Waste Management 32 (2012) 1069–1074

Contents lists available at SciVerse ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Tracking the evolution of waste recycling research using overlay maps of science

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ARTICLE INFO

Article history:
Received 22 July 2011
Accepted 20 January 2012
Available online 18 February 2012

Keywords:
Tech mining
Science map
Research forecasting
Recycling trends

ABSTRACT

Tracking the evolution of research in waste recycling science (WRS) can be valuable for environmental agencies, as well as for recycling businesses. Maps of science are visual, easily readable representations of the cognitive structure of a branch of science, a particular area of research or the global spectrum of scientific production. They are generally built upon evidence collected from reliable sources of information, such as patent and scientific publication databases. This study uses the methodology developed by Rafols et al. (2010) to make a "double overlay map" of WRS upon a basemap reflecting the cognitive structure of all journal-published science, for the years 2005 and 2010. The analysis has taken into account the cognitive areas where WRS articles are published and the areas from where it takes its intellectual nourishing, paying special attention to the growing trends of the key areas. Interpretation of results lead to the conclusion that extraction of energy from waste will probably be an important research topic in the future, along with developments in general chemistry and chemical engineering oriented to the recovery of valuable materials from waste. Agricultural and material sciences, together with the combined economics, politics and geography field, are areas with which WRS shows a relevant and ever increasing cognitive relationship.

1. Introduction

Changes in the amount and composition of waste, in prices of raw materials, and in the performance of recycling processes, are some of the facts that condition the research trends in waste recycling science (WRS). Tracking the evolution of these research activities is an issue of importance for environmental agencies and for recycling business, worldwide. Tracking allows decision makers to develop R&D strategy with empirical facts instead of bare intuition. Tech mining tools can be integrated in a decision support system to reach this goal (Porter and Newman, 2011), making it possible to analyze the very core of worldwide scientific production: the patent and scientific publication databases. Tech mining consists of the application of text mining tools to science and technology information databases, looking for answers to a wide set of key technology management questions (Porter and Cunningham, 2005). Some applications of tech mining include tracking the specialization of different countries in a specific scientific development (Islam and Miyazaki, 2010), or anticipating emerging research fronts, by analysis of citations (Shibata et al., 2008).

Maps of science are feasible using tech-mining tools; these maps are visual representations of the cognitive structure of a branch of science, a particular area of research or the global spectrum of scientific production. The strong points of these visualizations are their readability and the reliability of the sources of information upon which they are built (Noyons, 2005).

This paper aims to analyze the evolution of WRS following the overlay method introduced by Rafols et al. (2010), a method successfully employed with different basemaps to analyze the degree of interdisciplinarity of scientific production in (Rafols et al., 2011; Porter and Rafols, 2009; Rafols and Meyer, 2010) and the cognitive diffusion of particular research areas (Leydesdorff and Rafols, 2011; Kiss et al., 2010).

The overlay maps could also be used to locate bodies of research in the global map of science, obtaining an attractive and intuitive view of the research profile of a university, laboratory, country or enterprise. This application can be particularly useful for benchmarking activities. Some interesting examples can be found in the IDR website (Porter et al., 2010 updated).

The scientific publications pertaining to WRS, as contained in ISI's Web of Science (WOS), have been processed using the text mining tool Vantage Point (Search Technology, 2011 updated) for years 2005 and 2010, and the results overlayed upon the global map of science as shown in Rafols et al. (2010). This global map of science is a picture of the cognitive structure of all science, where the different cognitive areas are represented by Subject Categories

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doi:10.1016/j.wasman.2012.01.017

(SC), with the spatial proximity between SC acting as an indicator of the cognitive relationship between different knowledge areas. SC's are disciplinary categories established by the indexers of the Web of Science, on the basis of a number of criteria including the journal's title and its citation patterns (Pudovkin and Garfield, 2002). The information about the contents of each SC is available at the Journal Citation Reports website (Thomson Reuters, 2011 updated) Other maps of science built using the SC's as analytical unit can be found at Moya-Anegón et al., 2007 and Leydesdorff and Rafols, 2009.

The resulting overlay maps are analyzed, looking for clues about the evolution of research activities in the analyzed area and their relationship with other cognitive areas. A set of conclusions is extracted, seeking to anticipate future trends in WRS research.

An interesting effort has been made by Fu et al. (2010) to provide an overview of solid waste research during the period 1993–2008, by means of tech mining analysis applied to bibliometric fields like keywords and title words. In spite of the very different scope and methodology adopted by Fu et al., some of their conclusions come to reinforce the methodology of this study. It must be noted that the scope of this study is very different from theirs: this is a mapping of the whole of WRS research (including solid waste), overlaying it into the global map of scientific production. The objectives are to determine the main areas where WRS research takes place, and the main areas from where it takes intellectual nourishment, analyzing trends through time and putting them into the context of global worldwide scientific production.

2. Method

The explanation of the method followed is divided in two consecutive steps, namely, the prior study and the overlay process.

2.1. Prior study

The objective of prior study was to identify the main SC's behind WRS. The "Environmental Sciences and Pollution Management" database was chosen for this purpose, because of its specialization in environmental and recycling issues (CSA Illumina (ProQuest), 2011 updated), and queries were run to extract the publications related with WRS. A total of 11,677 articles published in 2067 journals were obtained in this search. A detailed explanation of this step can be found at Rio and Cilleruelo (2010).

The most important journals of this 2067 journal set were selected, following a criterion of relevance (having 20 articles or more in the retrieved dataset) and to the fact of being included in the Journal Citation Reports (JCR). This filtering left 40 journals for the analysis, forming the very core of this scientific field. As shown in Fig. 1, two SC dominated these 40 journals, with a lesser presence of other 17 SC's, without any remarkable SC taking third position.

This fact led to the conclusion that Environmental Sciences (ES) and Environmental Engineering (EE) were the key SC's in WRS. A similar conclusion was exposed in Fu et al. (2010), affirming that both SC's were the mainstream of scientific research around solid waste.

2.2. Overlay process

Having determined the main SC's in WRS in the prior study, the next step consisted in downloading from the WOS all the items published in journals classified in either SC EE or ES, for the years 2005 and 2010. A total of 276 journals met this condition, and a query containing them was made and run upon all the databases available in WOS (SCI-EXPANDED, SSCI, A&HCI, CPCI-S CPCI-SSH), obtaining a total of 23,104 items for year 2005 and 31,623 items for 2010.

The authors considered the inclusive definition given by the EEA for WRS: "A method of recovering wastes as resources which includes the collection and often involving the treatment, of waste products for use as a replacement of all or part of the raw material in a manufacturing process" (European Environment Agency, 2011 updated).This definition includes the recovery of contaminated water and soils into the boundaries of WRS.

The degree of cognitive relationship between the downloaded items and WRS was analyzed. This analysis was carried out on the "Author keyword" field, considering that these keywords give a good perception of the overall topic each paper deals with. Text mining software Vantage Point was used to detect their frequency of occurrence and merge detected synonyms, plural forms and equivalent expressions. After that, the keywords were grouped in topics. The topics water and soil science dominate the dataset, followed in 3rd place by wastewater treatment. It must be noted that many terms related to "water" and "soil" are quite frequent in a wide range of environmental issues, so the probabilities of having this terms leading the keyword list are high, regardless of the specific environmental field object of study. Other terms directly related with WRS occupy the 7th and 11th positions, as can be seen in Table 1, proving the connection between the sample and WRS. The topic "Waste General" has additionally been checked for its relatedness with recycling/recovering issues by concurrence analysis, with confirming results. All numeric results are available upon request to the corresponding author.

From this point forward, the process detailed in the Appendix A of Rafols et al. (2010) was followed to build the overlay maps, helped by the step-by-step manual made by Ken Riopelle, available at Leydesdorff's website (Leydesdorff, 2009 updated). The Overlay Toolkit, also available in this website, contains all the necessary files to build the maps in the visualization tool pajek, which can be obtained free of charge in their website, for academic purposes only (Batagelj and Mrvar, 1998). This method obtains the intellectual structure of WRS, finding the proportion of the different SC's behind the collection of data obtained for the years 2005 and 2010, and graphically reflects them in the context of all science using the global map of science developed by Rafols et al. (2010). It must be noted that every journal in JCR is classified in at least one SC and the same classification applies to the articles published in those journals. The proportions of articles in each SC were the input data for the "first round" of overlay maps.

The "second round" of overlay maps was made following the same method with different input data. The authors consider that a complete characterization of a scientific field should include the sources of information cited by it. The WOS allows tracking this information thanks to the "Cited References" field, which contains information about the journals cited by the set of articles which were the object of study. The text mining software Vantage Point permits the analyst to extract the "Cited SC's" from the "Cited References" field, and the proportions of SC's cited by the articles in the sample were the input data for this second round of overlays.

An example from the dataset is given to understand the significance of Cited SC's as a source of knowledge. The article below was published in Waste Management and has consequently been classified in the cognitive framework of SC's EE and ES. However, this piece of research about bio-based composites could not have been carried out without the knowledge coming from other areas, which can be tracked via the citations this article makes to other journals, and therefore, to other SC's (Table 2).

The authors believe that this act of knowledge transfer must be taken into account in the tracking of WRS research, and the overlay of Cited SC's is the tool chosen for this purpose.

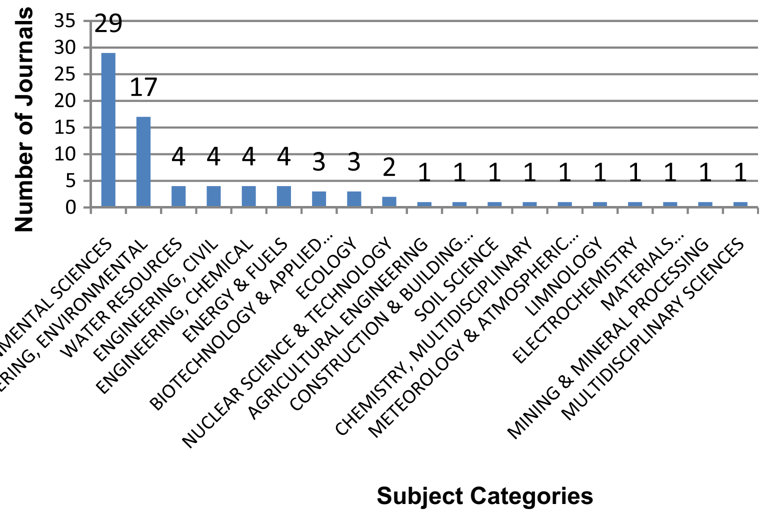

Fig. 1. Occurrences of each subject category in the selected set of 40 journals. Note that each journal could be classified in more than a single subject category.

Table 1
Main topics present in downloaded items.

Ranking position	Records	Author keywords (grouped by topic)
1	1816	Water Science
2	1053	Soil Science
3	819	Wastewater Treatment
7	476	Waste General
11	276	Waste Recycling
15	227	Arsenic

3. Results

Figs. 2 and 3 show the results of the "first round" overlay process for years 2005 and 2010, following the methodology described in Section 2.2. The colored circles represent SC's, the size indicates their relative importance in WRS. The labels are the names of the Macro-categories in which the global map of science can be divided (Rafols et al., 2010), and their colors do correspond to those of the nodes (SC's) they include. The particular name of each node is not indicated in order to improve the readability of the overlay map.

The proportion of main SC's in WRS remains fairly stable in both representations, with a sensible size growth of all the nodes, derived from the higher number of publications edited in 2010 (23,104 vs 31,623). Table 3 extracts the cognitive areas behind each Macro-category, as retrieved in the analyzed sample.

This set of SC's composes the intellectual fingerprint of WRS. Some relevant facts must be indicated.

The Environmental Sciences dominate the map, with the leading nodes EE and ES. Issues related with Ecology come next, followed by two groups quite closely situated in the map (remember that proximity implies cognitive relationship), namely, Chemistry and Engineering, which experience the most notable growth from 2005 to 2010. Biomedical Sciences appear in the form of Toxicology, not showing any growth in the analyzed period. More or less the same thing could be said about Geosciences, Health & Social Issues and Clinical Medicine areas, which maintain or decrease their initial size. Finally, the cognitive area of social sciences is represented in WRS, via the cognitive fields of Economics and Environmental Studies.

In order to extract more clues about the evolution which is taking place, the average growth of each SC from 2005 to 2010 has been determined (roughly 16%) and the SC's have been classified according to the growth experimented. SC's with a presence less than 1% in the 2010 map have not been considered. The results show that the booming SC's in WRS are Multidisciplinary Chemistry (514% growth) and Energy & Fuels (331% growth), each of them pertaining respectively to the Macro-categories Chemistry and Engineering, followed by the SC's Civil Engineering (+90%) and Chemical Engineering (+70%). The huge increase of Multidisciplinary Chemistry is explained by the fact that it was an almost inexistent field in 2005.

As explained in Section 2.2, the "second round" of overlays has been conducted using the data of Cited SC's to identify the sources of knowledge from where WRS takes information. Figs. 4 and 5 show the results:

Table 2
Example of SC's cited by an article in the retrieved dataset.

Title	Journal	SC	Cited journal (abbrev)	Cited SC's
Bio-based composites from waste agricultural residues	Waste Management	• Environmental Engineering (EE) • Environmental Sciences (ES)	Polym-Plast Technol • J Appl Polym Sci • Waste Manage • Compos Part A-Appls • ...	• Agricultural Engineering • Agronomy • Engineering, Manufacturing • Forestry • Materials Science, (Composites, Paper & Wood, Textiles) • Mathematics • Polymer Science

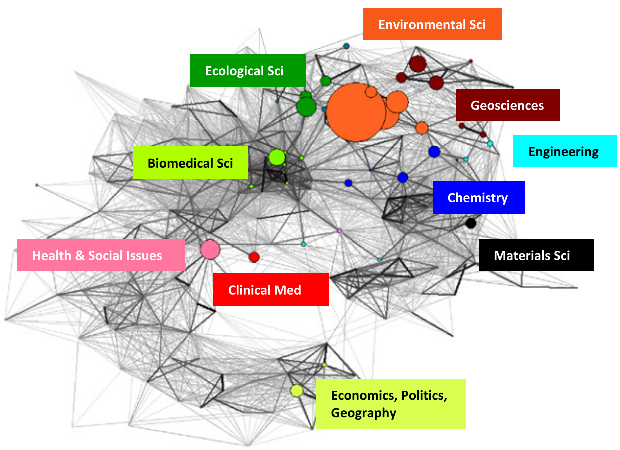

Fig. 2. WRS overlay for year 2005.

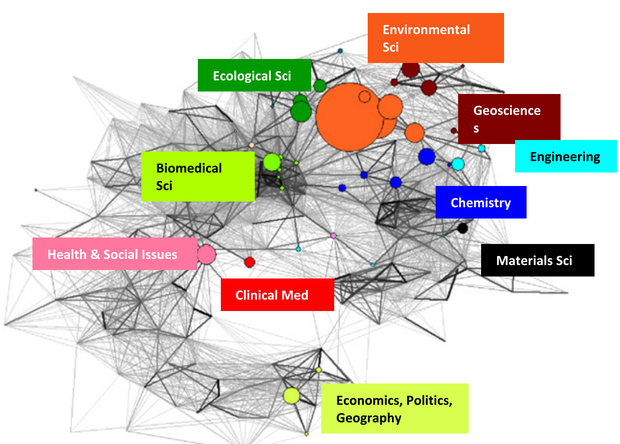

Fig. 3. WRS overlay for year 2010.

Table 3
Main SC's reflected in the map.

Macro-category	Main subject categories present in sample
Environmental Science	Environmental Sciences
	Environmental Engineering
	Engineering, Civil
	Water Resources
	Limnology
Ecological Science	Ecology
	Biodiversity Conservation
	Marine & Freshwater Biology
	Soil Science
Chemistry	Engineering, Chemical
	Chemistry, Physical
	Chemistry, Multidisciplinary (2010)
	Chemistry, Analytical
Geosciences	Meteorology & Atmospheric Sciences
	Geosciences, Multidisciplinary
	Geography, Physical
	Imaging Science & Technology
	Remote Sensing
Engineering	Energy & Fuels
	Construction & Building Technology
Biomedical Science	Toxicology
Health & Social Issues	Public, Environmental & Occupational Health
Economics, Politics, Geography	Environmental Studies
	Economics
Clinical Medicine	Radiology, Nuclear Medicine & Medical Imaging
Materials Science	Nuclear Science & Technology

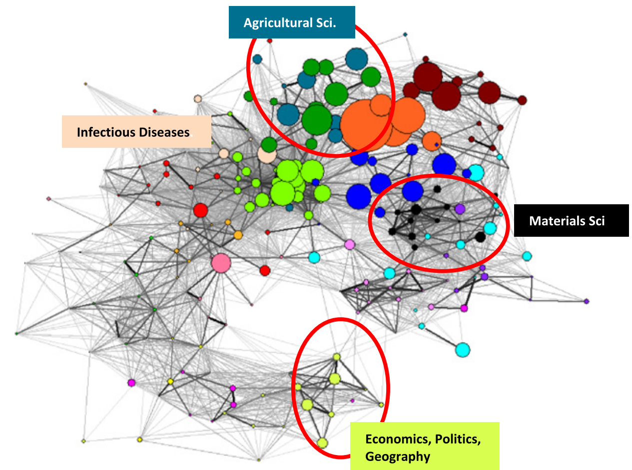

Fig. 4. Overlay of WRS cited SC's for year 2005.

The first observation leads to say that the core SC's identified in the previous overlay continue being the predominant, but there are some interesting facts to study:

First of all, the range of visualized SC's is much wider, and some SC's with no presence at all in the first overlay round show an important cognitive relationship with WRS, being heavily cited by it. This is the case of the SC's pertaining to the Macro-category Agricultural Science (highlighted), and to a lesser degree, Infectious Diseases. The nodes reflecting citations to Macro-categories Materials Science and Economics, Politics & Geography have also been highlighted to remark the increasing relationship between WRS and Materials Science, as well as the very significant role of the branch of social sciences represented by Macro-Category Economics, Politics & Geography, in an eminently scientific field like this.

The most prominent growths from 2005 to 2010 took place in Energy & Fuels, which has more than quadrupled its presence as a cited SC, and in Agricultural Engineering and Interdisciplinary Materials Science, with similar growth rates. Economics and Environmental Studies have grown by roughly 150%, which indicates the increasing cognitive relation between these social sciences and WRS.

4. Discussion

The following discussion is based upon the assumption that a major increase in the number of publications corresponding to a cognitive area implies an upgrade in the role this cognitive area plays in the analyzed field. Furthermore, we assume that an important number of citations to a cognitive area must imply a strong relationship between the citing and the cited scientific fields. It must be noted that analysis of trends and facts detected by tech mining methods should ideally be done accompanied by experts in the field object of study (Porter and Cunningham, 2005).

One of the most interesting behaviors is that of the cognitive field Energy & Fuels. In spite of not constituting at the moment a large fraction of the scientific production in WRS, its growing trend from 2005 to 2010 is notable, multiplying its weight by 6 in number of publications and by 4 in number of citations. This field covers the development, production, use and general management of renewable and non-renewable energy sources, excluding nuclear energy and technology (Thomson Reuters, 2011 updated). A significant part of the waste usually destined to landfills could be reused to obtain energy (Lombardi et al., 2006), whether in biomass energy plants or incinerated with energy recovery, and this is the idea being promoted by policy makers in the EU, via tax increase or

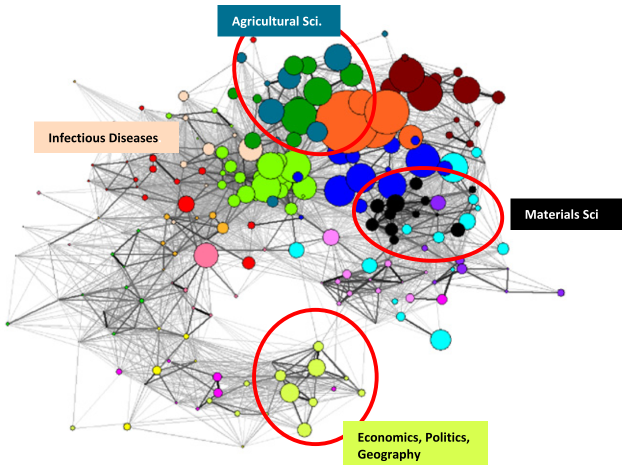

Fig. 5. Overlay of WRS cited SC's for year 2010.

stricter regulations. Data until 2006 show a positive trend in this direction, with a 43.6% of waste in the EU recovered and/or recycled and 4.9% incinerated. The dangers associated to landfills (soil contamination, gas emissions), as well as the rising prices of fossil fuels act as incentives to enhance research activities in this area (European Environment Agency, 2010 updated), and the detected growth of Energy & Fuels field can be an early indicator of this situation.

Chemistry forms a Macro-category composed of relevant SC's regarding to WRS, especially if paying attention to its citing patterns. Chemical treatments form the basis of many waste recovery processes. The special increase in Multidisciplinary Chemistry – contents not related with a specific branch of chemistry, but with a general approach to chemical science (Thomson Reuters, 2011 updated) – and Chemical Engineering – contents related with the chemical transformation of raw materials into products, design and operation of efficient and cost-effective plants and equipment for chemical production (Thomson Reuters, 2011 updated) – probably has to do with the development of new processes oriented to material recovery or chemical treatment of hazardous wastes. Some good examples of recycling processes that require chemistry knowledge are the recycling of plastic materials by chemical tertiary treatment versus secondary thermo mechanical treatment, with much less energy expense and a better quality product (Al-Salem et al., 2009), and the complex metallurgic processes like hydrometallurgy to recover valuable metals from the ever-growing amounts of electronic waste (Lee et al., 2007; Ongondo et al., 2010). These two examples can additionally explain the strong presence of the Materials Science Macro-category in the cited SC's overlay. Within the context of increasing shortage and subsequent increasing price of some metals and petroleum derivatives, the recovery of key materials becomes pressing, and the research into material testing, processing and handling is a major source of knowledge for WRS.

The SC Engineering Civil is one of the most prominent and most rapidly growing SC's in the Environmental Sciences Macro-category, and it is related to WRS via water management infrastructures and other engineering activities closely related with the environment (Thomson Reuters, 2011 updated). Apart from that, the management of construction and especially the management of the waste coming from construction industry is a key question in the field object of study (Christensen and Birgisdottir, 2011), since construction and demolition waste is one of the main sources of waste in many countries (Ekanayake and Ofori, 2004) and amounts to 32% of the total waste generated in EEA (European Environment Agency, 2010 updated).

Agricultural Science is a Macro-category that plays a role similar to that of Materials Science, strongly connected to WRS via citations. The relationship is partly produced by the water engineering, soil and plant science contents of this Macro-category. Agricultural Engineering is the SC of this Macro-category that shows the biggest growth as a cited SC, very probably due to its contents related with the exploitation of bioenergy (Thomson Reuters, 2011 updated).

Finally, the Macro-category Economics, Politics and Geography plays a relevant role in the definition of WRS. This is mainly due to the importance of public policies in the development of initiatives based around recycling (Mazzanti and Zoboli, 2008), hence the size of the SC Environmental Studies, and the importance of studies concerning the profitability of recycling or proper incentives to sustain recycling (Kuo and Perrings, 2010), hence the size of the SC Economics (Thomson Reuters, 2011 updated).

The approach of this study, based in a ''double overlay'' process, aims at reinforcing the extraction of reasoning from the maps obtained, taking into account the cognitive areas where the publications are cataloged, together with the cognitive areas from where the publications take their intellectual nourishment. This approach, applied with this goal in mind, is something original and innovative, and the authors will gratefully appreciate any feedback concerning it.

5. Conclusions

- Two different overlays have been done following the technique explained in Rafols et al. (2010), to map the evolution of WRS from 2005 to 2010, identifying the main cognitive areas behind this science and the main cognitive areas related to them.
- The scientific publication pattern of this scientific field remains stable, as seen in the first round of overlays, with a general growth in the number of items published from 23,104 (2005) to 31,623 (2010). The SC's that experiment the greatest growth are Energy & Fuels, Multidisciplinary Chemistry, Chemical Engineering and Civil Engineering.
- SC Energy & Fuels continues to have the greatest growth in the overlay of cited SC's, suggesting that an important part of future research in WRS might be oriented toward the recovery of energy from waste, whether in biomass or incineration-related processes, due to the increasing importance of this area, as detected in both overlays.
- The areas related with Chemistry are relevant in both overlays, especially in the cited SC one. Research in chemical procedures is probably related with WRS through the processes of feedstock recovery from waste, especially plastic materials and valuable metals. This is also linked with the importance of the Macro-category Materials Science in the overlay of cited SC's.
- Other facts highlighted by the overlay of cited SC's are the strong cognitive relationship between WRS and Agricultural Sciences, and social sciences like Economics and Environmental Studies, showing the strong dependence of recycling and waste management activities on the development of public policies. Studies into the profitability of waste management and the proper incentives to its promotion also show their importance on the map.

Acknowledgements

We gratefully thank Professor Alan Porter, for the technical support and advice given, as well as Professors Loet Leydesdorff and Ismael Rafols for making all the necessary files to complete the overlay process available. The authors are grateful to the suggestions of a number of anonymous referees.

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