# Accepted Manuscript


Emerging patterns in the academic literature on responsible research and innovation

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PII: S0160-791X(19)30108-3

DOI: https://doi.org/10.1016/j.techsoc.2019.101148

Article Number: 101148

Reference: TIS 101148

To appear in: *Technology in Society*

Received Date: 13 March 2019

Revised Date: 20 May 2019

Accepted Date: 26 May 2019

Please cite this article as: Loureiro PM, Conceiçao CP, Emerging patterns in the academic literature on responsible research and innovation, *Technology in Society* (2019), doi: https://doi.org/10.1016/j.techsoc.2019.101148.

## 1. Introduction

Over the past decade the term Responsible Research and Innovation (RRI) was increasingly introduced in the European Union policy discourse for science and technology [1]. Its meaning stems from the previous academic debate about responsibility in science and technology, coined as ‘responsible innovation’ within the theoretical backgrounds of Technology Assessment (TA) and Science, Technology and Society (STS) studies [2–4]. The concept of "Responsible Innovation" introduced ethical dimensions in contexts of increasing concern and uncertainty arising from the potential impacts of emerging technologies. Among other studies, Hellström [5] developed a general framework for ‘responsible innovation’ compatible with technology assessment and management of 'systemic' innovations; Owen and Goldberg [6] studied the implementation of problem anticipation as well as the responsible development of new technologies; and von Schomberg [7] proposed a regulatory ethical framework for new technologies. Several authors [1,8–10] argued in favour of improving the RRI concept, in order to obtain better social impact through the formulation and implementation of more effective public policies for science and technology.

Within the science policy domain, RRI was integrated as a soft-law in the European funding Framework Programme for Research and Technological Development, ‘Science with and for Society’, which in turn is described as an instrument to address European societal challenges tackled by the Horizon 2020 [11]. Formalized by the European Council with the declaration of Rome in November 2014, RRI was broadly defined as ‘the on-going process of aligning research and innovation to the values, needs and expectations of society’. For such purpose it requires that all stakeholders, including civil society, take shared responsibility for the processes and outcomes of

research and innovation. It operates in six predefined key dimensions: social engagement, gender equality, science education, open access to scientific results, ethics and governance [12].

However, the generic language involving the RRI discourse led to a debate calling for deeper clarification as the concept itself was regarded as vague and un-defined [4,13]. RRI entered the academic literature across fields of knowledge giving rise to diverse and often conflicting definitions and interpretations. Zwart et al. argue that the RRI discourse is a language shift, or a metonymic 'game of signifiers', aiming to promote change in the European scientific funding system with expected but uncertain impact on researchers and research groups [13]. Although it is not consentaneous, the most cited and widely accepted definition of RRI belongs to the European Commission officer, Rene von Schomberg [3,14], who is also an academic. According to his definition:

> *"Responsible research and innovation is a transparent, interactive process by which societal actors and innovators become mutually responsive to each other with a view on the (ethical) acceptability, sustainability and societal desirability of the innovation process and its marketable products (in order to allow a proper embedding of scientific and technological advances in our society)."*[8].

The strongest criticisms to this definition arise from its imprecise language as, for example, "*societal desirability*" is a subjective value prone to various understandings which may cause RRI to be interpreted and handled as an ideological tool [15–18]. Following this claim, RRI principles have been questioned based on the

premise that there are several societies within society, each one defending different values, needs and expectations for themselves, thus hindering a common ground of understanding [19]. More recently, Stahl et al. noticed a growing consensus on key features outlining RRI, but still highlighting some deeply-rooted contradictions and problems in putting them into practice [20].

Other prolific scholars already engaged in the earliest debate of 'responsible innovation' in science and technology seem to have helped draft the official Rome Declaration [21]. This cooperation between academics and policymakers may well explain the blend between technical and stereotyped language which characterize the complexity of the RRI discourse: on the one hand, buzzwords are used *ad-libitum* by institutions and science policy makers [22] in order to communicate general ideas to a wider public in a top-down manner; on the other hand, in a bottom-up direction, academics conceptualize these broad ideas into specific contexts with diverse and often contrasting meanings [23].

In this sense, 'responsible research and innovation' may have several meanings at once. Philosopher and linguist Ludwig Wittgenstein postured that the changing nature of language, enhanced by its continuous practice, is the phenomenon behind the formation of new simpler forms of language, the meaning of which can only be obtained from contextualization – language-games [24]. In fact, what Wittgenstein designates by language-games can be considered the foundation of Bensaude Vincent's definition of buzzwords: "*As linguistic units buzzwords are usually characterised by their poor semantics. Being deprived of consistent meaning they serve as slogans, advertisements.*" [22]. In a similar approach, Bos et al., use the term 'big words' to describe uncontested, all-encompassing concepts, which allow multiple interpretations and specifications in the structuring of scientific practice [23].

The goal of this study is not to search for meaning in the institutional science policy language, but rather to uncover the discursive properties in the academic literature about RRI, and to frame it in a disciplinary context. This is important because academic literature relies on a complex system of interactions, based on language communication between scholars that is expected to reveal new themes and trends, as opposed to the political institutional discourse about RRI that remains reasonably stable since its initial implementation – the same phrases of the first institutional definitions of RRI are still used in current documents of the European Commission. See, for example, the Horizon 2020 Work Program 2018-2020.

Text analysis studies on RRI have been conducted, making use of different methodologies [9,22,23], however these are focused on the contextual meaning and correlations of buzzwords and 'big words' in science policy discourses. Likewise, text analysis of official EU documents was conducted in order to discuss difficulties in implementing RRI [25]. More recently Mejlgaard et al. [26] proposed a quantitative approach to describe the European RRI landscape characterizing different countries from the six-dimensional model perspective. However, the literature keeps some gaps that we propose to fill. Our study differs from the others in that it seeks to uncover trending themes and linguistic traits changing overtime in the academic community, but also to frame the discussion about RRI in the context of academic disciplines and research topics. To accomplish such analysis we propose the combined use of computational tools, methodologies and strategies of social network analysis, text mining and content textual analysis in a data set of peer-reviewed articles related to the topic of responsible research and innovation – the application of these tools facilitates the analysis of large datasets and provides clearer insights into discursive phenomena, in addition to substantially reducing the human error of analysis as they are based on

increasingly sophisticated algorithms. With the results we hope to obtain a clearer understanding of the changing nature of the RRI discourse in the academic literature, as well as to identify and analyse its emerging themes, without losing sight of the European policy determinations stated in the Declaration of Rome. In this sense, we believe we are responding to the challenge posed by Mejlgaard and Bloch, according to whom there is a continued need to explore the patterns and trends within the emerging discourse on responsible research and innovation [27].

The article is organized as follows: in the next section we provide a description of the methodologies, disclosing why and how we got to the *corpus* of analysis, how data was managed, and what tools and strategies we used to analyse data. In the following section we present and describe the results, and in the final sections we open the discussion from the results and close with the final remarks, study limitations and future research.

## 2. Methodology

### 2.1.Dataset

For the analysis we used data extracted from Scopus, an abstract and citation database of international peer-reviewed research literature, covering a wide range of fields of knowledge with an emphasis on the social sciences and related subjects [28]. The Scopus database has been used extensively in analyses that map knowledge in specific research topics and academic disciplines, including studies that use methodologies similar to the one in our study [29,30]. By means of a Boolean search, we searched the term “responsible research and innovation” in the title, abstract and keywords of peer-reviewed articles only, published in the English language until the end of 2017. We chose not to include the search of the term “responsible innovation”, often

found in the science policy literature. “Responsible innovation” is an older and wider concept, not necessarily related to the European scientific policies of the RRI framework, although it is on the basis of its current conceptualization. By removing this term from our search we are aware that some articles may have been excluded. However, this methodological choice was applied to ensure the robustness of the sample in that it prevents the entry of many unrelated articles in the dataset which could cause inaccurate results. Also, we chose not to include the acronym RRI in order to avoid confusing results, as it has many other meanings, such as “Renal Resistive Index” or “Respiratory Infection”. The search delivered 147 articles published until 2017, with the first publication identified in 2009. Two of the articles were removed due to duplication, and the remaining 145 were downloaded (see table C.1).

### 2.2.Data management techniques and strategies of analysis

The main criterion applied in collecting and handling the data was the careful narrowing of the corpus of analysis. If the corpus of analysis is too broad, the text mining algorithms lose their sensitivity due to increased fuzziness and abundance of residual and unfocused subjects, thus hiding any emerging patterns [31]. This criterion was applied in the search process with Scopus, in the preparation of the data for the text analysis, and also through network filtering.

First of all, the articles were labelled by research topic according to their content. This process was based on the field of study or discipline in which the concept of RRI is contextualized in each article. For example the study, *Exploring responsible innovation: Dutch public perceptions of the future of medical neuroimaging technology*[1] is labelled

[1] Arentshorst, M.E., de Cock Buning, T., Broerse, J.E.W. (2016), Exploring responsible innovation: Dutch public perceptions of the future of medical neuroimaging technology, Technology in Society, DOI: 10.1016/j.techsoc.2016.01.003

in the neurosciences. The label *RRI* refers to articles devoted to the discussion of RRI as the main topic, either through empirical studies or through theoretical reflections, there being no clear association of a discipline or field of study in these cases. With these procedures we are able to draw a contextual landscape at the disciplinary level of the application of RRI, and also to highlight the set of articles whose main topic is RRI. After this process, the data was handled in two steps with different computational tools according to the intended objectives: Nvivo was used for the text analysis of the articles, and Gephi to analyse the network structure of the sample. Both software were used in similar analysis e.g [32,33] respectively (see Figure D.1).

In the first step, with Nvivo, the articles were coded in separate sections: “Title”, “Abstract”, “Keywords”, “Introduction”, “Body”, and “Discussion & Conclusions”. In order to overcome the different structures of the articles we defined the “Body” as all the text between the “Introduction” section and the “Discussion & Conclusions” section. Footnotes, tables and text boxes were not included in the analysis. This coding strategy was defined based on the existing evidence that the used language and communication purposes differ from section to section [34,35]. Not surprisingly, this was confirmed with a word similarity cluster analysis of the different sections, which showed a strong similarity between “Introduction”, “Body” and “Discussion & Conclusions” sections, and less similarities between the “Title”, “Abstract” and “Keywords” sections. This led us to narrow the text corpus of analysis down to the three similar sections – “Introduction”, “Body” and “Discussion & Conclusions”. After the coding process, buzzwords of the RRI terminology, such as *responsible*, *research*, *innovation*, *science* or *technology*, were manually removed. Stopwords like *the*, *if*, *and*, *or*, were removed automatically by the software. Stemmed words were also clustered in the same group, such as, for example, *ethic*, *ethics*, *ethical*, *ethically*, etc. The removal

of these frequent words reduced the residual effect of any result mined from the sample, and facilitated the observation of emerging patterns beyond the buzzword language. The text analysis was conducted making use of different techniques: *Word Frequency Queries* list the most frequently occurring words or concepts in the coded text, thus highlighting the main lexical trends and topics in the sample; comparative analysis of *Word Frequency Queries* implemented in different subsets of the sample, looking for language variations between them; and *Directed Content Analysis* with the aim of extracting deeper meanings from the most important themes revealed in the sample [36].

In the second step we created a citation network with Gephi, counting only the citations between the articles in the dataset, and thus obtaining a clear visualization of the network structure of the sample, in a similar fashion to the study by Hoffmann et al. [33]. Each article of the sample is represented by a node, and each citation is represented by a directional edge (arrow) connecting two nodes. The citation network enabled us to remove isolated articles from the sample, and also to calculate degree and betweenness centrality measures. *Degree* is a centrality measure that counts the number of edges connected to a node. Nodes with a higher degree are more central to the structure and tend to have a greater influence on the network [37]. When the network is directed, such as the one we built, it is possible to measure in-degree and out-degree centrality, according to the direction of the edges. *Betweenness* centrality measures how often a node is located on the shortest path between two other nodes. Nodes with high betweenness values function as bridges between clusters. In scientific networks this generally points to interdisciplinarity and also indicates high influence in the structure of the network [38].

Although social network analysis is generally not considered in the context of impact assessment of academic literature, studies show that centrality measures are highly-correlated with citation counts [37,38] and can be complementary to existing forms of impact assessment [33].

In the context of our study, network analysis is important because it is expected to reveal the most influential articles of the sample. Our assumption is that this influence has an impact on the thematic approach and discursive language of the remaining articles.

## 3. Descriptive analysis and results

### 3.1.Citation network and word frequency counts

Figure A.1 shows the structure of the citation network with 115 articles of the sample. The remaining 30 articles (not in the graph) were removed from our analysis, as they were isolated from the main cluster, that is, they didn't cite or weren't cited by any articles in the sample. Therefore, centrality measures for these outside articles are equal to zero, meaning that their influence on this network is null.

We observed the impact of the removal of these articles from the sample by comparing the word frequency analysis of two groups of articles. Group A consists of all 145 articles and group B consists of the 115 articles in the central cluster network which compose our main corpus of analysis. In Table B.1 the 25 most frequent words are ranked for both groups. Words in group B are marked according to their rank variation when compared with group A, thus showing the impact of the removal of the 30 articles outside of the network cluster. Results confirm that groups A and B are rather similar, with slight rank variations, showing only considerable disparity in the words, *Actor* (+5) and *Risk* (-6).

Table B.1 also characterizes group X consisting of the 30 articles removed from the sample. When compared with the main cluster articles in group B, group X contrasts by introducing eleven new words showing a high variation in the word frequency rank. This suggests that the language pattern and thematic approach of the articles in group X diverge from the patterns evidenced throughout the main sample.

### 3.2.Citation network centrality measures

Centrality measures are based on the structure of the citation network and do not take into account any text content in the articles. Figure A.2 shows both degree centrality, on the left, and betweenness centrality, on the right. Larger nodes represent higher values and higher influence on the network. The tables next to the graphs show the values for each of the three most influential articles in each measure. Degree centrality measurements show a clear overpowering influence of one single article[2] in the network, mainly because of the in-degree value which counts 67 citations incoming from the articles in the sample. The low out-degree value of this article can be explained by the fact that it is one of the first to address RRI, being that, at the date of its publication there were only four published articles in this sample that could be cited. Betweenness centrality measurements confirm the same article as the most influential of the sample, but introduce two other articles[3] with high values which characterize them as vital to the structure of the network.

The results of all centrality measurements led us to accept these three articles as the most influential in the sample and therefore with great potential to influence the academic discourse about RRI. These articles are taken as discursive references and will

[2] - R. Owen, P. Macnaghten, J. Stilgoe, Responsible research and innovation: From science in society to science for society, with society, Sci. Public Policy. 39 (2012)

[3] - B.E. Ribeiro, R.D.J. Smith, K. Millar, A Mobilising Concept? Unpacking Academic Representations of Responsible Research and Innovation, Sci. Eng. Ethics. 23 (2017)

- A. Rip, The past and future of RRI, Life Sci. Soc. Policy. 10 (2014)

be the starting point to content analysis of a broader set of articles aiming to deepen the results in the final discussion of our study.

### 3.3.Discourse changes overtime

With aim of investigating changes in the patterns of the RRI literature, we divided the sample of 115 articles into two groups in order to implement a comparative word frequency query: the first group consists of all articles published by the end of 2014, and the second group, all articles published between 2015 and 2017. The criterion for this division was based on the date of the Rome Declaration for Responsible Research and Innovation (November 2014), from which the number of RRI publications has substantially increased (see Figure A.3). Table B.2 ranks the 25 most frequent words for both groups. Group C consists of articles published from 2009 to 2014 and group D consists of articles published from 2015 to 2017. Words in group D were marked according to their rank variation when compared with group C. The comparison of the two groups showed three main outcomes: (1) the most stable trend on the top of the ladder is related with *ethics*, which is ranked second in group C and first in group D; (2) words like *health*, *nanotechnology* or *synbio*, fall out of the ranking, perhaps indicating that RRI became less dedicated to these specific disciplines, and is increasingly becoming more multidisciplinary. Also words like *ELSA*, *ELSI*, *fund*, *Europe*, *future* or *governance*, either drop in or fall out of the word frequency ranking, suggesting a decrease in the approach of science policy issues; (3) finally, words related with putting RRI to practice, public participation and stakeholder engagement, such as *public*, *participate*, *practice* and *stakeholder*, are either at the top of, or significantly high up in the ranking.

### 3.4.Research topics in RRI

All articles were labelled (Table B.3) according to identified research topics as described in the methodology section. The most frequent research topic in the sample is *RRI*, that is, articles that are specifically focused in the study and discussion of RRI. Figure A.4 shows the distribution of the main research topics by the two time periods defined in the previous subsection. The topic labelled as *Others* covers all topics with less than 4 published articles. In the period between 2009 and 2014, we identified 7 research topics, with a relevant concentration on articles mainly focused on *RRI*, *Nanotechnology*, *Technology Assessment*, *Science Policy* and *Synthetic Biology*. From 2015 to 2017 we observed a great increase in the number of research topics in the literature, with a total of 28 identified. In this period of time, the emphasis is on the same topics of the previous period, although with less concentration, as other relevant topics emerge, such as *Helth Sciences*, *Neuroscience*, *Education* and *ICT*. This result reinforces the idea that RRI is becoming increasingly multidisciplinary.

Figure A.5 shows the distribution of research topics by the two groups of articles identified in the citation network analysis (Group B and Group X of Table B.1). Group X is represented in black and is composed of a diversity of topics relatively well distributed, highlighting only the topic of nanotechnology as the most frequent. Nevertheless, in Group B, represented in grey, nanotechnology continues to be one of the most frequent topics. This means that, the removal of Group X from the sample does not call into question the diversity of topics in the main corpus of analysis.

In order to deepen the disciplinary aspect of RRI we disclosed the most frequent words of the five main topics in Table B.4, where a general tendency for the prominence of specific technical language of each topic is evident. These results are further discussed in the next section.

## 4. DISCUSSION & CONCLUSION

This article was motivated by our perception of a clear diversity of definitions and understandings in the academic literature around the concept of Responsible Research and Innovation. We have argued that the controversy surrounding RRI is often positioned in the discursive domain and lies particularly within the academic debate, rather than in the institutional discourses for science and technology of policy makers. In this study we analysed a set of articles dedicated to the subject of RRI, searching for emerging language patterns beyond the use of buzzwords that could illustrate the existence of a discursive homogeneity, possibly pointing to some consensus among scholars. Although it does not include all the existing literature on the subject, the corpus of analysis of our study was defined according to several criteria that sought greater robustness and representativeness of the sample. It was then analysed with computational tools, which facilitate the reading and visualization of large amounts of data. We used network analysis, first, to refine the sample to a set of 115 articles and, second, to find the most influential articles in the sample through centrality measurements; with this method we identified three central articles in the network. We then ran word frequency queries to different subsets of the sample, aiming to uncover emerging themes and patterns in the literature. Moreover, we labelled the articles by research topic in order to get a better understanding on the disciplinary landscape surrounding RRI. Following these results, we proceed to an in-depth discussion making use of directed content analysis.

Our findings confirm a discrepancy between the discourses of European policy makers for science and technology and academics participating in the debate about RRI. In 2014 the Rome Declaration recommended six key dimensions for Responsible

Research and Innovation: social engagement, gender equality, science education, open access, ethics and governance. However, only three of these dimensions seem to be of significant concern to academics, in that the majority of the most frequent words of our sample can be easily related with the dimensions of ethics, social engagement and governance. Gender equality, open access, and science education are less relevant for the academic debate about RRI. The words *gender* and *equality* are ranked below the top 500 words, moreover, a large part of the references to gender equality are embedded in the text as descriptions or transcriptions of the six dimensions of RRI, and not so much as the main topic of a discussion. This may suggest that gender studies scholars have not perceived RRI as a privileged field of discussion for gender-related ideas, and also that scholars involved in the debate about RRI do not focus so much on gender equality as a central topic of controversy. Similarly, the word *access* is ranked poorly amongst the most frequent words. Although content analysis also revealed the effect of a large quantity of descriptions and transcriptions of the six dimensions of RRI, it also revealed that a few articles in the sample approach open access in more detail[4]. The same occurs with the dimension of science education, as related words like *university*, *student*, or *education*, are very poorly ranked and only a couple of articles in our sample approach the topic directly[5].

But why is there such a discursive divergence between academics and policy makers regarding the six dimensions of RRI? We point out three possible causes: first, as

[4] - van Oost E, Kuhlmann S, Ordóñez-Matamoros G, et al. (2016) Futures of science with and for society: towards transformative policy orientations. Foresight 18(3): 276–296. DOI: 10.1108/FS-10-2014-0063
- Chatfield K, Iatridis K, Stahl BC, et al. (2017) Innovating responsibly in ICT for ageing: Drivers, obstacles and implementation. Sustainability (Switzerland). DOI: 10.3390/su9060971.

[5] - Heras M and Ruiz-Mallén I (2017) Responsible research and innovation indicators for science education assessment: how to measure the impact? International Journal of Science Education. DOI: 10.1080/09500693.2017.1392643
- Blonder R, Zemler E and Rosenfeld S (2016) The story of lead: A context for learning about responsible research and innovation (RRI) in the chemistry classroom. Chemistry Education Research and Practice. DOI: 10.1039/c6rp00177g.

noticed by Zwart et al. [13], the neologism RRI was not introduced bottom-up by the research community, but rather in a top-down manner by the European Commission. Second, before the inception off the term RRI a debate about responsible innovation was already going on in science and technology studies with significant literature on issues of *ethical* application of scientific knowledge [7,39], *public engagement* with science [40,41] and science *governance* [42,43]. On the other hand, *open access*, *gender equality*, and *science education* were also being debated in the academic literature, however in other research fields outside the context of responsible innovation. In this regard, further research might shed some light on the causes of lower commitment of some academic communities to the concept of RRI. Third, there is evidence that these divergences may also be related to broader aspects, beyond the specific interests of the academic communities. As a recent study seems to suggest [26] the weight of each dimension of RRI varies geographically due to contextual factors of social, cultural and political nature.

By comparing articles published by the end of 2014 with articles published between 2015 and 2017, we noticed a greater initial attention was given to issues related to European science and technology management policies, namely concerning funding programs. This first time-period can be regarded as a period of instability, most likely caused by the uncertainties resulting from the preannounced changes in the European scientific system. From 2015 onwards, as RRI became an established framework in the European funding programme for research and technological development, we noticed a decrease in the academic concerns about the future of science governance and policy in Europe, contrasting with an increasing emphasis on social engagement issues, since words like *participate*, *practice*, *stakeholder*, or *engagement* emerge at the top of the ranking, while words like *future*, *impact* and *fund* fall significantly down in the ranking.

Social engagement within the context of RRI can be seen as a policy instrument to promote changes, not only in general society but particularly in the forces at work of the European scientific system. From this perspective the emergence of social engagement evidenced in the literature means that efforts are being made to take RRI from theory to practice.

The concept of "responsible innovation" was first developed in contexts of increasing concern about complex technological systems with great potential for impact on society. The words *health*, *nanotechnology* or *synbio* (for synthetic biology), listed on the top of the most frequent in the first set of articles (group C), reveal some of the most significant fields of knowledge implementing RRI. With the increasing focus on social engagement issues, complexity is added to the debate as multiple stakeholders with different views, needs and demands have brought new ideas that definitely changed RRI into a much more complex and multidisciplinary field. But, despite changes in language identified over time in the academic literature, it is important to note that since the inception of the term “Responsible Research and Innovation”, terminology related with ethics remains unchanged on the top of the most relevant topics – in fact, *ethics* is a constitutive semantic property inherent to the meaning of the word *responsible*. In this sense, our findings reveal that the most trending academic perceptions of RRI emphasize the values of *ethics*, *public engagement* and *participation*.

The disciplinary aspect of RRI was deepened through the analysis of the sample decomposed into research topics. The most frequent topic is labelled as pure debate of RRI, and is increasingly growing in the literature. This might suggest that RRI is still subject of an ongoing self-reflective practice by academics aiming to define it conceptually, in a process that shows great similarities with the dimension of reflexivity proposed by Stilgoe et al. [10]. When comparing the most frequent words between the

main corpus (group B of Table B.1), and the topic *RRI* in Table B.4, no relevant variations are found, either in terminology or in rankings, with the exception for the word *participate* that is less frequent in the *RRI* topic. The same trend is verified in the remaining topics, with the words *participate* and *ethics* losing relative significance. This may be due to the more frequent use of lexis specific to each topic, and to the secondary prominence attributed to RRI in these articles.

The topics *RRI*, *Technology Assessment* and *Science Policy* are all interrelated and can be framed within the disciplinary field of the social sciences; while *Nanotechnology* and *Synthetic Biology* fall into the field of the natural sciences, approaching RRI in the context of its practical application. These are recent research fields working on the frontiers of knowledge, with many potential areas of risk and uncertainty, and therefore likely to be contextualized in a responsible framework. Other topics with similar features are identified, although with lower incidence. *Artificial Intelligence,* for example, which is currently debated worldwide as one of the most challenging research fields raising ethical and technical issues mostly related with its unpredictability and uncertain impacts on the future of humanity, has all the characteristics to be a topic of RRI *par excellence*. However, in our analysis the topic of *Artificial Intelligence* is almost absent and clearly underrepresented, suggesting a clue for future research: why have some cutting-edge scientific communities engaged more easily to the discussion around RRI than others?

Another notable absence in our results is patent in the low frequency of the words that identify the four dimensions to operationalize RRI, as proposed in 2013 by the European Commission report by Hoven et al. [44] and further developed by Stilgoe et al. [10]: *anticipation*, *inclusion*, *reflexivity* and *responsiveness*. According to the authors these dimensions are guidelines for stakeholder engagement in research and

innovation processes, designed to address ethical aspects and social needs. In our results *Responsiveness* is ranked 69th; *anticipation* is ranked 181st; *inclusion* is ranked 199th; and *reflexivity* is ranked 534th. From these ranks it is not possible to determine whether the contextual meaning of the words in each of the utterances refers to the four dimensions of the RRI operation. Since they are polysemic words, we assume that some of the uses refer to other contexts, and that a thorough examination would result in even lower ranks. In order to test this, by means of a collocation analysis to the full sample, we searched for the use of the four words together within the same article and the results showed only ten articles. One of the reasons for the low frequency of these words may be related to the fact that these dimensions were proposed in 2013, covering only part of our sample which starts in 2009. Additionally, a delay factor explained by the timing of the publication process may also have had an impact as only two out of these ten articles are published in 2014 and 2015, and the remaining eight articles are published in 2016 and 2017, which suggests that attention dedicated to the four dimensions of the RRI operation is increasing.

By analysing the citation network of the sample, three articles were identified as the most influential and the most interdisciplinary, based on the results of degree centrality and betweenness centrality measurements. All these three articles labelled as *RRI* topic revealed a similar pattern to that of group B, thus reinforcing the hypothesis of potential discursive influence of these on the remaining articles of the network. Words like *ethics*, *engagement* and *actors* are ranked as the most frequent, but on the other hand, the use of the word *participation* is rather rare. Accordingly, the term *public engagement* is clearly preferred to the term *public participation*, perhaps due the nature of these articles, debating the concept of RRI from a general perspective: public engagement is a broad concept, while public participation can be considered as one of its subcategories

[45]. Public participation can be assumed as an improved form of engagement, in that it implicates mechanisms of participatory democracy and public deliberation with greater potential to bring about change, rather than just the involvement of social actors in public dialogues or public consultations [46]. In this sense, the use of the term *engagement*, on the one hand clearly marks a change from the previous top-down deficit models of the relationship between science and society, but on the other hand it is still not committed to any specific model of communication between science and society.

The subject of public engagement as one of the most relevant is not so surprising since the agendas of RRI and public engagement converge with each other; on the one hand, RRI is broadly defined as the alignment of science with society and, on the other hand, public engagement is about involving lay people with experts either in decision making or in any knowledge production processes. To retrace the debate on public engagement, it was founded on the call for deep changes in the relationship between science and society. This resulted in the transition from the usage of the word *understanding* to the word *engagement* as an illustration of the change from the deficit model, which assumed the public as being ill-informed about science, to a dialogical model which allows the public as a valid contributor, regardless of its scientific literacy, as discussed by [35,47–49] and others.

The problems and controversies of the older debate on public engagement became deeply rooted in the academic discourse about RRI. As a result, and as we have previously mentioned, the dimensions of *gender equality*, *open access* and *science education* are underexplored in the RRI literature, perhaps also due to the fact that these are less dialogic modes of relation between science and society. Owen et al. [1] noticed that the distinctions between instrumental, normative and substantive motivations in the field of public engagement are applicable to the concept of RRI. Arguing further that

the primary point of discussion and clarification should be focused on the purposes and motivations of RRI at the policy level, insofar as RRI risks becoming just a new label for the prevailing *status quo*, as well as being used instrumentally to achieve pre-committed policies.

But other restrictions have been identified in the literature. For example, the problem that an overemphasis on public engagement may foster the misconception among the public that participatory processes are enough to prevent any undesirable outcomes [25,50]; or the fact that it is often observed that civil society actors may not be able, or willing, to participate or engage in any given practice with science and technology as an expression of a possible "engagement fatigue" [4] that would undermine both RRI and public engagement determinations. These examples, among others, make it clear that RRI agendas cannot be isolated from the problems of public engagement. Therefore, efforts should be made to develop participatory models to respond to the complexity of RRI, such as in the RRI Tools project [51], in which instruments are developed to assist the implementation of the various RRI dimensions.

Underlying many controversies in the literature about RRI are ethical and moral aspects that are, in fact, the foundations of the earlier discussion about the social aims of science, which gradually called the wider public to participate in the debate about the application of scientific knowledge for social benefit (see, for example [52,53]). In this sense, and since the phenomena of engagement also raise ethical questions, such as, for example, instrumental versus moral stakeholder engagement in [54], one would expect the RRI literature to disclose a debate combining *ethics* and *engagement* issues. A collocation analysis to all content in the sample didn't disclose a significant correlation between both. In other words, the dimensions of *public engagement* and *ethics*, with some exceptions, appear to be generally discussed separately.

One of the exceptions to this rule, is Rip's account [4] framing public engagement within the traditional division of moral labour, which can be assumed as a strategy to adjust diverse values by merging normative individual morality with ethical elements governing social institutions. This appears to be particularly suitable in a complex social setting where scientists, technologists, industrialists, government actors and other social actors are committed to maximizing the positive impact of science and technology on society. But this approach is not without problems, as the demand for the 'right impacts' has difficult ethical dimensions and include significant political and social dilemmas [1]. The notion of 'right impact' on society and the best ways to achieve it is definitely not only of ethical substance, but also suggests that social and political dilemmas may be conflicts of ideological nature underlying public opinion, institutional behaviour, politics and, ultimately, decision makers.

Ethics and ideology are interconnected and many ethical issues of our time are inevitably developed from and around ideological values [55,56]. The discussion of ideology in RRI is scattered throughout the sample and is mostly found in the context of engagement, as actors or stakeholders involved in participatory action either potentially carry ideological biases that contribute to the low productivity of engagement practices [18,57], or can be infected by the ideological aims of RRI [13]. Also, risk and scenario anticipation, namely in fields of emerging science and technology with high uncertainty levels, appear to be rich in ideological visions of the future [15,17]. However not representing a trending topic in the literature, ideological factors may constitute significant obstructions to the arrival of a consensus on the definition of RRI.

From the perspective of academic discourses, Responsible Research and Innovation is a dynamic ethical framework increasingly narrowing on issues of social engagement, bringing problems of an ideological nature which may prevent a consensual theoretical

definition of RRI. If there are in fact significant ideological constraints to the practice of RRI's ethical foundations, it would be thought-provoking to deepen the understanding on how potential ideological beliefs of different social actors are fuelling, or infecting the RRI debate, and bringing its controversies into an apparent everlasting state of entropy. In contrast, RRI is applied and put into practice in a growing number of academic disciplines and research topics, which can lead to a self-organized definition based on its ongoing implementation. The combination of these seemingly contradictory forces makes the future of RRI uncertain. We may witness the worsening of the buzzword effect of the concepts associated with RRI, turning the academic debate into an inconsequential litany, or in another way, RRI may become a complex and dynamic concept, resulting from the unpredictability of social interaction.

### 4.1 Limitations and future developments

In our study we pursued emerging patterns in the academic literature on Responsible Research and Innovation in a restricted set of articles. We are aware that there is a margin of error in the results to the extent that a part of the literature has been excluded from the sample. For example, by choosing to analyse peer-reviewed articles only, we left aside books, book chapters and conference papers, which also constitute an important medium of academic discourse. However, in all phases of the sample setting process we complied with criteria that favoured its robustness, in this sense we consider that the results can be admitted as reliable emerging trends.

Ethics and public engagement are the clearest thematic patterns revealed in our study. This led us to continue our research seeking deeper knowledge of public engagement and participation in science and technology policy, making use of not only quantitative methods but also qualitative methods which provide more detail to the

topics under study. We have solid reasons to consider that public engagement and participation are key elements to better understand practical and conceptual tensions underling RRI.

Finally, our perception is that the literature is largely composed of case studies, which, although of great value, are limited to the specificity of their contextual circumstances. In order to deliver a more extended vision into this academic debate, further impact assessment and evaluative research is needed, perhaps through more systemic approaches that provide wider insights into the RRI project.

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## Appendix A

Figure A.1

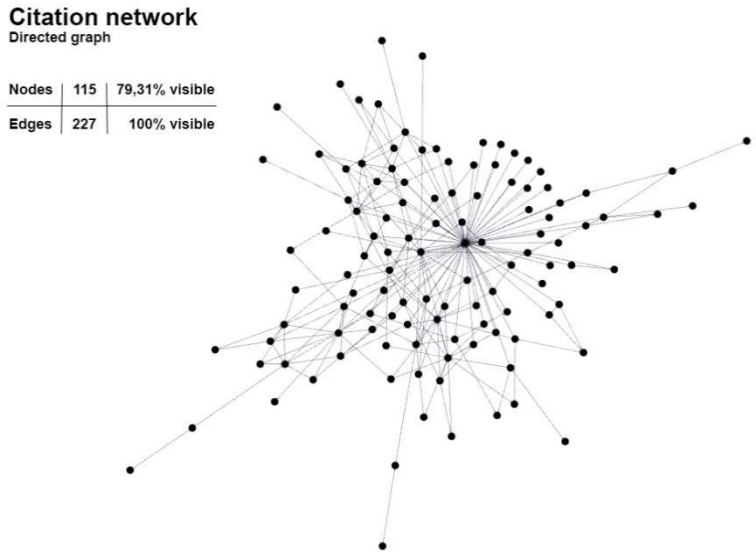
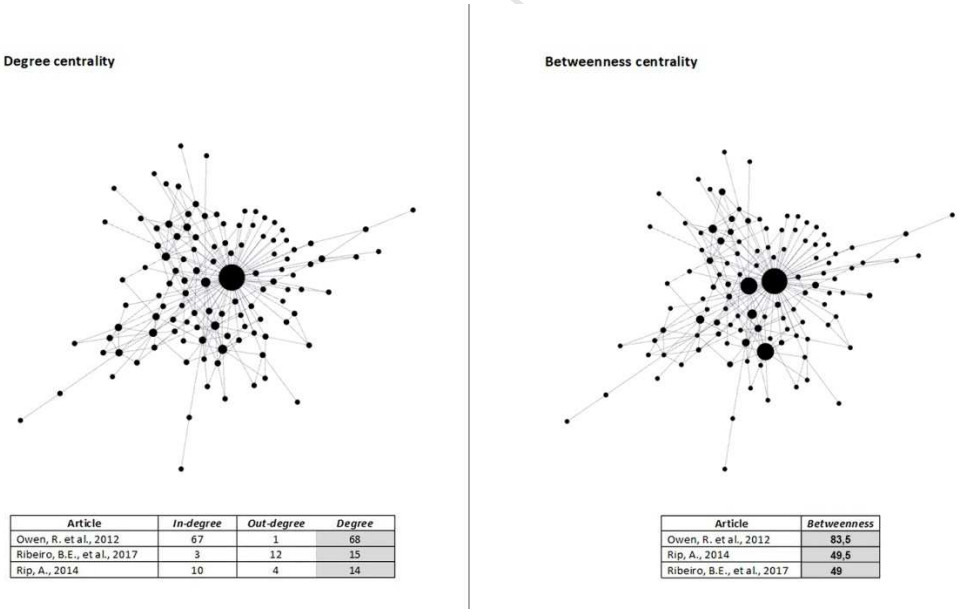



Figure A.2




| Article | *In-degree* | *Out-degree* | *Degree* |
|---|---|---|---|
| Owen, R. et al., 2012 | 67 | 1 | 68 |
| Ribeiro, B.E., et al., 2017 | 3 | 12 | 15 |
| Rip, A., 2014 | 10 | 4 | 14 |

| Article | *Betweenness* |
|---|---|
| Owen, R. et al., 2012 | 83,5 |
| Rip, A., 2014 | 49,5 |
| Ribeiro, B.E., et al., 2017 | 49 |

Figure A.3

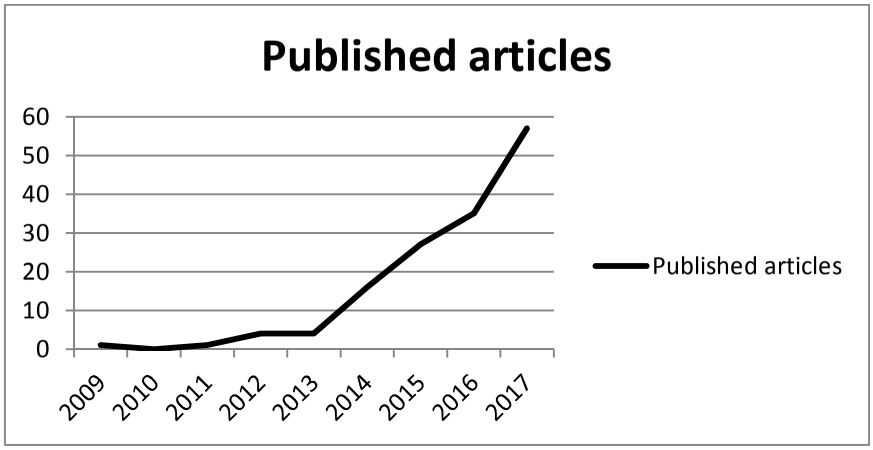



Figure A.4

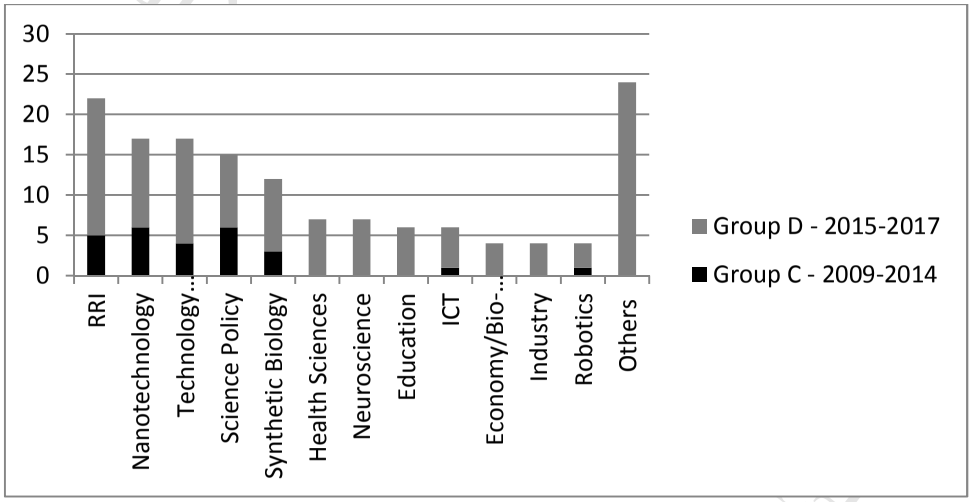
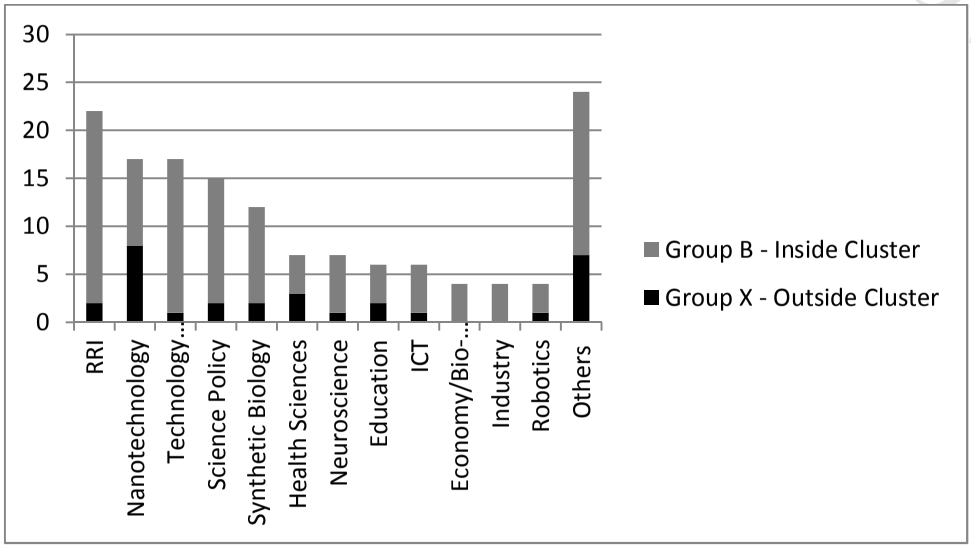



Figure A.5



## Appendix B

Table B.1

| Rank | A – all articles | B – main cluster | ↑↓ | X – removed from sample | ↑↓ |
|---|---|---|---|---|---|
| 1 | ethics | ethics | = | ethics | = |
| 2 | public | public | = | user | *new* |
| 3 | need | need | = | public | -1 |
| 4 | participate | policy | +1 | need | -1 |
| 5 | policy | practice | +2 | value | +6 |
| 6 | governance | participate | -2 | governance | +2 |
| 7 | practice | future | +1 | risk | +13 |
| 8 | future | governance | -2 | health | *new* |
| 9 | new | stakeholder | +1 | participate | -3 |
| 10 | stakeholder | new | -1 | new | = |
| 11 | value | value | = | policy | -7 |
| 12 | product | product | = | nanotechnology | *new* |
| 13 | assessment | assessment | = | knowledge | +2 |
| 14 | risk | actor | +5 | community | *new* |
| 15 | knowledge | knowledge | = | future | -8 |
| 16 | involve | engage | +2 | application | *new* |
| 17 | concern | involve | -1 | regulator | *new* |
| 18 | engage | concern | -1 | care | *new* |
| 19 | actor | impact | +3 | potential | +5 |
| 20 | emerge | risks | -6 | Europe | *new* |
| 21 | potential | emerge | -1 | information | *new* |
| 22 | impact | challenge | +1 | stakeholder | -13 |
| 23 | challenge | mean | +2 | scenario | *new* |
| 24 | community | potential | -3 | involve | -7 |
| 25 | mean | researcher | *new* | decision | *new* |

Table B.2

| Rank | C - 2009-2014 | D - 2015-2017 | ↓↑ |
|---|---|---|---|
| **1** | future | ethic | +1 |
| **2** | ethic | public | +7 |
| **3** | ELSA | participate | *new* |
| **4** | governance | practice | +19 |
| **5** | health | need | +1 |
| **6** | need | policy | +2 |
| **7** | new | stakeholder | +7 |
| **8** | policy | governance | -4 |
| **9** | public | value | *new* |
| **10** | nanotechnology | new | -3 |
| **11** | ELSI | product | +10 |
| **12** | impact | future | -11 |
| **13** | emerge | assess | *new* |
| **14** | stakeholder | engage | *new* |
| **15** | fund | actor | *new* |
| **16** | global | knowledge | +9 |
| **17** | Europe | concern | +7 |
| **18** | involve | risk | *new* |
| **19** | researcher | involve | -1 |
| **20** | synbio | mean | *new* |
| **21** | product | impact | -9 |
| **22** | challenge | emerge | -9 |
| **23** | practice | potential | *new* |
| **24** | concern | challenge | -2 |
| **25** | knowledge | information | *new* |

Table B.3

| Topics | Number of articles |
|---|---|
| RRI | 22 |
| Nanotechnology | 17 |
| Technology Assessment | 17 |
| Science Policy | 15 |
| Synthetic Biology | 12 |
| Health Sciences | 7 |
| Neuroscience | 7 |
| Education | 6 |
| ICT | 6 |
| Economy/Bio-Economy | 4 |
| Industry | 4 |
| Robotics | 4 |
| Business | 3 |
| Geoengineering | 3 |
| Science Communication | 3 |
| Energy | 2 |
| Sustainability | 2 |
| Aerospace engineering | 1 |
| Agriculture | 1 |
| Anthropology | 1 |
| Aquaculture | 1 |
| Artificial Intelligence | 1 |
| Computer Ethics | 1 |
| Earth observation | 1 |
| Port Development | 1 |
| Quantum Technology | 1 |
| Research Integrity | 1 |
| Techno-utopianism | 1 |

Table B.4

| | RRI | Nanotechnology | Technology Assessment | Science Policy | Synthetic Biology |
|---|---|---|---|---|---|
| 1 | ethics | nanotechnology | future | government | biology |
| 2 | practice | government | policy | public | synthetic |
| 3 | need | practice | assessment | policy | health |
| 4 | public | public | mean | ELSA | synbio |
| 5 | policy | standard | practice | need | global |
| 6 | stakeholder | actor | debate | participation | public |
| 7 | Europe | emerge | need | value | product |
| 8 | government | dialogue | new | fund | participation |
| 9 | value | new | public | challenge | policy |
| 10 | new | researcher | knowledge | knowledge | new |
| 11 | actor | individual | stakeholder | ELSI | application |
| 12 | care | need | value | ethics | reflection |
| 13 | involve | engage | technical | scenario | government |
| 14 | scientist | ethics | care | practice | ethics |
| 15 | concern | participation | impact | actor | need |
| 16 | engage | organize | world | stakeholder | potential |
| 17 | researcher | policy | risk | decision | concern |
| 18 | participate | stakeholder | engage | new | future |
| 19 | term | future | decision | Europe | scientist |
| 20 | concept | initiative | actor | researcher | stakeholders |
| 21 | open | involve | politics | involve | bacteria |
| 22 | mean | risk | challenge | programme | engineering |
| 23 | emerge | scenario | ethics | citizen | challenge |
| 24 | product | nano | consequence | community | regulation |
| 25 | decision | potential | present | future | emerge |

## Appendix C

Table C.1

| YEAR | AUTHORS | JOURNAL | TOPIC | GROUP | DOI |
|---|---|---|---|---|---|
| **Articles Published Between 2015 and 2017 - those marked in gray were removed from the citation network (Group X)** | | | | | |
| 2017 | Serholt S et al. | AI & Society | Education | B | 10.1007/s00146-016-0667-2 |
| 2017 | Almeida, MS; Quintanilha, A | Bioch. and Molecular Bio. Ed. | Education | X | 10.1002/bmb.20988 |
| 2017 | Pidgeon, NF; Spence, E | Biology Letters | Geoengineering | X | 10.1098/rsbl.2017.0024 |
| 2017 | Yang, P; Han, B | China & World Economy | Economy/Bio-Economy | B | 10.1111/cwe.12224 |
| 2017 | Jirotka, M et al. | Communications of the ACM | ICT | B | 10.1145/3064940 |
| 2017 | Low, S | Earth's Future | Geoengineering | B | 10.1002/2016EF000442 |
| 2017 | McLeod, C et al. | Energy Res. & Social Science | Synthetic Biology | B | 10.1016/j.erss.2017.06.017 |
| 2017 | Metze, T et al. | Environ. Science and Policy | Economy/Bio-Economy | B | 10.1016/j.envsci.2017.04.015 |
| 2017 | Coenen, C; Grunwald, A | Ethics and Information Tech. | Quantum Technology | B | 10.1007/s10676-017-9432-6 |
| 2017 | Gardner, J | Euro. J. of Paediatric Neur. | Neuroscience | B | 10.1016/j.ejpn.2016.04.019 |
| 2017 | Lynch, DHJ et al. | Ind. Crops and Products | Economy/Bio-Economy | B | 10.1016/j.indcrop.2016.10.035 |
| 2017 | Mittelstadt, B | Information | Health Sciences | X | 10.3390/info8030077 |
| 2017 | Heras, M; Ruiz-Mallén, I | Int. J. of Science Education | Education | B | 10.1080/09500693.2017.1392643 |
| 2017 | Glerup, C et al. | J. of Responsible Innovation | RRI | B | 10.1080/23299460.2017.1378462 |
| 2017 | Bechtold, U et al. | J. of Responsible Innovation | Technology Assessment | B | 10.1080/23299460.2017.1364617 |
| 2017 | Zimmer-Merkle S; Fleischer | J. of Responsible Innovation | Technology Assessment | B | 10.1080/23299460.2017.1338105 |
| 2017 | van Lente, H et al. | J. of Responsible Innovation | Technology Assessment | B | 10.1080/23299460.2017.1326261 |
| 2017 | Dickel, S; Schrape, J-F | J. of Responsible Innovation | Techno-utopianism | B | 10.1080/23299460.2017.1310523 |
| 2017 | Schulz-Schaeffer, I; Meister | J. of Responsible Innovation | Technology Assessment | X | 10.1080/23299460.2017.1326260 |
| 2017 | Bechtold, U et al. | J. of Responsible Innovation | Technology Assessment | B | 10.1080/23299460.2017.1360721 |
| 2017 | Torgersen, H; Fuchs, D | J. of Responsible Innovation | Technology Assessment | B | 10.1080/23299460.2017.1320157 |
| 2017 | Grunwald, A | J. of Responsible Innovation | Technology Assessment | B | 10.1080/23299460.2017.1360719 |
| 2017 | Decker, M et al. | J. of Responsible Innovation | Technology Assessment | B | 10.1080/23299460.2017.1360720 |
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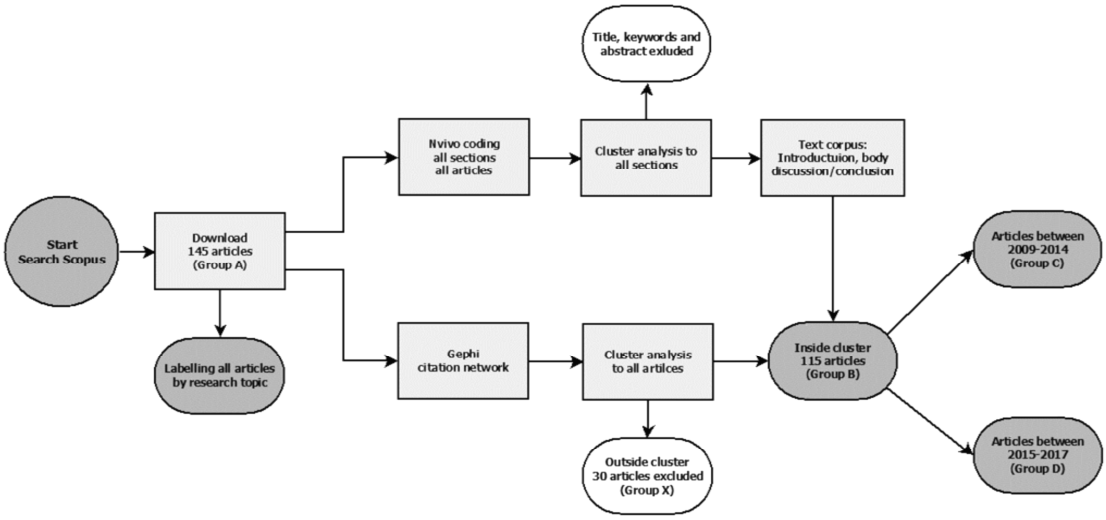
## Appendix D

Figure D.1



# Emerging patterns in the academic literature on Responsible Research and Innovation

**Highlights:**

1- Academic debate on RRI emphasises the dimensions of ethics and public engagement.

2- Academic discourse on RRI changed since 2014, along with the Rome Declaration.

3- RRI is increasingly multidisciplinary,

4- RRI is still away or absent from disciplines with high levels of risk and uncertainty

5- Ideology may be a major obstacle to reach consensus on theory and practice of RRI.