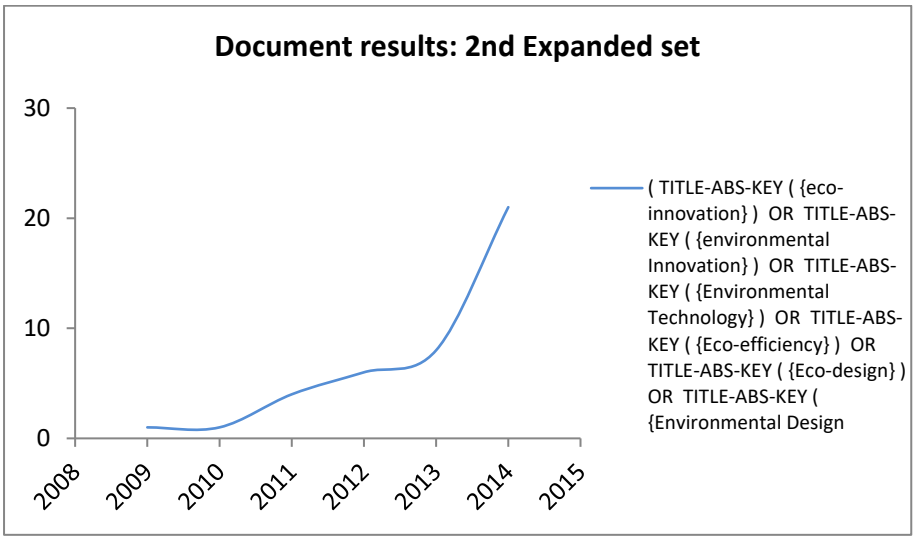

Figure 5: Publications that included both terms

From the analysis of the publications (provided in the supplementary spreadsheet), no conclusions can be made as to the top academic contributors, or the top contributing journals in the field, since the publications are widely distributed (see Table 5).

Table 5: Analysis of the 44 considered papers

SCOPUS NUMBER	NETWORK NUMBER	TITLE	AUTHORS	COUNTRY	JOURNAL / CONFERENCE
1	24	Policy integration strategy and the development of the 'green economy': Foundations and implementation patterns	Hamdouch A. Depret M-H.	France France	Journal of Environmental Planning and Management
2	2	The value of technology and of its evolution towards a low carbon economy	Tavoni M. de Cian E. Luderer G. Steckel J.C. Waisman H.	Italy Italy Germany Germany France	Climate change
3	10	Technology transfer, indigenous innovation and leapfrogging in green technology: The solar-PV industry in China and India	Fu X. Zhang J.	UK UK	Journal of Chinese Economic and Business Studies
4		Business value of toxics reduction and pollution prevention planning	Granek F.	Canada	Journal of Cleaner production

[4] This search used the broad definition of eco-innovation including innovation, technology, design and efficiency-related notions.

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SCOPUS NUMBER	NETWORK NUMBER	TITLE	AUTHORS	COUNTRY	JOURNAL / CONFERENCE
5		Green Growth	Jacobs M.	UK	Book chapter
6	6	The effects assessment of firm environmental strategy and customer environmental conscious on green product development	Tsai M.-T. Chuang L.-M. Chao S.-T. Chang H.-P.	Taiwan Taiwan Taiwan Taiwan	Environmental monitoring and assessment
7	1	Integrated logistics network design in hybrid manufacturing/remanufacturing system under low-carbon restriction	Wang Y. Lu T. Zhang C.	China China China	LISS 2012 - Proceedings of 2nd International Conference on Logistics, Informatics and Service Science
8		An analysis of eco-efficiency in energy use and CO2 emissions in the Swedish service industries	Pardo Martí_nez C.I.	Columbia	Socio-economic planning sceinces
9	1	Eco-efficient based logistics network design in hybrid manufacturing/ remanufacturing system in low-carbon economy	Wang Y. Zhu X. Lu T. Jeeva A.S.	China China China Australia	Journal of Industrial Engineering and Management
10	12	Innovation complementarity and environmental productivity effects: Reality or delusion? Evidence from the EU	Gilli M. Mancinelli S. Mazzanti M.	Italy Italy Italy	Ecological Economics
11		The link between environmental and economic performance: Evidence from some eco-innovative industrial clusters	Tessitore S. Daddi T. Iraldo F.	Italy Italy Italy	International Journal of Environment and Sustainable Development
12	1	Eco-clothing development based on energy saving and multi-functional transformation	Wang W. Yu S. Liu X. Shao B. Wang Y.	China China China China China	Applied Mechanics and Materials
13	4	Eco-innovations in more sustainable supply chains for a low-carbon economy: A multiple case study of human critical success factors in Brazilian leading companies	Jabbour C.J.C. Neto A.S. Gobbo J.A. Ribeiro De M.D.S. Sousa Jabbour A.B.L.	Brazil Brazil Brazil Brazil Brazil	International Journal of Production Economics

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SCOPUS NUMBER	NETWORK NUMBER	TITLE	AUTHORS	COUNTRY	JOURNAL / CONFERENCE
14		Next steps in developing thermally modified timber to meet requirements of European low carbon economy	Kutnar A. Sandberg D.	Slovenia Sweden	International Wood Products Journal
15	7	Smart plugs: Perceived usefulness and satisfaction: Evidence from United Arab Emirates	Ghazal M. Akmal M. Iyanna S. Ghoudi K.	UAE UAE UAE UAE	Renewable and Sustainable Energy Review
16		E-learning sustainability: Creation of a new platform for designing new community identity through lifelong learning	Gallico D.	Italy	World Review of Science Technology and Sustainable Development
17		Greening steel work: Varieties of Capitalism and the 'greening' of skills	Evans C. Stroud D.	UK UK	Journal of Education and Work
18		Research on energy policies and economic development for a carbon reduction Era in Taiwan	Lin W.-C. Chen T.-R.	Taiwan Taiwan	Advanced Matrials Research
19	3	Study on China's carbon emission three factors simulation in the 12th five-year plan:2011-2020 in an economy-energy-environment framework	Liu J.H. Wang Z.H. Jia R.N. Deng Y.J. Tu G.P.	China China China China China	2013 International Conference on Renewable Energy and Environmental Technology, REET 2013
20	25	Research of college students entrepreneurship education in low-carbon economy perspective	Sun Y.L. Qi X.X.	China China	2013 International Conference on Renewable Energy and Environmental Technology, REET 2013
21	16	Design research of environmental protection clothes based on low-carbon concept	Bian F. Cui Y.M. Liu C.M.	China China China	2nd International Conference on Renewable Energy and Environmental Technology, REET 2014

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SCOPUS NUMBER	NETWORK NUMBER	TITLE	AUTHORS	COUNTRY	JOURNAL / CONFERENCE
22	26	Enlightenment of Japanese garbage disposal on Jilin Province developing low carbon economy	Wu F. Chen Z.	China China	2nd International Conference on Renewable Energy and Environmental Technology, REET 2014
23	27	The low carbon financial development of jiangxi province based on low carbon economy	Deng X.Z. Yang Y.	China China	2nd International Conference on Renewable Energy and Environmental Technology, REET 2014
24	11	Philosophical connotation of the development of low-carbon economy	Wang G.L. Gong C.G. Wang Z.Z.	China China China	2nd International Conference on Renewable Energy and Environmental Technology, REET 2014
25	17	Sustainable development. Problems and perspectives	Anufriev V. Anufrieva E. Gudim Y.	Russia Russia Russia	2nd International Conference on Renewable Energy and Environmental Technology, REET 2014
26	9	Assessment about development level of low-carbon economy in resource-based city	Zhang W.H. Zhang J.H. Li R.	China China China	2nd International Conference on Renewable Energy and Environmental Technology, REET 2014
27		The researching on the critical path of clean production in automobile enterprises under low carbon economy	Liu X.R.	China	2nd International Conference on Renewable Energy and Environmental Technology, REET 2014
28	28	Study on the development of low carbon tourism in the era of low carbon economy	Cui L. Liu H.	China China	3rd International Conference on Energy and Envi-

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SCOPUS NUMBER	NETWORK NUMBER	TITLE	AUTHORS	COUNTRY	JOURNAL / CONFERENCE
					ronmental Protection, ICEEP 2014
29		Analysis of carbon emission structure of agricultural ecosystem - A case study of rural areas surrounding yuqiao reservoir in ji county of tianjin,China	Li X.M. Yang Y.A. Hao G.J.	China China China	Applied Mechanics and Materials
30	8	Research on the utilization of renewable energy in Tianjin	Tian L.L. Wang T.T. Guan X.J. Liu Z.B.	China China China China	Applied Mechanics and Materials
31		Technological innovation in the development of agricultural ecoeconomy in china	Zhu P.Y.	China	Applied Mechanics and Materials
32		The comprehensive evaluation and management of input-output of clean production in automobile enterprises under low carbon economy	Liu X.R.	China	2013 International Conference on Renewable Energy and Environmental Technology, REET 2013
33	23	Cloud computing: A collaborative green platform for the knowledge society	Mohamed M.A. Pillutla S.	USA USA	VINE
34	22	Sustainable development of leisure sports tourism under the low-carbon economy	Liu P.-H. Chen X.	China China	2nd International Conference on Renewable Energy and Environmental Technology, REET 2014
35	21	Research on the low-carbon evolutionary model of Chinese traditional industrial clusters based on evolutionary games theory under low-carbon constraints	Fan R.G. Zhang H.J.	China China	2013 International Conference on Renewable Energy and Environmental Technology, REET 2013
36	20	Green becomes the colour of the successful business	Bran F. Ioan I. Râ_dulescu C.V.	Romania Romania Romania	Quality - Access to Success

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SCOPUS NUMBER	NETWORK NUMBER	TITLE	AUTHORS	COUNTRY	JOURNAL / CONFERENCE
37	5	The carbon emission quantification of the low carbon road maintenance technology in China	Zhou K. Wong Y. Xu X. Chiang C. Zhang H.	China Hong Kong China Hong Kong China	2012 Asian Pacific Conference on Energy, Environment and Sustainable Development, APEESD 2012
38	-	Green new deal and tribology	Sasaki S.	Japan	Journal of Japanese Society of Tribologists
39	1	Integrated logistics network design in hybrid manufacturing/ remanufacturing system under low-carbon restriction	Wang Y. Lu T. Zhang C.	China China China	Advances in Information Sciences and Service Sciences
40	14	The new rural landscape architecture research basing on the background of low carbon economy	Cong L. Jiang D. Feng D.	China China China	1st International Conference on Energy and Environmental Protection, ICEEP 2012
41		The green executive: Corporate leadership in a low carbon economy	Kane G.		
42		A carbon assessment and design tool to assist in planning low carbon development	Beattie C.	Australia	19th International Congress on Modelling and Simulation
43	19	Analysis of domestic and overseas green building rating tools	Lian F. Qin X.	China China	16th International Symposium on Advancement of Construction Management and Real Estate, CRIOCM 2011
44	18	Eco-efficiency: A romanian perspective	Violeta S. Gheorghe I.G.	Romania Romania	12th International Business Information Management Association Conference, IBIMA 2009

It is important to note that the network number refers to the geographical distribution of the largest author network contributions relating to both concepts – in Figure 7.

4.2. Networks and focus areas associated with the publications

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The network analysis, by geographical region, authors, number of papers, and focus areas, also shows relatively small clusters that are isolated in the regions (see Figures 5 and 6). However, geographically it would seem that a network of researchers in the Asian (China) region have focussed on the two concepts (see Figure 7), specifically through a conference on renewable energy and environmental technology, since 2013, as well as in the journal Applied Mechanics and Materials. The focus areas of the papers span initiatives across sectors, namely:

1. Energy, and especially usage management and renewable energy solution;

2. Waste management; and

3. Cleaner production approaches in industry such as clothing, and automotive manufacturing, agriculture, and tourism.

Isolated papers focus on enabling such initiatives. For example, financing low carbon initiatives, or education in entrepreneurship. Increasingly there is a tendency to focus on regions, or cities, in terms of resource flows.

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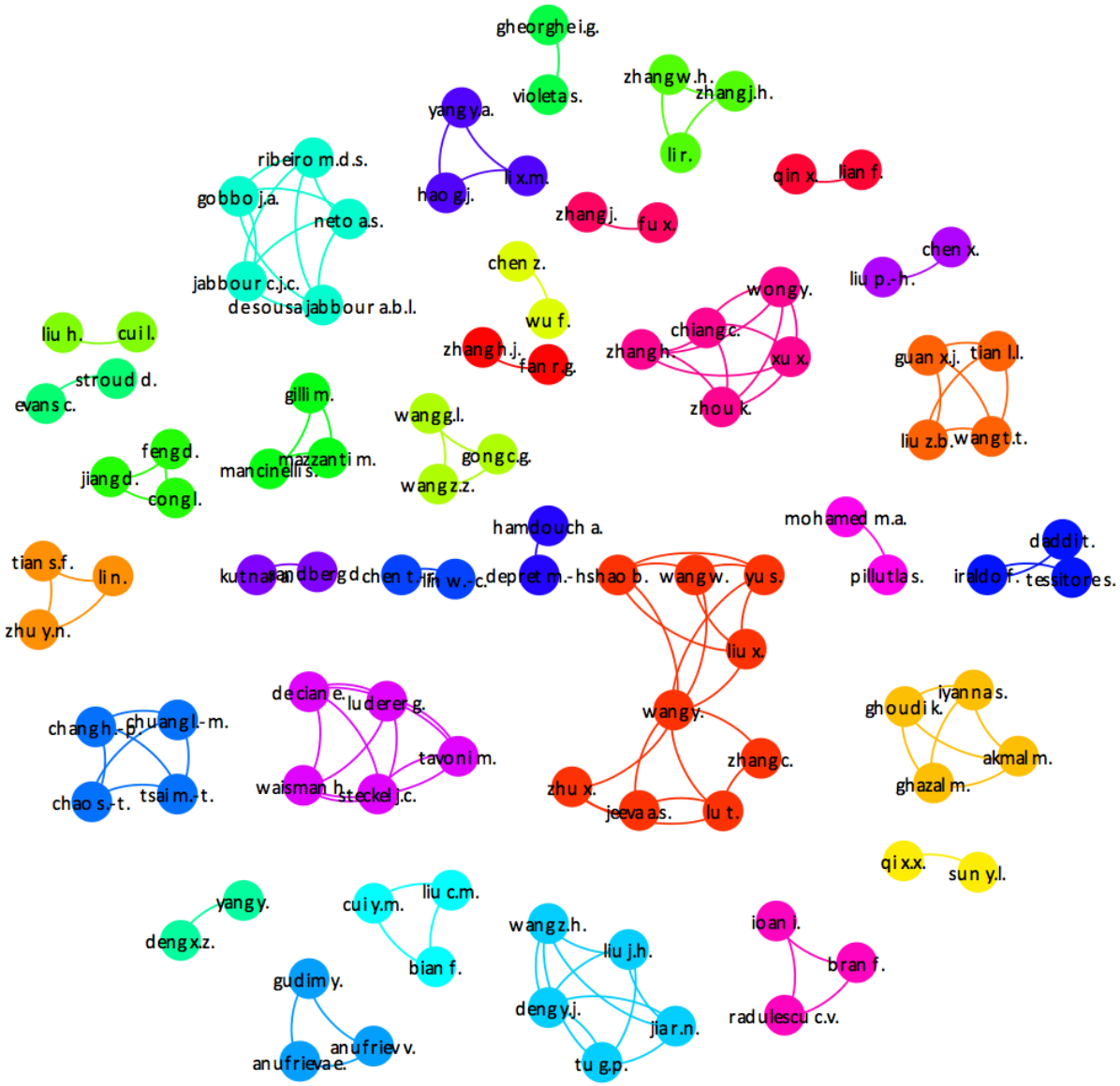

Figure 5: Network analysis by geographical region

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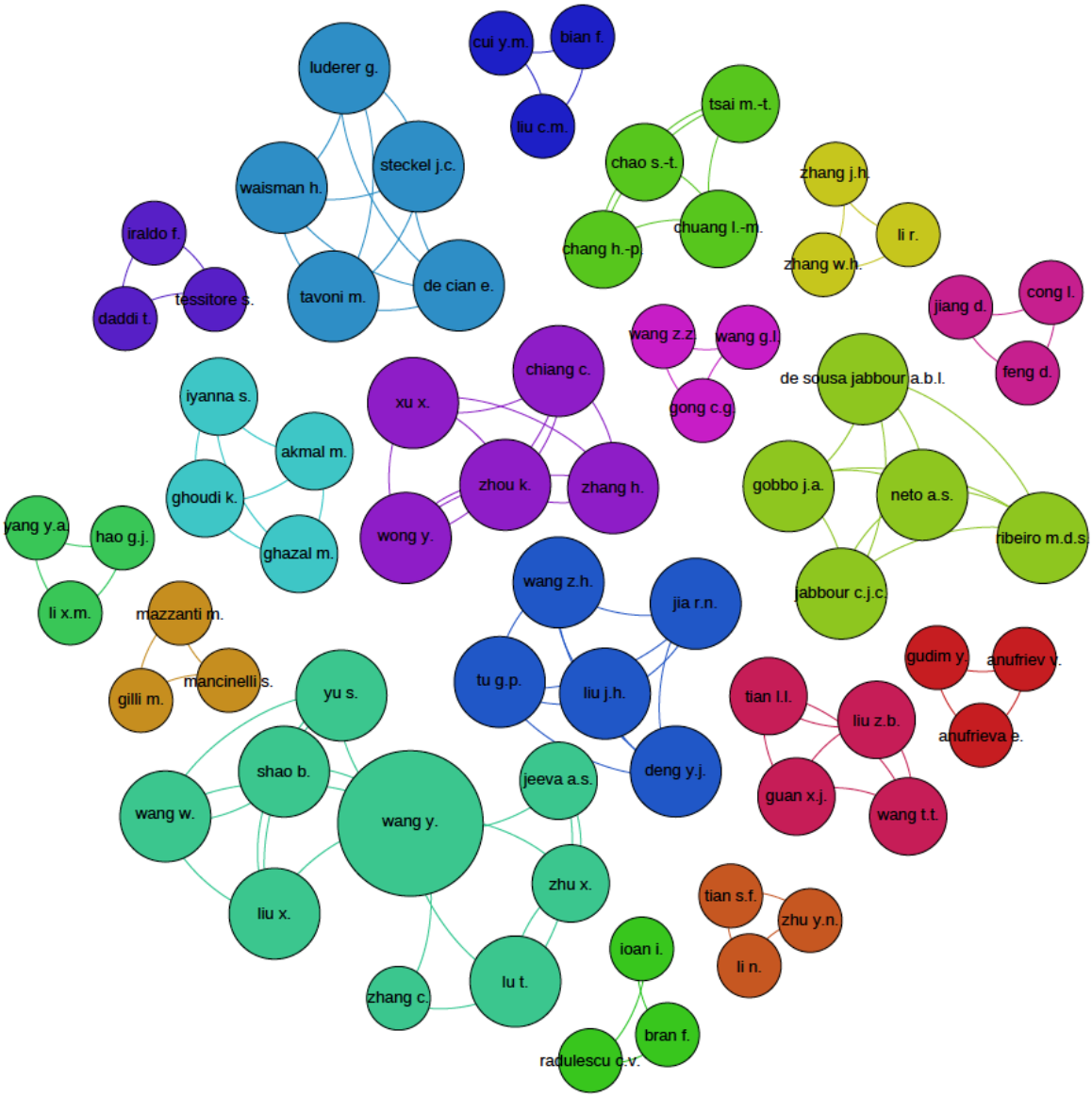

Figure 6: Network analysis of authors, number of papers, and focus areas

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Figure 7: Largest network contributions relating both concepts: eco-innovation AND green economy

4.3. Emerging research themes and trends

Keyword analyses have proven to be an effective means to gain an understanding of the emergence and evolution of new frontiers of science and research (Zheng et al. 2015). The analyses of keywords and papers referenced – or co-word networks (see Figure 8), were used to highlight and identify research themes and emerging directions of research and development.

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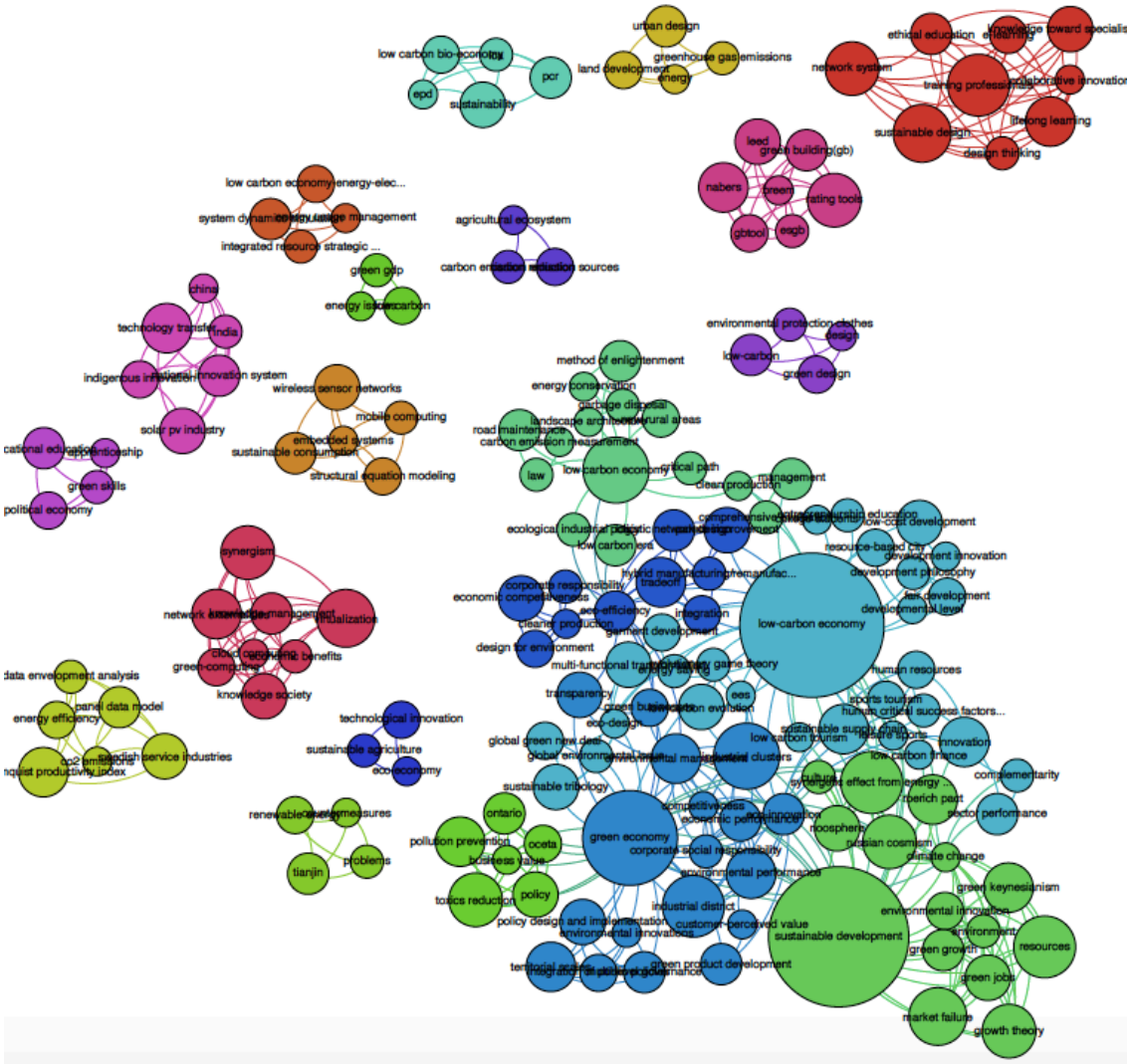

Figure 8: Paper keyword and references analysis – co-word networks

Only one network emerges that revolves around the keywords of 'sustainable development', 'low-carbon economy', and the 'green economy'. The analysis (summarised in Table 6) clearly shows a tendency to associate the concept of green economy with that of a low-carbon economy, although resources, and especially energy, and environmental pollution and management are also aspects that receive much attention. Eco-innovation, and innovation in general, occur less as explicit keywords, but are important linkages between the research efforts. Industrial clusters, and districts, to enable innovation is a clear theme, with related aspects such as logistics and cleaner production.

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Table 6: Prioritised keywords from the network analysis

Keywords	Occurrences Count	Eccentricity	Closeness Centrality	Betweenness Centrality	Modularity Class
Low-carbon economy	14	1	1.0	465.2	7
Green economy	7	2	1.3	360.0	5
Eco-efficiency	6	2	1.7	126.0	6
Sustainable development	6	1	1.0	14.8	15
Low carbon economy	5	1	1.0	38.0	1
Climate change	3	2	1.5	0.0	15
Eco-innovation	3	2	1.7	31.3	5
Hybrid manufacturing / remanufacturing system	3	2	1.7	0.0	6
Logistic network design	3	2	1.8	1.0	6
Clean production	2	2	1.8	0.0	1
Eco-design	2	2	1.8	0.0	7
Environmental management	2	3	2.0	16.3	5
Industrial clusters	2	2	1.8	30.8	5
Innovation	2	2	1.8	21.5	7
Integration	2	2	1.9	0.0	6

4.4. Results from content analysis of academic literature and publicly-funded reports

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As noted earlier the analysis of the publications was not sufficiently robust to allow scientifically valid results. For this reason it was considered adequate to further analyse the content of a sample of Eco-innovation articles in order to identify possible trends and themes. Computer-aided content analysis of 270 documents (193 academic articles and 77 project reports) was performed using the NVIVO10® software in order to identify salient messages from a narrower interpretation of eco-innovation literature, focusing exclusively on innovation-related terms (see 2.1 for a description of the results of this 'refinement' search).

A query searching specific text was in the abovementioned 193 peer-reviewed documents was performed. The output of this exercise identified that in 515 occasions the terms 'green economy' or 'sustainable development appeared in 110 articles published in the period 1995-2015. However, the majority of occurrences were in relation to the term sustainable development; only in 15 occasions the term 'green economy' appeared in 11 academic papers published in the period 2010-2015. The presence of the rest of the terms is not outstanding. The query 'search text' for the same terms in 77 publicly funded reports produced a quite distinctive profile. The results of this exercise resulted in a higher amount of mentions to terms related to green economy and sustainable development as early as 1998. What it seems to be evident from both datasets is that the agendas 'low carbon development' and 'resilient economy' may not be currently present in the realm of eco-innovation research, both from an academic and consultancy points of view.

Table 5: Content analysis of the 270 considered academic papers and public reports.

TERM	Articles	N=193	Period	Reports	N=77	Period
	# of documents	# of occurrences of term	(years)	# of documents	# of occurrences of term	(years)
Green economy OR Sustainable Development	110	513	1995-2015	65	1987	1998-2015
Green economy AND Sustainable development	9	113	2010-2015	23	1305	2004-2015
Sustainable development	108	498	1995-2015	63	1685	1998-2015
Green economy	11	15	2010-2015	25	302	2004-2015
Low carbon development	1	1	2008-2015	1	1	2014
Low carbon economy	11	19	2013	21	80	2004-2014
Resilient economy	0	0	NA	0	0	NA

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Since the frequency count says little about the relative important of each term above it was necessary to use an additional analytical method to attempt to identify how important those terms actually may be. Particularly for the second set of documents, possible bias may have been introduced in the analysis depending on the final selection of actual reports included in the analysis. The computer-aided content analysis of documents using NVIVO® produces figures called tag-clouds that contain information about the frequency of occurrence of a term and its relative importance (in this case, a word).[5]

The figure 9 below presents the tag cloud of the top-100 words in the frequency count of terms or words in the selected documents. The term 'innovation' is without doubt the most frequent term followed by the 'environment", with 'development' and 'sustainability' in the top 6th and 18th most-encountered factors in the reviewed academic articles.

In public reports the authors found a similar pattern than the one described in the above. The term 'innovation' is the most frequent term followed by the 'environment", with 'development' and 'sustainability' in the top 6th and 15th most-encountered factors in the reports included in this exploratory review.

[5] In NVivo® the most frequently occurring word is given a font size of 60 points whereas the 100th most frequently occurring word gets a font size of 10 points. The font size of words in between is calculated using a linear mapping between frequency and font size. For example, if the most frequently occurring word occurs 200 times and is given a font size of 60 points, and the 100th most frequently occurring word occurs 100 times and is given a font size of 10 points, then a word occurring 150 times is given a font size of 10 + (60-10)*(150-100)/(200-100) = 35 points. Refer to Diaz Lopez and Montalvo (2015b) for further details of this visual technique in innovation studies.

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Figure 9: Paper keyword and references analysis – co-word networks

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Figure 10: Public documents keyword and references analysis – co-word networks

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5. Conclusions

The paper has reviewed the evolution of the concepts of 'green economy' and 'eco-innovation' in the academic literature over the past three decades. Through biometric and network analyses the paper establishes how eco-innovation can effectively contribute to the green economy, and how these concepts may be better aligned to support the sustainable development goals.

5.1. Co-evolution of the concepts

Eco-innovation as a concept emerged with sustainable development, by the end of the 1980s, whereas the concept of a green economy was only realised a decade later; in the early 2000s. By the end of 2014 nearly 2000 academic papers were published that explicitly focussed on the green economy, while over 13000 academic papers engaged with eco-innovation. Where both concepts were jointly searched for, only 46 publications emerged, of which 44 were considered further. Of these, 41 were published by the end of 2014.

Only in the last five years did both concepts merge in publications as it is shown by both the bibliographic and content analyses of two complementary datasets.

5.2. Integration of the green economy and eco-innovation concepts

The published research efforts that integrated the two concepts highlight initiatives across various sectors, with an emphasis on energy, and especially usage management and renewable energy solutions, waste management; and cleaner production approaches in industry such as clothing, and automotive manufacturing, agriculture, and tourism. Isolated papers focus on enabling such initiatives. For example, financing low carbon initiatives, or education in entrepreneurship. Increasingly there is a tendency to focus on regions, or cities, in terms of resource flows.

The trend above seems to be confirmed by the analysis of the academic sample of documents using a narrower definition of terms associated to eco-innovation. It is only in the last five years that academic articles focusing exclusively on (innovation-related) terms of eco-innovation that both concepts have been addressed by scholars. The attention of eco-innovation as an enabler of sustainable development seems to be much more frequent from the start of both fields of research.

5.3. Structure of the scientific / academic network of the concepts

The network analysis, by geographical region, authors, number of papers, and focus areas, also shows relatively small clusters of research efforts that are disjointed and isolated in the regions. However, geographically it would seem that a network of researchers in the Asian (China) region have focussed on the two concepts, specifically through a conference on renewable energy and environmental technology, since 2013, as well as in the journal Applied Mechanics and Materials.

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5.4. The key research themes in the body of literature concerned

From the analysis only one network emerges that revolves around the keywords of 'sustainable development', 'low-carbon economy', and the 'green economy'. The analysis clearly shows a tendency to associate the concept of green economy with that of a low-carbon economy, although resources, and especially energy, and environmental pollution and management are also aspects that receive much attention. Eco-innovation, and innovation in general, occur less as explicit keywords, but are important linkages between the research efforts. Industrial clusters, and districts, to enable innovation is a clear research theme, with related aspects such as logistics and cleaner production.

In conclusion locality and context is of primary importance for research efforts pertaining to sustainable development, green economy and eco-innovation. The latter is viewed as a mechanism to enable transitions to a green economy, and much emphasis is then on how to foster eco-innovation through regional initiatives.

Further research efforts should focus on cross-regional learning and knowledge transfer, and address a seemingly geographical divide.

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The H2020 Green.eu project and inno4sd® network is coordinated by the Netherlands Organisation for applied Scientific research TNO, TNO Caribbean.

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