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Knowledge sharing and scientific cooperation in the design of research-based policies: the case of the circular economy

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Abstract

Building on the idea that the more general and systemic the policy objectives, the more cooperation and scientific support is needed for sound policy design, this paper explores the potential for knowledge sharing and research-based cooperation in the policymaking process in the field of circular economy. A sample of 1,244 research publications on circular economy from the Scopus database was collected to assess: i) how the research on CE is distributed among the main disciplines of scientific research, and how much attention each of them pays to the subject; ii) what potential they exhibit for interdisciplinary communication and knowledge sharing; and iii) the potential for developing a transdisciplinary cooperation under a common conceptual policy framework. The analysis shows that policies for circular economy at the micro/meso level (firm or inter-firm initiatives) can rely on a much more adequate knowledge base and potential scientific support than those at the macro level (circular economy as a model of systemic sustainable development). To improve the results on the macro side, a number of disciplines (including social sciences, economics and some behavioural sciences) should be solicited to devote more space to the study of the subject and to develop the basis for mutual understanding with other traditionally more involved research areas.

Keywords: circular economy; knowledge sharing; research-based policy; multi-inter-trans-disciplinarity; cluster analysis; network analysis

1. Introduction

Since its introduction (Pearce and Turner, 1990), the concept of circular economy (CE) has attracted great attention, because of the innovative way it looks at the relationship between industry and the environment, with a view to improving the long-term sustainability of production and consumption processes. CE has recently been described as the promotion of "an economic system that replaces the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production, distribution and consumption processes" (Kirchherr et al., 2017: 229). A number of definitions of this kind have been proposed by the many researchers who have studied the problem, sometimes with (slightly) different meanings, but having in common the idea of the centrality of cyclical closed loops in the organization of the economic system (Murray et al., 2017). Many advantages can be obtained in this way: a reduction of wasted energy, a more efficient use of natural resources, and, in general, better control of the environmental impacts of production and consumption. They were described in the literature. Ayres (1989) assimilates the industrial economy to the biosphere, and points out that industrial processes should be designed like natural cycles to increase reliance on regenerative processes and to increase efficiency, both in production and in the use of by-products. McDonough and Braungart (2002) argue that natural resources (once extracted from nature) should be used over and over again within circular industrial processes. Stahel (1997) claims that the 'river' structure of the industrial system needs to be converted into a 'lake' structure in order to decouple economic success from resource throughput.

A wide range of topics have found room within such a broad theoretical framework, from product-related issues (ownership over lifetime, for example) to reorganization of the whole economic process, with study of the profound and interrelated changes in the industrial practices, business models, and patterns of consumption required by a transition to CE (Ferdousi and Qiang, 2016). Acknowledging such variety, the literature has shown that CE can be approached on three different levels—micro, meso, and macro—and that the implementation of CE in the economic system and the relative policies can be studied on the same three levels (*inter alia*, Balanay and Halog, 2016; Banaité, 2016; Geng et al., 2009; Ghisellini et al., 2016; Yuan et al., 2006; Zhu and Huang, 2005).

CE implementation at the micro level concerns relatively standard sustainable development initiatives regarding the single business or product—i.e. practices regarding eco-design and cleaner production (Franco, 2017). CE implementation at the meso level concerns inter-firm initiatives—i.e. practices regarding the creation and maintenance of symbiotic relationships between firms and eco-industrial networks, where firms are able to utilize industrial by-products such as heat energy, wastewater and manufacturing waste (Geng and Doberstein, 2008). CE implementation at the macro level concerns cities, provinces, regions, nations; it is based on initiatives that involve redesigning the industry, the infrastructure, the cultural framework, and the social system, from local to global (Saidani et al., 2017).

According to Sauvé et al. (2016), there is a clear distinction between macro and other levels: "at the macro level—and in contrast to the micro and meso levels—production and consumption become integrated" (Sauvé et al. 2016: 44). While the implementation of CE at micro and meso levels takes place through initiatives involving single or multiple firms or production processes, at the macro level it requires initiatives involving socio-economic systems on different scales (national, regional or even urban: for example, in the case of so-called ‘circular cities’). This implies that, moving from micro/meso to the macro level, the complexity increases (Su et al., 2013), and, as a consequence, the design of policy interventions becomes more challenging, and their effectiveness more difficult to predict. Also in China—one of the first countries, together with Japan and Germany, to consider CE as a part of a wider policy for socioeconomic transformation and development, and to promote its implementation within a national programme—policy interventions supporting the adoption of circularity principles at the macro level are reported to be less dynamic and effective than those at the micro/meso levels by Lehmann et al. (2014) in a work where three country case studies and their different approaches to implementing CE are compared, and by Su et al. (2013) in their review on practices for the implementation of CE adopted in China.

In the European Union, the situation does not greatly differ. Policymakers and operators (industrial associations, large corporations, and financial institutions) seem convinced that CE should be the leading conceptual benchmark for systemic development strategies aimed at facilitating the decoupling of economic growth from resource availability and other environmental constraints. The Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions entitled ‘Closing the loop - An EU action plan for the Circular Economy’ (European Commission, 2015a) corroborates this view, also supported by (Franklin-Johnson et al., 2016). But despite the many acknowledgments and declarations of principles, policies for the CE at the macro level (also systemic policies for CE, hereinafter) have not found successful implementation other than in the parts relative to more conventional issues, such as material recovery and waste recycling (European Commission, 2016a). As pointed out by McDowall et al. (2017), scale and place issues should have received greater attention, i.e. through the individuation and funding of experimental zones at an urban, provincial or regional scale; moreover, a general approach could also have taken into account other aspects, such as the promotion of resource-saving behaviours, and of an environmentally friendly society through a process of ‘ecological civilisation’ based on a common vision of environmental ethics (holistic vs individualistic). In the same line Bačová et al. (2016: 5) argue, for example, that more incisive education and awareness campaigns promoting sharing economy as well as encouraging reuse and repair should have been part of the European approach. They also observe that together with technological issues, the transition towards a CE calls for a strong dose of social innovation, and especially requires innovative solutions for political and economic governance (new forms of cooperation among administration, citizens and other stakeholders) also at the local level (Bačová et al., 2016: 4). In such a framework, a number of legal issues, ranging from public law and administrative law (involved in the design of these renewed relations) to private law (rules of product liability as well as extended producer responsibility) become a relevant part of the problem.

In our view, such a state of affairs partially depends on the intrinsic features of the knowledge base on which policies for CE should be designed. As set forth by the European Better Regulation Guidelines (European Commission, 2017) and the Better

Regulation Toolbox (European Commission, 2015b), rational policymaking requires a conscious design of the measures to be adopted, and a careful evaluation of their potential impacts. When it is the successful design of macro level policies for CE that is at stake, such evaluation needs to be based on a thorough and complete comprehension of the complex and (often) de-structured relationships between natural, social, and economic systems. But, as will be shown in the following, the knowledge base on CE seems not to be sufficiently varied, and poorly suited to easing cross-disciplinary sharing. For this reason, major difficulties can emerge in promoting effective cooperation among researchers/experts from many different fields, even if it is needed to support the quality of the policymaking process.

The idea that the formulation of sound and effective policy strategies for CE calls for the synergic contribution of several fields of knowledge is not new in the literature. Ghisellini et al. (2016) claim that good prospects for policies aimed at gradually improving the current production and consumption models depend on the interdisciplinary framework underpinning CE. Heshmati (2016) argues that the implementation of CE requires greater intensification of the interdisciplinarity in research. Lieder and Rashid (2016) emphasise that effective implementation of CE can be ensured only by multidisciplinary approaches, involving business perspectives, technological developments, and policies. Murray et al. (2017) discuss the interdisciplinary perspectives inherent in the concept of CE that apply to the implementation of sustainable businesses. Sauvé et al. (2016) affirm that the complexity and novelty of the CE model raises a number of practical challenges that ask for solutions from experts in different disciplines, including natural sciences, engineering, economics, and management.

As noted above, when the level of the policies increases from micro to macro, the set of knowledge required for effective policymaking consistently widens. For example, environmental studies, process engineering, management, and business studies could provide the bulk of the competences mainly required within a micro level policy approach, as Stahel (2016) points out when he discusses tipping points in diffusion of circular business models, and also as Sauvé et al. (2016) claim, but if a macro level policy approach is in question, and CE is promoted as a model of systemic development, a much broader range of disciplines could be useful. They range from chemistry and industrial engineering to environmental and growth economics, from technical and economic regulation to industrial architecture, from territorial and urban planning to biology, ecology, and sociology, as Bruce et al. (2004) say in reference to the knowledge base necessary for the development of effective solutions for complex problems, and Kanbur (2002) argues in a commentary paper where he discusses critical issues related to the design of development policies. In particular, given the involvement of economic systems rather than productive systems alone, the role of economics and social sciences as instruments to evaluate the systemic implication of the measures adopted becomes particularly relevant. For example, behavioural sciences can be useful to suggest the best strategies to encourage changes in the consumption models (Thaler, 2016), and to foster their transition from linear to circular.

As it is evident, not all such knowledge can be held by each participant in the policymaking process. Researchers, operators, stakeholders, politicians and other technicians, instead, should be able to share and combine their competences throughout the process, from the early consultation stages to that of impact analysis.

Assuming that research on CE is the main source of knowledge for participants in the policy process, one way to assess the potential of this kind of knowledge sharing is to look at some characteristics of the scientific literature on CE to understand if it is wide enough, and how easily an expert from a field can interact (understand and be understood) and effectively cooperate with others in the complex evaluations implied by the policymaking process.

With this framework in mind, three basic questions will be addressed in the following: i) how the research on CE is distributed among the main disciplines of scientific research, and how much attention each of them pays to the subject; ii) what potential they exhibit for interdisciplinary communication and knowledge sharing; and iii) which disciplines are the best candidates to develop the kind of knowledge sharing and strict research-based cooperation that is needed to sustain better policymaking processes. The answer to these questions helps to delimit the knowledge base on which policymaking might rely, and to understand why policies for CE seem to perform better when the emphasis is on the micro rather than on the macro level.

The analysis is performed on a sample of 1,244 research publications on CE from the Scopus database. The three questions are answered using an index of dispersion across different disciplines; an original and quantitative measure of the potential for cross-disciplinary communication and a k-means clustering; and a network analysis.

The paper is organized as follows. Section 2 proposes a brief review of the literature on the need for knowledge sharing and scientific cooperation across disciplines in the study of CE. Section 3 presents the dimensions for investigating knowledge sharing and research-based cooperation in policymaking. Section 4 describes the dataset and provides a methodological overview to address each dimension. Section 5 illustrates and discusses the results. Section 6 concludes.

2. The macro level policies for circular economy and the need for knowledge sharing and research-based cooperation: a review

As noted above, the more general and systemic the purpose of the policies, the broader is the spectrum of knowledge required for their design, and the stricter should be the cooperation among the actors in the policymaking process. This is because the wider the scope of the policies, the more spheres of human activity can be interested by the interventions, and the more complex and multi-faceted the problems involved.

It is not a coincidence that one of the general principles stated by the European Better Regulation Guidelines (European Commission, 2017) and Better Regulation Toolbox (European Commission, 2015b) is that policies and instruments must be ‘comprehensive’. It means that policies and tools should result from a decision-making process in which all the relevant economic, social and environmental issues and all the relevant impacts underlying alternative solutions are considered. This is a central point. For example, the policies for ‘circular cities’ as a part of the CE policy platform require the involvement of researchers, experts and other technicians in a wide, diversified and coordinated spectrum that goes from the organization and regulation of public services to the setting of environmental and quality standards for economic activities, from public finance to urban planning, from social assessment to integration and education policies, as it emerges from a study focussed on the sharing economy and the role it can have in accelerating sustainable consumption and production patterns in cities around the globe (Cohen and Muñoz, 2016), and a study identifying common policy strategies to accomplish practical implementation of sustainable solutions throughout the city (Prendeville et al., 2016).

Another better regulation principle concerns participation, according to which all key stakeholders should be involved, including professionals with different experiences and scholars with diverse backgrounds. In such a scenario, enhanced reciprocal comprehension can reduce misalignments along the process. Interaction among people becomes easier and more effective if they are able to comprehend each other and share their respective points of view and bodies of specialised knowledge, and this can improve the quality of the policy solutions adopted (Marzano et al., 2006).

Not all stages of the policymaking process benefit from knowledge sharing and scientific cooperation in the same way. Taking into consideration the European Union policy cycle (European Commission, 2017, p.5), the stages that more than others ask for the availability of broad-spectrum scientific knowledge are those concerning 'design and preparation', in which policy proposals are formulated, and those including 'evaluation and revision', in which the potential impacts of different policy choices are assessed.

The need for knowledge sharing and research-based cooperation for effective policymaking is widely recognized in the literature. Mutz et al. (2014) claim that the complexity of world problems asks for cross-disciplinary cooperation at both the research and policy levels. Pohl (2008) stresses the utility of a co-production of knowledge and argues that cross-disciplinary cooperation and collaboration in knowledge production is crucial to ensure an adequate transfer of information among people involved internally in the policymaking (and towards other external stakeholders), and a comprehensive assessment of the social, ecological and economic pros and cons of different scenarios. Owens and Driffill (2008) argue that through effective cooperation among researchers, policy actors and stakeholders, it is possible to identify suitable policy levers and improve our ability to achieve environmental and economic goals simultaneously. This is the case for several energy/environmental policies. Due to their complexity, they cannot be designed by referring to technological, social, political or economic factors in isolation, but need a multi-dimensional and integrated approach to develop viable solutions, as Howarth and Monasterolo (2017) and Klenk and Meehan (2015) claim when they discuss decision-making processes around climate change. Similarly, Ghisellini et al. (2016) argue that only the development of an interdisciplinary knowledge base can offer an appropriate framework for policy actions in the field of CE to boost, for example, the adoption by firms of cleaner production schemes, increase consumers' awareness about end-life products, encourage the use of renewable technologies and materials, and thus minimize the overall employment of resources.

Policymakers, too, have perceived the need to improve the knowledge base on which policies are designed. This gap is particularly suffered in the case of macro level policies for CE, which have been defined as less vibrant than the micro/meso ones (Heshmati, 2016). They ask for a multifaceted knowledge base, which is still under construction (Murray et al., 2017). Some authors ask for more attention to this specific aspect (Pomponi and Moncaster, 2017). Unfortunately, it seems that such a demand has not been adequately met by researchers, despite the availability of considerable financial support, for example, within the Horizon 2020 Programme (European Commission, 2016b) and some best practices (see, for example, the DYNAMIX and POLFREE projects included in the Seventh Framework Programme, exploring the potential of resource efficiency in Europe).

3. Investigating the potential for knowledge sharing and cooperation in the policymaking process: hints from the literature on the cross-disciplinarity of research

As explained in the introduction, the quality of policymaking is strongly influenced by the specialised knowledge owned by the actors in the process (think for example at the wide range of technical knowledge – economics, finance, chemistry, physics – involved in the impact assessment of the EU Emission Trading System), and by the intensity of the cooperation they can put in place. Passing from micro to macro level policies for CE, a wider body of knowledge has to be involved and a stronger integration of different competences is required. The question arises, therefore, of whether the knowledge base is appropriate to support the kind of cooperation required by macro level policymaking. The answer is strongly related to some characteristics of the scientific literature on CE. The concepts of multidisciplinarity, interdisciplinarity and transdisciplinarity of research offer useful hints on how to explore them.

3.1. The concept of multidisciplinarity

Several authors defines multidisciplinarity as a situation in which more than one discipline works separately on the same issue, considering it from different perspectives (*inter alia*, Morillo et al., 2003; Mugabushaka et al., 2016; Van Den Besselaar and Heimeriks, 2001). In such a case, there is usually a mere juxtaposition of disciplines (Jacobs, 1989), each working in parallel (Aboelela et al., 2007), or sometimes sequentially (Rosenfield, 1992), and independently of each other (OECD, 2010), each according to its own discipline-specific perspective – this last point is also supported by Barry and Born (2013) and Stokols et al. (2008). Researchers from different disciplines also operate separately (Alvargonzález, 2011), maintaining their distinctiveness (Choi and Pak, 2006). Klein (1990) describes this style of research as additive and not integrative, a definition that seems to be consistent with those who argue that the outcome of multidisciplinary research is the sum of individual parts (Wilson and Pirrie, 2000). Klein (1990) cites the example of a centre for Asian studies that houses specialists from Oriental history, economics and sociology.

A measure of the level of multidisciplinarity of a research topic could be the first step towards an assessment of the potential for knowledge sharing and research-based cooperation in the policymaking process. According to the given definition, the level of multidisciplinarity in CE should strictly depend on: a) the number of disciplines dealing with CE; b) the number of research outputs for each discipline; and c) how equitable the distribution of research outputs is across the different disciplines. A high level of multidisciplinarity of the scientific knowledge base underlying the CE brings many benefits for the policymaking process. It means that the research topic is well known within a relevant number of research areas; therefore, there is a higher probability that the scientific base includes the knowledge required to find solutions to more complex and emerging policy problems. Moreover, it is easier for different disciplines to help answer relevant questions raised in the design or in the evaluation stages, or for a common interest to be solicited in specific issues, according to the needs of the policy cycle.

3.2. The concept of interdisciplinarity

A number of authors claim that research is interdisciplinary if it involves actual interaction between two or more disciplines (see for example: Atkinson, 2012; Moran, 2002; Rosenfield, 1992; Stokols et al., 2008; Tress et al., 2005). Interdisciplinarity has been defined by the US National Academy of Sciences as a mode of research involving teams or individuals that integrate information, data, techniques, tools, perspectives, concepts and/or theories from two or more disciplines or bodies of specialised knowledge to advance fundamental understanding or to solve problems, the solutions to which are beyond the scope of a single discipline or area of research practice (National Academy of Sciences, 2005). The distinctive feature of interdisciplinarity is the integrative nature of the cognitive content of research (Huutoniemi et al., 2010); it leads to outcomes that are greater than the sum of its individual disciplinary parts, as supported by Wilson and Pirrie (2000) and demonstrated by Larivière et al. (2015) on the success and failure of interdisciplinary papers.

Interdisciplinarity needs some degree of cooperation across disciplines (Moran, 2002), and such cooperation, in turn, needs researchers from different disciplines to be able to integrate sector-specific knowledge effectively, to discuss research topics with full reciprocal understanding, and to exchange ideas. Its fundamental prerequisite is efficient communication between experts from different research fields – this is emphasised in a number of studies (Bracken and Oughton, 2006; Hebert et al., 2009; Marzano et al., 2006) – based on a common and easily understandable language, or even meta-language (Hübenthal, 1994).

A high potential for interdisciplinary cooperation among the actors in the policymaking process can therefore be deduced by extensive use of a common language in the research outputs on CE. Knowledge sharing and research-based cooperation among the actors in policymaking are easier if they derive their specialised knowledge from research areas that use a common language in the dissemination of their findings. When this is the case, communication among experts from different disciplines is facilitated, and cooperation is expected to be much smoother and more efficient.

3.3. The concept of transdisciplinarity

The third dimension of the potential for cooperation is strictly linked to the attitude of different research areas towards developing a transdisciplinary approach to research. Transdisciplinarity refers to the opportunity to systematise interdisciplinary research according to a unifying vision (Klein, 1990). According to Gibbons et al. (1994), transdisciplinarity arises when researchers from different disciplines are encouraged to surpass their separate conceptual, theoretical and methodological orientations to develop an approach based on common conceptual and epistemological frameworks. This last is a recurrent element in the definitions of ‘transdisciplinarity’ formulated by the various authors, albeit under slightly different denominations: Rosenfield (1992) uses ‘comprehensive theoretical framework’, Stokols (2006) defines it as a ‘shared conceptual framework’, and Klein (2008, 2003) uses ‘common axiom that transcends separate disciplinary perspectives’.

These common frameworks can be grounded in theory or in policy (Klein, 1990). In the latter case, they should mainly be defined by policymakers and shared with the researchers, operators, experts, stakeholders and other technicians called to support the process of policy design. A common conceptual policy framework will ensure a shared comprehensive vision of the policy goals and a common paradigm for the assessment and discussion of the implications of policy measures, as required by the guidelines for better regulation. It should be based on a strong recognition of the reciprocal utility of the different disciplines for the policymaking process, and should consist of a common perception of: 1) the policy objectives and the general strategies to achieve them; 2) the relevant implications of policy choices and the methods to assess their impact; and 3) the relevance of other disciplines in contributing to the knowledge base and the methodological tools for the analysis required by a rational policymaking cycle. If a relevant number of different disciplines, coherent with the needs of macro level policies for CE, show a high potential to develop a cooperation within such a conceptual framework, the effectiveness of the interaction among the participants in the policymaking process and the ability to address complex challenges within a macro level approach are significantly improved.

A first hint of the attitude towards such cooperation can be achieved by performing a network analysis aimed at assessing the intensity of the connections across academic disciplines involved in the research on CE. Strong connections are a basic prerequisite for the development of a transdisciplinary approach, both to research and to applied reasoning like that implied by the policymaking process. The problem is to understand which disciplines are more interlinked, and what level of policymaking—micro, meso or macro–they are suited to support.

4. Data and methods

4.1. Data

The potential for knowledge sharing and research-based cooperation in the policymaking process is assessed through the analysis of a sample of research outputs published on CE. In particular, the dataset is composed of bibliometric data on all the research outputs indexed in Scopus that contain the term ‘circular economy’ in the title, abstract or keywords. Over the period January 2001 to December 2016, the dataset includes a total of 1,281 research outputs. Having removed retracted articles and duplications, 1,244 research outputs remain.

Figure 1 illustrates that the number of CE-related publications has grown substantially since 2004. Their annual number doubled between 2005 and 2007, increased almost four times between 2007 and 2014, and peaked at 345 in 2016. The main types of publication driving the growth in the sample are journal articles and conference proceedings. While from 2004 to 2009 and after 2014 the number of journal articles was greater than conference proceedings, from 2009 to 2014 the reverse was true.

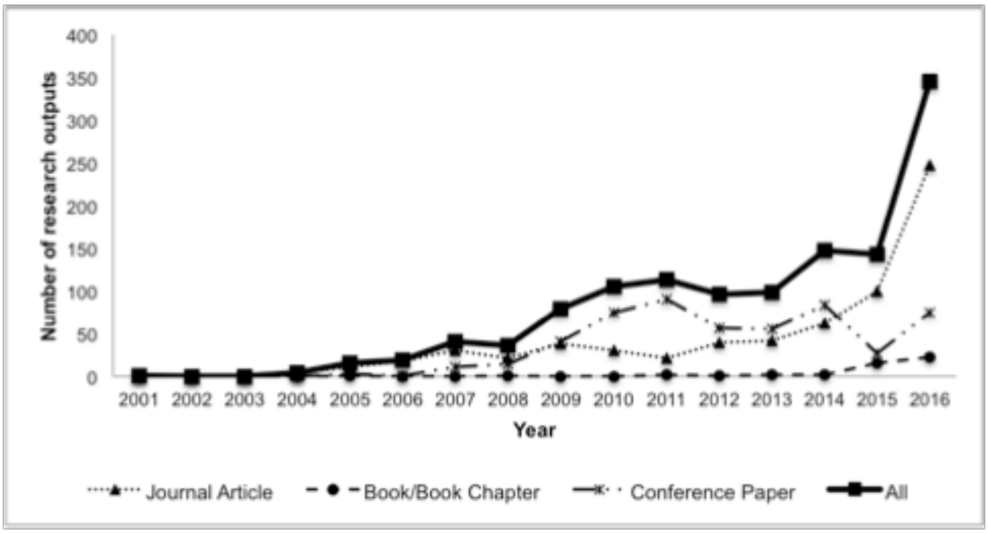

Figure 1. Number of CE-related outputs per year.

In the period 2001–2016, the researchers who contributed to the scientific production on CE were affiliated to institutions located in 49 countries: 27 European countries, 13 Asian countries, seven American countries, Morocco and Australia. Only a small portion of researchers active in the CE field collaborated with colleagues affiliated to institutions in other countries. As a result, an international collaboration network emerges where nodes are countries (in which the institution of affiliation is located) and links between nodes are given by the collaboration between authors from two different countries. The network shows 39 interconnected nodes (see Figure A1 in the Appendix A). The relationship between China and the United States is the strongest (nine co-authorships), followed by those between China and Japan (six), China and Canada, China and Italy, and Germany and the Netherlands (five). The remaining ten countries, where authors carried out their research not in collaboration with colleagues from other countries, are Argentina, Brazil, India, Israel, Latvia, the Philippines, Slovakia, Switzerland, Thailand and Turkey.

With regard to the research areas involved in the CE field, the Scopus database also offers an easy way to attribute the research outputs to the research areas to which they belong. Document sources (journals, book series and conference proceedings) are classified under four broad subject clusters (level 1), which are further divided into 27 major subject areas (level 2), and 313 minor subject areas (level 3). The four subject clusters coincide with the four main scientific areas (physical, social, health and life), while the 27 major subject areas (SAs) correspond to the (academic) disciplines (Table 1); finally, the 313 minor subject areas are sub-disciplines or thematic topics. Each research output automatically inherits the subject code (in some cases there is more than one) assigned to the source in which it is published.

Table 1. Scopus major SAs (grouped by subject cluster).

Physical Sciences	Social Sciences	Life Sciences	Health Sciences
Chemical Engineering (ChEn)	Arts and Humanities (A&H)	Dentistry (Den)	Agricultural and Biological Sciences (ABS)
Chemistry (Chem)	Business Management and Account. (BM&A)	Health Professions (HePr)	Biochemistry, Genetics, and Molecular Biology (BGMB)
Computer Science (CoSc)	Decision Sciences (DeSc)	Medicine (Med)	Immunology and Microbiology (I&M)
Earth Sciences (EaSc)	Economy Econometrics and Finance (EE&F)	Nursing (Nur)	Neuroscience (Neu)
Engineering (Eng)	Psychology (Psy)	Veterinary (Vet)	Pharmacology, Toxicology, and Pharmaceutics (Phar)
Energy (Ener)	Social Sciences (SoSc)		
Environmental Science (EnSc)			
Material Science (MaSc)			
Mathematics (Math)			
Physics and Astronomy (P&A)			

Note: 26 subject areas are reported in the table above. The 27th SA is multidisciplinary, which by definition cannot be considered a subject area per se and thus has been excluded from the analysis.

4.2. The level of multidisciplinarity of the literature on CE

In order to assess the level of multidisciplinarity, the multidisciplinarity index (MI) proposed by Heinze and Bauer (2007) was adapted to explore the dispersion of research outputs across SAs:

$$MI = \left[1 - \left(1 - \frac{1}{n}\left(2\sum_{i=1}^{n-1} wSA_i + 1\right)\right)\right]\sum_{i=1}^{n} SA_i \quad (1)$$

where $\sum_{i=1}^{n} SA_i$ denotes the number of SAs actually involved in the study of the subject under investigation out of the total possible SAs, and w is the cumulative percentage of the outputs per SA over the total number of research outputs in the sample. The MI sums up the information on the number of SAs involved in the study of CE with the dispersion of research outputs across the disciplines.

Since this formula includes the Gini index, it can also be expressed as follows:

$$MI = (1 - GINI)\sum_{i=1}^{n} SA_i \quad (2)$$

The value of the index equals the number of the SAs involved in the study of CE when the research outputs are equally distributed across SAs; it equals 0 if all the research outputs are concentrated in a single SA or discipline.

4.3. The potential for interdisciplinarity

The second relevant dimension to evaluate the potential for knowledge sharing and research-based cooperation in the policymaking process for CE is associated with the extent to which research outputs from different SAs make use of a common language. The use of common technical terms is a prerequisite for interdisciplinary cooperation, since it makes communication easier among researchers, experts, stakeholders and other subjects participating in the policymaking process with specialisation in different SAs, and favours a synergic approach to the policy problems implied by CE. Furthermore, a common language increases the comprehensibility of research results for experts from other disciplines, thus making their diffusion across a wider scientific audience easier and enhancing the potential for cooperation.

To capture these aspects, an original measure of potential interdisciplinarity is proposed. It is based on the idea of representing quantitatively, rather than qualitatively, the measure by which research products use a language shared with disciplines (SAs) different from those from which they originate.

To that end, a keyword analysis in four stages was performed. In step 1, the keywords of all research publications relating to each SA were grouped together. This process was repeated for every SA. The number of ‘baskets’ of keywords equals the number of major SAs to which are attributed research outputs relating to CE. In step 2, the weight of each keyword within each single basket was calculated (that is, if keyword x_i is mentioned three times in basket Z_j out of a total of 100 entries of keywords, the weight of x_i in basket Z_j is 3%). In step 3, the values of each keyword within each basket were reattached to the research outputs in which they were used, so that publications were depicted not in terms of qualitative keywords, but in terms of the quantitative relevance of each keyword within each SA. In step 4, the final matrix was constructed with a number of rows equal to the number of research outputs considered and a number of columns equal to the number of major SAs to which are attributed research outputs relating to CE. The generic element a_{ij} of the matrix represents the total relevance of the keywords employed per research output in each single basket or SA. Values along each row of the matrix can thus be interpreted as indices of the degree of affiliation of each research output to different SAs. From another point of view, such values express the degree to which research outputs associated with a specific SA might be understood by researchers from other SAs. This is a good measure of the interdisciplinary comprehensibility of each research output and of the extent to which they could contribute to knowledge sharing and to fertilizing research in other SAs.

A k-means analysis (one of the simplest unsupervised learning algorithms for resolving the well-known clustering problem) is then proposed to classify the sample through k clusters, with k (the number of clusters) fixed a priori, according to the level of the potential for interdisciplinary cooperation and knowledge use. The main goal of such an analysis is to determine the share of the research outputs with a relevant degree of interdisciplinary comprehensibility of the total number of research outputs. The higher this share, the stronger the potential for knowledge sharing and research-based cooperation in policy-related issues.

4.4. The potential for transdisciplinarity

The proposed measure of interdisciplinarity works at the research output level and not at the discipline level: we can realize how many and what share of the total number of publications are actually characterized by high interdisciplinary comprehensibility, and from this derive the potential for knowledge sharing and research-based cooperation in the policymaking process. It is not possible instead to derive from such a measure any indication about which specific SAs effectively show the strongest potential for transdisciplinary cooperation, and what kind of policy approach to CE, micro/meso or macro, can be best supported.

This question can be approached through a network analysis linking SAs on the basis of the co-occurrence of keywords used for both. The hypothesis is that keywords synthesize characterizing concepts, methodologies and approaches. When they are consistently shared by different SAs (when the edges of the network through which they are connected are stronger), these SAs could develop the reciprocal recognition and intense knowledge sharing which is the basis for transdisciplinary cooperation under a common conceptual policy framework. Obviously, the more SAs are strictly linked, the wider, more inclusive and systemic the common conceptual policy framework can be under which they can cooperate.

5. Results and discussion

5.1. The level of multidisciplinarity of the literature on CE

Almost all disciplines (22 out of the 26 SAs) have been directly involved in the study of CE (with research outputs directly citing CE in the title, abstract or keywords) over the entire period under consideration (see Table 1 for the abbreviations of the SAs): BGMB, I&M and Phar in the subject cluster of life sciences; A&H, BM&A, DeSc, EE&F and SoSc in the subject cluster of social sciences; all SAs composing the subject cluster of physical sciences; HePr, Med and Vet in the subject cluster of 'health sciences'. Other disciplines could have contributed in an indirect way, for example by providing theoretical and empirical background for the research outputs attributed to the directly involved SAs. Therefore, the disciplinary involvement in the study of CE or in related aspects seems to be very wide.

However, data show that there is a non-homogeneous dispersion of research outputs across SAs. According to the MI index, which in this case can assume values from 0 to 22, multidisciplinarity in the CE research field is low at 8.8.

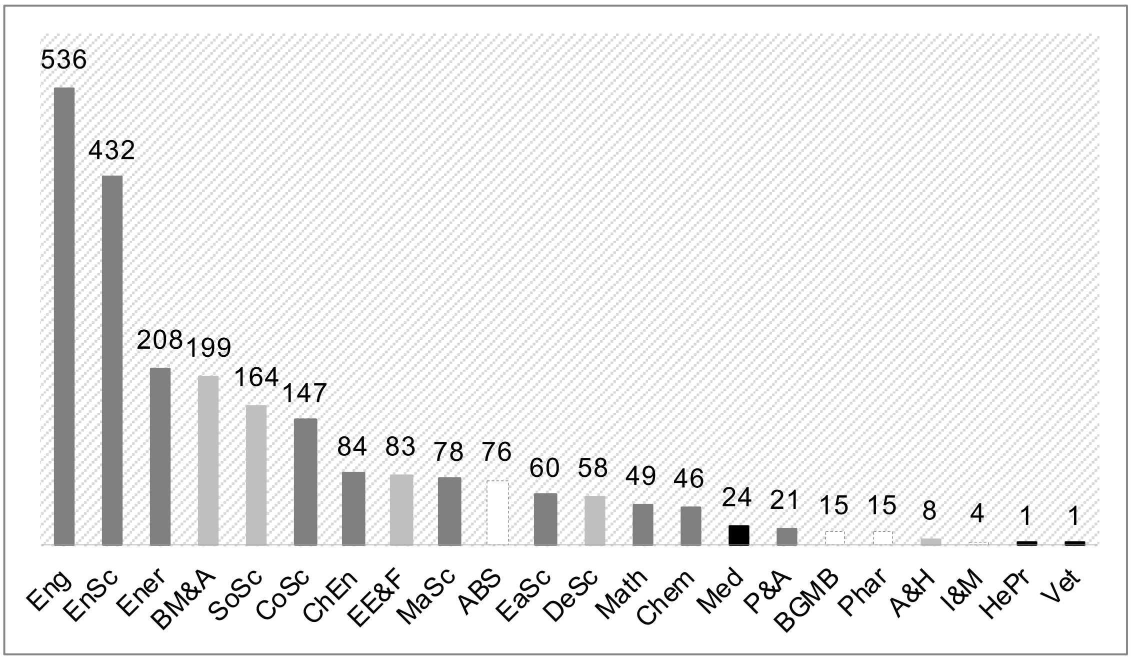

Figure 2. Number of CE-related outputs per single SA.

Note: The colours indicate the subject clusters: dark grey=physical sciences; light grey=social sciences; white=life sciences; black=health sciences. See Table 1 for the abbreviations of the SAs.

The study of CE (Figure 2) is heavily concentrated in physical sciences, and in particular in Eng (536), EnSc (432) and Ener (208), which represent the top three SAs in the list of disciplines by number of research outputs. BM&A (199) and SoSc (164), respectively the fourth and the fifth in ranking per number of research outputs, are the most productive disciplines within the social sciences area, which is the most productive scientific subject cluster behind physical sciences. Note that DeSc (58) encompasses some sub-disciplines closely linked to BM&A, such as management science and operational research, and information systems and management. By summing up the research outputs published by researchers in DeSc and outputs from researchers involved with BM&A, the involvement of business-related disciplines is significant. The same cannot be said for economic disciplines that study the structure and the development of socioeconomic systems: EE&F (83) is ranked eighth.

Disciplines belonging to life sciences and health sciences offer only a negligible contribution: excluding ABS (within the life sciences area), which is ranked tenth in the list per number of research outputs (with 76 publications), all other disciplines belonging to these subject clusters are ranked very low, with positions below fourteenth.

Finally, it has to be noted that two of the four SAs not yet involved in the CE research field are Psy and Neu. Until 2016, no research output belonging to such SAs has been indexed in Scopus as directly addressing CE-related issues. They are two important sections of the behavioural sciences, the utility of which in the study of the evolution of social systems is more and more recognized in recent times. As said in the introduction, an effective implementation of CE requires profound changes not only to industrial practice but also to patterns of consumption; psychological researches could help to understand the determinants of consumer behaviour models and how they are related to the shift from linear to circular.

The evolution of the level of multidisciplinarity in the literature on CE across time has been also studied. The period under observation has been divided into three temporal windows (2001–2006, 2007–2011 and 2012–2016) and the MI has been calculated for each window. Results show that the number of SAs has increased, even though the dispersion of research outputs has gradually decreased over time (see Figure A2 in the Appendix A). In fact, the MI index assumes a value of 7.54 (with the maximum possible value equal to 13, given by the number of involved SAs) for the first temporal window (2001–2006); a value of 8.35 (with the maximum possible value equal to 19) for the second window (2007–2011); and a value of 8.62 (with the maximum possible value equal to 21) for the third window (2012–2016). This trend is mainly due to a rapid growth in the research outputs relative to technical disciplines useful for both micro/meso and macro approaches (Eng, EnSc, Ener), and BM&A, a typical discipline of micro interest.

5.2. The potential for interdisciplinarity

As seen above, the mere dispersion of research outputs across different SAs gives only a preliminary clue with regard to the potential for knowledge sharing and cooperation in research. Eng, EnSc, Ener, BM&A, SoSc and CoSc represent the bulk of scientific publication on CE and seem to be the best candidates to cooperate and share knowledge. Additional information can be obtained by looking at the level of interdisciplinary comprehensibility of research outputs (see section 4.3).

The reduction of the number of SAs to the most relevant ones (Eng, EnSc, Ener, BM&A, SoSc, CoSc, ChEn, EE&F, MaSc, ABS, EaSc, DeSc and Math), while still accounting for more than 97% of the total number of research outputs, eases the reading of the results of the analysis. The k-means algorithm partitions the dataset into eight clusters of research outputs, from A to H. Table 2 shows the value of centroids for each cluster per single relevant SA.

Table 2. Centroids per single cluster of research outputs.

	Eng	EnSc	BM&A	Ener	CoSc	SoSc	ABS	DeSc	EaSc	EE&F	ChEn	MaSc	Math
G	0.44	0.55	0.50	0.54	0.39	0.57	0.64	0.46	0.35	0.58	0.44	0.28	0.29
E	0.29	0.35	0.32	0.34	0.26	0.35	0.38	0.29	0.24	0.38	0.27	0.19	0.25
B	0.18	0.22	0.20	0.21	0.17	0.21	0.23	0.19	0.17	0.24	0.19	0.14	0.17
A	0.12	0.14	0.14	0.14	0.12	0.14	0.15	0.14	0.11	0.15	0.12	0.09	0.11
D	0.08	0.09	0.08	0.09	0.07	0.08	0.09	0.08	0.07	0.09	0.08	0.06	0.07
H	0.05	0.05	0.05	0.04	0.05	0.04	0.05	0.05	0.05	0.05	0.03	0.03	0.05
C	0.03	0.03	0.03	0.02	0.03	0.03	0.03	0.02	0.04	0.02	0.07	0.08	0.03
F	0.02	0.01	0.02	0.01	0.02	0.01	0.01	0.01	0.02	0.01	0.02	0.01	0.01

Note: See Table 1 for abbreviations of the SAs.

Clusters G and E include those publications with the highest degree of interdisciplinary comprehensibility. Despite outputs in cluster G relating to a lower number of SAs than in cluster E, they show a similar pattern when only the most relevant SAs are considered (values of centroids are relatively high in ABS, EE&F, SoSc, EnSc, Ener, BM&A and Eng). The research outputs grouped in these clusters share a language that can be easily understood by researchers from disciplines that are different and distant from each other (the subject clusters of physical, social and life sciences are involved). Unfortunately, they are a large minority of the total (their shares of the total research are 2.3% and 4.4% respectively).

Cluster B, the third by degree of interdisciplinary comprehensibility, accounts for 8% of all research outputs and presents a similar pattern to that of clusters G and E. Cluster A accounts for 10.9% of all research outputs, while clusters D (18.4%), H (19.7%), C (8.8%) and F (27.5%) show gradually lower levels of interdisciplinary comprehensibility. In particular, cluster C includes research outputs with a low degree of affiliation to most relevant SAs, except ChEn and MaSc, SAs that are far less central in all other clusters, mainly because they are characterized by very technical language and knowledge use that is difficult to understand outside these specific disciplines.

In conclusion, the share of the research outputs with a significant degree of interdisciplinary comprehensibility is very low (6.7% or 14.7%, depending on the inclusion of the third cluster). However, it seems not to be constrained to certain SAs, but rather to be distributed across all relevant SAs. The potential for knowledge sharing across SAs therefore remains very low. Moreover, no significant sign of a trend towards greater integration emerges from the average date of publication (year and month) of research outputs per single cluster (2012.2 for cluster G versus 2011.7 for F, respectively the most and the least interdisciplinary).

5.3. The potential for transdisciplinarity

To investigate the potential for transdisciplinary cooperation, the open-source software R (R Core Team, 2017) was used to build a network with 20 nodes (SAs)—all disciplines involved in the CE research field except Vet and I&M, which have no connections—and 190 edges (Figure 3). The thickness of the edges is proportional to the number of times two SAs share a keyword. As said in section 4.4, the stronger the edges which link two SAs, the stronger is their potential for transdisciplinary cooperation.

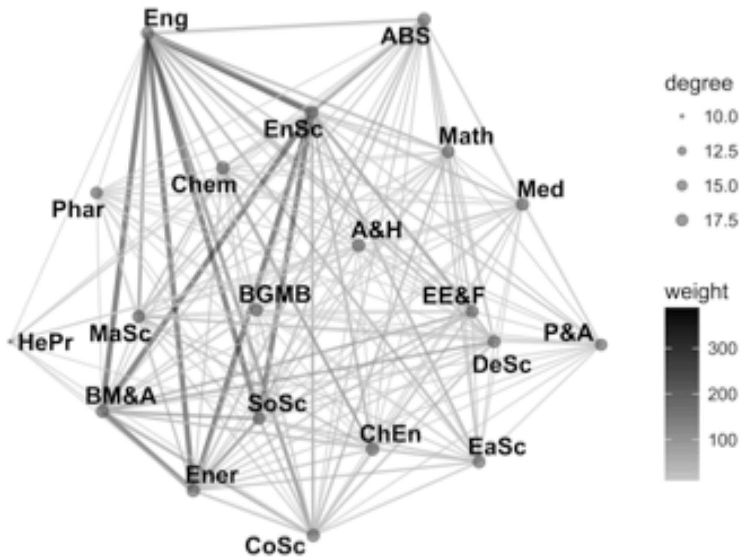

Figure 3. Output of the network analysis across SAs (restricted view).

Note: See Table 1 for abbreviations of the SAs.

The most connected nodes were found to be those corresponding to technical disciplines useful for both micro/meso and macro approaches. In fact, among the strongest links are those between Eng and EnSc (391 keywords and terms in common), Ener and EnSc (328), and Ener and Eng (319). BM&A is strongly connected with Eng (336), EnSc (318) and Ener (290). The connection would be even stronger were DeSc considered a part of managerial disciplines. To sum up, SAs more interested at the micro/meso level of CE (industrial processes and systems) show good potential for mutual recognition and for developing transdisciplinary cooperation in policy design.

A very different picture is that of the disciplines which contribution is especially required for the design of macro level policies for CE. While the connections of SoSc with EnSc (321) and Eng (312) are strong, much less tight are those between SoSc and EE&F (72), and the remaining SAs. Moreover, EE&F has only very weak connections with other SAs and a moderate value of the clustering coefficient (a measure of how complete the neighbourhood of a node is) within the network, with values just below the average. Finally, some SAs which would be typically considered within the behavioural sciences (Psy and Neu) are not even part of the network, having produced no research output on CE in the considered period.

Due to the loose interconnections of these SAs (SoSC, EE&F, Psy and Neu), among themselves and with the others, it is unlikely that experts from these fields could adhere to a widely shared conceptual policy framework. The level of transdisciplinary cooperation useful to improve the quality of the macro level policies for CE seems, therefore, difficult to be attained.

To better show the evolution across time of the relationships between different SAs, a network per year for the entire period has been drawn. Each network has been drawn adding new relationships established during the year to those established in the previous years. A static visual summary of the main changes in the network is shown in Figure A3 (in Appendix A), while the evolution of the network can be watched at the link below (see Appendix B). Figure A3 displays a network with one node in 2001 because only researchers publishing within the Ener discipline were involved in the study of CE. In 2004, a network with eight nodes (Eng, EnSc, Ener, CoSc, SoSc, EE&F, Math and Phar) and 24 edges emerged. From 2005 to 2008, every year some SAs have been added to the network: in 2005, ABS, EaSc, Chem and MaSc, but these last two were isolated nodes; in 2006, BM&A; in 2007, DeSc; in 2008, BGMB. Med and HePr joined the network in 2010, while Chem and P&A established their first relations with other disciplines studying CE in 2012. A&H was the last SA to join the network.

What is striking, in this case, is that EE&F emerged early as a node of the network, but its connections developed and diversified very slowly. Quite different was the evolution of BM&A, which appeared two years later in the network, but quickly established and intensified connections with other nodes. In other words, the earlier interest of economic disciplines in the study of CE was not followed by the development of a structure of relations comparable to the one built by business-related disciplines. As said, this circumstance has probably limited the ability of the experts in economic disciplines to effectively and easily participate in transdisciplinary policymaking processes. Also, this result can help to explain the lower dynamism of macro level policies for CE compared to micro/meso policies, often reported in literature.

6. Conclusions

When research-based policies are at stake, a better regulation in the sense adopted by the European Institutions is strongly influenced by the specialised knowledge owned by the actors in the process, and by the intensity of the cooperation they can put in place. Passing from micro to macro level policies for CE, a wider body of knowledge is necessary and a stronger integration of different competences is required. In particular, given the involvement of economic systems rather than productive systems alone, the role of economics and social sciences as instruments to evaluate the systemic implication of the measures adopted becomes particularly relevant. The same can be said for psychology and other behavioural sciences with reference to demand/consumption related issues.

The paper builds on the idea that the lower dynamism of macro level CE policies in comparison to the micro/meso level ones could be partially due to some intrinsic features of the knowledge base on which policies for CE are designed.

In this paper, an analysis of the potential for knowledge sharing and research-based cooperation in the policymaking process has been presented in terms of the level of multidisciplinarity and the preconditions for interdisciplinary and transdisciplinary research displayed by the scientific literature on CE.

The main findings can be summarised as follows.

First, a wide number of disciplines are involved in the CE research field, but most of the available scientific knowledge on the subject has been produced by just a few of them. In particular, less involvement of economics and social sciences has been registered, and no involvement at all of psychology and other sections of the behavioural sciences is registered, so that the body of knowledge seems to be best suited to policymaking at the micro/meso level rather than at the macro level. Moreover, during the entire period taken into consideration, a slight trend towards greater concentration of scientific production has occurred. In order to provide a knowledge base suitable to address CE-related issues at the macro level, the body of scientific knowledge should be enriched, promoting research in the fields more connected with the socioeconomic systemic implications of CE.

Second, the number of research outputs comprehensible to researchers and experts from different backgrounds represents a very small part of the total research developed on CE and comes from a reduced number of research areas. The use of a common language, therefore, seems to be very limited. Anyway, among them, both the disciplines more linked to micro/meso aspects and those linked to the macro ones are represented, and the research outputs make use of a common language to a high degree. This is a sign that at least a few aspects of CE can be debated from an interdisciplinary perspective. This situation does not seem to have significantly changed over the period of analysis. In order to make the exchange of knowledge among different disciplines and the dialog among the participants in the policymaking process easier, a wider effort to promote the use of a common language in the research on CE should be put in place.

Third, the best candidates among the academic disciplines to develop the kind of transdisciplinary research-based cooperation that is needed to sustain better policymaking processes seem to be found mainly in the disciplines useful for micro/meso approaches to CE. The low connectedness of social sciences and economics, of economics with the rest, and the absence of at least psychology among behavioural sciences could hinder the development of a common conceptual policy framework suited to supporting the policymaking cycle in the case of macro level policies for CE. In order to facilitate the development of a common conceptual policy framework suited to macro level policymaking, a better integration of social sciences, economics and behavioural sciences should be encouraged.

In the European Union, these results were usually pursued by promoting research or cooperation programmes involving a minimum number of different disciplines. They can give relevant help in relation to points 2 and 3 above. Those instruments, anyway, give the best results when a consolidated research base on CE is already present in the different disciplines. Unfortunately, in the case of macro level policy programmes for CE, some relevant disciplines seem not to have a pertinent research base at present, and this should be built, starting with the involvement of the university system. For example, doctoral programmes on CE should be encouraged in the fields of economics, social sciences and behavioural sciences, as well as a specialised professional formation through Master’s degrees.

Future research efforts should include the use of alternative ways to attribute research outputs to the SAs in order to make such attribution more adherent to their specific content. A possibility is that of elaborating on the reference list of each research output instead of using the SA attributed by the Scopus database to the document source.

This research can also be enriched gathering information on the main disciplinary specialisation of the authors of co-authored research outputs. In this case, more precise information on the real connections among disciplines could be obtained, building a network where the nodes are the reference disciplines of each author and the intensity of the links is proportional to the number of times two authors belonging to different nodes are co-authors in a research output. Moreover, by adding to this the already available information on the affiliation of the authors, it should be possible to assess if a geographical pattern of specialisation of the knowledge base emerges.

Finally, a new interesting direction for further research is that of complementing the analysis proposed here with a similar exercise on actual policy documents. The research should focus on the range of knowledge used, the potential range of knowledge that could have been used, and on the benefits that might derive from widening the knowledge base. Nevertheless, some critical issues must be addressed before moving in this direction, as the identification or the development of valid and reliable methods of extracting keywords from policy documents, together with rigorous criteria to refer the extracted keywords to subject areas and weight their relative relevance.

Appendix A

Figure A1. The international collaboration network in the CE field.

Note: Links between nodes refer to collaborations between researchers affiliated to institutions located in different countries. Bubble sizes are proportional to the number of research products produced by the country. The thickness of the lines (edges) between countries represents the intensity of collaboration (number of co-authored research products between each pair).

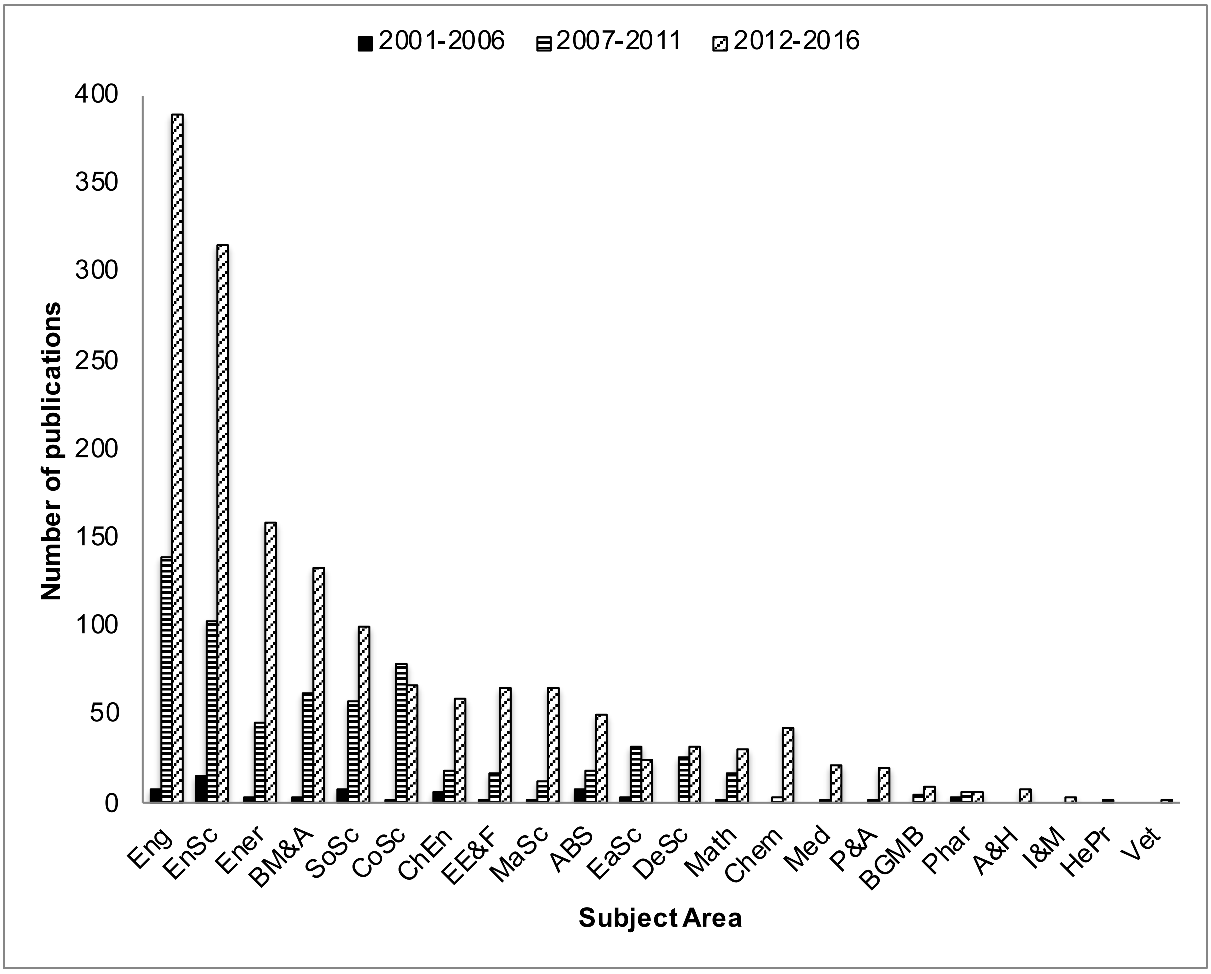

Figure A2. Number of CE-related outputs per single SA in 2001–2006, 2007–2011 and 2012–2016.

Figure A3. Evolution of relationships between disciplines across time.

Appendix B

An interactive video displaying temporal evolution of the network in Figure 3 (from 2001 to 2016) has been created using the NDTV package in R (Bender-deMoll, 2016). In addition to playing and pausing the movie, it is possible to click on nodes and edges to show their IDs, double-click to highlight neighbours, and zoom into the network at any point in time.

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