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THE EVOLUTION OF SUSTAINABILITY TRANSITIONS: A CONTENT ANALYSIS APPROACH

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1. INTRODUCTION AND LITERATURE REVIEW

Renewable Energy Technologies have been hailed as the most promising mechanisms to cut emissions and to develop more sustainable societies. Much progress has been made and the share of these new technologies in relation to overall power generation has increased over the past 10 years with them increasingly becoming mainstream sources of energy. Despite the current efforts in promoting their continuing growth, there has been a slower diffusion of renewables, especially in developing country contexts.

A new field of research, named sustainability transitions emerged in recent years, in order to gather more insights into how such renewable energy technologies – among others – can penetrate faster and become mainstream. As research grew, several sub-fields appeared, including technological innovation systems (TIS), the multi-level perspective (MLP), transition management and strategic niche management approach.

The (TIS) framework (Bergek, Jacobsson, Carlsson, Lindmark, & Rickne, 2008; Hekkert, Suurs, Negro, Kuhlmann, & Smits, 2007; Jacobsson & Bergek, 2004) was originally derived from the innovation system concept, which has been used to study the relationships between technological change and economic development (Lundvall, Johnson, Andersen, & Dalum, 2002). Drawing on Neo-schumpeterian and Evolutionary Economics (Nelson & Winter, 1982; Schumpeter, 1934), the innovation systems approach was initially conceived at the national level, in an effort to understand how actors, networks and institutions interact in order to produce innovations within a national economy (Lundvall et al., 2002).

The TIS dimension focuses on understanding the interrelationships between technologies, actors, networks and institutions and in doing so, it seeks to answer how the innovation system around a particular technology functions (Bergek et al., 2015). It has and can be used to study mature technological fields or emerging ones, such as renewable energy technologies (Bergek, Jacobsson, Carlsson, et al., 2008; Carlsson & Stankiewicz, 1991; Hekkert et al., 2007; Markard & Truffer, 2008). In this sense, a large share of the studies applying the TIS framework in the last decades has focused on studying how to accelerate - and by which mechanisms – the diffusion of renewables in both, the developed and the developing world, becoming a major building block of the sustainability transitions research field (Markard, Raven, & Truffer, 2012).

Perhaps one of the key developments in the field of TIS in recent years, has been the so-called 'functions of innovation systems' (Bergek, Jacobsson, Carlsson, et al., 2008; Hekkert et al., 2007) which are used to perform detailed assessments of innovation system dynamics around particular technologies by assessing a set of key functions needed for the system to perform well.

According to Markard et al. (2012) sustainability transitions accounts for "long-term, multi-dimensional and fundamental transformation processes through which established socio-technical systems shift to more sustainable modes of production and consumption". Within the

literature on sustainability transitions[1] several strands of research were developed through the years, including i) the multi-level perspective (MLP), ii) transition management and iii) strategic niche management.

The MLP explains sustainability transitions at three different levels: the niche, the socio-technical regime and the landscape (Geels, 2002; Markard & Truffer, 2008). The niche represents the micro-level, referring to the protected spaces or incubating rooms, in which emerging technologies grow or develop isolated from the selection mechanisms of the 'normal' market (Geels, 2004; Markard & Truffer, 2008). The socio-technical regime represents the meso-level, characterized by established institutional set-ups (norms, regulations, etc.), knowledge base, products and technologies. And finally, the landscape represents the macro-level which might put pressure on the socio-technical regime and open windows of opportunities for niches to break through but is hardly affected by them (Markard et al., 2012).

As was the case for the TIS framework, the multi-level perspective draws upon evolutionary economics (Nelson & Winter, 1982) but it incorporates the theoretical framework of history and sociology of technology (Hughes, 1987) highlighting the fact that technologies are embedded in a larger socio-technical system (Markard et al., 2012).

In this sense, all three levels interact and evolve through time, where new radical technologies, such as solar PV or wind turbines, compete against incumbent technologies in a sort of natural selection process. To some scholars within this field, it means new radical technologies should be protected at first, within the niche and therefore, the 'strategic niche management' stream has dealt with investigating how niches might grow, stabilize or decline as well as looking for means to create and support such niches (Kemp, Schot, & Hoogma, 1998; Schot & Geels, 2008).

In a broader perspective, the third strand named 'transition management', delves into complex systems theory to conceptualize the transition process as evolutionary with a focus on action oriented research using management and governance instruments as tools to influence sustainability transitions (Markard et al., 2012; Rotmans, Kemp, & van Asselt, 2001).

As evidenced above, there have been a rapid growth and evolution of several strands of research within the sustainability transitions field. This calls for a need to trace the trajectory and possible future developments by means of a literature review. Moreover, to best of our knowledge there is only one previous study which quantitatively analyzes the sustainability transitions literature (Markard et al., 2012), however, our paper goes beyond traditional citation counts. Also, there is evidence of previous studies focusing on the 'innovation systems' field of research (Liu, Yin, Liu, & Dunford, 2015; Sun & Grimes, 2016; Teixeira, 2013; Uriona-Maldonado, dos Santos, & Varvakis, 2012) yet no study exist, to the best of our knowledge about quantitative literature surveys of the evolution of the sustainability transitions body of research.

In spite of this matter, we propose the use of the content analysis method to delve into the main work carried out in the field

The remainder of the paper is organized as follows: In Section 2 we explain the method and data used in our study. In Section 3 we present the results, by means of content analysis. The paper ends with the conclusions (section 4) and references.

[1] In our search strategy we have used the term 'sustainability transitions' to retrieve the documents about the overall theme of transitions and about the multi-level perspective, strategic niche management and transition management literature.

2. METHOD AND DATA

The method used to perform the bibliometric analysis and content analysis was the SYSMAP (Scientometric and sYStematic yielding MApping Process) (Vaz & Uriona Maldonado, 2017), which offers a structured way to carry out a literature review, through the combination of a scientometric analysis and a content analysis (Vaz & Uriona Maldonado, 2017). In this paper we will carry out only three steps of the SYSMAP method (Fig.1):

i. Construction of the database of raw articles, which, in turn, comprehends: selecting keywords, selecting databases, searching for articles and verifying the adherence of keywords;
ii. Filtering, which include duplicate filtering, alignment filtering and full-text alignment filtering; and
iii. Content analysis based on co-citation network analysis

In order to retrieve a relevant sample of articles, we used all databases from Thomson Reuters ISI Web of Science, as it is one of the most comprehensive databases of peer reviewed journals in the world. The WoS also accounts with a unique feature of citation counts, which allows quantifying the relative importance of documents, authors, journals and cited references by using an objective measure of influence.

We have searched for all articles with the words "Technological Innovation Systems" and "Sustainability Transitions" in the Title, Keywords and Abstracts (the Topic field). We have used all years available in the WoS database at the time of the study, getting a range from 1998 to 2017 (19 years) and the resulting sample was 311 articles. This set was then fixed as the basis for all future analysis.

The sample of 311 articles was then exported in .txt format to the software packages we used, namely Histcite, VOSviewer and CitNetExplorer in order to run further analysis. Our methods allowed us to analyze specific data, stemming out of the 311 articles: 47 countries, 303 organizations, 94 journals, 609 authors, 999 keywords and 14.873 cited references.

Fig. 1 Research method used, based on the SYSMAP (Scientometric and sYStematic yielding Mapping) Process

Source: Vaz and Uriona Maldonado (2017, pp., 24).

3. RESULTS

A total of 311 records in dataset have been published covering 47 countries of 303 organizations, 94 journals, 609 authors, 999 keywords and 14.873 cited references.

3.1 Top-cited documents

We begin by listing the top 10 documents from our collection with the highest citation score in Table 1. For instance, the paper by Markard and Truffer (2008) which reviews the state-of-the-art literature on all three (ST, MLP and TIS) or the papers by Smith and Raven (2012), focusing on the strategic niche management (SNM) and sustainability transitions (ST) and Smith, Voss, and Grin (2010), focusing on the MLP and ST.

In terms of the most cited documents within the top 20, we identified the paper by Markard et al. (2012) as the most cited one, with 96 citations, which along with Markard and Truffer (2008) – the third most cited article in our collection (86 citations) – developed a full in-depth review of the field of sustainability transitions and the possible opportunities of integrating the TIS and MLP frameworks. Bergek, Jacobsson, Carlsson, et al. (2008) is the second most cited work, with 96 citations, contributing to the field by proposing a full method to apply the functional analysis of TIS, called the scheme of analysis. A further work by Bergek, Jacobsson, and Sanden (2008) – 8th in our ranking with 26 citations - also develops new insights within the functional approach, by discussing the importance of two functions: legitimacy building and the creation of positive externalities.

The fourth (55 citations), fifth (53 citations) and sixth document (52 citations) in our ranking further develop the multilevel perspective, more specifically in niche development and their importance for sustainable innovation transitions (Smith & Raven, 2012; Smith et al., 2010) as well as the importance (and current lack of) a spatial perspective in the sustainable transitions literature (Coenen, Benneworth, & Truffer, 2012). In the seventh position in our ranking, we identified the paper by Farla, Markard, Raven, and Coenen (2012), which offers a literature review about strategies, actors and resources in innovation systems and sustainability transitions. It is worth mentioning the seven most cited documents in our collection are highlighted in bold due to their appearance in the top 10 most cited references, which will be explained later in the paper.

Table 1. Top 10 cited documents

Rank	Authors	Title	Journal	Year	Citation Count	Topic
1	Markard, J; Raven, R; Truffer, B	Sustainability transitions: An emerging field of research and its prospects	Res Policy	2012	96	ST
2	Bergek, A; Jacobsson, S; Carlsson, B; Lindmark, S; Rickne, A	Analyzing the functional dynamics of technological innovation systems: A scheme of analysis	Res Policy	2008	96	TIS
3	Markard, J; Truffer, B	Technological innovation systems and the multi-level perspective: Towards an integrated framework	Res Policy	2008	86	MLP/ ST/TIS
4	Coenen, L; Benneworth, P; Truffer, B	Toward a spatial perspective on sustainability transitions	Res Policy	2012	55	ST
5	Smith, A; Raven, R	What is protective space? Reconsidering niches in transitions to sustainability	Res Policy	2012	53	SNM/ ST
6	Smith, A; Voss, JP; Grin, J	Innovation studies and sustainability transitions: The allure of the multi-level perspective and its challenges	Res Policy	2010	52	ST/ MLP
7	Farla, J; Markard, J; Raven, R; Coenen, L	Sustainability transitions in the making: A closer look at actors, strategies and resources	Technol Forecast Soc	2012	29	ST
8	Bergek, A; Jacobsson, S; Sanden, BA	'Legitimation' and 'development of positive externalities': two key processes in the formation phase of technological innovation systems	Technol Anal Strateg	2008	26	TIS
9	Truffer, B; Coenen, L	Environmental Innovation and Sustainability Transitions in Regional Studies	Reg Stud	2012	20	ST
10	Surrs, RAA; Hekkert, MP	Cumulative causation in the formation of a technological	Technol Forecast Soc	2009	20	TIS

		innovation system: The case of biofuels in the Netherlands				

Legend: TIS: Technological Innovation Systems; ST: Sustainability Transitions; SNM: Strategic Niche Management; MLP: Multi-level Perspective

Source: Web of Science and Histcite, 311 article.

Besides identifying the top 10 documents in our collection, it is also important to identify the relationships between the documents, in terms of citation network analysis, so highly linked studies can also help in shedding light on the nature and evolution of our subject of study.

3.2 Document citation network

In Fig. 1 we present the document citation network, including all documents with 15 or more citations, totaling 57 documents, 13 clusters and 175 links. Fig. 1 is depicted in the 'density visualization' mode of VosViewer, which allows identifying the 'hot topics', by which several documents relate to each other, forming "heat zones" in red.

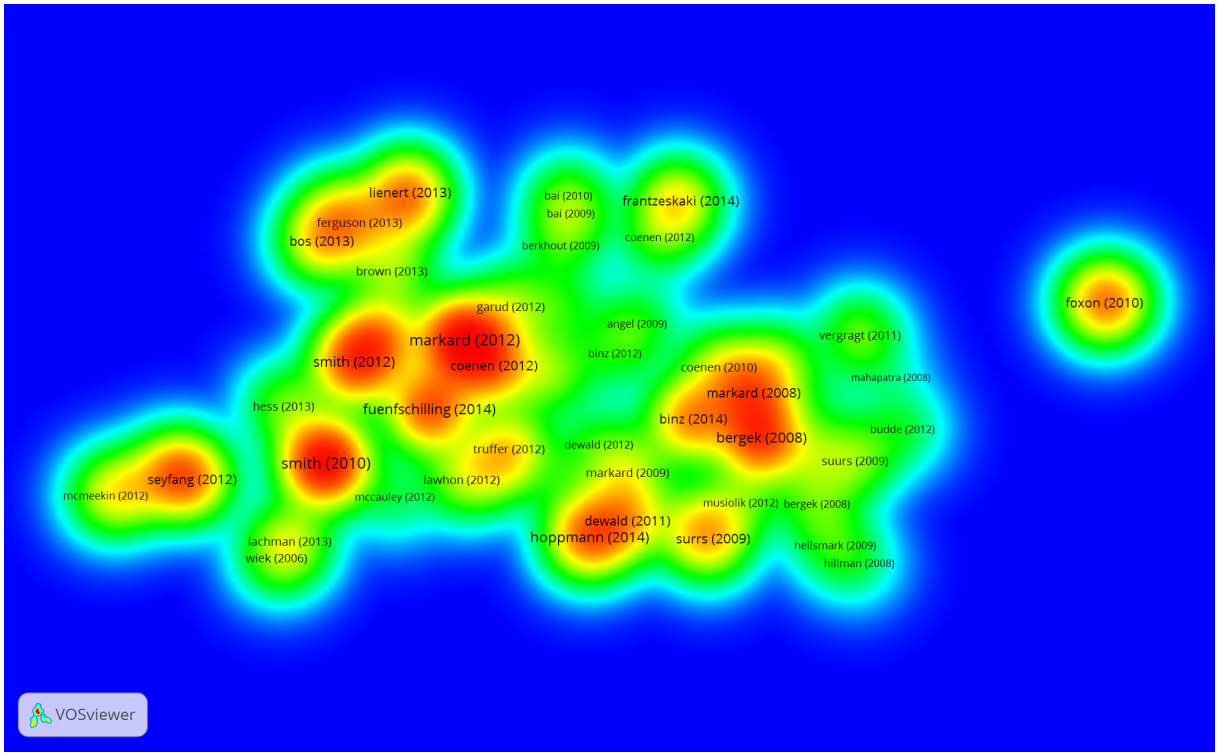

Fig. 1 Document citation network

Source: Visualization in VOSviewer from Web of Science. 311 articles, minimum number of citations = 15, 57 items & 13 cluster & 175 links.

As shown in Fig. 1, the largest 'heat zone' is formed by the works of Markard et al. (2012), Coenen et al. (2012), Smith and Raven (2012) and Fuenfschilling and Truffer (2014), this last one, focusing on developing further, the theory behind socio-technical regimes. The second largest 'heat zone' is represented with the work by Markard and Truffer (2008) – the review on sustainability transitions; Bergek, Jacobsson, Carlsson, et al. (2008) – the functions of

innovation systems and the scheme of analysis; Binz, Truffer, and Coenen (2014) – the need to account of different spatial scales and perspective for TIS; and Coenen and Lopez (2010) – offering a systematic literature review on three systems approaches in the sustainability transitions literature (sectoral systems of innovation, TIS and socio-technical systems).

3.3 Top-cited references

Next, we show in Table 2, the top 10 cited references in our collection. The studies highlighted in bold appear as well, in the top 10 cited documents of Table 1 above. Surprisingly, all works, except two – the seminal book on National Innovation Systems by Lundvall (1992) and the book chapter by Rip and Kemp (1998) – are journal articles, with a strong presence of *Research Policy*.

Table 2 Top 10 cited references

Rank	Author	Title	Type	Year	Citation Count	Topic
1	Geels FW	Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study	Research Policy	2002	105	MLP
2	Geels FW and Schot J	Typology of sociotechnical transition pathways	Research Policy	2007	98	MLP
3	Bergek A et al.	Analyzing the functional dynamics of technological innovation systems: A scheme of analysis	Research Policy	2008	96	TIS
4	Markard J, Raven R and Truffer B	Sustainability transitions: An emerging field of research and its prospects	Research Policy	2012	96	MLP/ ST
5	Hekkert MP et al	Functions of innovation systems: A new approach for analysing technological change	Technol Forecast Soc	2007	92	TIS
6	Markard J	Technological innovation systems and the multi-level perspective: Towards an integrated framework	Research Policy	2008	86	MLP/ TIS
7	Kemp R, Schot J and Hoogma R	Regime shifts to sustainability through processes of niche formation: the approach of strategic niche management	Technol Anal Strateg	1998	81	SNM
8	Smith A, Stirling A and Berkhout A	The governance of sustainable socio-technical transitions	Research Policy	2005	74	ST
9	Geels FW	From sectoral systems of innovation to socio-technical systems: Insights about dynamics and change from sociology and institutional theory	Research Policy	2004	65	MLP/ TIS
10	Carlsson B and Stankiewicz R	On the nature, function and composition of technological systems	J Evolutionary Ec	1991	60	TIS

Legend: TIS: Technological Innovation Systems; IS: Innovation Systems; ST: Sustainability Transitions; SNM: Strategic Niche Management; MLP: Multi-level Perspective

Source: Web of Science and Histcite, 14.873 cited references.

Among the top 10 cited references list of Table 2, we find several works by F.W. Geels, including the seminal work in which he develops the idea of multilevel perspective (Geels, 2002) – first among the most cited references in our list; by proposing the idea of several transition pathways in combinations of timing and nature (Geels & Schot, 2007) – second among the most cited references in our list; by discussing the similarities and differences between sectoral systems of innovation and socio-technical systems (Geels, 2004) – ninth in our ranking; by replying to several previous criticisms to the multilevel perspective (Geels, 2011) – 16th in our ranking; by developing the idea of strategic niche management along with J. Schot (Schot & Geels, 2008) – 19th in our ranking; by improving agency and causal mechanisms discussions within the multilevel perspective (Geels, 2010) – 21st in our ranking; and finally, the application of the MLP to explain the energy transition in the Netherlands (Verbong & Geels, 2007) – 30th in our ranking.

Also, in the fifth position, the work by Hekkert et al. (2007) which is one of the seminal papers in the technological innovation systems literature, and in particular, for the functional analysis approach. The work by Kemp et al. (1998) – in the 7th position, which discusses the niche formation process in order to accelerate sustainability transitions, based on the case of electric vehicles in the automotive sector. Then, the work by Carlsson and Stankiewicz (1991)- in the 10th position, which is the first known paper developing the idea of technological systems; and the work by Unruh (2000) which introduces the idea of carbon lock-in as the main barriers to sustainability transitions are not only of technological nature but of institutional nature as well, among others.

3.4 Document co-citation network

Next, we present the document co-citation network[i] (Fig. 2). As in the previous figure, we use the 'density visualization' mode which allows identifying the 'hot topics', by which several cited references relate to each other, forming "heat zones" in red.

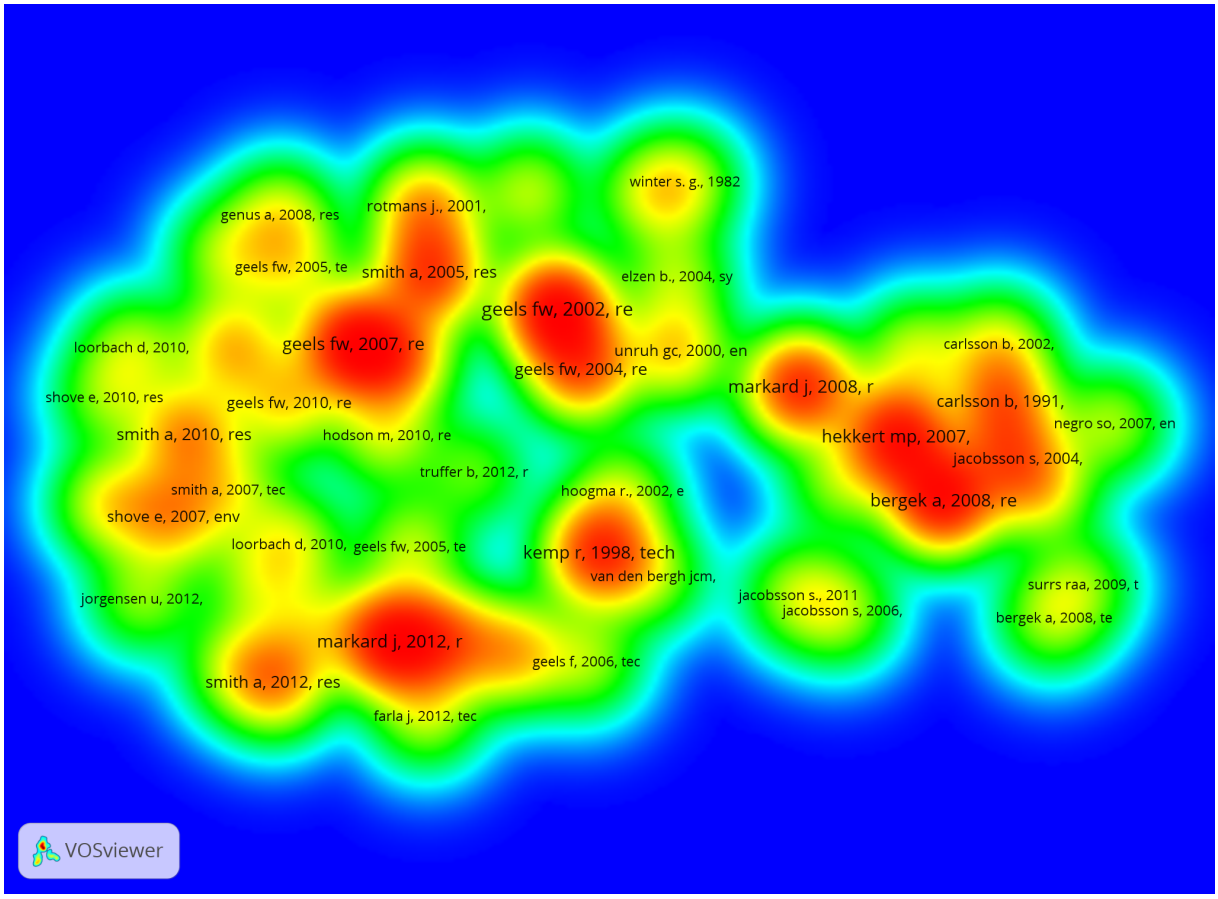

Fig. 2 Document co-citation network

Source: Visualization in VOSviewer from Web of Science. 14.873 cited references, minimum number of citations: 20. 53 items & 3 cluster & 1.347 links.

The co-citation network reinforces our previous findings on the relevance of the most cited references in our collection, by identifying several 'heat zones' in which several important works emerged in the network analysis, such as Bergek, Jacobsson, Carlsson, et al. (2008), Markard and Truffer (2008) and Markard et al. (2012), Hekkert et al. (2007), Geels (2002), Geels (2004) and Geels and Schot (2007), Kemp et al. (1998) and Unruh (2000), among others.

Most importantly, however, another important cited references emerged, in terms of co-citation and thus, in terms of their relevancy to our subject of study.

Among the technological innovation systems literature, we can cite the work by Suurs and Hekkert (2009) which develops a novel understanding of the cause-effect relationship between the functions of TIS; the work by Negro, Hekkert, and Smits (2007) which accounts for the systemic failures leading to a slow implementation of biomass in the Netherlands and using functional analysis of TIS in order to develop insights on this case; also of relevance, the work by Jacobsson and Bergek (2004) which enlarges the life cycle model of industry evolution by using the functions of TIS.

Within the transitions literature, the co-citation network revealed the importance of works such as the book edited by Elzen, Geels, and Green (2004) which offers theoretical, empirical and policy-oriented applications of the transitions literature; the work by Rotmans et al. (2001) which discusses the importance of the 'management' of transitions, primarily through

governments and public policy; a similar line of work is followed by Smith, Stirling, and Berkhout (2005) which discusses about the importance of governance for effective transformation of sociotechnical regimes; and the work by Genus and Coles (2008) and Shove and Walker (2007) about a critique to the multilevel perspective and transition literature in general, on topics such as the lack of systematical procedures on conducting case studies, on the very definition on what is a transition and the underestimation of the role of agency and politics, among others.

Moreover, co-citation network analysis is helpful in identifying the links between cited references, but fails in showing the chronological development of such network. Thus, with the help of CitNetExplorer, a citation network of highly cited papers through time, has been produced (Fig. 3). CitNetExplorer removes all nodes which do not have the minimum of 20 citations and connects the ones left through a timeline.

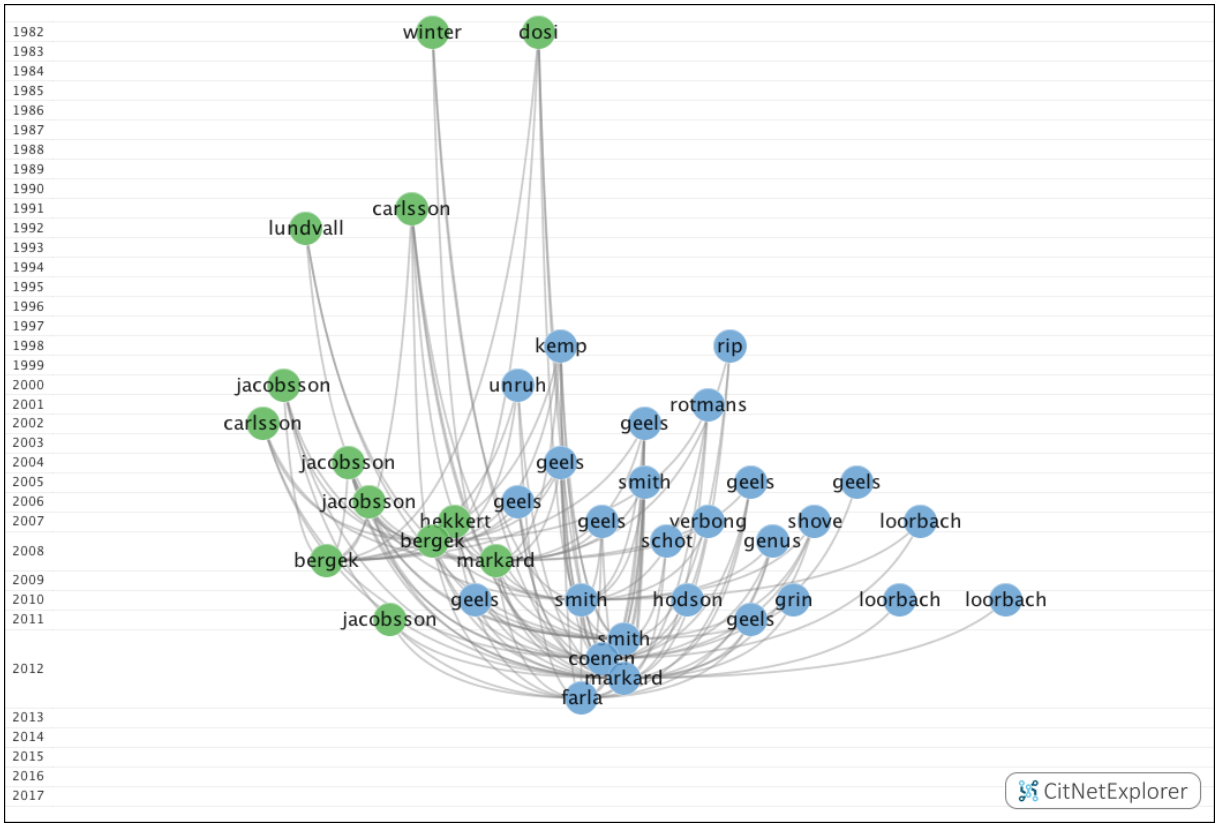

Fig. 3 Historiograph of 20 most cited works in the collection

Source: Visualization in CitNetExplorer from Web of Science. minimum number of citations: 20.

The result is a so-called a historiograph[ii]. Our historiography shows two main clusters that evolved through time, both, however, developed under the contributions of Nelson and Winter (1982) and Dosi (1982), which developed the idea of technological regimes and technological paradigms/trajectories, despite being instrumental in proposing the evolutionary perspective of firm behavior. Both clusters (green and blue) were inspired by them.

The green cluster also received theoretical contributions from the work by Carlsson and Stankiewicz (1991) – with the first appearance of the concept of technological innovation systems; and the work by Lundvall (1992) – with the first book referring to the National Innovation System. Other important contributions to the green cluster were the work by

Jacobsson and Johnson (2000)[2] which discusses key issues for the diffusion of renewable energy technologies and several other contributions to the technological innovation systems literature (Jacobsson & Bergek, 2004; Jacobsson & Bergek, 2006; Jacobsson & Bergek, 2011). Other papers appearing in the green cluster are the already mentioned in previous analysis (Bergek, Jacobsson, Carlsson, et al., 2008; Hekkert et al., 2007; Markard & Truffer, 2008).

The blue cluster shows the evolution of the sustainability transitions field. Its first inspiration, besides Nelson and Winter (1982) and Dosi (1982) was the book chapter by Rip and Kemp (1998) and the paper by Kemp et al. (1998). In particular, the blue cluster visualizes the evolution of the multi-level perspective (several works by F.W. Geels appear), of the transition management framework (Rotmans et al., 2001), of the critics to the multilevel perspective (Genus & Coles, 2008; Shove & Walker, 2007) and to the niche management (Coenen et al., 2012; Smith & Raven, 2012) and the state-of-art literature reviews of Markard et al. (2012) and Farla et al. (2012).

4 CONCLUSIONS

In terms of the most important contributions of this paper (both, documents in our collection and cited references), we were able to identify the core body of literature, composed mainly by journal articles, which in some cases were included in the collection and in the cited references.

Out of the two top 10 lists we presented in Table 1 and Table 2, some of the most important studies were: Markard and Truffer (2008), Markard et al. (2012), Bergek, Jacobsson, Carlsson, et al. (2008), Bergek, Jacobsson, and Sanden (2008), Hekkert et al. (2007), two papers by A. Smith (Smith & Raven, 2012; Smith et al., 2010), Smith et al 2010, Farla et al. (2012), and several highly cited papers by F.W. Geels (Geels, 2002, 2004, 2010, 2011; Geels & Schot, 2007; Schot & Geels, 2008; Verbong & Geels, 2007). Also of importance, the work by Coenen et al. (2012), Fuenfschilling and Truffer (2014), Binz et al. (2014), Coenen and Lopez (2010). Within the seminal – classical – works, two were of special mention, the book "*National Innovation Systems: towards a theory of innovation and interactive learning"* by Lundvall (1992) and the book chapter by Rip and Kemp (1998)

Finally, as main shortcoming, we acknowledge the use of a single database might have omitted some other relevant works, even though WoS is recognized as the most important source of scientometric and literature review data.

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[2] The author Anna Johnson is the same as Anna Bergek in future papers.

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[i] Document Co-citation network is used to reveal specific patterns of the underlying intellectual structure of a knowledge domain (Chen, Ibekwe-SanJuan, & Hou, 2010; Liu et al., 2015; Small, 1973). Document co-citation analysis is a network of co-cited references, in other words, it uses the cited references of a collection to identify clusters of literature which are cited together.

[ii] The historiography was firstly introduced by E. Garfield with the aim to shed light on network linkages among nodes – in our case, cited references – in a historical perspective (Garfield, 2009; Garfield & Pudovkin, 2004).