Foundation and Evolution of Responsible Research and Innovation Research: A Review Based on Bibliometrics

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\textbf{Abstract.} Using the bibliometric citation and content analysis approach, this paper analyzes the key structure and the relationship over 34 core articles in RRI research which were published on "web of science" in the past 30 years, on the topic of "Responsible Research and Innovation". The evolution and development of RRI research are determined. Through the author's key words, four hot topics of RRI research are determined. The results show that the research of RRI framework is the core content of RRI research. The research on the concept and definition of RRI, the application and analysis of RRI in emerging technology, and the relationship between RRI and other related theories are the hot research contents in the core literature of RRI research.

1 Introduction

Responsible research and innovation (RRI) is an innovative concept emerging in Europe and the United States in recent years, which is an important part of the horizon 2020 framework plan of the European Union. The basic connotation of RRI is to emphasize that innovation and research is a transparent and interactive process, recognizing the common responsibilities of different participants. The purpose of RRI is to solve the ethical acceptability of research and, innovation and the sustainability of development. RRI focuses on how to achieve positive impact and how to integrate scientific and technological progress into our society. RRI not only emphasizes the great role of scientific and technological innovation in promoting social development, but also emphasizes the guidance and construction of society for scientific and technological development. The concept of RRI has attracted the attention of European and American countries as well as developing countries including China.

A systematic review of the core research results of RRI will be conducive to better research of RRI in the future. Therefore, this paper aims to solve the following three problems:

RQ1. What is the theoretical foundation of RRI research?
RQ2. How does RRI research evolve?
RQ3. What are the main contents of these basic researches?

To address these questions, we rely on bibliometrics to analyze the knowledge map of RRI research literature. This is because science is formed by the continuous spiral evolution and accumulation of knowledge inheritance and creation. The relationship between scientific citations reflects the flow of knowledge. Along that flow direction, we can trace the history of scientific knowledge\cite{1}\cite{2}. Knowledge map can be quantified by word frequency clustering and other approaches to identify key research streams in the field.

2 Data Sources and Research Methods

2.1 Data Sources

The database of RRI related research literature is from the WOS platform, I used five databases as the source: Science Citation Index Expanded (SCI-Expanded), Social Sciences Citation Index...
(SSCI), Arts & Humanities Citation Index (A&HCI), Conference Proceedings Citation Index - Science (CPCI-S), Conference Proceedings Citation Index—Social Science & humanity (CPCI-SSH), Emerging Sources Citation Index (ESCI). The search term is "ts= (responsibl* AND research* AND innovat*)", between 1975 and 2019, language and file type are unlimited, search work was done on May 17, 2019, and 2190 articles were yielded.

2.2 Research Method

This paper uses the knowledge mapping analysis tools of HistCite, Pajek and VOSviewer to analyze the collected documents. HistCite is a historiography visualization tool system led by Dr. Garfield. It has two important indicators, GCS (Global Citation Scores) and LCS (local Citation Scores). GCS counts the number of citations of papers from different fields in the database, reflecting the papers’ comprehensive influence, whereas LCS counts the citation number of the articles which has been downloaded. The higher the LCS value is, the higher the attention and influence of researchers in this field. The core research literature in this field can be judged by LCS. Pajek is a large-scale social network analysis tool, which provides complex network analysis methods, realizes graph visualization and data processing, and can be used for the study of citation directed-chain of nonlinear network relations. The main path analysis method can make up for the deficiency of historiography, and the combination of the two can better reveal the main process of scientific development[3]. VOSviewer is a free software for building and viewing Bibliometrics maps. It can draw knowledge maps in various fields based on citations, keywords, co-citations, partnerships, etc.

Table 1. LCS distribution of RRI research literature.

| LCS Values | Publications |
|------------|--------------|
| LCS≥1      | 190          |
| LCS≥2      | 101          |
| LCS≥3      | 67           |
| LCS≥4      | 44           |
| LCS≥5      | 34           |
| LCS≥6      | 19           |
| LCS≥7      | 18           |
| LCS≥8      | 12           |
| LCS≥11     | 10           |

The LCS distribution of 2190 articles is shown in Table 1. It can be seen that only 190 among them are cited in this field. The results show that 34 articles with LCS ≥ 5 best reflect the research network structure of RRI. Therefore, a sample of 34 core articles are used as the basic literature data for this study.

First of all, a citation historiography is generated to analyze the relationship between these 34 core articles. Then, they were imported into Pajek to analyze the research context of RRI. In the end, they are read into VOSviewer to display the research hot clustering of these core research literature by analyzing the author's keywords.

3 Citation Chronology of Basic Documents in RRI Research

Fig.1 is a historiography with LCS >= 5. Table 2 illustrates the details of the node literature. In the historiography, each circle represents an article, the circle size represents the LCS value of the responding article, and the direction of the arrow represents the development direction. The articles in the figure form the basis for RRI research, and their mutual citation form a complex network diagram.
Table 2. List of literatures on the citation chronology of RRI.

| No. | Reference Number | Details | LCS | GCS |
|-----|------------------|---------|-----|-----|
| 1   | 364              | Robinson DKR, 2009, TECHNOL FORECAST SOC, V76, P1222 | 13  | 53  |
| 2   | 441              | Owen R, 2010, RISK ANAL, V30, P1699 | 37  | 62  |
| 3   | 548              | Schuurbiers D, 2011, SCI ENG ETHICS, V17, P769 | 20  | 53  |
| 4   | 613              | Voegtlin C, 2012, J BUS ETHICS, V105, P1 | 5   | 67  |
| 5   | 628              | Lee RG, 2012, TRANSNATL ENVIRON LA, V1, P105 | 5   | 13  |
| 6   | 629              | Stahl BC, 2012, EUR J INFORM SYST, V21, P207 | 7   | 18  |
| 7   | 649              | Brey PAE, 2012, ETHICS INF TECHNOL, V14, P305 | 5   | 16  |
| 8   | 661              | Owen R, 2012, SCI PUBL POLICY, V39, P751 | 141 | 300 |
| 9   | 738              | Pandza K, 2013, RES POLICY, V42, P1112 | 15  | 23  |
| 10  | 739              | Rodriguez H, 2013, RES POLICY, V42, P1126 | 8   | 28  |
| 11  | 758              | Flipse SM, 2013, SCI ENG ETHICS, V19, P703 | 7   | 8   |
| 12  | 759              | Flipse SM, 2013, SCI ENG ETHICS, V19, P1141 | 7   | 21  |
| 13  | 772              | Stilgoe J, 2013, RES POLICY, V42, P1568 | 172 | 383 |
| 14  | 780              | Stahl BC, 2013, SCI PUBL POLICY, V40, P708 | 26  | 34  |
| 15  | 890              | Stahl BC, 2014, TECHNOL FORECAST SOC, V84, P74 | 11  | 19  |
| 16  | 896              | Flipse SM, 2014, TECHNOL FORECAST SOC, V85, P185 | 5   | 13  |
| 17  | 908              | Stahl BC, 2014, INFORM MANAGE-AMSTER, V51, P810 | 7   | 26  |
| 18  | 931              | Halme M, 2014, BUS STRATEG ENVIRON, V23, P547 | 5   | 53  |
| 19  | 934              | Davis M, 2014, SCI ENG ETHICS, V20, P963 | 7   | 12  |
| 20  | 951              | Gorgiu G, 2015, PROCD SOC BEHV, V180, P600 | 5   | 5   |
| 21  | 952              | Petrescu AM, 2015, PROCD SOC BEHV, V180, P682 | 5   | 5   |
| 22  | 1000             | Deblonde M, 2015, J RESPONSIBLE INNOV, V2, P20 | 5   | 8   |
| 23  | 1006             | Stemerding D, 2015, J RESPONSIBLE INNOV, V2, P140 | 5   | 7   |
| 24  | 1008             | Schroeder D, 2015, J RESPONSIBLE INNOV, V2, P169 | 5   | 6   |
| 25  | 1108             | Davies SR, 2015, SOC STUD SCI, V45, P371 | 5   | 13  |
| 26  | 1125             | Krabbenborg L, 2015, SCI COMMUN, V37, P452 | 5   | 11  |
| 27  | 1126             | Forsberg EM, 2015, TECHNOL SOC, V42, P21 | 6   | 10  |
| 28  | 1140             | Wickson F, 2015, SCI ENG ETHICS, V21, P1159 | 8   | 12  |
| 29  | 1254             | Wong PH, 2016, J RESPONSIBLE INNOV, V3, P154 | 5   | 7   |
| 30  | 1257             | Pelle S, 2016, J RESPONSIBLE INNOV, V3, P233 | 5   | 7   |
| 31  | 1259             | Rip A, 2016, J RESPONSIBLE INNOV, V3, P290 | 7   | 21  |
| 32  | 1659             | Burget M, 2017, SCI ENG ETHICS, V23, P1 | 18  | 23  |
| 33  | 1660             | Ribeiro BE, 2017, SCI ENG ETHICS, V23, P81 | 15  | 17  |
| 34  | 1902             | Ribeiro B, 2018, J RESPONSIBLE INNOV, V5, P316 | 5   | 7   |
The documents in the historiography are divided into two parts. Part 1 is a complex network starting with document 364. These articles represent the structure of RRI research. The nodes of 661 and 772 are very large, and they are in the center of the network, indicating that they have the greatest contribution. It is also found from Table 2 that the GCS values of these two articles are also very high, indicating that these two articles are also widely concerned by researchers in other fields. Notably, the part 2 on the right is composed of 4 highly cited documents (613, 1006, 952 and 1000), which has not formed a complex network, means that it is very likely to become a research hotspot for subsequent research. Table 2 is the details of the literature.

4. Analysis of the Development of RRI Research

Citation historiography can reveal the key relevant research area, but the formation and change process of these key research contents need to be obtained through the main path analysis. For the citation network, the main path can not only represent the rigorous basic idea, but also means the literature which is in connection position is more significant than the ones in the island position. This method can filter out the articles which represents the main knowledge evolution direction in the field of urban sustainable development, identify the knowledge flow with special evolution significance, and explore its unique characteristics.

Fig.2 is the main path analysis diagram for RRI citation historiography through the SPC algorithm, using the Pajek tool. Each node in the main path represents an article, and the arrow trend is the vein and development direction of literature research. The content of each document can represent the RRI research content in this period.

According to the content of literature in main path, and the literature of the same period in the citation chronology, the research of RRI is divided into four stages.
4.1 The Rudiment and Foreshadowing Period of RRI Theory (1990–2009)

This period is the rudimentary development period of RRI, only one article is reflected in the citation historiography, but it does not enter the main path. One of the earliest articles reflecting the rudimentary thoughts of RRI is the social responsibility of the chemical industry proposed by a German chemist Quadbeck-Seeger [4] from the perspective of scientific history in 1990. He believes that the goal of chemical innovation and research is market and human needs, and that chemistry opens up new solutions through material transformation. With the accumulation of knowledge and the increasing social responsibility of scientists, scientists must take responsible actions for the knowledge they have acquired.

At this stage, the concept and framework of RRI have not been formally put forward, mainly about some rudimentary ideas of RRI, among which the innovation management embodied in the business activities of enterprises in the field of management is particularly obvious, including enterprise innovation management, industrial chain research, etc. The ethical research of preparatory responsibility in emerging technology is also reflected, including innovative medical care, social responsibility of scientists, etc. From the tests on chemical enterprises, Tierney et. al [5] tells the ability of responsible innovation is related to the enterprise environment, leadership and employee characteristics. Petersen et. al [6] proposes to let suppliers participate in enterprise design and take full responsibility for the components or systems provided by them, so as to promote the overall improvement of product quality. Ciliberti et. al [7] believe that in small and medium-sized enterprises, different strategies and various management systems and tools can be used to solve the problem of corporate social responsibility (CSR) in the supply chain (SC). Cooper [8] believes that radiology research must comply with relevant ethics and laws. Doctors who perform innovative care or quality improvement should be guided by the institutional review committee and consider the moral obligations of future patients. Japanese scholar Ishizu et. al [9], believes that in Japan's Nanotechnology research and innovation, research and development institutions should fully understand and constantly meet the social needs to win the acceptance and support of the public; as the interface between the government and the industry, public research institutions should strengthen cooperation, and cooperate with Nanotechnology enterprises to formulate relevant nanotechnology industry standards as soon as possible.

Until the German scholar Hellstxom [10] first proposed the concept of "Responsible Innovation" for the first time in 2003, RRI research has attracted more and more scholars' attention in the world, and the relevant research began to deepen gradually. In 2009, Robinson [11] from the University of Twente in the Netherlands, put forward a systematic view on the assessment and risk prediction of emerging technologies such as Nanotechnology i.e. the document No.364. This document is the only one to enter the chronology map in this stage, and also the first one to appear in the citation chronology map and form a complex network. The author of this paper compares the innovation of Nanotechnology and other emerging technologies as "the journey of innovation", and believes that innovation itself is a nonlinear, mixed and tortuous process, in which there will be setbacks or even dead ends, and innovation is unexpected behavior. The journey of innovation depends on the environment of technological innovation and research institutions, namely innovation chain plus. This environment has different characteristics in different stages of technology and product, is influenced by developers and promoters. New technology itself has endogenous futures, that is, the development of new technology breaks the original rules to some extent, but the subsequent development may create a stable new model. For some breakthrough technologies, considering the endogenous future of technology, we should consider the factors (industry, market, society, supervision, research, etc.) that form these paths in innovation chain plus, and adopt a Co-evolutionary scenario to carry out technology evaluation and risk prediction.

Overall, since the 1990s, with the increasingly prominent issues of responsibility in scientific research, enterprise production and new technology innovation, in the process of research and innovation of emerging and human welfare-related technologies, enterprises, scientific research institutions, and scientists need a wide range of responsible behaviors to ensure and promote the
sustainable development of innovation, which has been basically recognized by foreign scholars and reached a consensus. In this period, the research on responsible innovation is mostly embryonic, which has made sufficient ideological foreshadowing and preparation for further research on responsible innovation.

4.2 The Formation Period of the Framework of RRI (2010-2013)

This period is the most important period of RRI development, that is, the core part of RRI research framework. There are 441, 628, 661 and 772 four literatures on the main path. With the in-depth research of RRI and the promotion of the European horizon plan, the framework of RRI has been gradually established. The connotation and extension of RRI have been constantly discussed and updated, and the research of RRI has become mature.

The article NO.441 which was published in 2010 is the beginning of the main path, and an important one - Reflexivity in RRI framework was proposed here for the first time. It is a pilot experiment conducted by Owen Richard[12], a British scholar, in the UK engineering and Natural Science Research Council (EPSRC) to understand the method of embedding responsible scientific and innovative research in funding activities. The results show that embedding technology assessment and public interest-related methods in innovation research into iterative risk and interest analysis, provides a mechanism to consider technology risk and related uncertainties. It can also provide opportunities to identify unidentified risks and facilitate upstream stakeholder and public engagement on how to receive new impacts. Owen believes that in the key areas (such as nanoscience, geoengineering, synthetic biology and Robotics), integrated methods are adopted to encourage multidisciplinary proposals, including: (1) promoting continuous reflection, participating in and strengthening social learning; (2) embedding comprehensive and multidisciplinary methods related to the core innovative research, including technology assessment, risk analysis and benefit analysis (3) provide continuous feedback process to allow adjustment of innovation approaches at specific decision points; (4) ensure continuous dialogue with policy makers as the process evolves; (5) embed responsible science and innovation concepts as early as possible within the framework of technology maturity (TRL).

In 2012, the document 628 inherits part of the views of document 441. The author[13] believes that the development of RRI framework is likely to be a long-term task. This is because first of all, the objectives of RRI framework is supposed to solve a wide range of social problems, which to not only be participatory, but also be predictable. It is not subject to balancing interests and risks, because it should not only care about material wealth, but also about moral health. Secondly, the scale of responsible innovation should change according to the specific innovation content involved, which will be a multi-level innovation Governance.

The same year, the author of Document 661, is still Owen et.al[14], a British scholar. Published an article entitled "Responsible research and Innovation: From science in society to science for society", summarized three emerging characteristics of RRI research: (1) Science for society: democratizing the governance of intent, (2) Science with society: institutionalizing response, (3) Reframing responsibility. The author explained three main purposes for RRI: (a) to promote the transformation of research and innovation governance methods, from avoiding negative impacts to a "open" democratic process explicitly involving "intention issues" in research and innovation; (b) when considering the uncertainty and potential unexpected consequences of research and innovation, it is necessary to build a comprehensive, participatory, reflective and reactive review process (c) extends the concept of responsibility in research and innovation to areas other than scientists and promotes the transformation of this concept of responsibility from consequentialism to a collective responsibility.

In 2013, Stilgoe and Owen et.al[15] published an article "Developing a framework for responsible innovation", namely document 772, which is another important document in this process. This paper establishes the RRI framework, which includes four aspects: Anticipation, Reflexivity, Inclusion and Responsiveness. It is believed that RRI has more extensive application and relevance.
The RRI framework is the core part. This paper is the first time to clearly put forward a broad framework of responsible innovation, which has been widely cited by relevant research institutes in the later period, providing an important reference value for the subsequent research of RRI. At this point, the research on the subjectivity of responsible innovation has been completed.

4.3 The Period of Practical Transformation of Theory (2014–2015)

This stage is the period of the practical transformation of RRI, that is, the time of the combination of RRI theory and the development of emerging science and technology, including 1126 and 1140 documents. After the proposal of RRI framework with relative universality by Stilgoe and Owen, RRI framework was basically established. Based on the RRI research framework, this stage of research began to develop in practice and depth. On the one hand, it continued to study the essence of responsible innovation, on the other hand, it began to shift to the practical application of responsible innovation. There are two branches in the main path, 1126 and 1140 which are both published in 2015.

Document 1126[16] discusses the technical evaluation of RRI, which is not only a further study of responsible innovation, but also reflects the characteristics of RRI research gradually moving towards practice. The author believes that the issue of responsible science and technology governance under the concept of RRI is becoming more and more important among policy makers and researchers. It is necessary to rethink the relationship between science and society and the roles and responsibilities of different participants in the innovation system. Focus on the function and practice of science and technology assessment. Based on the discussion on responsible science and technology governance and RRI, we hope to discuss with scholars, assessors, policy makers and stakeholders the potential needs of reforming existing assessment practices and consulting institutions.

The author of No.1140 document[17] took Nano R&D as a case to illustrate that the formulation of international standardization is closely related to responsible innovation, but there is a gap in the current research on responsible innovation, that is, RRI research on international standardization. There have been some researches on the quality and legitimacy of standardization, but they did not directly connect this issue to RRI. If we want to promote truly responsible research and innovation methods, it is essential to attach great importance to standardization. This branch shows that the research on RRI has been basically mature, and new requirements are put forward for the research of RRI in some more specific fields and the blank points of RRI research.

4.4 The Period of Reflection, Summary and Further Progress (2016-2019)

After the framework and social practice, the research of RRI is moving forward again. The main feature of this period is the reflection and summary of the previous period. The literature on the main path includes: 1659,1660,1254,1257 and 1902. From the main path literature, we can see that there are three branches.

The first branch is document 1659, which goes down along document 1126. It is an extension of the previous research on RRI framework. The main contribution of document 1659[18] is to discuss the so-called concept dimension of RRI. The concept dimension aims to determine the breadth of the concept and help its understanding. As a result of the current literature review, four conceptual dimensions are mentioned and discussed: inclusion, expectation, response and reflection. In addition, two new conceptual dimensions have been added: sustainability and care. So far, the framework of RRI has been updated into six contents: inclusion, expectation, response, reflection, sustainability and care.

The second branch is article No. 1660 and 1902 which inherit 1126 and 1140. It is the summary and further development of RRI research. Among them, 1660[19] article reviews the previous RRI research literature. The paper analysis suggests that its greatest potential may be in its ability to unify and provide political momentum to a wide range of long-articulated ethical and policy issues.
At the same time, RRI’s dynamism and resulting complexity may represent its greatest challenge. Further clarification on what RRI has to offer in practice—beyond what has been offered to date—is still needed, as well as more explicit engagement with research and institutional cultures of responsibility. In the following document 1902[20], it is believed that in the field of science, technology and innovation policy, the consideration of social consistency is scattered and neglected in some communities, and social unity is further considered in responsible research and innovation research.

The third branch is from No. 1254 to 1257, which is down along No. 1140. Another development path is the deep reflection and summary over the ethical principles of responsible innovation. The authors[21] believes that scientific research and technological innovation are global in nature. Even in a none liberal democracy country, the values of responsible innovation are also applicable. The following document No. 1257[22] reveals the normative basis that forms the basis of RRI's various liability concepts.

5. Hot Cluster Analysis on RRI Research

34 basic literature were imported into VOSviewer, and the author's key words were used for analysis. A total of 103 author keywords appeared. As the words co-occurrence frequency shown in Fig 3, the common key words are: responsible innovation, governance, nanotechnology, ethics, responsibility, emerging technologies, technology assessment, innovation, research policy, etc.

The cluster analysis of 103 key words was conducted. Figure 4 shows the keywords cluster into four categories. Each cluster is described separately below.

![Figure 3. Analysis of co-occurrence frequency of author's key words.](image-url)
Figure 4. Network map of author keywords for RRI.

5.1 The Purpose and Motivation of RRI Research

In Cluster1, the keywords and total link strength are as follows: nanotechnology (21), responsibility (14), innovation (11), research (7), biotechnology (7), business ethics (4), care ethics (4), civil society (5), co-evolutionary scenarios (4), csr (4), dialogical governance (5), emerging science and technologies (3), funding (3), globalization (4), innovation systems (5), institutional practices (5), knowledge economies (3), leadership ethics (4), nanosciences (3), outcome-oriented theory (4), policy (4), proceduralism (4), regulation (7), responsible (4), responsible development (4), responsible leadership (4), risk (7), science (4), scientific cultures (3), selection environment (4), standardisation (5), technologies (7), upstream public engagement (5). The research content of this cluster is mainly on the research purpose and motivation of RRI. Most of the literature discusses the research purpose of RRI in combination with nanotechnology and other emerging technologies.

The risks brought by the development of modern technology may have negative effects on the environment and society, which are often caused by unexpected consequences or potential effects[23]. Ideally, these consequences should be anticipated before the technology is fully developed and implemented, so the RRI wants to avoid these unexpected and potential crises. The purpose of RRI research is to improve the governance needs of all aspects in the process of scientific and technological change. People generally believe that under the condition of high uncertainty and decentralized governance, management uncertainty and decentralized governance is an idea of uncertainty governance[24]. RRI is usually closely connected to the participation of the public and stakeholders. Here, "engagement" is seen as a way to understand and predict the specific configuration[25] of technology that may be "embedded in society," so that its appropriateness can be assessed in the face of a series of social challenges. Stahl[26] believes RRI can support social actors to review and understand technology in the process of technology development, so as to cope with the trend of expert driven process. Zenko et el.[27] believe that RRI makes social and environmental governance change from passive form to active form by focusing on the potential benefits of innovation. RRI should seek to improve the innovation process by better adapting the innovation process to social expectations and "needs"
5.2 Research on the Connotation and Framework of RRI

In Cluster 2, the keywords and the total link strength are as follows: responsible research and innovation (60), ethics (19), research policy (10), horizon 2020 (9), social responsibility (8), irresistible project (7), european union research policy (6), research governance (6), creative prototyping (5), emerging technology (5), ICT (5), IS0 (5), robotics (5), care (4), craft (4), education facing contemporary issues (4), information systems (4), morality (4), non-formal learning (4), norms (4), RCR (4), research groups (4), research management (4), societally desirable research (4), students' feedback (4), assessment (3), european commission (3), formal education (3), glocal sustainability research (3), knowledge arena (3), non-formal education (3), policy advice (3), projected reality (3), technology governance (3), meta-responsibility (2), privacy (2). The main research content of this clustering is the research content of RRI, such as the connotation, framework and attribute. It also includes RRI research from the perspective of science and technology ethics.

The most widely used definition of RRI was proposed by Schomberg[28]: "RRI is a transparent and interactive process. Through this process, social actors and innovators respond to each other, focusing on the (moral) acceptability, sustainability and social needs of the innovation process and its marketable products (the purpose is to integrate the progress of science and technology into our society correctly)." Then, Schomberg[29] defines RRI as "a design strategy that drives innovation and provides guidance to achieve the desired social goals". Stahl[30] regards RRI as a kind of meta responsibility, which is defined as follows: RRI is a higher-level responsibility or meta responsibility, which aims to shape, maintain, develop, and coordinate the existing and novel research and innovation related processes, participants and responsibilities to ensure the satisfactory research results. Stahl et al.[31] think RRI is a concept, which covers "all aspects of how to solve problems to ensure that science, research, technology and innovation have positive, socially acceptable and desirable results". Owen et al.[32] emphasizes the concept of shared responsibility among actors. It arouses "collective care obligation, first of all, we need to rethink what we want to get from innovation, and then rethink the response way in the face of uncertainty." Pidgeon and other options[33] focus on the assessment process: "responsible innovation aims to embed a clear assessment of the broader value, impact, unexpected risk and moral impact into the R&D process of new products. Although "technology" does not provide a specific definition of the concept, early understanding of responsibility in innovation sees it as a means of enabling alternative, more sustainable forms of practice.

5.3 Research on the Application of RRI in Practice

The keywords and total link strength in Cluster 3: governance (22), emerging technologies (13), technology assessment (13), anticipatory technology ethics (9), design (9), ethical impact assessment (9), forecasting (9), futures studies (9), geoengineering (4), responsible research & innovation (9), synthetic biology (2), uncertainty (9). The main research content of this cluster is about policy governance, emerging technology and technology evaluation in RRI. It focuses on the research of RRI in practice, especially in the technology assessment and policy-making of emerging technology.

RRI plays an important guiding role in the development of science and technology policy in European countries, especially in the communication technology, biotechnology and other controversial, emerging science and innovation areas of science and technology policy-making and management[34]. The conceptualization of RRI usually takes the social and ethical aspects of research and innovation as the primary goal. This can be done at the level of scientific or engineering practice and or through the governance and evaluation of technology. It includes environmental sustainability, public health and safety, and research integrity, but also issues related
to innovation uncertainty and assumptions, commitments, and frameworks contained in scientific practice[35]. Stahl[36] highlights the basis for public and stakeholder engagement in any RRI approach. Owen et el.[37] emphasized the importance of "upstream" transfer of governance process. Robinson[38] focuses on "scenario forecasting," which aims not only to predict the potential risks and benefits of emerging technologies, but also to understand the complex configuration of their development.

5.4 The Relationship Between RRI and Relevant Theories

The keywords and total link strength in Cluster 3 are: responsible innovation (31), midstream modulation (7), socio-technical integration (9), anticipatory coordination (4), decent nonliberal peoples (3), dilemma (3), elsa (ethical legal and social aspects) (5), engineering ethics (3), ethics of science & technology (3), ethics of science and technology (4), eu framework programmes (5), liberal democracy (3), organizational capability (4), professional identity (4), research solicitations (5), science and technology studies (3), social and ethical aspects (3), stakeholder engagement (5), strategy (4), upstream engagement in industry (3), virtue ethics (4). The main content of this clustering involves the study of the relationship between RRI and other related theories. The researchers of RRI come from many disciplines, including the relationship with many disciplines, so scholars will be influenced by their own discipline theory when they carry out RRI related research.

Pandza et al.[39] tried to contribute to the theoretical development of RRI by considering the impact of RRI implementation in research projects on the concept of individual agency and responsibility in research institutions, while a strong theme of RRI emphasized the importance of collective responsibility. Stahl[40] emphasizes the role of ethical theory in providing information for the normative basis and implementation of RRI, and defines RRI as a higher-level responsibility or meta responsibility, aiming to shape, maintain, develop, coordinate existing and novel research and innovation related processes, participants and responsibilities, so as to ensure satisfactory research results. Dondorp et al. [41] combined the concept of responsibility with the tradition of ethical analysis and regulation and the ethical theory in the development of health technology. Pandza et al.[42] tried to contribute to the theoretical development of RRI by considering the impact of RRI implementation in research projects on the concept of individual agency and responsibility in research institutions, while a strong theme of RRI emphasized the importance of collective responsibility. Dondorp et al.[43] combined the concept of responsibility with the tradition of ethical analysis and regulation and the ethical theory in the development of health technology. Schuurbiers[44] used the theory of engineering ethics and STS to consider the ethics of science and technology in the laboratory environment.

6. Conclusion

In this paper, we aim to provide a systematic review of RRI literature over the past 30 years. This paper analyzes the structure, main context and research focus of the basic research literature of RRI. It is found that, before 2009, the concept and framework of RRI have not been formally put forward, mainly about some rudimentary ideas of RRI, among which the innovation management reflected in the business activities of enterprises in the field of management is particularly obvious, including enterprise innovation management, industrial chain research, etc. The ethical research of preparatory responsibility in emerging technology is also reflected, including innovative medical care, social responsibility of scientists, etc. 2010-2013 is the most important period of RRI development, and the core content of RRI research (research framework) has been formally established. With the in depth of RRI research and the promotion of the European horizon plan, the research framework of RRI has been gradually established. The connotation and extension of RRI have been constantly discussed and updated, and the research of RRI has become mature. During
2014-2015, RRI research began to develop in practice and depth based on RRI research framework. On the one hand, it continued to study the essence of responsible innovation, on the other hand, it began to shift to the practical application of responsible innovation. Since 2016, RRI research has entered the stage of theoretical reflection and summary, and it is moving forward again toward diversified development. The research of RRI core literature can be divided into four hot clusters: the purpose of RRI research, the connotation and framework of RRI, the research of RRI combined with emerging technology, and the research of RRI combined with ethics, STS and other related theories.

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