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Addressing Climate Change in Responsible Research and Innovation: Recommendations for Its Operationalization

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Abstract: Responsible Research and Innovation (RRI) has only lately included environmental sustainability as a key area for the social desirability of research and innovation. That is one of the reasons why just a few RRI projects and proposals include environmental sustainability, and Climate Change (CC) in particular. CC is one of the grand challenges of our time and, thus, this paper contributes to the operationalization of CC prevention in RRI. To this end, the tools employed against CC were identified. Tools originated in corporate social responsibility and sustainable innovation which help to operationalize strategies against CC in RRI practice. Complementarily, the latest proposals by RRI projects and actors related to CC were reviewed. The findings of the document analysis and the web review were arranged in a framework intended for research and innovation that has an indirect but relevant negative impact due to CC. Thus, four main strategies for CC prevention in RRI were determined: a voluntary integration of the aims, a life cycle perspective, open access databases and key performance indicators, and stakeholder management. The article is finished acknowledging diverse barriers hindering the operationalization of CC prevention in RRI, and we introduce future avenues for research in this area.

Keywords: responsible research and innovation; climate change; sustainable innovation; corporate social responsibility

1. Introduction

Responsible Research and Innovation (RRI) has emerged significantly in the last decade as a way to tackle the great challenges of our time [1]. One of these great challenges is Climate Change (CC), a transversal and global environmental problem that also has socio-economic implications. The Brundtland declaration [2], the Kyoto Protocol [3] and other initiatives such as the EU emissions trading system [4] or the Paris Agreement of 2016 [1,5] have highlighted the role of research and innovation in tackling CC. The importance of research and innovation (R&I) teams as actors for CC adaptation and mitigation goes beyond their actions during the innovation process: their design of choice scales up when applied to wider contexts, maximizing the potentially harmful results. Two examples of such scaled up negative side effects are rising energy consumption due to the development of ICT technologies [6], and the potential environmental impacts of the outputs of research on genetically modified organisms [7,8].

Since RRI recognizes the responsibility of researchers in providing socially desirable, ethically acceptable and sustainable outcomes, it should be a strong lever for research teams to tackle CC.

However, tools ("tools" refers to strategies, guidelines, procedures, databases, standards, indicators, scales and instruments that aim to facilitate the implementation and management of actions and strategies directed at fighting climate change) aiming to support innovators or researchers in the introduction of these goals in the R&I process have not included CC as part of their goals. Sustainable development is not a central anchor for RRI, as shown in the work of Lubberink et al. [9], which compares RRI to sustainable and social innovation. In fact, The European Commission included sustainability as a key area for stakeholder dialogue in the RRI agenda at a later stage, which has resulted in the underdevelopment of the operationalization of environmental concerns—and more particularly CC—in the set of tools available for RRI. Therefore, the aim of this paper is to look at other disciplines—corporate social responsibility and sustainable innovation—that have provided tools that operationalize measures to tackle climate change to better understand how RRI can support activities that confront climate change. Corporate Social Responsibility (CSR), which included environmental concerns earlier, has provided tools for CC accounting and reporting that can be useful in measuring the impact of research activities on CC. Furthermore, several efforts have been made from the field of Sustainable Innovation (SI) to introduce measures in the design and innovation process that reduce climate impact throughout the life cycle. Therefore, this paper suggests that the existing knowledge accumulated in these fields may help to advance RRI and its response to climate change.

1.1. Conceptual Framework

1.1.1. Responsible Research and Innovation

With the intention of fostering responsible research, no matter whether it is basic or applied, public or privately funded, the European Commission (EC) has been promoting a cross-cutting issue named "RRI". The most widely used definition of RRI could be the one given by von Schomberg [10]: "(RRI) is a transparent, interactive process by which societal actors and innovators become mutually responsive to each other with a view to the (ethical) acceptability, sustainability and societal desirability of the innovation process and its marketable products". The ultimate aim is to allow a proper embedding of scientific and technological advances in our society. Nevertheless, the concept is not free of criticism [9].

RRI is concerned with substantive issues (ethical acceptability, sustainability and societal desirability) and procedural issues, expressed as mutual responsiveness in Von Schomberg's definition [10]. In addition, procedural issues include transparency and democratic governance [11]. Stilgoe and coworkers' [12] governance framework for RRI addresses such procedural issues and operationalizes them in four dimensions: anticipation, reflexivity, inclusiveness and responsiveness. In parallel, several works under the auspices of the EC have found that RRI involves six key areas for the dialogue with stakeholders [13]: (i) Public Engagement; (ii) Gender Equality; (iii) Science education; (iv) Open Access; (v) Ethics; and (vi) Governance. Lately, two more areas were added: Sustainability (environmental) and Social Justice [13,14].

For the six key areas of RRI, guidance for tools has also been provided. However, the later addition of sustainability as a key area of RRI in the European program, and the reliance on the values represented in the European treaty as a guidance for identification of the great challenges, have led to an underrepresentation of (environmental) sustainability in the objectives of RRI. Kettner et al. [14] put forward a framework for RRI indicators with two dimensions: perception and performance, the latter further divided into process and outcomes. Moreover, indicators are suggested for the six key areas and the two dimensions [14]. Unfortunately, the framework neither is applied to nor are there tools suggested for the added areas of social justice and sustainability. Some guidelines have been provided in the work of [14], without providing specific tools. The fields of CSR and SI, on the other hand, have devoted more attention to the development of tools covering the challenge of CC, as illustrated below.

1.1.2. Corporate Social Responsibility

The European Commission defines CSR as "The responsibility of enterprises for their impacts on society" and adds "To maximise the creation of shared value, enterprises are encouraged to adopt a long-term, strategic approach to CSR, and to explore the opportunities for developing innovative products, services and business models that contribute to societal wellbeing" [15]. Originally, CSR was mostly focused on the legal, ethical and discretionary responsibilities of firms towards society, from a perspective of corporate citizenship. Later, the Brundtland Declaration (among others) illustrated how social, economic and environment issues are intertwined [2]. This started a movement to also integrate environmental issues as part of CSR [15].

The main research streams have looked at the governance and accountability issues that CSR poses, looking at it as a function of the firm rather than a transversal issue in the value creation approach of the firm. The concern lies mostly with accountability, transparency and responding to stakeholders' demands for measures, for example, to reduce activities contributing to CC. With that purpose, various CSR guidelines, handbooks, standards and other tools have been proposed to help companies integrate CSR in their operations [16,17]. For a good compendium, see the annexes of the ISO 26000 [18]. Nevertheless, most of these tools are concerned with the accountability of business rather than innovation as a core activity for sustainable value creation.

1.1.3. Sustainable Innovation

Because of this separation of CSR and innovation [19,20]—notwithstanding some research on corporate social innovation [21]—a new research stream on SI emerged [22], looking at the issues of product stewardship and development of clean technologies and management models for the bottom of the pyramid, as highlighted by Hart [23]. SI is concerned with the development of new products, services, processes or business models that have an improved social or environmental performance (as compared to its previous version or its non-existence) [24]. Therefore, SI observes the innovation outcomes from a life-cycle perspective, beyond what falls into the governance capability of the firm, looking at the wider impact that will result from the existence of the innovation [25].

Multiple tools have been developed within the realm of SI that aim to integrate environmental—and more specifically climate change—concerns in the innovation process. Approaches to introduce considerations on the whole life-cycle in the innovation process are introduced in tools such as eco-design [26], life-cycle analysis throughout the supply chain [27], or cradle-to-cradle [28]. Since SI also calls for economic profitability, these tools are directed mostly to commercial enterprises. However, the way in which they integrate potential climate impacts in the design of the innovation is useful in providing tools for researchers.

1.1.4. Addressing Climate Change through RRI

As illustrated, RRI has not thoroughly included environmental considerations in the available strategies, despite its potential for addressing the great challenge of climate change. Notwithstanding some efforts to draw guidelines on what these strategies should include [14], data on the proposed indicators are often not available or difficult to obtain, reducing the usability of such tools. On the other hand, CSR has operationalized strategies for CC from the governance and accountability perspective, while SI has provided strategies to incorporate CC considerations into innovation. This paper aims to build on these existing strategies, focused mainly on businesses, to help RRI practitioners to include measures for CC in their R&I. In particular, it focuses on RRI teams that are willing to include CC reduction in their requirements and goals but do not know how to assess, firstly, if their contribution to CC is or will be relevant and, in that case, how to tackle it.

Since CSR and SI included environmental issues earlier, the field has advanced more when it comes to tackling CC than RRI has. Therefore, the first question aims to identify how tools originally developed in the field of CSR and SI may inform RRI practice in preventing CC. Then, as lately RRI

has started to address CC, a supplementary question is added to include the up-to-date developments against CC from RRI. Hence, the research questions are:

1. How can strategies against climate change originated in CSR and SI help to operationalize strategies against climate change in RRI practice?
2. How are the latest proposals by RRI projects and international actors addressing CC?

Therefore, the understanding of RRI for this matter aligns with the substantive frameworks (Von Schomberg, 2013), whereby RRI is understood as a means to tackle the great challenges and increase the ethical acceptability, social desirability and sustainability of innovation. Moreover, the paper contributes to the grounding of this theoretical approach in the field of CC, which has been largely neglected in the theoretical development of RRI. This is done by organizing the findings in a framework of four main strategies, hence providing the basis for further research on the operationalization of CC-oriented RRI.

Furthermore, by exploring the four tenets on which RRI strategies addressing CC may be substantiated the paper helps to operationalize RRI against CC. This proposal of framework is intended for R&I that has an indirect but relevant impact on the environment due to CC. The tools put forward will allow those R&I teams or policy makers to, firstly, become aware of the relevance of their CC impacts, and, secondly, to identify the what, when and why of those contributions to CC, hence contributing to the social desirability of their projects.

2. Materials and Methods

2.1. Research Methods

To answer the research questions, a review in two different stages was conducted: (1) document analysis; and (2) web review of projects and actors. The aim was that of complementing and triangulating the findings, and providing different perspectives to validate the discoveries from each activity. Document analysis was performed as a research method following Bowen [29]. For that, a specific literature review was carried out, which was complemented later with some results of the web review. Later, the selected documents from the review were analyzed following the research questions. In a second step, and based on the results of the document analysis, an analysis of RRI projects and actors was conducted. These outcomes were then compared and combined with those of the document analysis.

The search had three main areas of data: the CSR and SI documents and the RRI documents and practitioners, although sometimes they overlapped. In both stages, a one-step query was undertaken with several search equations (see Table 1 and Section 2.1.2). Below, each of the research stages is explained.

2.1.1. Document Analysis

The specific literature review started by searching for previous studies of the state of the art (e.g., [12,22,30–32]). Those works helped us to understand the research done, the significance of (environmental) sustainability and CC in RRI and the current approaches and applications. Based on those initial papers, the key words for the search were selected and the search equations were designed. The focus was only on scholarly publications as the so called "grey sources" (blogs, news, seminars, etc.) were found to be inappropriate for the goals. By scholarly publications it is meant peer reviewed papers, chapters of books in competitive editorials and deliverables from publicly funded projects, although the latter are not peer reviewed and are normally considered "grey literature". The search equations were applied to each database, specifically to the fields title, keywords and abstract, as we were looking for specific publications. Databases were the Web of Science (WOS), Scopus, Science Direct and Google Scholar (although in this case only the title could be chosen, and few documents resulted). It was decided to address "responsible research", "responsible innovation" and similar

terms in the search as the focus was intended on the R&I activities, either publicly or privately funded. There is an abundant literature on CSR and CC, but it is mainly devoted to reporting and governance. Therefore, as in the CSR realm, the aim was to find the specific literature about R&I, and combining CSR and CC was not attempted. After studying the first findings, initial keywords and equations were reviewed yielding the ones included in Table 1.

Table 1. Outcomes of the literature review.

No.	Equation Query: ("Responsible Research" OR "Responsible Innovation" OR "RRI" OR "Responsible Research and Innovation")	WOS	Scopus	Science Direct	Google Scholar
1	AND ("climate change")	13	13	3	1
2	AND ("greenhouse effect")	1	1	1	0
3	AND ("global warming")	3	5	0	0
4	AND ("sustainability")	32	52	10	6
5	AND ("sustainable development")	17	31	1	3
6	AND ("sustainab*")	68	91	19	0
7	AND ("environment")	45	72	19	1
8	AND ("sustainable innovation")	2	6	1	5
9	AND ("CSR" OR "corporate social responsibility")	11	17	1	3
10	AND ("corporate responsibility" OR "social responsibility")	14	31	4	7
Heading	Total (without unrelated and duplicates)	124	169	37	17

Several potentially related publications were found, 610 at the time of writing this paper. As shown in Table 1, afterwards, a screening for relevance was performed, which eliminated many unrelated documents as well as many duplicates. Then, the final starting number of publications was 347 mainly consisting of papers, but also book chapters, guidelines and project reports. That list was further trimmed by discarding publications for any of the following reasons:

1. The publication is too theoretical and does not help to implement its proposals (if any).
2. The publication coincides with others that supply more suitable information for the research.
3. The publication is more than twenty years old and cannot include the latest tools and proposals.

In the end, the document analysis comprised a definitive set of 67 papers and 11 book chapters, reports and guidelines. They were read in full and analyzed guided by the research questions. Afterwards, as introduced, the document analysis was supplemented with an assessment of projects and actors based on the Snowball method, and a subsequent in-depth web review.

2.1.2. Analysis of RRI Projects and Actors and Subsequent Web Review

The purpose of this stage was to determine the main projects and activities devoted to RRI and CC (see Appendix A), and their "actors" (institutions, research centers, research teams, journals, etc.). For that reason, taking advantage of some of the results of the document analysis, a web review was carried out. The search was performed with the following keywords: "Responsible Research"; "Responsible Innovation"; "RRI"; "Responsible Research and Innovation"; "Institute"; "Research Centre"; "Research Group"; "Projects"; "Research Projects"; and "Journal". Next, the web and the available documents that had been found were reviewed.

Afterwards the "Snowball sampling method" was applied to the starting list of projects [33]. Snowball sampling is a non-probability sampling technique where study subjects (RRI actors and projects) lead to future subjects from among their connections [33–36]. For example, projects Res-AGorA [37], FotRRIS [20] and HEIRRI [38], among others, included lists of other RRI related projects that were subsequently reviewed. As the sample builds up, enough data are gathered to be useful for research: project partners, associated networks, related projects and resources offered, etc.

The method finishes when each new actor mentions or leads to an actor already identified and no new actor or project is added to the final list.

Once the sample was arranged, the work of each project and actor was analyzed by applying the research questions. Of the nearly 800 potential projects and actors, around 50 projects and actions and 20 actors were identified as suitable for the research questions. For a social network analysis, and an overview of the vast amount of potentially eligible projects, see Figures 17 and 18 in [39]. The rest of the projects were discarded after reviewing their websites and documents for one or more of the following reasons:

1. The website does not provide information about RRI.
2. The website does not provide methods, indicators, examples or other tools useful for the RRI in practice.
3. The actor/project is actually part of a superior actor/project and the alternatives were merged.

Once the actors and projects were acknowledged, an in-depth analysis was conducted of the materials available on their websites. As the purpose of our research was fundamentally descriptive, and not really normative, we did not contrast whether the information of the website was biased by the possibility of a too optimistic self-presentation of actors and projects. Nevertheless, the research helps RRI practitioners to focus on the most promising sources of information and provides tools for applying RRI to CC, or environmental sustainability in general.

3. Results

3.1. Findings of the Document Analysis

As shown in Table 1, combining "responsible research" or similar terms with CC, global warming or greenhouse effect returned few documents. After discarding the repeated ones or those not aligned with the research questions, the final sample included only two documents, both deliverables from publicly funded projects [6,40], and no peer reviewed documents.

There were clearly more publications obtained from the combination of "responsible research" (and related terms) and sustainability (and related terms). The results of this search provide most of the final 78 studied publications, among papers, project deliverables and book chapters.

The combination of responsible research or similar and SI, CSR or similar also gave limited documents. However, some of them were really important for the research and have helped us to understand how CSR and SI can inform RRI [9,41–43].

The findings of the document and web analysis, together with their references, are discussed in Section 4. To end this subsection, some journals are highlighted as they are specifically dedicated to RRI, namely:

1. *Journal of Responsible Innovation*
2. *The ORBIT Journal*—an online Journal for Responsible Research and Innovation on ICT
3. *Responsible Research und TA—Innovationen neu gestalten*, edited by the Karslruhe Institute of Technology (in German)
4. A section of *Responsible Science* in *EuroScientist*, the official journal of EuroScience
5. *Debating Innovation*, the journal of the *Observatory for Responsible Innovation* (last issue in 2014).

However, various other journals have lately accepted for publication papers directly or indirectly about RRI. In addition, some journals have launched Special Issues on RRI or similar.

3.2. Analysis of Projects and Actors

The web search undertaken with the terms "responsible research" and similar terms, combined with "projects", gave a list of projects and a few databases of projects, for example the website of Vinnova [44] that includes information about signed contracts in Horizon 2020 for a certain cut-off

date (December 2017 in this case). After reviewing them with the research questions, and applying the Snowball sampling, a set of 46 projects was arranged (see Appendix A). The majority of the projects found were Horizon 2020 projects [45], which is to be expected due to the novelty of RRI and the explicit support given to it in the current framework program [45]. However, we also found a variety of projects funded by the 7th Framework program (for instance, CONSIDER, Res-AGorA, GREAT, PROGRESS, RESPONSIBILITY, Responsible Industry, Irresistible, etc.). After the revision, only six have been found to be researching how to address CC or sustainability in RRI and, hence, can be a good reference for R&I teams (Table 2).

Table 2. RRI Projects including CC or Sustainability.

Project	Sustainability or Climate Change	Methods, Indicators, Examples	Top-Down or Bottom-UP	Area
CASI2020 [46]	Both directly	Yes	Both	Sustainable innovation.
COMPASS [47]	Both indirectly	Yes	Bottom-up	Cyber security, Nanoelectronics and Biomedicine
Engage2020 [48]	Both directly	Yes	Both	General
Res-AGorA [37]	Both directly	Yes	Both	General
RRI Tools [49]	Both indirectly	Yes	Both	General.
SMART [50]	Both directly	Yes (expected)	Both	Life cycle of textiles and mobiles.

The rest of the projects were not selected as reference, most of them due to five main reasons:

1. The project's main aim is educating about RRI: Ark of enquiry, EnRRICH, FRRIICT, IRRESISTIBLE, NUCLEUS, PARRISE, SPARKS, and SYNERGENE.
2. The aim is stakeholder engagement in RRI, but at a strategic level, not at a tactical level, not intended for practice: CIMULACT, CONSIDER, NanoDiode, PE2020, PERARES, PIER, TRUST, and VOICES.
3. The aim is monitoring RRI evolution: Res-AGorA_MoRRI, NERRI, Responsibility (project, forum and observatory), and STARBIOS2.
4. Even though they include the application of RRI to practice, they neither consider environmental sustainability nor CC in particular: Orbit, PRISMA, PROSO, RRI-Practice, RESPONSIBLE-INDUSTRY, RRI-ICT Forum, SATORI and SMART-map. Conversely, if they address CC or sustainability, their proposals were not considered detailed or concrete enough for helping R&I teams to apply them to their activities: GREAT, KARIM and ProGReSS.
5. The project has just started and has not provided results at the time of writing this paper: InSPIRES, JERRI, NewHoRRIzon, and Fit4RRI.

Other projects were not selected for other particular reasons: for example, FotRRIS has a line about transition to renewable energy based societies, but, at the time of the analysis, very little was uploaded about it. However, FotRRIS website includes a deliverable about the state of the art of RRI [20] which is very interesting for this research. Particularly a series of appendixes with the reviewed RRI papers, the RRI projects and RRI case studies. Likewise, the HEIRRI project includes a very interesting state of the art of RRI publications and projects, but it was not possible to find anything to guide RRI on CC [32,38].

To finish, the project Res-AGorA_RRI Trends includes a database of "key documents", and some of them were found to address CC and/or sustainability. However, the project neither includes the dimension of sustainability in its trends analysis, nor could there be found any particular documents in the database addressing the research questions, and hence it was discarded.

3.3. Actors of RRI That Address Sustainability or CC

The web review, and its contents, allowed not only the identification of projects and initiatives but also agents with resources, experience and leadership in the research field of RRI and CC. Below, some

of the actors most directly related to the research questions and most active are introduced, although it is acknowledged there may be other relevant funders and research centers that were overlooked.

Starting with funders and promoters, besides the European Commission's implementation of RRI in Horizon 2020 (objective "*Science with and for Society*"), *The Climate and Development Knowledge Network* (CDKN) stands out because it shares the dimensions of RRI and promotes research for preventing CC, although it is not specifically dedicated to RRI or CSR. Besides, there are three national organizations supporting RRI, including sustainability and thus CC: the *Engineering & Physical Sciences Research Council* (EPSRC); the *Netherlands organization for Scientific Research* (NWO); and *The Norwegian Research Council* (NFR). Among research centers and other institutions, next some of the most active and directly related to the research are listed.

- *Fraunhofer Centre for Responsible Research and Innovation* (CeRRI) in Berlin
- *Fraunhofer Institute for Systems and Innovation Research ISI* in Karlsruhe
- *Karlsruhe Institute of Technology Climate and Environment Centre*
- *Centre for Computing and Social Responsibility* (CCSR) in Leicester
- *Institute for Managing Sustainability* in Wien
- *Danish Board of Technology Foundation* in Hvidovre, Copenhagen

In addition, and for completion, the actors leading the 46 selected projects are included in Appendix A. The deliverable 1.4 of the COMPASS project adds annexes with lists of RRI related industry initiatives, including the leading actors are also of interest [39].

4. Discussion

As previously stated, the aim of this paper is to inform RRI practitioners on the assessment of their potential contribution to climate change, and its prevention, especially when RRI activities are not directly related to CC, or to closely related research topics such as energy, air pollution, etc. For those R&I teams committed to the CC challenge, but without enough expertise to tackle it, a description of what CSR, SI and RRI experts are proposing on the matter will help to understand the task ahead.

Results are discussed in three parts, firstly a framework for arranging the findings is given with four main approaches. Finally, most mentioned barriers for addressing CC during RRI are identified and briefly explained.

4.1. Main Contributions to CC Prevention in RRI

As introduced in Section 3, it was confirmed that in the last decade, in contrast to the terms CC, SI and CSR, the term RRI was not well known and authors may refer to it by different names. Only in the last 3–5 years is RRI becoming a common reference to responsibly research and innovation. Besides, the theory of RRI is not fully developed yet [30,51]. Hence, a variety of new research projects and publications are expected in this realm as authors participate in its development. Particularly climate change, and environmental sustainability in general, are bound to attract ever more interest in RRI activities.

However, the literature review and the web search returned a variety of tools related to the research questions. To add clarity to the discussion of the diverse findings, they were grouped into four main strategies or approaches to operationalize addressing CC within RRI (see Figure 1) [40,47,52]. Hereafter, they are discussed in further detail. The general strategies are:

1. Efficient integration in the core management of research and innovation;
2. Stakeholder management;
3. Apply a life cycle perspective; and
4. Open access databases.

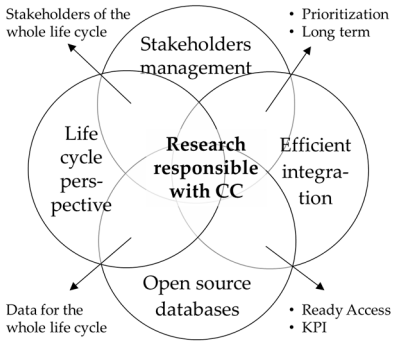

Figure 1. General strategies from CSR, SI and RRI to inform RRI on CC.

Hereafter, each of the four tenets is discussed in specific subsections. To be more concise, and to facilitate understanding of the discussion, the findings of the research questions are combined. In that way, repeating concepts, examples or tools is avoided whenever a coincidence was found between the two realms. The emphasis is not so much on what each research question yielded in particular. The discussion emphasizes more how tools against climate change help to fight CC within RRI practice, whether they come from CSR and SI documents or from RRI projects and actors.

4.1.1. Effective and Efficient Integration in the Core Management of Research

The majority of authors in the CSR and SI realm, and various in the RRI realm [10,13,14], propose that the most effective way of implementing responsibility for companies is following a bottom-up approach; for example, see the work of Hemphill [42] or Gianni [43], and the approach of the aforementioned projects: Res-AGorA_MoRRI [53], NERRI [54], Responsibility [55] and STARBIOS2 [56]. Conversely, as discussed later, the majority of RRI publications were found to assume a Top-down approach addressing science policy makers.

A bottom-up approach means teams research to prevent CC in view of their responsibility, and following the demands of their stakeholders on a voluntary basis, not forced by legislation, public funding requirements, etc. Consistent with that approach, public policy makers would be expected to act mainly as facilitators. The argument given is that responsibility can only develop its maximum effectiveness if voluntary [42,57,58]. Indeed, some authors [13] argued that forcing RRI in R&I teams could lead to unintended consequences such as:

1. Teams do the minimum for compliance and do not actually get to incorporate RRI to their core management.
2. The tools for assessing the responsibility of research projects lead to devoting precious resources to filling out forms and writing compliance reports.
3. The RRI assessment system penalizes those that are not good at filling out forms although they may be excellent at research itself.
4. The evaluation system unintentionally leads practitioners to particular research fields, diverting them from initiatives that could represent great advances in society's wellbeing or scientific knowledge.

Therefore, the task pending for researchers would be to, firstly, assess if their contribution to CC is relevant compared with other responsibilities they may identify, and, if this is the case, to include CC within the goals and concerns of the research. For that, teams will have to assess and manage the carbon footprint of their research, i.e., the contribution to CC of all activities of the life cycle of the project [59–61]. Below, the tools that can support this aim are discussed.

4.1.2. Life Cycle Perspective

CC has been traditionally assessed as a carbon footprint. This is so because greenhouse gases (GHG) released into the atmosphere, the ones that produce CC, are normally added and referred to their Carbon Dioxide equivalent (CO_2e) [62,63]. Carbon Dioxide is the main contributor to Anthropogenic CC. The main methodologies for assessing the carbon footprint are [6]:

- PAS 2050 [62,64]
- GHG Protocol Product Standard [65]
- ISO 14064-2:2006 [63]
- ISO 14040 [66]

In addition, the life cycle perspective is a requirement for carbon footprint methods to incorporate [62,64,66]. The life cycle comprises the following life stages of a product or service:

1. Collecting raw materials/information
2. Manufacturing/transformation process
3. Distribution
4. Use and maintenance
5. End of life

There are several research and innovation activities aiming to develop a new product or system which later will be industrialized and widely used. Therefore, the contributions to CC in those projects normally will be more relevant for the life cycle of the outcomes of the research than for the research activities themselves [40,61,67]. Currently, there are proven tools to guide Life Cycle Assessment (LCA), including the ISO 14040 series of standards [66] and, to lesser extent, the PAS 2050 [64].

LCA is very laborious and, thus, for R&I teams, one of its essences is to identify and prioritize the main contributions to CC during the life cycle of the innovation, as rigorously as possible [63]. That way, LCA allows us to identify the minimum indicators to add to the research management key performance indicators (KPI) [57,63,68–70], and can be re-run later in an abridged manner based on those KPI.

Besides, LCA helps to make responsible decisions in the face of uncertainties of the long-term environmental impacts of the emerging technologies [59,61]. For example, it may occur that it is more responsible to produce and market an innovation in one region than in another, based on the envisaged scenarios, the regions' energy mix, the waste treatment systems, etc. [60,71]. This is what several authors define as "aiming at glocal sustainability research", for instance [20,72].

Nevertheless, Wender et al. [60] argued that LCA must be adapted to successfully promote RRI. LCA "as usual" may not be effective for two main reasons: (i) approaches to LCA are mostly retrospective, relying greatly on data collected from established activities with existing supply chains; and (ii) LCA only consider stakeholders for supplying information, but not to participate in critical modelling decisions [73]. Hence, they put forward "*Anticipatory LCA*" as an adapted tool for generating models with a high degree of uncertainty in order to explore a broad spectrum of possible scenarios, building capacity to prepare for many potential outcomes [20,60,73].

4.1.3. Use and Develop Open Access Databases

If R&I teams have to estimate what the environmental performance of the research outcome will be, besides their own performance, they will need abundant and reliable information (or to cooperate with, or hire, good specialists). Furthermore, LCA practitioners claim the most laborious and resources consuming task is the life cycle inventory of all interactions with the environment [14,64,74]. Thus, ready and user-friendly open access databases would save a great deal of time and resources.

As an example of the type of open source data, the "Environmental Product Declaration (EPD®)" is a verified and registered document that communicates transparent and comparable information about the life-cycle environmental aspects of products or services [75]. Unfortunately, only around

650 EPDs are currently included in the online database, despite belonging to a wide range of product categories. Besides, Ibáñez-Forés et al. [76] explain that EPD are still generally unknown, and that is the reason why few EPD are used, and even fewer are added to the database. Consequently, EPD cannot cover the research demand for many disciplines. The same applies to the other open access database "European reference Life Cycle Database (ELCD®)" with around 600 items [77].

Nevertheless, RRI studies have identified open access science as one of the key areas for RRI and, thus, a larger amount of environmental information is expected to be available for research teams [58,78,79]. Besides, disclosure and accountability are key for a fruitful engagement of stakeholders to prevent CC [80]. Shared information about CC on the one hand, should help raise awareness and educate the principal stakeholders and, on the other hand should facilitate gathering information and support from them [47,48,50]. In that way, environmental assessments, even if not precise, will be more accurate and more efficient [50,70]. In any case, nowadays, several other open access databases were identified and available for the assessment of their contribution to CC, the main ones being:

- Inventory of Carbon & Energy (ICE) Version 2.0 [81]
- Sustainability Disclosure Database [82]
- 2006 IPCC Guidelines for National Greenhouse Gas Inventories [83]

4.1.4. Stakeholder Management

It is today understood that no single research team, policymaker or organization can successfully work in isolation to address current complex social and environmental challenges. As introduced in [84], sustainability challenges are multifaceted and have, amongst others, the following characteristics:

- Their understanding is not unequivocal and different sensitivities apply.
- Only "potential" solutions can be suggested; it cannot be accurately stated how "good" for the environment alternatives can be.
- Hence, solutions are not simply right or wrong, but better or worse. It is difficult to assess them in absolute terms; several alternatives could all be good for the environment, or all bad, or combinations thereof.

Therefore, in the framework of a research project, stakeholders should be invited to participate in the development of goals, definition of activities, the innovation processes, the assessment of the consequences of each alternative, decision making, etc. [80]. In particular, in face of the uncertainties about CC impacts of the innovative process and outcome, stakeholders can play a decisive role informing R&I teams, and identifying, assessing and managing the related risks [61]. For this, the AA1000 series of standards [80], and the findings and proposals of RRI related works are a better contribution for RRI practitioners. In fact, it is one of the most developed dimensions of RRI [22,30].

Several publications, projects and actors can be used as a guide and reference for stakeholder management during RRI; a good example is [9,85]. Specifically addressing the case of CC, among the few obtained, References [40,71,86] are recommend. Some authors argue numerous research teams will need to overcome their reluctance to really engage with stakeholders; a reluctance that is due to several reasons, for instance [20,52,58]:

1. Protecting innovation, avoiding key information getting to the competitors;
2. Lack of skills for managing stakeholders: difficulties for identifying stakeholders, their interests and powers, who represents or speaks on behalf of them, etc.;
3. "A lot of work is required to educate stakeholders" [58]; and
4. Time and resources consumption, and obstacles to the agility of the research processes.

4.2. Difficulties in Operationalization

Complementary to the difficulties of operationalization already introduced in the previous sections, comments on further barriers and difficulties for a complete implementation of RRI were

found in several publications. The following list is not the result of studies on barriers and difficulties as such, but a selection of the best supported objections that were found. Below, for discussion completeness, they are identified and briefly explained together with their references.

- It is inherently difficult to apply the whole concept of responsibility to the innovation process [51,79]. This is mainly related to the extent to which RRI practitioners can foresee what is to come, or be blamed for the unexpected impacts of their innovations. Conversely, to give another example, to which extent avoiding CC is more important than other socially desirable goals in a context of limited resources and time, and different relevant negative impacts.
- A culture gap between RRI academic researchers and R&I practitioners: Differences in languages, goals, indicators, timespans, tools and research styles act as barriers to a mutual understanding [40,57,58].
- Rising awareness: While research teams in disciplines such as energy, transport, infrastructure, plastics, etc. are aware of their responsibility towards CC [57,72], others devoted to disciplines such as ICT, finance, retail, agriculture, food, nanotechnologies, etc. normally do not consider themselves as having an impact on CC [6,40,57,61,71,87].
- More practice, more examples, more RRI practitioners: The majority of R&I teams are cautious about novel trends and wait until they become general practice [39,58].
- Specific to CC prevention, to adapt to RRI the proven and available tools for assessing CC, i.e., guidelines and standards for carbon footprint calculations (see Section 4.1.2) and open access databases of environmental aspects and indicators (see Section 4.1.3) is necessary. None of the reviewed RRI publications or projects (nor the ones of Table 2) were found to apply those tools.

5. Conclusions, Limitations and Future Research

This paper contributes to the operationalization of the inclusion of CC in RRI. To this end, the tools against CC originated in corporate social responsibility and sustainable innovation are identified. Those tools help to operationalize strategies against CC in RRI practice. Moreover, the latest proposals by RRI projects and international actors addressing CC have been reviewed. The findings of both research questions have been combined to present the main strategies that RRI practitioners have at their disposal, either coming from the realm of CSR, SI or, lately, RRI.

As anticipated, as RRI has only lately included sustainability as a key area for the social desirability of research and innovation, few projects and proposals were found addressing sustainability, and CC in particular. Nevertheless, various R&I teams and projects were found and their findings have a great potential for informing the operationalization of RRI related to CC. Thus, the majority of the findings came from the realms of CSR and SI. CSR and SI have tackled CC far earlier than RRI has, and somehow with complementary approaches that allow the gathering of a complete set of tools that may answer our research questions.

The findings of the document analysis and the web review were arranged in four main strategies for the mentioned RRI operationalization. This framework is intended for R&I that has an indirect but relevant impact on the environment, and then on society, due to CC. The tools put forward will allow those R&I teams or policy makers to, firstly, become aware of the relevancy of their CC impacts, secondly, to identify the what, when and why of those contributions to CC, and finally, to integrate in their procedures means to tackle the problem.

To start with, the majority of consulted authors and practitioners claim RRI will be more effective and efficient if assumed voluntarily in a bottom-up process. Policy makers and R&I funders can be drivers of RRI diffusion, but currently the main barriers are the lack of awareness and proper tools for implementing RRI related to CC. This conclusion can be applied to RRI in general.

Hence, if found relevant, CC prevention must be included in the core goals and procedures of the R&I teams. This needs to encompass the full life cycle of R&I projects, that is to say, not only research activities but expected outcomes of R&I must be assessed. For that, tools were identified for life cycle assessment, open databases and stakeholder management. The final aim would be to identify the key

performance indicators that would drive R&I activities, allow us to monitor improvements and, on a broader scale, to help to prevent, and to educate about, CC.

Nevertheless, diverse barriers were also found hindering the operationalization of CC prevention beyond the lack of awareness, specific expertise or tools for the purpose. There are as yet unsolved philosophical and ethical difficulties in clarifying to which extent R&I practitioners should be assigned responsibilities related to what could happen in the future. Besides, problems of communication among RRI promoters and R&I practitioners were found. Many of the RRI concepts, terms, arguments and even indicators related to CC (but not only) are still obscure for R&I practitioners. Another major drawback is the perceived stakeholders' general lack of interest or education on the RRI key areas, and CC in particular.

Having said all the above, this study has some limitations that need to be acknowledged. On the one hand, the purpose was not so much normative as descriptive. Therefore, an avenue for future research on normative proposals has been identified, as introduced below. This analysis may have taken no notice of some important publications or projects. We have reviewed mainly FP7 and H2020 projects, and some interrelated projects when introduced by other projects or actors. There could be meaningful proposals that have been unintentionally skipped.

In addition, in the realm of CSR and SI, only what was available was reviewed. However, there being abundant literature, quite often the R&I methods, processes and results take place in firms and are not made public.

The review on RRI relies significantly on what authors include in their project deliverables. Although those documents were not peer-reviewed, they were substantial for the findings and conclusions as they presented the results of related research. The rigor of the information included in those deliverables remains to be proved. Nevertheless, whenever a document that was not peer reviewed stated something that had not been read somewhere else, good care was taken in contrasting the statement with more trusted sources.

To end the conclusions, the identified avenues for future research are presented. As introduced before, and in the context of a bottom-up approach, normative proposals are needed for teams to address CC in RRI activities. Those normative proposals can adapt the proven tools of CSR and SI to the available RRI practices. Coherent with those normative proposals, new tools are needed, for example, key performance indicators based on open access databases, i.e. ready and easy to understand information to help practitioners to integrate CC prevention in their R&I activities. Those KPI should help, on the one hand, to improve the accountability of RRI practitioners and, on the other hand, to analyze and foresee impacts that may happen in the future. In that sense, another avenue for research is the adaptation of the current life cycle assessment and social life cycle assessment, mainly backward looking, into a forward looking assessment tool that is useful for determining possible responsibilities of research and innovation with a life cycle perspective. Finally, other research questions arise related to how to effectively engage stakeholders' cooperation for CC prevention in R&I activities.

All these research lines would help to finally operationalize CC prevention in RRI. Their outcomes would be of great help for the same purpose in the wider scope of environmental sustainability.

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Appendix A. Data of the Reviewed Projects

Table A1. Reviewed Projects.

Project	Sustainability or CC	Methods, etc.	Top-Down	Bottom-Up	Leader	Web Link	Area	Situation
Ark of Inquiry	Indirectly	Yes	Yes	Yes	University of Tartu	http://www.arkofinquiry.eu/RRI	Education	On going
CASI2020	Yes	Yes	Yes	Yes	ARC Fund. Sofia.	http://www.casi2020.eu/about/description/	Sustainable innovation	Finished
CIMULACT	Indirectly	Yes	Yes	Yes	Danish Board of Technology Foundation. Hvidovre	http://www.cimulact.eu/	General	On going
COMPASS	Indirectly	Yes	No	Yes	Institute for Managing Sustainability, university of Wien	https://innovation-compass.eu/	Cyber security, nanoel. and biomedicine	On going
CONSIDER	Indirectly	Yes	No	Yes	Montfort University. Leicester	http://www.consider-project.eu/	Governance	Finished
Engage2020	Yes	Yes	Yes	Yes	Danish Board of Technology Foundation. Hvidovre	http://engage2020.eu/	General	Finished
EnRRICH	No	Yes	No	Yes	Vrije Universiteit Brussel	http://www.livingknowledge.org/projects/enrrich/	Higher education	On going
FIT4RRI	No	No data	No data	No data	Universitá di Roma Sapienza. Rome	https://fit4rri.eu/	Open Science	On going
FoTRRIS	Yes	Yes	No	Yes	VITO. Mol	http://fotrris-h2020.eu/	General	On going
FRRIICT	No	Yes	Yes	Yes	Oxford University	http://www.oerc.ox.ac.uk/projects/frriict	ICT. Ethics	Finished
GREAT	Yes	Yes	Yes	No	University of Namur	http://www.great-project.eu/	Governance	Finished
HEIRRI	Indirectly	Yes	No	Yes	Universitat Pompeu Fabra. Barcelona	http://heirri.eu/	Higher education	On going
INSPIRES	No	No data	No data	No data	ISGlobal. Barcelona	http://www.livingknowledge.org/projects/inspires	General	On going

Table A1. *Cont.*

Project	Sustainability or CC	Methods, etc.	Top-Down	Bottom-Up	Leader	Web Link	Area	Situation
IRRESISTIBLE	Yes	Yes	No	Yes	University of Groningen	http://www.irresistible-project.eu/index.php/en/	Education	Finished
JERRI	Yes	Yes	Yes	Yes	Fraunhofer ISI. Karlsruhe	http://www.jerri-project.eu/jerri/singlepage/index.php	General	On going
KARIM	Yes	Yes	No	Yes	Paris region innovation centre	http://www.karimnetwork.com/about/	Six, including environment and energy	Finished
NanoDiode	Indirectly	Yes	No	Yes	IVAM. Amsterdam	http://www.nanodiode.eu/	Nanotechnology	Finished
NERRI	Indirectly	Yes	No	Yes	CIENCIA VIVA. Lisbon	http://www.cienciaviva.pt/projinternacionais/nerri/index.asp	Neuro science and technology	Finished
NewHoRRIzon	Indirectly	No data	No	Yes	Institute for advanced studies. Wien	http://newhorrizon.eu/	General	On going
NUCLEUS	No	Yes	No	Yes	Rhine-Waal University. Klever	http://www.nucleus-project.eu/	Higher education	On going
Orbit	No	Yes	No	Yes	Montfort University. Leicester	http://www.orbit-rri.org/	ICT	On going
PARRISE	Indirectly	Yes	No	Yes	Utrecht University	http://www.parrise.eu/	Education	On going
PE2020	No	Yes	Yes	Yes	University of Helsinki	https://pe2020.eu/about/	Public engagement	Finished
PERARES	Indirectly	Yes	Yes	Yes	Bonn Science Shop (WILA Bonn)	http://www.livingknowledge.org/projects/perares/	General	Finished
PIER	Yes	Yes	No	Yes	F. IDIS-CITTÁ DELLA SCIENZA. Naples	http://www.pier-project.eu/	Sea	On going
PRISMA	No	Yes	No	Yes	TU Delft	http://www.rri-prisma.eu/	Synthetic biology, nanotechnology, self-driving vehicles, the internet of things	On going
ProGReSS	Yes	Yes	Yes	Yes	University of Central Lancashire	http://www.progressproject.eu/	General	Finished
PROSO	No	Yes	No	Yes	DIALOGIK. Stuttgart	http://www.proso-project.eu/	General	On going

Table A1. *Cont.*

Project	Sustainability or CC	Methods, etc.	Top-Down	Bottom-Up	Leader	Web Link	Area	Situation
Reponsibility	No	Yes	No	Yes	Fraunhofer IPK. Munich	http://responsibility-rri.eu/	General	Finished
Reponsibility_Forum	No	Yes	No	Yes	Fraunhofer IPK. Munich	http://responsibility-rri.eu/	General	Finished
Reponsibility_Observatory	No	Yes	No	Yes	Fraunhofer IPK. Munich	http://responsibility-rri.eu/	General	Finished
Res-AGorA	Yes	Yes	Yes	No	Fraunhofer ISI. Karlsruhe	http://res-agora.eu/about/	General	Finished
ResAGorA_MoRRI	Indirectly	Yes	Yes	No	IPRED. Brussels	http://www.technopolis-group.com/morri/	General	On going
ResAGorA_RRI trends	Indirectly	Yes	Yes	Yes	Aarhus university	http://www.rritrends.res-agora.eu/masis	General	Finished
RESPONSIBLE-INDUSTRY	Indirectly	Yes	No	Yes	Montfort University-Leicester	http://www.responsible-industry.eu/	ICT for ageing people	Finished
RRI-Practice	No	No	Yes	No	Oslo and Akershus University College of Applied Sciences	https://www.rri-practice.eu/	General	On going
RRI Tools	Indirectly	Yes	Indirectly	Indirectly	La Caixa Foundation. Barcelona	http://www.rri-tools.eu/	General	Finished
RRI-ICT Forum	No	Yes	No	Yes	Sigmaorionis. Paris	https://rri-ict-forum.nexacenter.org/	ICS and SSH	On going
SATORI	No	Yes	No	Yes	University of Twente	http://satoriproject.eu/the-project/	Ethics	On going
SMART	Yes	No data	Yes	Yes	University of Oslo	http://www.smart.uio.no/	Life cycle of textiles and mobiles	On going
SMART-map	No	Yes	No	Yes	Aarhus University	http://projectsmartmap.eu/	Synthetic biology. Biomedicine.	On going
SPARKS	No	Yes	No	Yes	ECSITE. Brussels	http://www.sparksproject.eu/	Health Science, Science museums	On going
STARBIOS2	No	No data	Yes	Yes	University of Rome Tor Vergata. Rome	http://starbios2.eu/	Biosciences	On going
SYNENERGENE	No	No data	No data	No data	Karlsruhe Institute of Technology	https://www.synenergene.eu/	Synthetic biology	Finished
TRUST	No	Yes	No	Yes	University of Central Lancashire	http://trust-project.eu/	Ethical standards	On going
VOICES for Innovation	Yes	Yes	Yes	Yes	ECSITE. Brussels.	http://www.voicesforinnovation.eu/	Urban waste as resource	Finished

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