A Delineating Procedure to Retrieve Relevant Research Areas on Nanocellulose

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Abstract
Advances concerning publication-level classification system have been demonstrated striking results by dealing properly with emergent, complex and interdisciplinary research areas, such as nanotechnology and nanocellulose. However, less attention has been paid to propose a delineation procedure using specific subjects and understand how it could provide interesting regards about it. This study aimed at proposing a delineation procedure to retrieve relevant research areas addressed to nanocellulose using the research areas clustered by the CWTS Web of Science Publication-level Classification System. The procedure involved an iterative process, which includes developing and cleaning set of core publication regarding the subject and analysis of which cluster they might be associated. Nanocellulose was selected as the subject of study. A discussion about each step of the procedure was also provided. The proposed delineation procedure enabled to retrieve relevant publications from research areas involving nanocellulose. Twelve research topics were identified, mapped and associated with current research challenges on nanocellulose.

Conference Topic
Methods and techniques

Introduction
In recent years, bibliometrics has been used often to monitor and quantitatively assess scientific fields within the context of science policy and research management (Moed, Glänzel, & Schmoch, 2004; Okubo, 1997; Raan, 2014). Partly, it is a consequence of the increased use of Internet since the early 1990s and the development of information technologies. Together, they made a huge volume of scientific databases available. Meanwhile, scientific studies have become more complex and interdisciplinary, involving the exchange of knowledge between scientists from different disciplines. Nanotechnology-focused research is a good example. Bibliometric indicators and tools are useful instruments to study and gain insight in science and, in particular, complex fields or research areas, c.f., van Raan (2004). Therefore, many studies on nanotechnology relied on bibliometric approaches (Hullmann & Meyer, 2003; Igami, 2008; Kostoff, Koytcheff, & Lau, 2009; Milanez, Faria, Amaral, Leiva, & Gregolin, 2014; Mogoutov & Kahane, 2007; Wang, Notten, & Surpatean, 2012). The problems often are: how to delineate a field or research area, how to retrieve the relevant data, and which publications to include and which not.
In this sense, classification systems have been used as an indispensable tool to study the structure and dynamics of scientific fields (Boyack, Klavans, & Börner, 2005; Glanzel & Schubert, 2003; Leydesdorff, Carley, & Rafols, 2013; Waltman & van Eck, 2012). They can simplify literature search and retrieving procedures (Glanzel & Schubert, 2003; Waltman & van Eck, 2012). According to Glanzel and Schubert (2003), classification of science into a disciplinary structure can be as old as science and, currently, most of them are based on journal assignment, such as the Web of Science and Scopus systems. The drawback of these

journal-based classification systems is the fact they do not deal properly with multidisciplinary journals or interdisciplinary research (Waltman, van Eck, & Noyons, 2010).

The development of publication-level classification systems has been a current subject of research (Boyack et al., 2011; Waltman & van Eck, 2012). Boyack et al. (2011) clustered a corpus of 2.15 million biomedical publications from Medline database (2004-2008) which generated coherent and concentrated cluster solution of text-based similarity approaches based on keywords extracted from titles and abstracts. They found their approach more precise than the Medical Subject Headings. Waltman and van Eck (2012) proposed a methodology to clustering a large-scale set of scientific publication indexed on Thomson Reuters' Web of Science database. Each publication was assigned to a single research area, which was organized in a three-level hierarchical structure. Their methodology took into account direct citation to cluster the publication. They labelled each research area with discriminative keywords extracted from titles and abstracts. Such publication-level classification systems may be used to gain insights on research areas involved in specific subjects.

In the present study, we intended to map relevant research areas associated with nanocellulose, which is a sustainable nanomaterial that has a great potential for innovation (Isogai, 2013; Mariano, Kissi, & Dufresne, 2014; Milanez, Amaral, Faria, & Gregolin, 2013; Moon, Martini, Nairn, Simonsen, & Youngblood, 2011). Nanocellulose has been a research area for many countries, including the major producers of cellulose worldwide, such as the USA, Canada, Finland, Sweden and Brazil (Milanez et al., 2013). Different disciplines are involved with nanocellulose research since its properties and behaviour have allowed applications as reinforcement agent in composite materials, packing material, optically transparent paper for electronic devices, texturizing agent in cosmetics and food, bio-artificial implants and bandages (Isogai, 2013; Klemm et al., 2011; Mariano et al., 2014; Moon et al., 2011; Siqueira, Bras, & Dufresne, 2010).

Nanocellulose is a generic term referring to cellulose nanofibrils on the one hand and cellulose nanocrystals on the other (Dufresne, 2013; Klemm et al., 2011; Moon et al., 2011; Siqueira et al., 2010; TAPPI, 2011). Cellulose nanocrystals are basically shorter and rod-like crystalline cellulose, whereas cellulose nanofibrils are long chains of alternate amorphous and crystalline cellulose. Consequently, they differ on their mechanical and functional properties (Eichhorn et al., 2010; Mariano et al., 2014; Moon et al., 2011). Both types of nanocellulose can be obtained from renewable sources, including natural fibres, plants, pulp and forest and agricultural residues. Moreover, cellulose nanocrystals can be biosynthesized by bacteria, resulting in the also called bacterial cellulose (Klemm et al., 2011; Milanez et al., 2013; Moon et al., 2011).

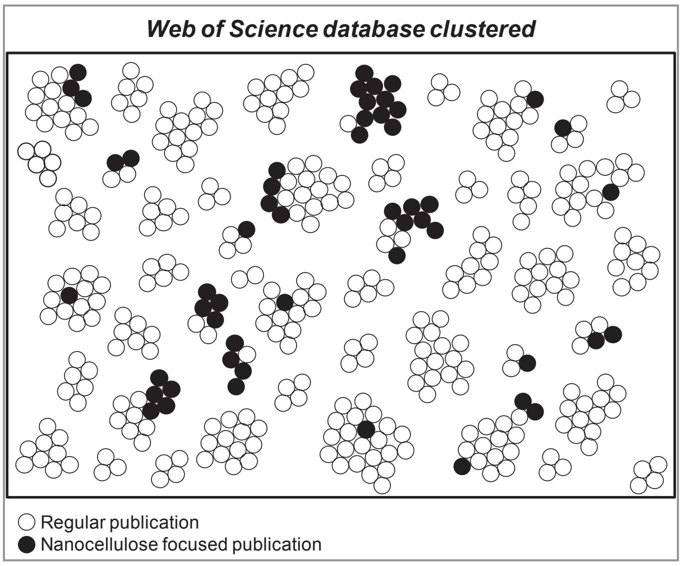
Checking the research topics associated with nanocelluloses will provide insights into current technical challenges concerning this nanomaterial, such as increasing the scale of production minimizing costs, characterization of sources and mechanical properties. Surface modifications to reduce moisture adsorption and improve the adhesion between the nanomaterial and the polymeric matrix, thermal degradation, and biocompatibility with living tissues has also been target of research (Gardner, Opo, Oporto, Mills, & Samir, 2008; Isogai, 2013; Klemm et al., 2011; Mariano et al., 2014; Milanez et al., 2013; Moon et al., 2011; Siqueira et al., 2010).

This study aims at proposing a delineation procedure to retrieve relevant research areas addressed to a specific topic. Nanocellulose was selected as a case, but it may be used for other subjects, of course. The approach involves research areas identified in the CWTS Web of Science Publication-level Classification System, a 2014 update of the version introduced by Waltman & van Eck (2012). This paper is structured as follows. In the next section, we describe the overall delineating procedure and its general issues. Next, we discuss details concerning specific parts and tasks. We present and discuss results in Section 3 and finally in Section 4 we draw our conclusions.

Methodology

Overall delineation procedure

To delineate the field, i.e., to collect a relevant set of publications to represent it, we will select clusters from the CWTS publication level classification system. By this method we will identify papers that will not easily be picked up by keyword or journal based search strategies. Figure 1 presents a schematic representation of the distribution of the clustered Web of Science publications according to CWTS Publication-level classification system (Waltman & van Eck, 2012). Predefined nanocellulose publications are indicated as black circles and the first step is retrieving all research area that contains at least one of them.



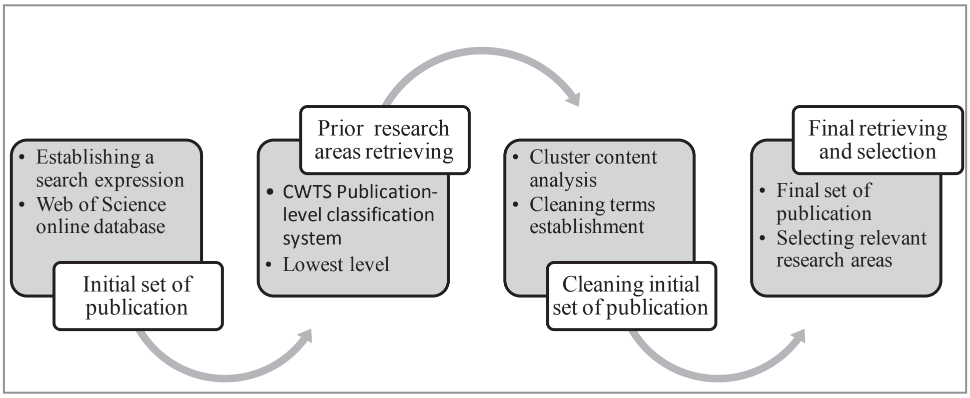
Source: authors.

Figure 1. Schematic representation of Web of Science publications clustered according to the CWTS Publication-level Classification System. The black nodes represent the publications focused on nanocellulose.

Figure 2 depicts the proposed procedure as an iterative process which can be described in four main steps:

1. *Determine an initial set of publication concerning the theme of interest.* In this first step, a set of publication which well represents the theme of interest (nanocellulose) is retrieved via the online Web of Science database, using a straightforward search strategy. This set of publication is a starting set and will be refined as well as expanded through the next steps;
2. *Prior retrieval of nanocellulose research areas*. The second step involves locating the research areas (publication clusters) with at least one publication from the initial set of nanocellulose. The bottom level of the classification scheme was used in this study (Waltman & van Eck, 2012);
3. *Analysis of retrieved research area and cleaning of the initial set*. The content of each research area was analysed pragmatically. A cleaning task was developed by selecting terms to eliminate part of the initial set of nanocellulose publication. This step provided a final set of nanocellulose publication clusters and enhanced the precision of research area assigned to nanocellulose;

4. *Final retrieval and selection of relevant nanocellulose research areas*. After cleaning the initial set of nanocellulose publication, the research areas (publication clusters) were retrieved again. Finally, as the number of topics retrieved was high, a selection that relies on the 80/20 rule was conducted reaching the final research areas associated with nanocelulose.



Source: authors.

Figure 2. Iterative process of the overall procedure proposed.

Determine an initial set of publication on nanocellulose

A search expression was developed considering several terms and synonyms recommended by experts and found in nanocellulose literature (Klemm et al., 2011; Milanez et al., 2013; Siqueira et al., 2010; Siró & Plackett, 2010), as can be seen from Table 1. The search expression encompassed different words that refer to cellulose nanocrystals, cellulose nanofibrils, and bacterial cellulose as well as other generic forms, such as nanocellulose, cellulose nanoparticles, and cellulose nanofiller. The search was conducted in March 31th 2014 in the online Web of Science database (topic search). Only articles that attended the CWTS Web of Science publication-level classification system criteria[1] were used, though.

Table 1. Boolean search expression to retrieve the initial set of nanocellulose publications.

("bacterial cellulos*") OR ("cellulos* crystal*") OR ("cellulos* nanocrystal*") OR ("cellulos* whisker*") OR ("cellulos* microcrystal*") OR ("cellulos* nanowhisker*") OR ("nanocrystal* cellulos*") OR ("cellulos* nano-whisker*") OR ("cellulos* nano-crystal*") OR ("nano-crystal cellulos*") OR ("cellulos* micro-crystal*") OR ("cellulos* microfibril*") OR ("microfibril* cellulos*") OR ("cellulos* nanofibril*") OR ("nanofibril* cellulos*") OR ("micro-fibril* cellulos*") OR ("nano-fibril* cellulos*") OR ("cellulos* micro-fibril*") OR ("cellulos* nano-fibril*") OR ("cellulos* nanofiber*") OR ("nanocellulos*") OR ("cellulos* nanoparticle*") OR ("nano-cellulos*") OR ("nanoparticl* cellulos*") OR ("nanosiz* cellulos*") OR ("cellulos* nanofill*") OR ("nano-siz* cellulos*") OR ("cellulos* nano-fiber*") OR ("cellulos* nano-particle*") OR ("cellulos* nano-fill*") OR ("nano-particl* cellulos*"))

Source: Developed considering nanocellulose-focused terms found in the literature (Klemm et al., 2011; Milanez, Amaral, Faria, & Gregolin, 2013; Siqueira, Bras, & Dufresne, 2010; Siró & Plackett, 2010) and expert opinions.

Prior retrieval of nanocellulose research areas

Research areas that contained at least one publication from the nanocelulose set were retrieved from the CWTS Web of Science Publication-level database. In total, 533 research

[1] The classification system takes into account only *article*, *letter* and *review* published from 2000 to 2013 and indexed in the Science Citation Index Expanded and the Social Science Citation Index. Moreover, to be part of one research area, a publication must be related, either directly or indirectly, to at least 49 other publications in terms of citation (Waltman & van Eck, 2012).

topics were found. These clusters showed large differences in terms of volume (number of publications included). The largest cluster contains 2,751 publications whereas the smallest one covers only 50 publications. Almost 80% of these clusters contained less than three publications from the initial set.

Interestingly, we found that two research areas (clusters) included 56.3% of the initial nanocellulose set of publications. Moreover, in these two clusters, more than 80% overlapped with the initial set. Their descriptive labels also pointed towards nanocellulose research. Therefore, they were considered as nuclei of research in nanocellulose. Other clusters in which the representation of the initial set was much lower, were considered peripheral research areas and their relevance to nanocellulose research was evaluated (see next section).

Analysis of retrieved research area and cleaning of the initial set

An analysis of the content of publications in the peripheral research areas was conducted. We wanted to check whether these articles focused on the nanomaterial as an object of research. If not they were considered noise. Because an evaluation of all research area retrieved would be too labour intensive, we made a selection. The checking task was performed only on those clusters that matched one of the following criteria:

- Research topics that contained at least 20 publications from initial dataset;
- Research topics of which at least 5% overlapped (percentage proportion) with the initial set.

A total of 20 (peripheral) clusters were evaluated. The analysis regarded only articles from the initial dataset. The task involved reading each title to decide whether the article was a study focused upon nanocellulose or not. When the title was not clear, the abstract was also consulted.

Once the checking process was completed, specific terms were identified to clean the initial set of nanocelulose publications. Only research topics with high percentage of "noise publication" were used[2]. Noun-phrases were obtained with support of VOSviewer corpus map analysis applied to titles and abstracts from publications belonging to these clusters. Table 2 present the terms used to clean the nanocellulose-focused publications retrieved using the search expression from Table 1. They were applied on the title, abstract, author's keyword and keyword plus search field. The effect of this cleaning task on the nuclei clusters and the peripheral clusters we used will be discussed in the results.

Table 2. Boolean expression of terms used to clean the nanocellulose-focused publications.

"gene" OR "xyloglucan" OR "microtubule" OR "*cyto*" OR "kinesi" OR "tubulin" OR "*cell wall*" OR "spindle" OR "phragmoplast" OR "mitosis" OR "preprophase" OR "phenotype" OR "*plant growth*" OR "meiosi" OR "*lignin distribution*" OR "delignification" OR "hemicellulose" OR "saccharification" OR "ethanol yield" OR "lignocellulos*" OR "glucosidase" OR "xylanase"

Source: Authors.

Final retrieving and selection of relevant research areas

The final set of nanocellulose publication comprised 2,600 nanocellulose publications (named now as core-nanocellulose) and they were assigned to 428 research areas, which still would be a highly number of cluster to be evaluated. Furthermore, 81.0% of these clusters included only one or two publications from the core-nanocellulose publication, which questions their actual relevance to the advances on nanocelulose studies. Therefore, a selecting step was introduced.

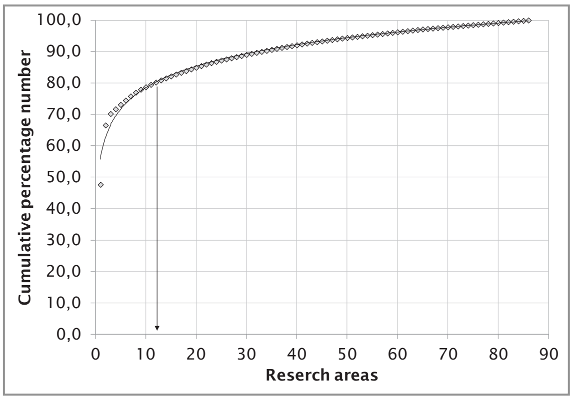
We introduce here the *Pareto Principle* (or 80/20 rule). This principle states that "roughly 80% of the effects come from 20% of the causes" (Juran & Godfrey, 1998) and is found in

[2] The presence of "noise publications" is usual in bibliometric analysis because there is no exhaustive search.

bibliometric and library studies (Gupta, 1989; Kao, 2009; Stephens, Hubbard, Pickett, & Kimball, 2013). We hypothesize that 80% of the core set will be assigned to 20% of the areas. To reach these relevant research areas, the steps below were carried out:

1. The research areas were listed in descending order of the total number of publications from the core-nanocellulose;
2. Research topics with one or two publications from the core-nanocellulose were excluded[3]. This yields 85 research areas remaining;
3. The representativeness of each research area was calculated by the number of publication of the core-nanocellulose of that cluster divided by 2,200 (which is the total of publication found in the 85 remaining research areas);
4. The cumulative percentage number of publications from the core-nanocellulose was obtained summing the values from the step before, as can be seen from Figure 3. The number of research to be assessed was those where the cumulative percentage number of publication reach approximately 80%.

We found that twelve research areas covered the required 80%, which means 14.1% of the total of 85 research topics. We do not claim that our selecting procedure was perfect, but a quick analysis of the chosen research topics showed themes currently found in nanocellulose literature.



Source: CWTS Web of Science Publication-level database.

Figure 3. Cumulative percentage number to research areas with six or more publications from the core-nanocellulose.

Independency test

An independency test was conducted to evaluate the effectiveness of the procedure proposed. The test involved retrieving the number of publication from the top five authors before and after cleaning and selecting the relevant research areas. The percentage decreases of their overall number of publication and from their main cluster were verified.

Results and discussion

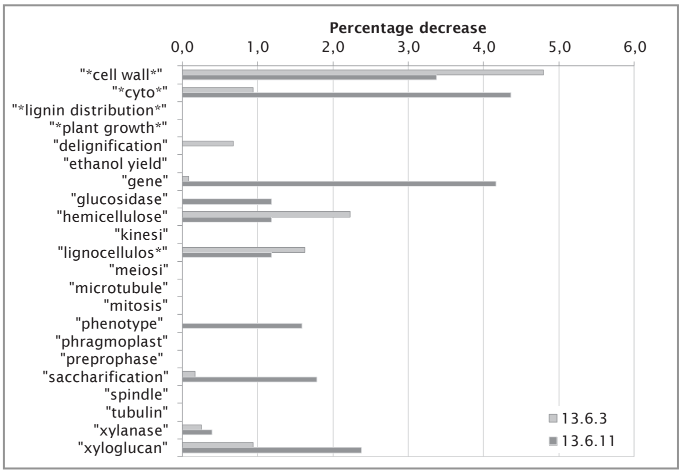
In this section we discuss the effect of cleaning up the core set of publications by using 'cleaning terms', i.e., terms to increase the accuracy of our initial set. Moreover, we present a basic structure of the field on the basis of the delineation we developed.

Effect of cleaning the initial set of nanocellulose publications

Half of the 22 terms we used to clean the nanocellulose search strategy did not affect the coverage of core-nanocellulose publications in the nuclei research areas, as depicted in Figure

[3] According to Waltman and van Eck (2012), the lowest research area contains 50 publications, consequently, clusters with less than 1% of proportion were not accounted for.

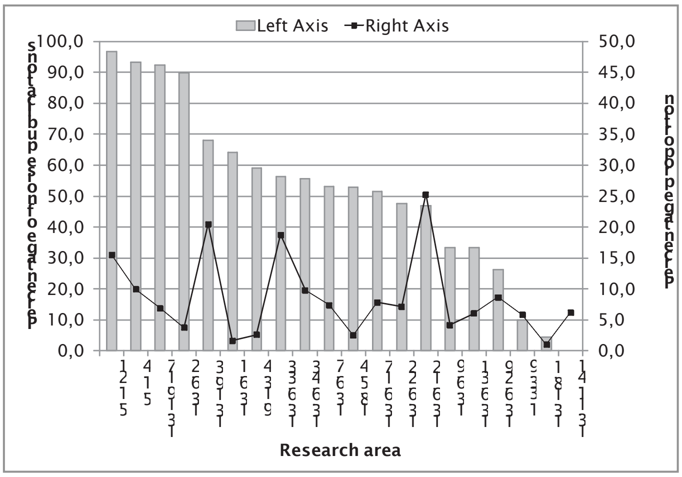
4. To the other half, none term could reduce the coverage in more than 5%. The terms that influenced research area 13.6.4 the most were “*cell wall*” and “hemicelluloses” while “*cyto*”, “gene” and “*cell wall*” were the ones that decreased the most core-nanocellulose coverage in cluster 13.6.11. Overall, research topic 13.6.11 had its core-nanocellulose publication reduced in 17.5% while the decrease to cluster 13.6.3 was 10.2%. Nonetheless, both clusters still concentrated publication from the core-nanocellulose after the cleaning tasks (the proportion was 74.0% to research area 13.6.3 and 72.1% to 13.6.11). Therefore, they still had the status of nuclei research areas.



Source: CWTS Web of Science Publication-level database.

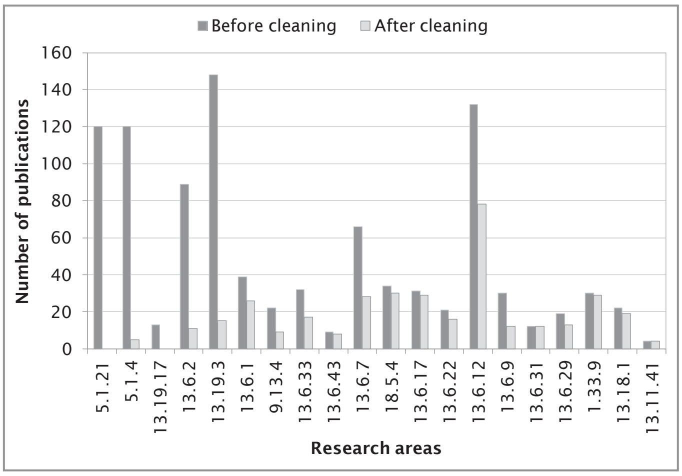
Figure 4. Effect of cleaning terms on the number of publication from nuclei research areas.

As to the 20 peripheral research topics whose nanocellulose set of publication were evaluated, no direct correlation was observed between the proportional relevance of each clusters and the percentage of noise, according to Figure 5. Four research topics had a high percentage (>70%) of ‘noisy’ publications mainly focusing on biological issues of plants, ethanol production, and enzymes aspects, not having the nanomaterial as a final object of research. Since these four were used to select the cleaning terms, the cleaning affected them highly. Two of them were even eliminated. Furthermore, other peripheral clusters had their nanocellulose publication coverage diminished, as shown on Figure 6.



Source: CWTS Web of Science Publication-level database.

Figure 5. Percentage of noise of core-nanocellulose publications and proportion between core-nanocellulose publications and total number of publications over research area.



Source: CWTS Web of Science Publication-level database.

Figure 6. Effect of cleaning terms on the number of publication from selected peripheral research areas.

Effect of cleaning procedure on top five authors (independency test)

A second test verified the effect of the cleaning process on the coverage of key-authors (top 5). The decrease in the number of publication is presented in Table 3. All authors concentrated their publications on nuclei research topics, mainly on 13.6.3. Only author E focuses primarily on research area 13.6.11. Although the result shows that the overall number of publication diminished in more than 10%, their position as the top authors did not changed but for author E, who went down to the seventh position. It should be noted, however, that research area 13.6.11 was affected more by the cleaning procedure than 13.6.3.

Table 3. Effect of on main authors publications.

Author	*Number of publication*		*Decrease (%)*	
	*Before**	*After**	*Overall*	*Nuclei*
A	87	78	-10,3	-6,33
B	51	40	-21,6	-14,9
C	50	43	-14	0
D	50	39	-22	-18,2
E	48	29	-39,6	-26,5

* Before and after the cleaning step.

Source: CWTS Web of Science Publication-level database.

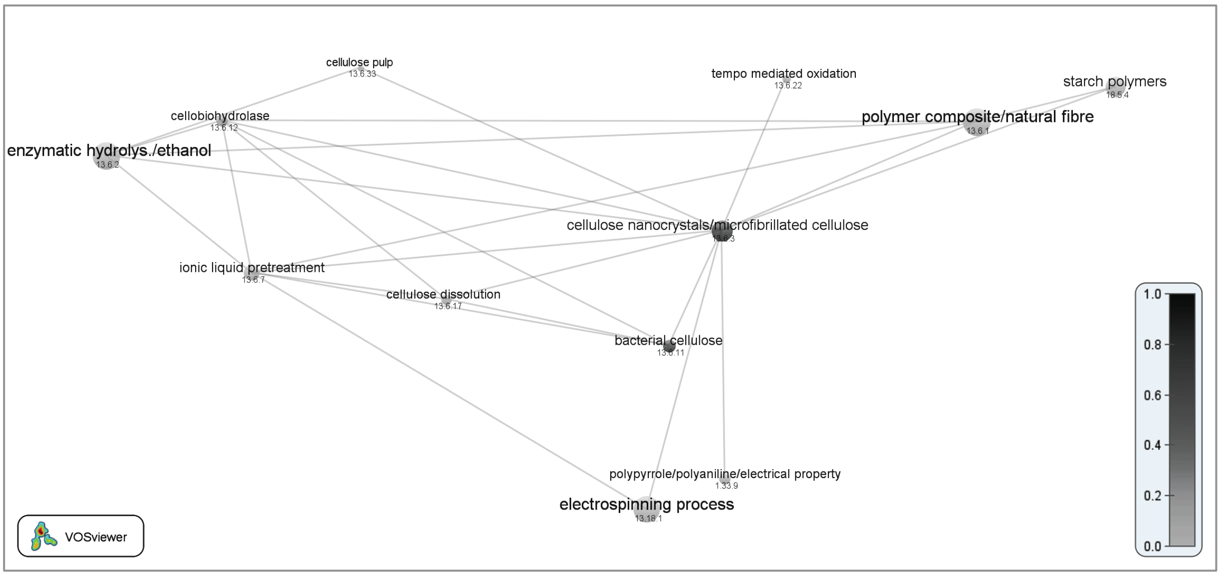
Map of the Nanocellulose research topics

The delineating approach was able to retrieve two nuclei research areas, one associated with cellulose nanocrystals and nanofibrils and other to bacterial cellulose. The peripheral research topics regards biodegradable polysaccharides (starch polymers), polymer composites based on natural fibres, and intrinsically conducting polymers. Other peripheral research areas included enzymatic hydrolyses and ethanol production, cellobiohydrolyse, cellulose pulp and cellulose dissolution, and ionic liquid pre-treatment. Electrospinning process and tempo mediated oxidation, which is an treatment that uses the chemical compound (2,2,6,6-Tetramethylpiperidin-1-yl)oxy (TEMPO), were also part of the final selection. These themes appears frequently in nanocellulose-focused studies (Azizi Samir, Alloin, & Dufresne, 2005; Charreau, Foresti, & Vazquez, 2013; Chirayil, Mathew, & Thomas, 2014; Dai et al., 2014; Domingues, Gomes, & Reis, 2014; Durán, Lemes, & Seabra, 2012; Eichhorn et al., 2010; Isogai, 2013; Klemm et al., 2011; Moon et al., 2011; Orts et al., 2005; Pääkkö et al., 2007; Siqueira et al., 2010; Siró & Plackett, 2010)

Figure 6 presents a map with these research topics (nodes). The map positions the topics on the basis of their citation relations. The closer two topics, the more frequent the citation traffic between them. The node labels match the main content of the clusters. Moreover, all selected clusters had their set of nanocellulose publication evaluated in the cleaning task.

The nuclei research areas are darker and positioned in the centre of the map. Research area 13.6.3 (cellulose nanocrystals/microfibrillated cellulose) has citation connections to all clusters. On the other hand, research topic 13.6.11 is connected only with four other clusters, which might indicate its lower relevance than the other nucleus research area. At the top right of the map are located two research areas addressed to starch polymers and polymer composites based on natural fibres. These research topics regard the development of sustainable materials (Durán et al., 2012; Moon et al., 2011; Siqueira et al., 2010; Isogai, 2013).

Research area concerning enzymatic hydrolysis is highly close to the research topic cellobiohydrolase, i.e., enzymes that perform the process of hydrolyse, and ionic liquid pre-treatment, which also relies on enzymatic approaches. However, they were located further than the nuclei clusters. Indeed, one of them was considered as highly noisy (13.6.2), but we should take into account that nanocellulose obtainment has been also studied as a secondary product of bio-ethanol production (Beecher, 2007; Zhu, Sabo, & Luo, 2011). Moreover, enzymatic pre-treatment has been researched to improve nanocellulose defibrillation (Pääkköet al. 2007; Moon et al., 2011; Klemm et al., 2011; Siqueira et al., 2010; Isogai, 2013).



Source: CWTS Web of Science Publication-level database.

Figure 6. Selected research area according to the procedure proposed.

At the bottom of the map, electrospinning process and conductive polymers were positioned closely, but there is no citation connection between them. Electrospinning is a technique used to produce micro- and nano-sized polymer-based fibres, and nanocellulose has been studied to improve the mechanical property of the final fibre (Dai et al., 2014). Nanocellulose electrical and magnetic properties have also been explored to be used with conductive polymers (Moon et al., 2011; Klemm et al., 2011). The other three research areas (cellulose pulp, cellulose dissolution and tempo mediated oxidation) are the smallest ones, and probably the publications that belong to them might be associated with other clusters on new updates performed using the classification system (Waltman & van Eck, 2012). Tempo mediated oxidation is a current technique to perform pre-treatment of nanocellulose (Klemm et al., 2011; Isogai, 2013).

Conclusion

The proposed delineation procedure enabled us to retrieve relevant publications from research areas involving nanocellulose. Twelve research topics were identified, mapped and associated with current research challenges on nanocellulose. Two of them were highlighted as nuclei since they contain most part of the initial set of publications. The effect of the cleaning step on nuclei and peripheral clusters provided valuable feedback and demonstrated its importance to establishing relevant clusters afterwards. The independency test showed that the cleaning procedure could have been too rigorous and further research should be carried out to understand how it affected core authors' publication.

Delineating scientific fields is a complex task as boundaries are not frequently well established since scientific studies have become more complex and interdisciplinary. More and more exchange of knowledge between scientists from different disciplines is involved. Our approach retrieves and delineates the real nuclei and the peripheral research areas concerning nanocellulose studies. This clear separation provides suggestions for further research, putting the nuclei research in context. One of the ideas involves the knowledge flow from peripheral research topics to the nuclei areas. We intend to map how they provide the necessary knowledge to face nanocellulose current challenges and how country and scientific institutions are contributing to this evolution.

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