Addressing Climate Change in research and innovation projects

A tool for anticipatory carbon footprint calculation

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Abstract

Global Warming, and the climate change (CC) it produces, is one of the most global and urgent threats humankinds is responsible for. The challenge of mitigating and adapting to CC, among others, is a responsibility that has reached all disciplines, including the research and innovation (R&I) process. For more than 10 years, and as a way to tackle these great challenges of our time, with the intention of fostering responsible research, the European Commission has been promoting a cross-cutting issue named: "Responsible Research and Innovation (RRI)". The aim is to bring the problems (such as research integrity, non-inclusion of stakeholders, application of ethical or sustainability principles, etc.,.) related to R&I to light, to anticipate the possible consequences of R&I process and outcomes, and to engage society in the discussion of how science and technology can help create the kind of world and society we want for generations to come.

This thesis emerges as a bridge between the great challenge represented by CC and the demand for responsibility from R&I process and outcomes, addressed in the context of RRI. Research funders and society as a whole claim that R&I teams must provide socially desirable, ethically acceptable, and sustainable outcomes. Hence, the general question to be answered in this thesis is: how does a research team, while not being specialists, know if its research is responsible for relevant contributions to CC, and how can they include measures to reduce or compensate such contributions (Greenhouse Gas emissions, GHG)?

To respond to this question, the present dissertation begins with the main foundations that are central to it (chapter 1): CC and RRI. As regards the former concept, we explain the importance and means to calculate the contribution of GHG to CC, mainly the carbon footprint approach. In addition, regarding the latter, how this thesis aligns with the key RRIs' area of environmental sustainability, its substantive frameworks and its anticipation and reflexivity dimensions. Once these two foundations are established, CC is addressed in the context of RRI (chapter 2), reviewing the literature on RRI projects and proposals, which include environmental sustainability, and CC in particular. As a result, two avenues of research arise, which are developed in the following sections. An avenue about how to assess the stakeholders' influence in a research project within the context of RRI, which is developed in chapter 3, and an avenue about the need for new tools based on open-access databases to help practitioners to integrate CC prevention in their R&I activities, which is developed in chapter 4.

Chapter 3 presents a methodology to assess the stakeholders' influence in a research project within the context of RRI. The methodology is based on a combination of the multicriteria decision making technique Analytic Network Process and the key areas of

responsible research. The methodology allows ranking and ordering of the project's stakeholders based on their influence upon project responsibility. The purpose of such an assessment is to help research teams to more efficiently devote their limited resources to stakeholder management.

Chapter 4 presents the design of a novel tool with a didactic algorithm for anticipatory carbon footprint measuring in R&I projects. This tool allows researchers who are untrained in environmental impact assessment to estimate the greenhouse gas emissions of their R&I projects at early stages, when anticipation and reflexivity are the core RRI dimensions. We followed a two-phase method: (i) tool designing, based on a literature review on carbon footprint tools and open sources databases, and (ii) tool testing, carried out through three case studies. The results show that the designed tool for anticipation and reflection on CC works as expected. Indeed, it is useful in helping researchers' decision making at the early stages of an R&I project by estimating the GHG emissions that could be generated, both during the research process and during the exploitation of its outcomes.

Finally, in chapter 5, the general discussion of the results, the general conclusions and the main contributions of the thesis are presented. In addition, the limitations and future research avenues are outlined.

Keywords: responsible research and innovation (RRI); climate change; anticipation and reflexivity in research and innovation; GHG assessment tool.

Resumen

El calentamiento global, y el cambio climático (CC) que produce, es una de las amenazas más globales y urgentes de las que es responsable la humanidad. El desafío de mitigar y adaptarse a la CC, entre otros, es una responsabilidad que ha alcanzado a todas las disciplinas, incluyendo el proceso de investigación e innovación. Durante más de 10 años, y como una forma de abordar estos grandes desafíos de nuestro tiempo, con la intención de fomentar la investigación responsable, la Comisión Europea ha estado promoviendo una temática transversal llamada: "Investigación e innovación responsable (RRI, en sus siglas en inglés)". El objetivo es sacar a la luz los problemas relacionados con la investigación y la innovación, anticipar sus consecuencias y hacer participar a la sociedad en el debate sobre la forma en que la ciencia y la tecnología pueden contribuir a crear el tipo de mundo y de sociedad que deseamos para las generaciones futuras.

Esta tesis surge como un puente entre el gran desafío que representa el CC y la demanda por parte de la sociedad de investigación e innovación responsable, abordada en el contexto de la RRI. Los financiadores e impulsores de la investigación y la sociedad en su conjunto esperan que los equipos de investigación e innovación proporcionen resultados socialmente deseables, éticamente aceptables y sostenibles. Por lo tanto, la pregunta general que se responde en esta tesis es: ¿cómo sabe un equipo de investigación, sin ser especialista en evaluación ambiental, si su investigación es responsable de emisiones contribuyentes al cambio climático, y cómo puede incluir medidas para reducir o compensar esas emisiones de gases de efecto invernadero (GEI)?

Para responder a esta pregunta, la presente tesis doctoral inicia con la descripción de los principales fundamentos que son centrales en ella (capítulo 1): CC y RRI. En lo que respecta al primer concepto, explicamos la importancia y los medios para calcular la contribución al CC, principalmente el enfoque de la Huella de Carbono. En lo que respecta al segundo concepto, se explica la alineación de esta tesis el área clave de la sostenibilidad ambiental de la RRI, sus marcos sustantivos y sus dimensiones de anticipación y reflexividad. Una vez establecidos estos dos fundamentos, el cambio climático se aborda en el contexto de la RRI (capítulo 2), revisando la literatura sobre los proyectos y propuestas de la RRI, incluyendo la sostenibilidad ambiental, y el CC en particular. Como resultado, surgieron dos avenidas de investigación, que se desarrollan en las siguientes secciones. Una avenida sobre cómo evaluar la influencia de las partes interesadas en un proyecto de investigación en el contexto de la RRI, desarrollada en el capítulo 3, y una avenida sobre la necesidad de nuevas herramientas basadas en bases de datos de acceso abierto para ayudar a los profesionales a integrar la prevención del CC en sus actividades de I + D, desarrollada en el capítulo 4.

En el capítulo 3 se presenta una metodología para evaluar la influencia de los grupos de interés en un proyecto de investigación en el contexto de la investigación y la innovación responsables. La metodología se basa en una combinación de la técnica de toma de decisiones multicriterio Proceso Analítico en Red (ANP, en sus siglas en ingles) y las áreas clave de la investigación responsable. El método permite clasificar y ordenar a los grupos de interés en el proyecto en función de su influencia sobre su responsabilidad. El propósito de esa evaluación es ayudar a los equipos de investigación a dedicar más eficazmente sus limitados recursos a la gestión de los grupos stakeholders.

El capítulo 4, presenta el diseño de una novedosa herramienta con un algoritmo didáctico para la medición anticipada de la huella de carbono en los proyectos de investigación e innovación. Esta herramienta permite a los investigadores que no tienen formación en evaluación del impacto ambiental estimar las emisiones de gases de efecto invernadero de sus proyectos de investigación e innovación en las primeras etapas, momento en el que la anticipación y la reflexividad son las dimensiones fundamentales de la RRI. Hemos seguido un método de dos fases: i) el diseño de la herramienta, basado en una revisión de la bibliografía sobre herramientas de huella de carbono y bases de datos de acceso abierto, y ii) el testeo de herramienta, llevado a cabo mediante tres estudios de casos. Los resultados muestran que la herramienta diseñada para la anticipación y la reflexión sobre la Huella de Carbono funciona como se esperaba. De hecho, es útil para ayudar a los investigadores a tomar decisiones en las primeras etapas de un proyecto de investigación y innovación, al estimar las emisiones de los GEI que podrían generarse, tanto durante el proceso de investigación como durante la potencial explotación de sus resultados.

Por último, en el capítulo 5 se presenta la discusión general de los resultados, las conclusiones generales y las principales contribuciones de la tesis. Asimismo, se describen las limitaciones y las futuras avenidas de investigación.

Palabras clave: investigación e innovación responsable (RRI); cambio climático; anticipación y reflexividad en la investigación e innovación; herramienta de evaluación de GEI.

Resum

L'escalfament global, i el canvi climàtic (CC) que produeix, és una de les amenaces més globals i urgents de les que és responsable la humanitat. El desafiament de mitigar i adaptar-se a la CC, entre d'altres, és una responsabilitat que ha arribat a totes les disciplines, incloent el procés de recerca i innovació. Durant més de 10 anys, i com una forma d'abordar aquests grans desafiaments del nostre temps, amb la intenció de fomentar la investigació responsable, la Comissió Europea ha estat promovent una temàtica transversal anomenada: "Recerca i innovació responsable (RRI, en seves sigles en anglès)". L'objectiu és treure a la llum els problemes relacionats amb la investigació i la innovació, anticipar les seves conseqüències i fer participar la societat en el debat sobre la forma en què la ciència i la tecnologia poden contribuir a crear el tipus de món i de societat que desitgem per a les generacions futures.

Aquesta tesi sorgeix com un pont entre el gran desafiament que representa el CC i la demanda per part de la societat d'investigació i innovació responsable, abordada en el context de la RRI. Els finançadors i impulsors de la investigació i la societat en el seu conjunt esperen que els equips de recerca i innovació proporcionin resultats socialment desitjables, èticament acceptables i sostenibles. Per tant, la pregunta general que respon a aquesta tesi és: com sap un equip d'investigació, sense ser especialista en avaluació ambiental, si la seva investigació és responsable d'emissions contribuents a el canvi climàtic, i com pot incloure mesures per reduir o compensar aquestes emissions de gasos d'efecte hivernacle (GEH)?

Per respondre a aquesta pregunta, la present tesi doctoral s'inicia amb la descripció dels principals fonaments que són centrals en ella (capítol 1): CC i RRI. Pel que fa a el primer concepte, expliquem la importància i els mitjans per calcular la contribució a l'CC, principalment l'enfocament de la Petjada de Carboni. Pel que fa a el segon concepte, s'explica l'alineació d'aquesta tesi l'àrea clau de la sostenibilitat ambiental de la RRI, els seus marcs substantius i les seves dimensions d'anticipació i reflexivitat. Un cop establerts aquests dos fonaments, el canvi climàtic s'aborda en el context de la RRI (capítol 2), revisant la literatura sobre els projectes i propostes de la RRI, incloent la sostenibilitat ambiental, i el CC en particular. Com a resultat, van sorgir dues avingudes de recerca, que es desenvolupen en les següents seccions. Una avinguda sobre com avaluar la influència de les parts interessades en un projecte d'investigació en el context de la RRI, desenvolupada en el capítol 3, i una avinguda sobre la necessitat de noves eines basades en bases de dades d'accés obert per ajudar els professionals a integrar la prevenció de CC en les seves activitats d'R + d, desenvolupada en el capítol 4.

En el capítol 3 es presenta una metodologia per avaluar la influència dels grups d'interès en un projecte d'investigació en el context de la investigació i la innovació responsables.

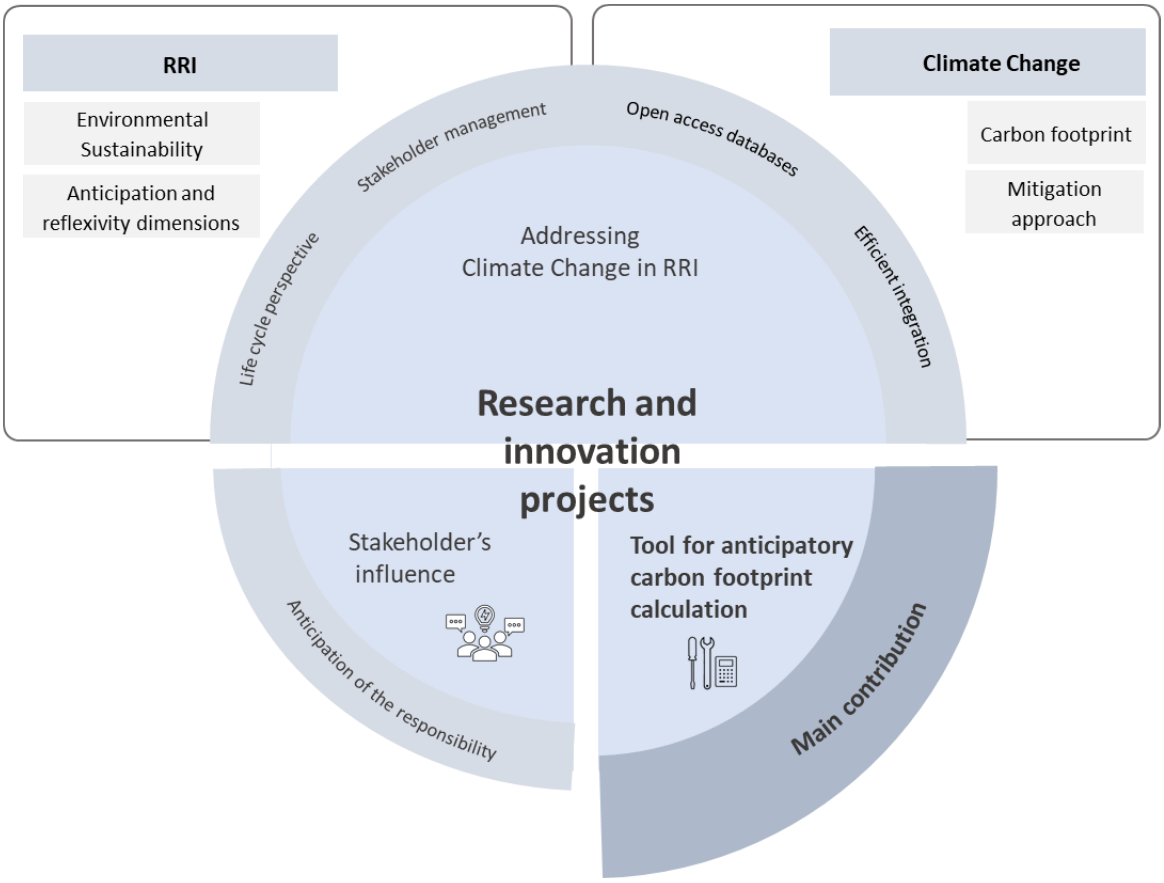
La metodologia es basa en una combinació de la tècnica de presa de decisions multicriteri Procés Analític en Xarxa (ANP, en les seves sigles en anglès) i les àrees clau de la investigació responsable. El mètode permet classificar i ordenar als grups d'interès en el projecte en funció de la seva influència sobre la seva responsabilitat. El propòsit d'aquesta avaluació és ajudar els equips d'investigació a dedicar més eficaçment els seus limitats recursos a la gestió dels grups interessats.

El capítol 4, presenta el disseny d'una nova eina amb un algoritme didàctic per al mesurament anticipada de la petjada de carboni en els projectes de recerca i innovació. Aquesta eina permet als investigadors que no tenen formació en avaluació de l'impacte ambiental estimar les emissions de gasos d'efecte hivernacle dels seus projectes de recerca i innovació en les primeres etapes, moment en el qual l'anticipació i la reflexivitat són les dimensions fonamentals de la RRI. Hem seguit un mètode de dues fases: i) el disseny de l'eina, basat en una revisió de la bibliografia sobre eines de petjada de carboni i bases de dades d'accés obert, i ii) el testeig d'eina, dut a terme mitjançant tres estudis de casos. Els resultats mostren que l'eina dissenyada per l'anticipació i la reflexió sobre la Petjada de Carboni funciona com s'esperava. De fet, és útil per ajudar els investigadors a prendre decisions en les primeres etapes d'un projecte de recerca i innovació, a l'estimar les emissions dels GEH que podrien generar-se, tant durant el procés d'investigació com durant la potencial explotació dels seus resultats .

Finalment, en el capítol 5 es presenta la discussió general dels resultats, les conclusions generals i les principals contribucions de la tesi. Així mateix, es descriuen les limitacions i les futures avingudes d'investigació.

Paraules clau: recerca i innovació responsable (RRI); canvi climàtic; anticipació i reflexivitat en la investigació i innovació; eina d'avaluació de GEH.

Graphical Abstract



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CHAPTER 1

General Introduction

1.1 Introduction

In this introductory chapter, the foundations that are central to this thesis will be addressed: climate change (hereafter CC) in section 1.2.1 and Responsible Research and Innovation (hereafter RRI) in section 1.2.2. The following sections will then describe the aim and research questions that drive this research. Finally, the outline of this dissertation is presented.

1.2 Theoretical Framework

This thesis begins with the main foundations that are central to it, CC and RRI. Figure 1.1 shows how these two pillars built-up the theoretical framework of the thesis and how the breakdown of each pillar ends-up opening the ground of the research. On the one hand, from the main drivers of CC to the carbon footprint, and on the other hand, from the substantive frameworks, whereby RRI is understood as a means to tackle the great challenges to the dimensions of anticipation and reflection with which this thesis is aligned. In this way, in the context of Research and Innovation (hereafter R&I) projects, this thesis serves as a bridge between the great challenge represented by CC and society's demand for responsibility in R&I, addressed in the context of the RRI.

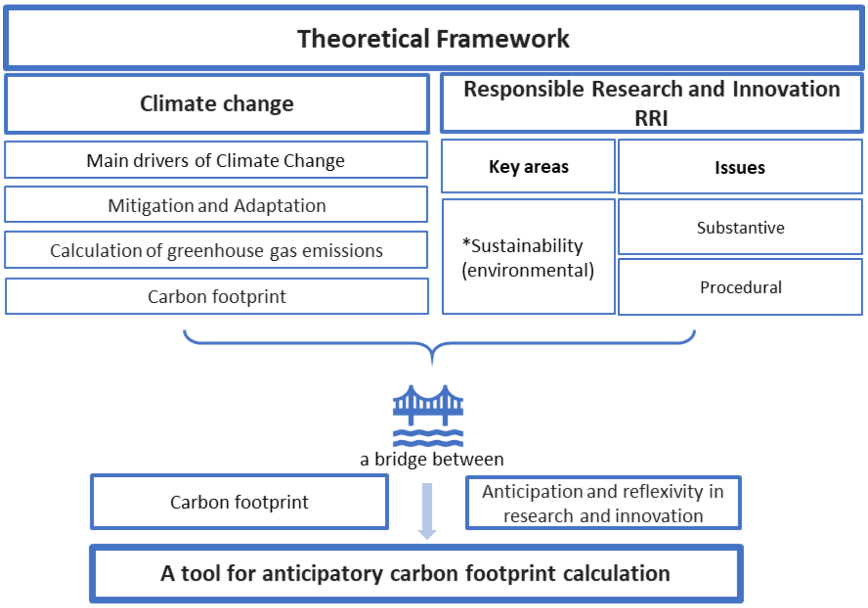

Figure 1.1 Theoretical Framework schema

1.2.1 Climate Change

Main drivers

The earth's atmosphere is a mixture of gases. Within these gases are the gases that trap solar heat and warm the earth; these are known as greenhouse gases (hereafter GHG).

These gases, mostly water vapour and carbon dioxide, move between the land, the atmosphere, and the oceans, maintaining a natural balance in earth's temperature that allows us to live on it. This balance has been maintained for centuries, until 150 years ago, when, due to human activities (starting with the Industrial revolution) like mining, oil extraction or transport (land and air), among others, we began to burn fossil fuels (coal, oil and natural gas), releasing carbon that was contained and separated from the natural balance for centuries. This carbon binds with oxygen and forms the carbon dioxide (hereafter CO_2) that eventually reaches the atmosphere and modifies the natural balance (Tyndall, 1861). The more carbon dioxide trapped in the atmosphere, the more solar radiation and energy is trapped, causing more heat. The more we have of this out-of-balance heat, the more the climate will change. Evidence can be found in shrinking ice sheets (Velicogna et al., 2020), global temperature rise (University of East Anglia and UK Met Office, 2014), sea level rise (Nerem et al., 2018), warming oceans (NCEI Accession 0164586, 2017), and many more.

CO_2 is the GHG emitted in greatest quantity by human activity. It is the most dominant GHG over long time periods, as it is chemically stable and can remain in the atmosphere for many thousands of years. Although natural CO_2 emissions from plants, soils and oceans are much greater than human emissions, these natural emissions are in equilibrium with removal of CO_2 by natural 'sinks' (such as oceans and plants). See Figure 1.2.

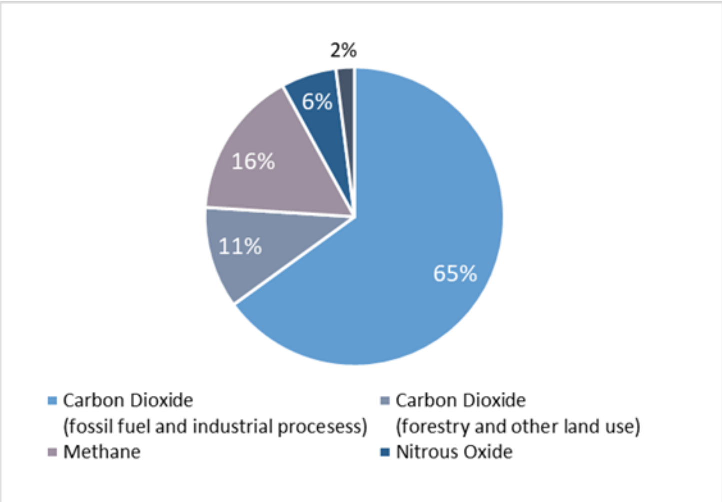

Figure 1.2 Global greenhouse gas emissions by gas

In addition to CO_2, there are also other gases responsible for the greenhouse effect: Sulphur hexafluoride (SF_6), Nitrous oxide (N_2O), Hydrofluorocarbons (HFCs), Methane (CH_4) and Perfluorocarbons (PFCs). A global unit of measurement is used to account for the measurement of all these gases: carbon dioxide equivalent (CO_2e). This unit is defined as the amount of CO_2 emissions that would have the radiative intensity of a determined group of greenhouse gases. To take into account the periods of time these gases remain in the atmosphere, the amount of CO_2 emissions are multiplied by their respective global warming potential (GWP), obtaining in that way the unit of measurement CO_2e (IPCC, 2014). This unit is used in the majority of emissions databases, also in the ones used in this dissertation.

In this thesis we will use ***tons of carbon dioxide equivalent (tCO_2e)*** as unit of measurement, to express the calculation of the carbon footprint of the R&I projects that will be evaluated as case studies. See chapter 4.

Mitigation and adaptation

The evidence, the causes and the effects, behind climate change are unequivocal (IPCC, 2014). Taking into account all the published evidence, everything points to the fact that the alterations produced by climate change will increase and continue for decades. Even if we now find a way to stop all greenhouse gases emissions, climate change will continue to affect the natural balance of the climate for many years to come.

In this scenario, what we can try to control is how fast we accelerate the global warming caused by greenhouse gas emissions. Despite the evidence, the causes, the effects and the scientific consensus on climate change, emissions continue to increase dramatically. In August 2020, levels of carbon dioxide in the air reached a peak of 414.87 ppm (see Figure 1.3), after exceeding 400 ppm for the first time in recorded history in 2013. In this context of coexistence, the response to climate change comes from two approaches: adaptation and mitigation. The first seeks to adapt to the current or future climate. The second seeks to reduce emissions and stabilize the levels of greenhouse gases trapped in the atmosphere.

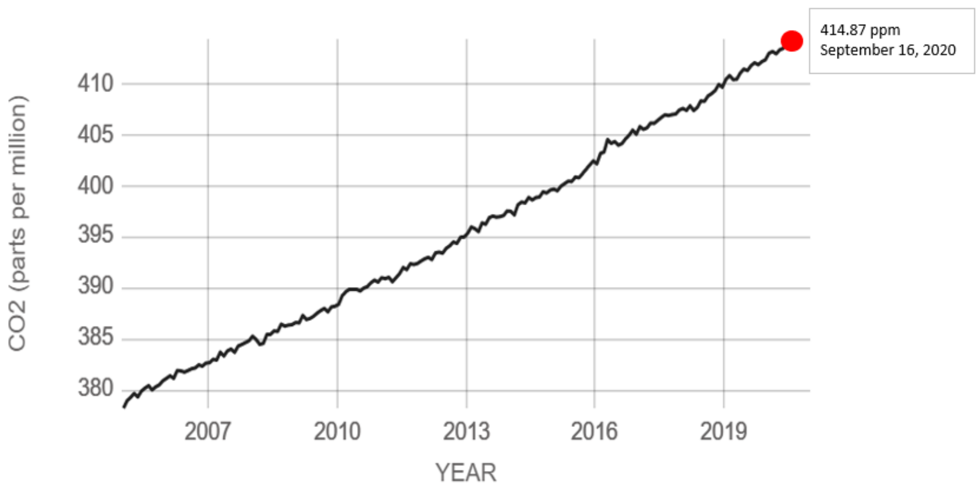

Figure 1.3 CO_2 levels (ppm). Source: climate.nasa.gov

Adaptation. The aim of this approach is to reduce our vulnerability to the effects of climate change such as rising sea levels, droughts, heat waves. It is about adapting to constant climate change.

Mitigation. The purpose of this approach is to prevent human impact on the climate system by reducing greenhouse gas emissions into the atmosphere, especially by reducing the source of these gases which are mostly from transport, the burning of fossil fuels for energy or heating.

The (IPCC, 2014) points out that "Mitigation options are available in every major sector. Mitigation can be more cost-effective when using an integrated approach that combines measures to reduce energy use and the greenhouse gas intensity of end-use sectors, decarbonizing energy supply, reducing net emissions and enhancing carbon sinks in land-based sectors."

This thesis contributes to this mitigation approach by proposing a tool for research teams to calculate possible tCO_2e emissions in advance, and thus make decisions that will help in their reduction.

Calculation of greenhouse gas emissions

GHG emissions are classified into direct or indirect emissions (World Resources Institute and World Business Council for Sustainable Development, 2011).

Direct GHG emissions are those produced in the place where the activity is carried out. Their sources are controlled or belong to an organisation. Examples of these emissions are those generated by fuel combustion or transportation with the organisation's vehicles.

Indirect GHG emissions are those that are produced as a consequence of the activity carried out by an organisation but the source from which they come is controlled or belongs to another organisation. Examples of these emissions are those generated by the electrical energy consumed by an organisation, which generally comes from a power plant outside of the organisation, or those generated by transport with vehicles that do not belong to said organisation.

In addition, these emissions are divided into **three (3) scopes**:

Scope 1 (direct emissions): These are the direct emissions generated by the activities that belong to or are controlled by an organisation. These emissions are derived from industrial processes (physical or chemical) in the organisation, such as fuel combustion, transport with own vehicles, etc.

Scope 2 (indirect emissions): These are indirect emissions caused by the consumption or purchase of electricity generated in an external organisation (e.g. power plant).

Scope 3 (other indirect emissions): Are the remaining indirect emissions generated by i) the use of products and services offered by another organisation, ii) travel through external means, iii) the extraction and production of materials demanded by the organisation, iv) the transport of fuels, products or raw materials carried out by another organisation or v) waste management and disposal carried out by another organisation.

In this research, researchers were asked about elements of the three scopes. Additionally, the chosen data from databases also includes the three scopes.

There are different approaches to the calculation of the CC impacts (GHG emissions) of products and activities. As was described in (European Commission, 2013a) and (Ligardo-Herrera et al., 2018b) the main methodologies for assessing the contribution to CC of products and activities found in the literature are: i) PAS 2050 (The British Standards Institution (BSI), 2011a, 2008); ii) GHG Protocol Product Standard (World Resources Institute and World Business Council for Sustainable Development, 2011); iii) ISO 14064-2:2006 (ISO, 2009); iv) ISO 14040 (ISO, 2006)**;** and more recently this document was included v) ISO14067 – 2018 (ISO, 2018).

Carbon footprint

Carbon footprint refers to the amount of CO_2 and other greenhouse gases emitted over the whole life cycle of a product or process. This quantity is expressed as CO_2 equivalent (CO_2e) per the activity or process being evaluated, which represents the global warming effects of a set of greenhouse gases (ISO, 2009; The British Standards Institution (BSI), 2011b). It is calculated by the life cycle assessment (LCA) method. In particular is a concept used to describe the impact on climate by the emission of greenhouse gases from a product or process into the atmosphere. For this reason, the carbon footprint represents a fundamental starting point for undertaking actions to reduce environmental impact, such as the use of less contaminating materials, use of renewable energies, reduction of travel, reduction of energy consumption, etc. (Ligardo-Herrera et al., 2018c)

Carbon footprints are calculated using LCA, and is also referred to as the 'cradle-to-grave' approach (Technology, 2006). This method is used to analyse the cumulative environmental impacts of a process or product during all the stages of its life. The LCA method is internationally accredited by ISO 14000 standards.

All R&I projects have a 'carbon footprint', due to the fact at some points during their process stage and potential outcomes carbon dioxide (CO_2) is emitted. This is the approach used in this thesis for calculating the emissions contributions of R&I projects.

Carbon footprint Assessment tools

A review of relevant literature and carbon footprint assessment tools was carried out. The purpose was to take advantage of the developments already made as a guide for the design of the anticipatory carbon footprint in R&I Projects Tool presented in this PhD. Thesis (more details in chapter 4). Furthermore, we review the interface of many carbon footprint calculators to helps us in the didactic component of our tool design. For a list of the reviewed calculators see Appendix 1.

The carbon footprint calculators are based on conversion factors. They work by multiplying the activity or component by a number that converts it into CO_2e units of mass per unit of component or product. Likewise, the conversion factors are based on the LCA of these activities/components and are specific average values for certain regions, times, technologies, etc. In particular, for this thesis we have chosen the most updated conversion data possible. With regard to technologies and the region, we have taken for the former the data of the most automated technologies possible, and for the latter we have taken mixed data, as they reflected the scope for the majority of cases.

Nowadays, there are only a few open databases available, but both society and research funders are pushing for more open databases (European Commission, 2020). Indeed, open-access research and data is one of the key areas of RRI. We have built a model based on available on-line databases: Bath University (Hammond and Jones, 2008) and Ecoinvent 3.5. The purpose is to show that using data from currently available on-line databases is useful and that it is easy to make calculations that allow anticipation and reflection in R&I projects. However, one of the databases, Ecoinvent, is not open. We could not find an open database with enough information. We tried European reference Life Cycle Database (ELCD®) (European Commission, 2006a), Inventory of Carbon & Energy (ICE) Version 2.0 (Hammond and Jones, 2008), Sustainability Disclosure Database (Global Reporting Initiative (GRI), 2017) and 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Eggleston et al., 2006), and combining all of them they would not offer as complete a catalogue as Ecoinvent. Other existing databases were not selected as references, due to several reasons:

- DB not updated
- DB of a very specific region: USA, China, etc.
- DB that does not provide information on the calculation of conversion factors.
- DB that does not provide scientific background.

Hence, we decided to use Ecoinvent as we had access via UPV's licence. In the Conclusions and Future Lines sections we discuss the need for complete, rigorous, updated, easy to read and open-access databases, and why this methodology proves their enormous potential for anticipation and reflection.

Based on its closer relationship with R&I activities, the carbon footprint approach is taken in this thesis. Our methodology is an abridged LCA, focused only on climate change following ISO14040, and we used general data conversion factors from the databases of Bath and Ecoinvent, as these are databases in the European and global realm. In a first approximation we took the average data of the components (panels, materials such as steel, etc.,), but in future developments the methodology may help to edit the databases' items in order to make a more specific study.

1.2.2 **Responsible research and innovation (RRI)**

Society sees R&I activities as the driving force for economic and social development. It also expects these activities to provide solutions to the major challenges facing society: public health, ageing population, water, food, climate change, among others. For society, the results of R&I must be positive or, at the very least, not negative. What can societal actors and stakeholders do to ensure that R&I is conducted in a responsible manner, so that the results benefit all parts of society?.

In the last decade, many efforts have been made to reduce the distance between science and society. RRI has emerged in recent years as a potential bridge between science and the society, aiming to increase the public value of science (Yaghmaei, 2018). RRI endeavours emerge as a public policy discourse supported by the European Commission EU (Owen and Pansera, 2019) to bring the problems related to R&I to light, to anticipate their consequences, and to engage society in the discussion of how science and technology can help to create the kind of world and society we want for generations to come. RRI is an approach that anticipates and assesses potential implications and societal expectations with regard to research and innovation, with the aim of fostering the design of inclusive and sustainable R&I (European Commission, 2020). Most research, science, development and innovation are funded through R&I projects and these are precisely the object of study in this thesis. Hence, RRI is the other framework that serves as a foundation for this thesis.

RRI has come a long way, efforts to make it operational are bearing more and more fruit. Unfortunately, after 10 years of promoting it, the concept of RRI is still quite unknown, poorly institutionalized, considered unclear, and hard to operationalise and evaluate (Malene Vinther Christensen, Mika Nieminen, Marlene Altenhofer, Elise Tancoigne, Niels Mejlgaard, Erich Griessler, 2020). However, many academics and scientists are still betting on the continued relevance of RRI (Gerber et al., 2020b).

Civil society, industry and business, academia or policy makers are all actors in society with different interests and priorities. The RRI is a framework, which tries to integrate all actors in the social fabric to work towards common and sustainable goals over time (Timmermans et al., 2017). The RRI framework is designed to ensure that all actors in society are included in how and for what purpose R&I is undertaken (Bryce et al., 2020).

As shown in (Figure 1.4) RRI simultaneously addresses both substantive and procedural issues, the latter then being operationalised in four (4) dimensions: anticipation, reflexivity, inclusiveness and responsiveness (Jack Stilgoe et al., 2013). In parallel, under the auspices of the European Commission, it has been found that RRI must involve a dialogue among stakeholders during the whole R&I process. The aim being to better align both the research process and its outcomes with the stakeholders' interests. Six key areas for that dialogue were first identified: (i) Public Engagement; (ii) Gender Equality; (iii) Science education; (iv) Open Access; (v) Ethics; and (vi) Governance (Geoghegan-Quinn, 2012). Later, two more areas were added: Sustainability (environmental) and Social Justice (Strand et al., 2015a). For the six former key areas of RRI, guidance for measure and indicators have been provided. With a framework with two dimensions: Performance (divided into Process and Outcomes); and Perception. Other initiatives to operationalize the RRI have been developed, like projects MoRRI (and the new version SuperMoRRI) and RRI Tools. But for the later added areas no framework is applied, and no indicators are suggested. This is a GAP that we want to help to fill, from the perspective of Climate Change prevention.

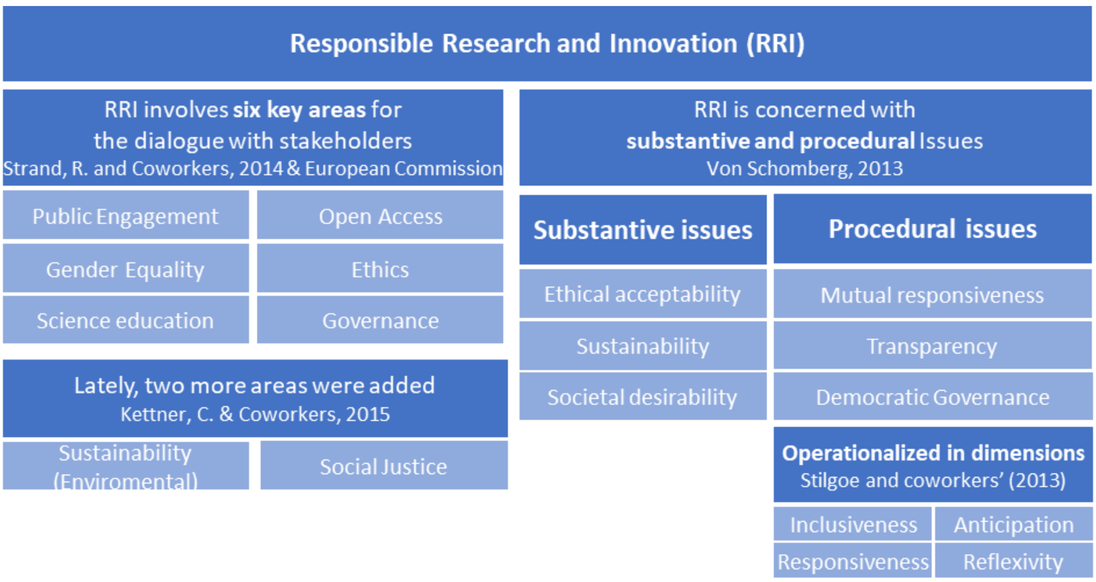

Figure 1.4 RRI approach

The latter addition of sustainability as a key area of RRI on the European agenda, and the reliance on the values represented in the European treaty as a guide for the identification of major challenges, has led to an under-representation of (environmental) sustainability in the objectives of RRI (Claudia et al., 2014; Strand et al., 2015a).

Of all the risks and negative effects to be avoided by research and innovation, in this thesis, we will work with climate change. From the RRI approach we will focus on the anticipation and reflection by the research teams of what the possible GHG may be generated in the entire life cycle of a R&I project, including the development stage and the results.

In many cases the members of a research team are not trained to make this reflection, but it is not essential that the members of the research teams are trained in the area of sustainability or any of the other areas of the RRI framework in order to be responsible. It would be sufficient for them to have open-access tools that allow them to make some calculations and then look for specialists to guide them. In chapter 3, we work on stakeholder's influence in an R&I project, where we propose how to undertake this anticipation and reflection, based on calculations, not on feelings, ideas, rumours or beliefs, but taking into account the appropriate stakeholders.

There is a gap in terms of tools and indicators to measure of all that the sustainability area of the RRI represents. In particular, this thesis will work on the contributions (GHG) to climate change from R&I projects.

From the RRI discourse, this thesis aligns with:

- The substantive frameworks, whereby RRI is understood as a means to tackle the great challenges and increase the ethical acceptability, social desirability and sustainability of innovation (Substantive issues).
- Anticipation and reflexivity dimensions (Procedural issues)
- The RRI's key area of Sustainability (Environmental)

In summary, the last two sections of this dissertation have been laid out with the two topics that support it. In section 1.2.1, CC was addressed explaining how the carbon footprint approach can be used to calculate the contribution to CC of R&I activities. In this section, we have discussed how this thesis is aligned with the RRI approach. Therefore, this thesis emerges as a bridge between the great challenge represented by CC and the demand from society for responsible research and innovation, addressed in the context of RRI.

1.3 Research aim and questions

The aim of this PhD thesis is therefore:

To assess in terms of responsibility the contribution of research project teams to climate change.

The purpose is to help to fill the gap in terms of measuring tools in research projects for CC prevention. Apart from those research teams directly involved in CC, or closely related to subjects like energy or energy intense activities, research teams are not aware of the contributions of their research to CC.

The main research question is:

How does a research team, while its members are not specialists in environmental impacts, know if its research is responsible for relevant contributions to Climate Change, and how can they include measures to reduce or compensate such contributions (GHG)?

In order to answer this central research question, 3 sub-questions have been formulated. They are discussed in detail in the following chapters

RQ1: How does a research team know if its research is responsible for relevant contributions to Climate Change?

RQ2: How to prioritize stakeholders based on their contribution to the responsibility of a research and innovation project?

RQ3: How can a research team untrained in environmental impact assessment estimate the carbon footprint at the early stages of a research and innovation project that does not specifically address fighting climate change?

Methodological issues of this thesis:

- Paradigm: Post positivism
- Type of research: Exploratory-descriptive
- Method approach: Hypothetical-deductive
- Methodological approach: Mixed methods (mainly quantitative)
- Research strategy: Case studies
- Methods of data collection: Inventory Carbon Energy ICE database; SimaPro Software; EcoInvent database; Document analysis; web review; Structured interviews; Questionnaires.
- Reliability / Quality: Relevance; Publication of results; Feed Back to participants; Replicability

In each chapter, there is a detailed description of the methods used in this thesis.

1.4 Outline of this dissertation

The thesis is carried out in the "traditional" monograph format but with the strategy of publishing its parts before or during the preparation of the monograph itself. In this sense, chapters 2 and 3 have already been published in high-quality journals, while the chapter 4 is under review.

To respond to the main research question and the three sub-questions formulated above, this dissertation begins with the description made in previous sections of the two foundations that serve as a framework for this research: CC and RRI (chapter 1). The purpose is to address the framework within this dissertation, which is being developed, describing, on the one hand, the unavoidable challenge represented by climate change, passing through the identification of its main drivers to the carbon footprint approach as a means of calculating emissions contributions by R&I projects, and on the other hand, as RRI's approach, it serves as an umbrella to address the demand for responsibility from different society stakeholders towards R&I activities.

Once these topics have been established, chapter 2 opens the ground for a first exploration on how climate change is addressed in the context of RRI. Here, we develop a specific review of the literature on (environmental) sustainability and CC in RRI, and an analysis of the main projects and activities devoted to RRI and CC. These results were grouped into a framework of 4 main strategies to address CC within RRI: i) Efficient integration in the core management of research and innovation; ii. Stakeholder management; iii). Applying a life cycle perspective; and iv). Open-access databases. Hence, Chapter 2 aims to answer the following research sub-question:

RQ1: How does a research team know if its research is responsible for relevant contributions to Climate Change?

Paper 1. Addressing Climate Change in Responsible Research and Innovation: Recommendations for Its Operationalization.
Authors: Iván Ligardo-Herrera; Tomás Gómez-Navarro; Edurne A. Inigo and Vincent Blok
https://doi.org/10.3390/su10062012
Journal: Sustainability (2018), 10(6)
JCR (Q2)
Scimago (Q1)

The insights obtained in chapter 2 allowed us to identify two research avenues that guided the formulation of two more research sub-questions. The answers to these questions were developed respectively in chapters 3 and 4.

Chapter 3 develops one of the research avenue identified, by assessing the influence of stakeholders in a research project in the context of RRI. The Analytical Network Process (ANP) technique is applied. Then a detailed description of the methodology based on ANP and the key areas of RRI, with the help of a case study, is presented, explaining the procedure and the results of the application. The method allows ranking and ordering of the project's stakeholders based on their influence upon its responsibility. The purpose of such an assessment is to help research teams to more efficiently devote their limited resources to stakeholder management. Hence, Chapter 3 aims to answer the following research sub-question:

RQ2: How to prioritize stakeholders based on their contribution to the responsibility of a research and innovation project?
Paper 2. Application of the ANP to the prioritization of project stakeholders in the context of responsible research and innovation.
Authors: Iván Ligardo-Herrera; Tomás Gómez-Navarro and Hannia Gonzalez-Urango
https://doi.org/10.1007/s10100-018-0573-4
Journal: Central European Journal of Operations Research (2019) 27:679–701
JCR (Q2)
Scimago (Q1)

The other research avenue identified in the chapter 2 is developed in chapter 4, where a new tool with a didactic algorithm for anticipatory carbon footprint calculation in R&I projects is presented. This tool allows researchers who are untrained in environmental impact assessment to estimate the greenhouse gas emissions of their R&I projects at early stages, when anticipation and reflexivity are the core RRI dimensions. We followed a two-phase method: (i) tool designing, based on a literature review on carbon footprint tools and open sources databases, and (ii) tool testing, carried out through three case studies. The results show that the designed tool for anticipation and reflection on CC works as expected. Indeed, it is useful in helping researchers' decision making at the early stages of an R&I project by estimating the GHG emissions that could be generated, both during the research process and during the exploitation of its outcomes. Hence, Chapter 4 aims to answer the following research sub-question:

RQ3: How can a research team untrained in environmental impact assessment estimate the carbon footprint at the early stages of a research and innovation project that does not specifically address fighting climate change?
Paper 3. The design and testing of a tool for anticipatory carbon footprint calculation in research and innovation projects.
Authors: Iván Ligardo-Herrera and Tomás Gómez-Navarro
Journal: ongoing evaluation

Finally, the set of results and conclusions obtained from these 3 sub-questions led us to the answer to the main question of this thesis. In chapter 5, the general discussion of the results, the general conclusions and the main contributions of the thesis are presented. Likewise, the limitations and future avenues of research are also outlined.

Figure 1.5 below gives a general view of the five chapters of this dissertation.

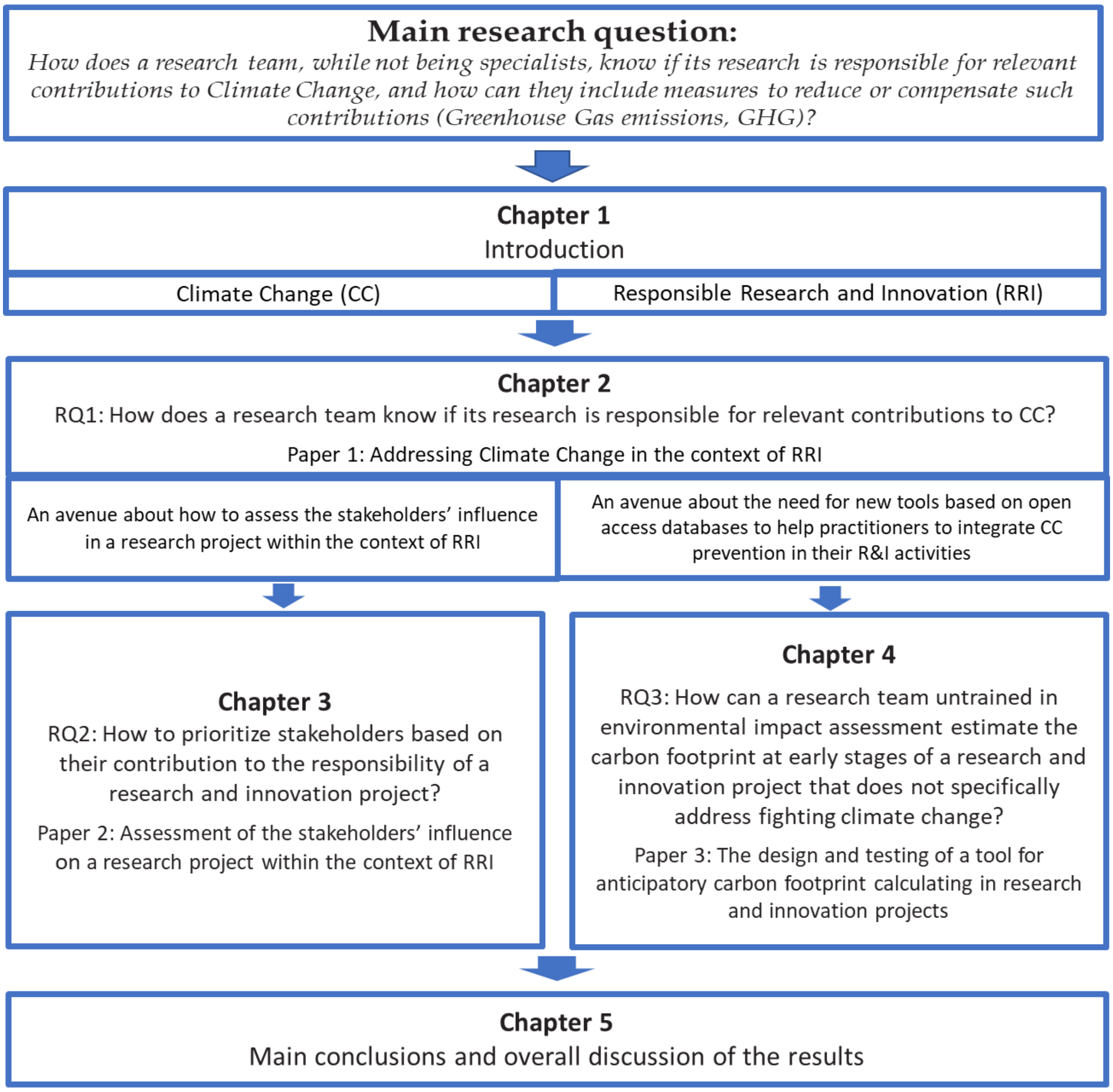

Figure 1.5 Thesis outline

CHAPTER 2

Addressing climate change in responsible research and innovation: recommendations for its operationalization*

Based on the paper: *Addressing Climate Change in Responsible Research and Innovation: Recommendations for Its Operationalization*. Iván Ligardo-Herrera; Tomás Gómez-Navarro; Edurne A. Inigo and Vincent Blok. (2018), Sustainability 10(6). https://doi.org/10.3390/su10062012

2.1 Abstract

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 chapter 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 R&I 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.

2.2 Introduction

RRI has emerged significantly in the last decade as a way to tackle the great challenges of our time (United Nations, 2015). One of these great challenges is Climate Change (CC), a transversal and global environmental problem that also has socio-economic implications. The Brundtland declaration (World Commission on Environment and Development, 1987), the Kyoto Protocol (United Nations, 1997) and other initiatives such as the EU emissions trading system (Ellerman and Buchner, 2007) [4] or the Paris Agreement of 2016 (United Nations, 2016, 2015) have highlighted the role of R&I in tackling CC. The importance of 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 (European Commission, 2013a), and the potential environmental impacts of the outputs of research on genetically modified organisms (Brookes and Barfoot, 2015; Hilbeck et al., 2015).

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., 2017c), 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 chapter 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 chapter suggests that the existing knowledge accumulated in these fields may help to advance RRI and its response to climate change.

2.2.1 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 (René Von Schomberg, 2013): "(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 (Lubberink et al., 2017c).

RRI is concerned with substantive issues (ethical acceptability, sustainability and societal desirability) and procedural issues, expressed as mutual responsiveness in (René Von Schomberg, 2013) definition. In addition, procedural issues include transparency and democratic governance (Owen et al., 2012). Stilgoe and co-workers' (Jack Stilgoe et al., 2013) 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 (Strand et al., 2015a): (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 (Claudia et al., 2014; Strand et al., 2015a).

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. (Claudia et al., 2014) 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 (Claudia et al., 2014). 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 (Claudia et al., 2014), 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.

2.2.2 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"* (Gladwin et al., 1995). 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 (World Commission on Environment and Development, 1987). This started a movement to also integrate environmental issues as part of CSR (Gladwin et al., 1995).

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 (Chatterji et al., 2009; Searcy, 2011). For a good compendium, see the annexes of the ISO 26000 (ISO, 2010). Nevertheless, most of these tools are concerned with the accountability of business rather than innovation as a core activity for sustainable value creation.

<u>Sustainable Innovation</u>

Because of this separation of CSR and innovation (Fernández et al., 2015; Karner et al., 2015)—notwithstanding some research on corporate social innovation (Mirvis et al., 2016)—a new research stream on SI emerged (Adams et al., 2016), 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 and Dowell, 2011). 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) (Hansen et al., 2009). 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 (Lubberink et al., 2017a).

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 (Brezet and van Hemel, 1997), life-cycle analysis throughout the supply chain (Matos and Hall, 2007), or cradle-to-cradle (Bakker et al., 2010). 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.

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 (Claudia et al., 2014), 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 chapter 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 question is: How does a research team know if its research is responsible of relevant contributions to Climate Change?

Therefore, the understanding of RRI for this matter aligns with the substantive frameworks (René 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 chapter 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 chapter 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.

2.3 Materials and 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, 2009). 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 analysed 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 2.1 and Section 2.3.2). Below, each of the research stages is explained.

2.3.1 Document Analysis

The specific literature review started by searching for previous studies of the state of the art (e.g., (Adams et al., 2016; Burget et al., 2017a; Klewitz and Hansen, 2014; Niels Mejlgaard, 2015; Jack Stilgoe et al., 2013)). 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 2.1.

Table 2.1 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 chapter. 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 analysed 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.

2.3.2 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 2), 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 (Given, 2008). Snowball sampling is a non-probability sampling technique where study subjects (RRI actors and projects) lead to future subjects from among their connections (Atkinson and Flint, 2001; Cohen and Arieli, 2011; Given, 2008; Vogt, 2005). For example, projects Res-AGorA (Res-AGorA Project, n.d.), FotRRIS (Karner et al., 2015) and HEIRRI (Niels Mejlgaard, 2016), 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 analysed 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 (Nwafor et al., 2016). 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.

2.4 Results

2.4.1 Findings of the Document Analysis

As shown in Table 2.1, 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 (European Commission, 2013a; Vermeulen et al., 2016), 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 (Gianni, 2016; Hemphill, 2016; Iatridis and Schroeder, 2016; Lubberink et al., 2017c).

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.

2.4.2 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, 2017) 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 (European Commission, 2013b), which is to be expected due to the novelty of RRI and the explicit support given to it in the current framework program (European Commission, 2013b). 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 2.2).

Table 2.2 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 Chapter: 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 (Karner et al., 2015) 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 (Niels Mejlgaard, 2016, 2015).

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.

2.4.3 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 organisations supporting RRI, including sustainability and thus CC: the Engineering & Physical Sciences Research Council (EPSRC); the Netherlands organisation 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 2. 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 (Nwafor et al., 2016).

2.5 Discussion

As previously stated, the aim of this chapter 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.

2.5.1 Main Contributions to CC Prevention in RRI

As introduced in Section 2.4.1, 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 (Blok and Lemmens, 2015; Burget et al., 2017a). 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 2.1) (COMPASS Project, n.d.; Mejlgaard et al., 2012; Vermeulen et al., 2016). 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.

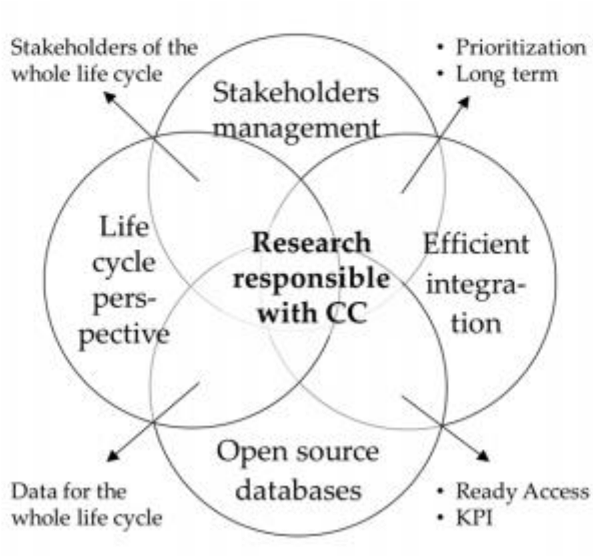

Figure 2.1 General strategies from CSR, SI and RRI to inform RRI on CC.

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

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 (Claudia et al., 2014; Strand et al., 2015a; René Von Schomberg, 2013), propose that the most effective way of implementing responsibility for companies is following a bottom-up approach; for example, see the work of Hemphill (Hemphill, 2016) or Gianni (Gianni, 2016), and the approach of the aforementioned projects: Res-AGorA_MoRRI (Res-AGorA_MoRRI Project, n.d.), NERRI (NERRI Project, n.d.), Responsibility (RESPONSIBILITY Project, n.d.) and STARBIOS2 (STARBIOS2 Project, n.d.). 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 (Hemphill, 2016; Iordanou, 2017; Schroeder, 2017). Indeed, some authors (Strand et al., 2015a) 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 (Owen and Goldberg, 2010; Thorstensen and Forsberg, 2016; Wender et al., 2014). Below, the tools that can support this aim are discussed.

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) (ISO, 2009; The British Standards Institution (BSI), 2011b). Carbon Dioxide is the main contributor to Anthropogenic CC. The main methodologies for assessing the carbon footprint are (European Commission, 2013a):

- PAS 2050 (The British Standards Institution (BSI), 2011b, 2008)
- GHG Protocol Product Standard (World Resources Institute and World Business Council for Sustainable Development, 2011)
- ISO 14064-2:2006 (ISO, 2009)
- ISO 14040 (The International Standards Organisation ISO, 2006)

In addition, the life cycle perspective is a requirement for carbon footprint methods to incorporate (The British Standards Institution (BSI), 2011b, 2008; The International Standards Organisation ISO, 2006). 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 R&I 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 (Gómez-Navarro and Ligardo-Herrera, 2016; Owen and Goldberg, 2010; Vermeulen et al., 2016). Currently, there are proven tools to guide Life Cycle Assessment (LCA), including the ISO 14040 series of standards (The International Standards Organisation ISO, 2006) and, to lesser extent, the PAS 2050 (The British Standards Institution (BSI), 2008).

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 (ISO, 2009). That way, LCA allows us to identify the minimum indicators to add to the research management key performance indicators (KPI) (Capuz-Rizo and Gómez-Navarro, 2002; ISO, 2009; McAloone and Hare, 2015; Schroeder, 2017; Szabo, 2016), 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 (Owen and Goldberg, 2010; Thorstensen and Forsberg, 2016). 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. (Engelhard et al., 2014; Wender et al., 2014). This is what several authors define as "aiming at glocal sustainability research", for instance (Karner et al., 2015; Mitkidis, 2016).

Nevertheless, Wender et al. (Wender et al., 2014) 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 (Guinée et al., 2011). 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 (Guinée et al., 2011; Karner et al., 2015; Wender et al., 2014).

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 (Institute for Environment and Sustainability (ECJRC), 2010; Kettner et al., 2014; The British Standards Institution (BSI), 2008). 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 (International EPD® System, 2017). 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., 2016) 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 (European Commission, 2006a).

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 (Flipse et al., 2014; Iordanou, 2017; Kettner et al., 2012). Besides, disclosure and accountability are key for a fruitful engagement of stakeholders to prevent CC (AccountAbility, 2015). 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 (COMPASS Project, n.d.; Engage2020 Project, n.d.; SMART Project, n.d.). In that way, environmental assessments, even if not precise, will be more accurate and more efficient (SMART Project, n.d.; Szabo, 2016). 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 (Hammond and Jones, 2008)
- Sustainability Disclosure Database (Global Reporting Initiative (GRI), 2017)
- 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Eggleston et al., 2006)

Stakeholder Management

It is today understood that no single research team, policymaker or organisation can successfully work in isolation to address current complex social and environmental challenges. As introduced in (Deblonde, 2015), 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. (AccountAbility, 2015). 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 (Owen and Goldberg, 2010). 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 (Adams et al., 2016; Burget et al., 2017a).

Several publications, projects and actors can be used as a guide and reference for stakeholder management during RRI; a good example is (Lubberink et al., 2017c; Paredes-Frigolett, 2016). Specifically addressing the case of CC, among the few obtained, References (Bierwirth et al., 2015; Engelhard et al., 2014; Vermeulen et al., 2016) 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 (Iordanou, 2017; Karner et al., 2015; Mejlgaard et al., 2012):

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” (Iordanou, 2017); and
4. Time and resources consumption, and obstacles to the agility of the research processes.

2.5.2 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 (Blok and Lemmens, 2015; Flipse et al., 2014). 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 (Iordanou, 2017; Schroeder, 2017; Vermeulen et al., 2016).
- Rising awareness: While research teams in disciplines such as energy, transport, infrastructure, plastics, etc. are aware of their responsibility towards CC (Mitkidis, 2016; Schroeder, 2017), others devoted to disciplines such as ICT, finance, retail, agriculture, food, nanotechnologies, etc. normally do not consider themselves as having an impact on CC (Engelhard et al., 2014; European Commission, 2013a; Khan et al., 2016; Owen and Goldberg, 2010; Schroeder, 2017; Vermeulen et al., 2016).
- 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 (Iordanou, 2017; Nwafor et al., 2016).
- 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 2.5.1) and open-access databases of environmental aspects and indicators (see Section 2.5.1) is necessary. None of the reviewed RRI publications or projects (nor the ones of Table 2.2) were found to apply those tools.

2.6 Conclusions, Limitations and Future Research

This chapter 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 analyse 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 R&I 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

CHAPTER 3

Application of the ANP to the prioritization of project stakeholders in the context of responsible research and innovation*

*Based on the paper: *Application of the ANP to the prioritization of project stakeholders in the context of responsible research and innovation*. Iván Ligardo-Herrera; Tomás Gómez-Navarro and Hannia Gonzalez-Urango (2019). Journal: Central European Journal of Operations Research 27:679–701. https://doi.org/10.1007/s10100-018-0573-4

3.1 Abstract

This chapter presents a methodology to assess the stakeholders' influence in a research project within the context of RRI. The methodology is based on a combination of the multicriteria decision making technique Analytic Network Process and the key areas of RRI. The method allows ranking and ordering the project's stakeholders based on their influence upon its responsibility. The purpose of such an assessment is to help research teams to more efficiently devote their limited resources to stakeholder management. The procedure is applied to a case study of the Information and Communication Technology business sector. It is an ongoing project at an early phase of development. Influential stakeholders have been identified first, and have been further classified into groups based on their relative importance. The assessment of their influence has been based on up to 16 different criteria, mainly belonging to the framework of responsible research and innovation. In the case study, the most influential criterion was the capability to promote public engagement, while developers were found to be the stakeholders most contributing to the research project responsibility. However, as explained, this is a temporary situation, valid for the current project development situation. It may vary over time as criteria vary in weight and stakeholders vary in influence.

3.2 Introduction

3.2.1 Responsible research and innovation

The European Commission has been promoting a cross-cutting issue named "RRI". The aim is to encourage researchers to take into consideration the potentially unwanted impacts of their research process and of its outcomes, and make responsible decisions about them. The most widely used definition of RRI could be the one given by Von Schomberg (2011, p. 9): '*RRI is a transparent, interactive process by which societal actors and innovators become mutually responsive to each other with a view to the (ethical) ac ceptability, sustainability and societal desirability of the innovation process and its marketable products*'. Therefore, researchers and innovators are expected to answer questions from society about the aims and the consequences of any research, or innovation activity (European Commission, 2011).

Therefore, the works under the auspices of the European Commission have found that RRI must involve a dialogue with stakeholders during the whole R&I process. The aim being to better align with the stakeholders' interests both the research process and its outcomes. Six key areas for that dialogue were first identified: Public Engagement; Gender Equality; Science Education; Open Access; Ethics; and Governance (Geoghegan-

Quinn and European Commission, n.d.). More recently, two more areas have been added, Sustainability (environmental); and Social Justice (Strand et al., 2015b).

Furthermore, Burget et al. (2017b) added to the RRI definition that: “Responsible Innovation is essentially an attempt to govern research and innovation in order to include all the stakeholders and the public in the early stages of research and development. The inclusion of different actors and the public is, in turn, meant to increase the possibilities of anticipating and discerning how research and innovation can or may benefit society as well as preventing any negative consequences from happening” (Burget et al. 2017, p. 15).

According to Koops (2015) and Stilgoe et al. (2013), RRI can be conceived as an approach and an ideal. The first one involves the available tools and how we can innovate responsibly. The second involves the inclusion and promotion of self-learning via Anticipation, Reflection, Deliberation and Responsiveness of the innovation process (de Jong et al., 2016). Stakeholders are expected to participate from the beginning in the Anticipation stage, at which the potential benefits and harm of the research and its possible outcomes are envisaged.

A consortium funded by the EU developed the project RRI-TOOLS (https://www.rri-tools.eu/). In it they have considered RRI as: “doing science and innovation with society and for society, including the involvement of relevant stakeholder groups which are very upstream in the process of research and innovation to align its outcomes with the values and expectations of society”. Under this umbrella, scientist share with society’s stakeholders the traditional dynamic of setting agendas and exploring desirable futures to be reached with their research. Stakeholders are now more than just beneficiaries, or users of research and innovation (Stahl and Coeckelbergh, 2016).

The insertion of relevant stakeholders in R&I activities over time is complex, but necessary as the context has a significant impact on the utility of RRI activities (van de Poel et al., 2017). This procedure considers an inclusive deliberation with a broader set of stakeholders related to the aim of research, its processes and, also, a disposition of stakeholders to act according to novel perceptions (Owen et al., 2013).

However, authors have found a wider than expected reluctance to really engage with stakeholders (Ligardo-Herrera et al., 2018b). Barriers to stakeholder management in R&I projects are, among others, (i) lack of the skills for managing stakeholders, i.e. difficulties in identifying stakeholders, their interests and powers, who represent or speak on behalf of them, how to engage in a productive collaboration, etc. (ii) protecting innovation, avoiding key information getting to the competitors; (iii) resources needed for educating stakeholders so that they can really help; or (iv) its perception as an obstacle to the agility of the research practices.

One way to facilitate the process and answer those problems is to prioritize the influential stakeholders. This way, the research team can apply the “Pareto principle” and anticipate the majority of issues related to their responsibility, by working with a reduced set of important stakeholders. Providing those teams can really determine who the most influential stakeholders are.

3.2.2 Stakeholder’s influence in research projects

There is extensive literature on stakeholder management and evaluation (Aragonés-Beltrán et al., 2017). In fact, Corporate Social Responsibility (CSR) and Project Management theories, have already highlighted the relevance of a detailed analysis of stakeholders and their impact (Dahlsrud, 2006).

Stakeholder management starts by the identification of stakeholders and the analysis of their interests or expectations, and their impacts on the project (Brugha and Varvasovszky, 2000). There are several other stakeholder analyses like the one which classifies them in terms of Power, Legitimacy and Urgency (Mitchell et al., 1997); the one based on their Assertiveness and Cooperativeness; the analysis of Influence and Interest in the project (Colin and Ackermann, 1998; De Lopez, 2001); or the one based on a map of Impact for stakeholders vs Impact for the Project promoters.

Nevertheless, none of those analyses are suitable for assessing the influence of stakeholders on the responsibility of a R&I project, or of the future exploitation of its outcomes. Features like interests, power, legitimacy, impact for the promoters, etc. are too indirectly related to RRI.

Hence, the research question this chapter seeks to answer is: How to prioritize stakeholders based on their contribution to the responsibility of a R&I project?

Thus, this chapter proposes a methodology for evaluating the stakeholders of a research project in the framework of RRI. For this goal the Analytical Network Process (ANP) is applied.

The rest of the chapter is organized as follows. In the next two sections, a detailed description of the methodology with the help of a case study is presented, explaining the procedure and the results of the application. Finally, conclusions and some challenges posed by this work are included.

3.3 Research methods

To solve the research questions, a methodology is put forward based on the combination of two realms: the RRI approach as the framework and the analytic network process (ANP) as the tool.

3.3.1 Analytic network process

ANP is a multicriteria decision making (MCDM) technique that allows the relative measurement of intangible criteria, as proposed by Saaty (2001). The ANP procedure generalized his original Analytic Hierarchy Process AHP (Saaty 1990). Both theories provide a framework to address decisionmaking or problem assessment. AHP has been accepted as a leading MCDM method due to its ease of use for preferential information elicitation from expert subjects, in order to assign priorities to the criteria or indicators involved in a problem (Akbari et al., 2017; Ramzan et al., 2008; Šijanec et al., 2009; Sólnes, 2003). However, AHP does not allow us to consider the interdependencies among criteria.

For this reason, the use of the ANP is proposed because it develops a better representation of the complex interactions, interdependencies and feedback relationships among the different components of problems like those of RRI (Botero et al., 2015; De Lotto et al., 2016; Saaty and Peniwati, 2008; Shiau and Chuen-Yu, 2016; Sipahi and Timor, 2010; Wu and Cui, 2016). This way, besides, it avoids the compensation problem of other models (Peris et al. 2013). A problem is modelled as a structure or network system composed of different elements (criteria and alternatives), grouped in clusters and connected to each other by influences among them.

The main steps to solve a multicriteria decision-making problem using ANP are the following (Saaty, 2001):

1. Identifying the components and elements of the network and their relationships. The problem is then structured as a network.
2. Conducting pairwise comparisons of the elements. Elements are compared using Saaty’s 1-to-9 scale. The ANP prioritizes not just elements but also groups or clusters of elements as is often necessary in the real world.
3. Placing the resulting relative importance weights (eigenvectors) in pairwise comparison matrices within the matrix (unweighted matrix).
4. Conducting pairwise comparisons of the clusters.
5. Weighting the blocks of the unweighted matrix, by the corresponding priorities of the clusters, so that it can be column-stochastic (weighted matrix).

6. Raising the weighted matrix to limiting powers until the weights converge and remain stable (limit matrix).
7. Obtaining the prioritizations of the elements according to any of the columns of the limit matrix.
8. Once the results are obtained, in case some alternatives achieve very similar results, a sensitivity analysis should be carried out in order to demonstrate the robustness of the ranking obtained.

Mathematical foundations of AHP and ANP can be found in Saaty (2008, 2005, 1994, 1990) (1990, 1994, 2005, 2008). Several authors introduce the use of ANP in different areas; a review of the main developments in the AHP and ANP can be found in Vaidya and Kumar (2006), Görener (2012), and Sipahi and Timor (Sipahi and Timor, 2010).

Some recent applications of ANP to the field of stakeholder management are found in Sangle and Babu (2007), Bhupendra and Sangle (2017) and Rosso et al. (2014). Evidence regarding the use of ANP for assessing or developing indexes or indicators related to stakeholders of a complex problem has been found in Aragonés-Beltrán et al. (2017).

3.3.2 Methodology

The methodology proposed is organized in three main phases: (i) Designing the case study, (ii) Modelling the influence assessment with an ANP model and (iii) Assessing stakeholder influence for RRI by means of ANP Figure 3.1 shows an outline of the methodology.

Designing the case study

This phase is divided into three stages (Figure 3.1).

i. **“Identify the RRI goals of the specific project stage”**. At this stage, the RRI challenges to be addressed are identified by the research team based on their knowledge of the discipline. It is a preselection of RRI issues that will be later reviewed with the selected prioritized stakeholders.
   The six key areas for social desirability of the research activity proposed by the European Commission help in designing a starting set of questions.
ii. **“Analysis the Project context and define the procedure”.** This stage is carried out in two steps. The first step continues the previous stage, but focusing now on the context of the project. That means, identifying how the people, culture, infrastructure, institutions, etc. directly related to the project may be impacted socially, environmentally, economically, etc. Also, whether the impacts are positive or negative. Finally, who in particular may be most harmed or who the potential beneficiaries, partners, etc. may be.

In the second step, a procedure based on ANP is designed to determine the assessment of stakeholders. In this first contact with ANP the goal is set. For the purpose of this investigation, the goal of the ANP is: To assess how much stakeholders contribute to the anticipation of the responsibility of the project and the exploitation of its outcomes. That means, the dependence among elements will be the influence of each element on the others towards the achievement of the ANP goal.

iii. **"Identify Experts".** In this stage it is determined who can develop an ANP model of the problem to be solved. Those experts identify the elements of the model: alternatives and criteria; arrange them into a network of several layers and clusters, the ANP model; and judge which element is preferred to which element, and to what extent, in pairwise comparisons of the same cluster.

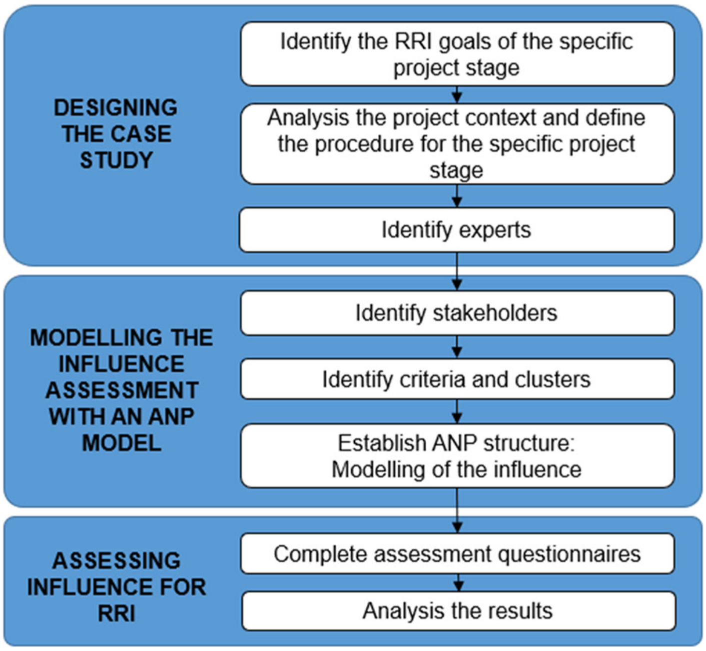

Figure 3.1 Methodology proposed

Modelling the influence assessment with an ANP model

This phase is also divided into three stages:

i. **"Identify Stakeholders"**: The Stakeholders represent the alternatives that are evaluated in the project. Thus, in this stage the work is focused on identifying all possible Stakeholders; singling them out and arranging them into a list of different stakeholders, although they may have dependencies among them; and identifying who represents those stakeholders and may act as their spokespersons.

ii. **"Identify criteria and clusters":** At this stage, the remaining elements are identified, i.e. decision making criteria. Hence, experts identify which characteristics of the stakeholders act as criteria for assessing their contribution to the ANP goal. Later the criteria that arise (generally not generated in an orderly manner) are hierarchically ranked into clusters using the ANP procedure.

iii. **“Establish ANP structure”:** After having the alternatives and criteria, this third stage comprises two steps: first, experts establish the structure of the ANP model by finding out dependencies that connect elements among them. Then, questionnaires are elaborated for judging those dependencies, in this case, judging how much more one element or another influences a third one. The influence meaning the contribution to anticipating the responsibility of the innovation project.

Assessing stakeholders’ influence for RRI by means of ANP

In this phase, experts complete the questionnaires and analyse the results. All the time they were supported by the ANP facilitators. Also, they worked in coordination with the project research team. The latter will decide later how to manage the prioritized stakeholders. A detailed description of the methodology implementation is presented in the case study in the following sections.

3.4 Case study: assessing stakeholders’ contribution to the anticipation of the responsibility of a research project

3.4.1 Case study design

Identify the RRI goals of the specific project stage

The model has been applied to ongoing research. The project aims to develop a real-time recommendation system with dynamic content based on the context of the user in mobility and their social networks to reduce the human interaction with the mobile device and improve the user’s experience. The system is a novel Information and Communication Technologies (ICT) application aimed at encouraging consumption in smart cities based on consumer preferences. Allowing local businesses to offer personalized products and services in real time through an app in the beneficiaries’ smartphones.

This project is currently in an early stage (phase 1 of 7) of development. The six key areas of RRI were reviewed and, based on the researchers’ experience, they were all selected for the research. They found challenges to be correctly anticipated in all the six areas.

Analysis the Project context and define the procedure

In this case the project is developed in order to improve the tourist experience and support local businesses for a city. It consists of the following phases:

1. Analysis, requirements and specifications of information consumption regarding mobility: The purposes of this first phase are to identify, describe and specify the most relevant requirements of end users, stakeholders and technology, at a detailed level to inform and guide the research project and development work on subsequent phases.
2. User profiles and clustering: This phase focuses on the storage of large amounts of data, a variety of information sources, and high capacity data processing and modelling.
3. Cognitive processes of the user: The main objective here is to offer a comprehensive understanding of the different clusters of potential end-users of the platform and their needs.
4. Tools for the analysis and semantic management of conversations in Social Networks: The main objective of this phase is to provide the methods for semantic analysis of conversations on social networks.
5. Real-time recommendation systems: This phase addresses creating a real-time advisory system based on the management and exploitation of information in the context of mobile users and social media participation.
6. Mobile app: Here, a robust mobile application is developed for the purposes of the research.
7. Validation and evaluation: The aim of this phase is to carry out a user-centred design process throughout the project, involving the end user in all phases of the project.

The project is currently in its first phase, developed by a multidisciplinary team from a local University, a Local Tourist Office and several firms in the private sector.

Identify experts

Three experts have been selected for the procedure, representing different approaches to the problem. Expert 1 is a project manager; a person with an engineering background with years of experience in management of research projects. Management ranging from technical issues of small projects to complex management of multiyear big projects with dozens of human resources, hundreds of thousands of Euros budget, several scientific disciplines involved, etc.

Expert 2 is an RRI researcher. This person started in Corporate Social Responsibility and in the last 5 years has participated in European and national projects about RRI and how to operationalize it. Expert 2 has experience the analysis of RRI in both publicly and privately funded R&I projects.

Expert 3 has a wide experience in stakeholder participation, multicriteria decision making and negotiation methods. Expert 3 usually participates in great scope projects with complex interaction with different stakeholders that produce important social, environmental and economic impacts, both positive and negative.

In ANP, due to the kind of information available, the quality of experts is more important than the number of them, as discussed in Barrios Ortiz et al. (2016). To be considered an appropriate expert for the research, requisites were: broad experience on the issue, to belong to a specific category of key actors of the problem: expert on research projects, RRI expert, or stakeholder expert and willingness to learn the procedure. Only the above listed experts fulfilled all the requirements. Unfortunately, other experts who could have enriched the outcomes were not available or not suitable.

In order to prevent biasing the results, only one expert per approach was selected.

3.4.2 Modelling the ANP model

The first step to build the ANP model is to determine the main goal. In this case it is "To assess how much stakeholders contribute to the anticipation of the responsibility of the project and the exploitation of its outcomes in a context of RRI". Afterwards the following elements of the model were identified. The author of this thesis acted as ANP facilitator.

Identification of stakeholders

Stakeholders are considered the first cluster of elements in the ANP model. They represent the elements that will be evaluated. A first list of stakeholders was developed based on a literature review. An initial list was elaborated with fourteen stakeholders.

Later, a panel of interested actors was arranged to discuss the list of stakeholders based on the project activities and expected outcomes, the experience of the members of the project consortium, and the early stage at which the project stands currently. The panel was formed by the ANP experts, the authors of the chapter and selected members of the project consortium. Seven of the former stakeholders were discarded as "not influential now": "Media", "Regional government", "Suppliers", "Labour unions", "Competitors", "Law institutions" and "Owners of the business or partners in the consortium".

Finally, of the seven stakeholders in the list, "Neighborhood associations" (they are directly affected or benefited by tourism) and "NGO's" (interested in the social environmental impacts of tourism) were also discarded. They were found to be much less influential than the other five for this specific project at this current stage, and it was not necessary to assess them.

Hence, five stakeholders were finally added to the ANP model:

- S1. Users: They are beneficiaries of the project. Anyone who is or could be interested in the city's offer. Mainly: Tourists, visitors or residents. The main interest of this group in the project is in the services of the final results, the app for smartphones.
- S2. Business: They are also beneficiaries. Anyone who offers an activity of leisure or entertainment in the city, e.g., restaurants, museums, hotels, mobility and transportation, concerts, events, exhibitions, etc. Their main interest is to improve the communication of their offer of products and services.
- S3. Local Tourism Office (LTO): It takes the role of the stakeholder "policy maker". In this case, the policy maker would be the LTO, which is the most relevant authority in terms of tourism management. Its main interest is contributing to the tourist
- development of the city.
- S4. Developers: It takes the role of the stakeholder "employees". The group that creates and designs all the digital content. They are the intermediators between users' preferences and business offer.
- S5. The National Ministry of Economy: It takes the role of "funders" It provides the economic resources and demands to meet the goals, deadlines and quality requirements of the project.

<u>Identification of criteria and clusters</u>

The rest of the network elements are the criteria which could evaluate the influence of stakeholders in the project responsibility. Elements that have a general character to evaluate influence in terms of RRI were identified at the cluster level. Each of them was further divided into sub-elements (criteria). According to the method followed in other AHP/ANP applications (Saaty, 2001; Sipahi and Timor, 2010).

An initial list of criteria for each cluster was defined based on a literature review (Claudia et al. 2014; Rosso et al. 2014; Strand et al. 2015; Aragonés-Beltrán et al. 2017; Lubberink et al. 2017; RRI-TOOLS project). It was necessary to make sure that these criteria were relevant and not redundant (Görener, 2012; Saaty, 1990; Yüksel and Dagdeviren, 2007). With the assistance of the experts, the final criteria list was obtained. Experts established the definition and the purpose of each criterion, making sure that each expert understood them. The final list has 16 criteria grouped in three clusters (Table 3.1).

Table 3.1 Evaluation criteria

Cluster	Definition	Criteria	Definition
C1. Knowledg	Criteria aimed at assessing stakeholders'	C1.1 Public engagement	It refers to the societal commitment to provide encouragement, opportunities and competences in order to empower

Cluster	Definition	Criteria	Definition
e of RRI areas	knowledge of RRI concepts. In general this is a weak point, since there is a general lack of knowledge of the topic, which implies the need to inform the stakeholders about the most basic concepts of responsibility. The Criteria of this cluster are the eight key areas of the RRI.		citizens to participate in debates around R & I, with potential feedback and feed-forward for the scientific process.
		C1.2 Gender equality	Promotes the equal participation of men and women in research activities and the inclusion and integration of gender perspectives in R & I content.
		C1.3 Science education	The need to enhance the current education process to better equip future researchers and other societal actors with the necessary knowledge and tools to fully participate and take responsibility in the R&I process.
		C1.4 Ethics	Related to research integrity and good research practice, the protection of the objects of research and, the societal relevance and ethical acceptability of R & I outcomes.
		C1.5 Governance	Any form of coordination designed to foster and mainstream RRI within an organisation or in the interaction with other stakeholders
		C1.6 Open access	Practice in which the scientific process is shared completely and in real time.
		C1.7 Sustainability	Evaluates to what extent a research field, a research program or an RRI initiative contributes to sustainable growth.
		C1.8 Social justice	Impact of research and its effect on social justice/inclusion. Considered from the relationship between the researchers and the research subjects; and the participation of social groups in benefits arising from research.
C2. Diffusion	Refers to some attributes that allow stakeholders to engage in the dialogue and spread the project, to generate debates and networking and to identify relevant aspects.	C2.1 Transversality	It refers to the diversity of stakeholders, to how complex it is.
		C2.2 Group size	The number of members in society of a stakeholder.
		C2.3 Activism	How active, critical or proactive a stakeholder is.
		C2.4 Relations with the project	Evaluates how the relationships between the project consortium and the stakeholders are. It takes into account previous relationships.
C3. Possible	Refers to the willingness and capability of one	C3.1 Financial	How much a stakeholder can contribute with financial resources to anticipate the project responsibility.

Cluster	Definition	Criteria	Definition
resources providers	stakeholder to provide the project with resources.	C3.2 Communication	How much a stakeholder can spread out and communicate the project to help achieve the desired anticipation.
		C3.3 Personal	How much a stakeholder can contribute with human resources to anticipate the project responsibility.
		C3.4 Hard-data	How much a stakeholder can contribute with reliable and accurate data to help to anticipate the project more responsibility

Establishing ANP structure

After the identification of the elements, dependencies among them were determined by experts using a relationship matrix, where one (1) means that the element of the column depends on the element of the row, and cero (0) means that there is no dependence among them (Table 3.2).

Table 3.2 Dependence matrix of all elements of the model

	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	2.1	2.2	2.3	2.4	3.1	3.2	3.3	3.4	S1	S2	S3	S4	S5
1.1		1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	1	1	1	1	1
1.2	1		0	0	1	0	0	1	1	0	1	0	0	0	0	0	1	1	1	1	1
1.3	1	0		0	0	0	0	1	1	0	1	0	0	1	0	0	1	1	1	1	1
1.4	0	0	0		0	0	1	1	0	0	0	1	0	0	0	1	1	1	1	1	1
1.5	1	0	0	1		1	1	1	0	0	1	0	0	0	0	0	1	1	1	1	1
1.6	0	0	1	0	0		0	1	0	0	0	0	0	1	0	1	1	1	1	1	1
1.7	1	0	0	1	0	0		1	0	0	0	0	0	0	0	0	1	1	1	1	1
1.8	1	1	0	0	0	1	1		1	1	1	0	0	0	0	0	1	1	1	1	1
2.1	0	0	0	0	0	0	0	0		1	1	1	0	1	0	1	1	1	1	1	1
2.2	0	0	0	0	0	0	0	0	0		0	1	0	1	0	1	1	1	1	1	1
2.3	0	0	0	0	0	0	0	0	0	0		1	0	1	0	1	1	1	1	1	1
2.4	0	0	0	0	0	0	0	0	0	0	0		1	1	1	1	1	1	1	1	1
3.1	0	0	0	0	0	0	0	0	0	0	0	1		1	1	1	1	1	1	1	1
3.2	0	0	0	0	0	0	0	0	0	0	0	1	0		0	1	1	1	1	1	1
3.3	0	0	0	0	0	0	0	0	0	0	0	1	0	0		0	1	1	1	1	1
3.4	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0		1	1	1	1	1
S1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1
S2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1
S3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1
S4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1
S5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	

Dependence of A on B, as explained, means B influences A as regards the ANP goal, i.e. B influences A for the assessment of how much a stakeholder contributes to the anticipation or RRI issues of the project. For example, cell a12 =1 means the element *1.2. Gender equality* is influenced by the element *1.1. Public engagement* for the assessment. And experts considered that on the grounds that for identifying gender inequality issues public engagement is needed. But the contrary was found to be true too, element 1.1 is influenced by element 1.2 and experts filled cell a21= 1. That is so because they consider that if there is gender inequality the public will more easily get engaged in the debate about the desirability of the projects and their outcomes, and go beyond the specific gender issues.

The proposed model is illustrated by the network shown in Figure 3.2 The arrows indicate dependencies between clusters. That is to say, the elements in a cluster (i) exert some influence over elements in another cluster (j). Feedback arrows mean that there are influences among criteria belonging to the same cluster. Bidirectional arrows indicate influences in both directions.

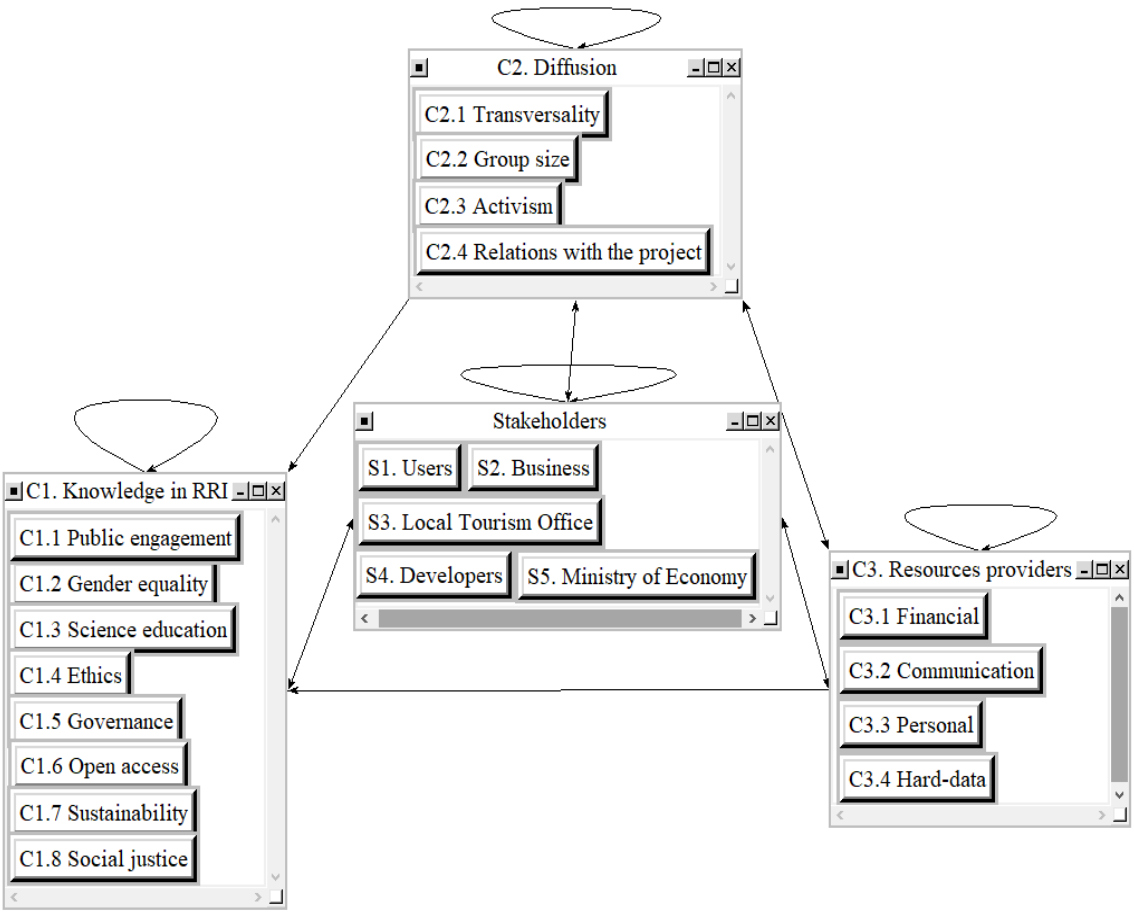

Figure 3.2 ANP network model of the case study

3.4.3 Assessing stakeholders' influence by means of ANP

Once the model was agreed upon, the ANP questionnaire was designed with the aim of determining a relative importance for each stakeholder with regard to all the considered criteria. That is to say, how much each stakeholder can contribute to the anticipation of the responsibility of the project. The required judgements were collected from the experts through a questionnaire designed with pairwise comparisons. Figure 3.3 shows an example of one of the questions.

In your opinion, which of the two criteria influence more on the criteria C1.1 Public engagement?
Place an X where appropriate.

	Extreme		Very strong		Strong		Moderate		Equal		Moderate		Strong		Very strong		Extreme	
C1.2 Gender equality	9	8	7	6	5	5	x	2	1	2	3	4	5	6	7	8	9	C1.3 Science education

The answer in this example indicates that the Critera *C1.2 Gender equality* is moderately more influential on the element *C1.1 Public Engagement* than *C1.3 Science education*.

Figure 3.3 Example of a question used for the ANP questionnaire

All the calculations were performed using the Superdecision© v.2.0.8. software. Once experts finished all pairwise comparisons, a limit supermatrix per expert was obtained.

The final limit matrix has the same values in all the columns. It shows the weight obtained for each element, relative importance as regards the ANP goal (Jaafari et al., 2015). These values were normalized [by multiplying them by a constant that is the reciprocal of their sum (Saaty, 1990)] to obtain the final results (Caballero-Luque et al., 2010). Care was taken to ensure that all pairwise comparison matrices had a consistency ratio (CR) of less than 10%, as required by the method.

Since 3 experts were interviewed, 3 individual results were obtained. Each one shows the relative importance according to their judgments. Aggregation of Individual Priorities (AIP) was performed in order to obtain a global judgement for all the experts, that is to say, a new limit supermatrix with the aggregation by means of the geometric mean of the judgments of the three experts. Then another final limit matrix was calculated showing the aggregated preferences of the experts.

3.5 Discussion of results

In order to present the results, three different analyses have been carried out. First, the weights of the clusters have been obtained and compared both for the individuals and for the group. Secondly, criteria have also been analysed for the individuals and for the group. Thirdly, the ranking of the analysed stakeholders has been obtained, which is the final aim of this whole evaluation process.

3.5.1 At the cluster level

The cluster weighting provides some important insights into the overall perspective and underlying participants' conception of how the project consortium could involve stakeholders in responsible research. Individual preferences show that Expert 1 and Expert 3 give the highest importance to C2. Diffusion (Table 3.3 and Figure 3.4). This means that in order to anticipate the RRI issues of the project, these experts consider it to be more important to take advantage of the stakeholders' potential to spread out the project engaging people in the debate. While for Expert 2 C1. Knowledge of RRI areas is clearly more important than any other characteristic or resources that a stakeholder might have.

The aggregated result shows more balanced weights, as usual. The most important clusters are *C2. Diffusion* (0,387) and *C1. Knowledge in RRI Areas* (0,270). In a second level *C3. Resources* (0,135) would be classified.

Table 3.3 Results obtained for the clusters

Cluster	Expert 1	Expert 2	Expert 3	Aggregation
C1. RRI Areas	0,0965	0,6884	0,1645	0,2698
C2. Diffusion	0,4094	0,1816	0,4330	0,3868
C3. Resources	0,2895	0,0501	0,0939	0,1348
Stakeholders	0,2047	0,0799	0,3085	0,2086

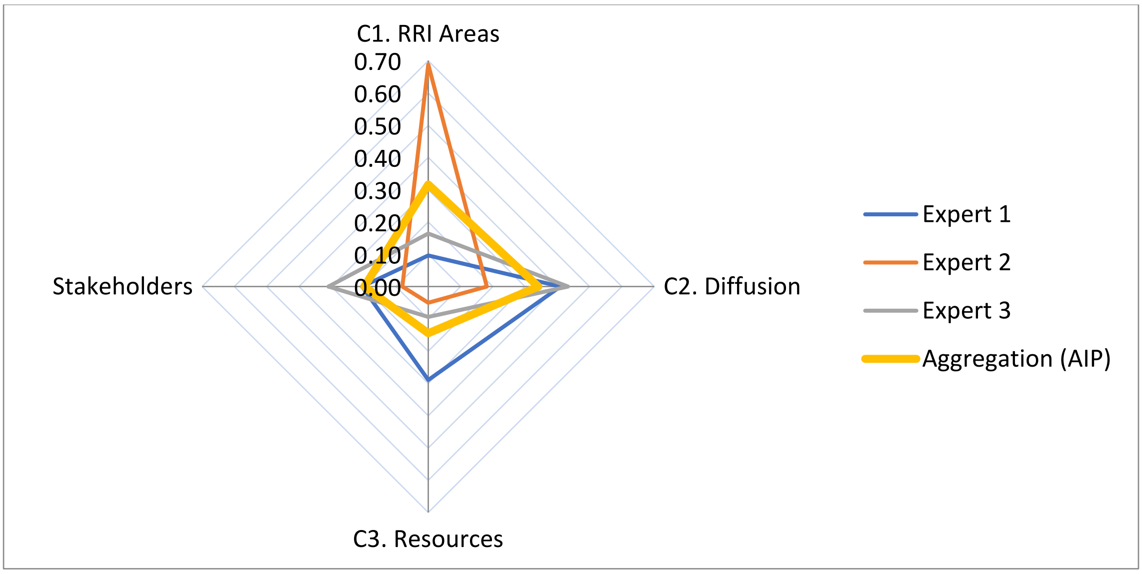

Figure 3.4 Cluster results according to experts, and aggregated results

3.5.2 At the criteria level

Regarding these results the main conclusion is that the most relevant criterion is *C1.1 Public engagement* (Table 3.4). In fact, it is the first criterion for Experts 2, and the second most important for Expert 1 and 3. Following in importance we obtain a group of criteria formed by, *C1.8 Social Justice*, *C2.1 Transversality* and *C2.4 Relations with the project*. Expert 2 shows different preferences compared with Experts 1 and 3, who show more similar profiles.

The most important criteria after *C2.4 Relations with the project* for Expert 1 are *C1.1 Public engagement*, and *C2.1. Transversality*. For expert 2 there are two main criteria: *C1.1 Public engagement* and then *C1.8 Social justice*, the others fall clearly behind. Finally, Expert 3 considers as does Expert 1 that *C2.4 Relations with the project* is most influential, then *C1.1 Public engagement*, and then *C2.1. Transversality*.

Table 3.4 Results obtained for the criteria

Criteria	Expert 1	Expert 2	Expert 3	Aggregation
C1.1 Public engagement	0,115	0,230	0,115	0,163
C1.2 Gender equality	0,034	0,107	0,062	0,069
C1.3 Science education	0,073	0,060	0,024	0,053
C1.4 Ethics	0,022	0,079	0,040	0,046
C1.5 Governance	0,039	0,101	0,078	0,076
C1.6 Open access	0,046	0,022	0,026	0,034
C1.7 Sustainability	0,012	0,057	0,030	0,031
C1.8 Social justice	0,059	0,171	0,099	0,113
C2.1 Transversality	0,113	0,060	0,113	0,103
C2.2 Group size	0,037	0,014	0,065	0,037
C2.3 Activism	0,101	0,025	0,084	0,067
C2.4 Relations with the project	0,129	0,033	0,148	0,096
C3.1 Financial	0,087	0,009	0,042	0,035
C3.2 Communication	0,055	0,017	0,014	0,026
C3.3 Personal	0,027	0,006	0,024	0,018
C3.4 Hard-data	0,051	0,012	0,037	0,032

Global results of Table 3.4 are shown in Figure 3.5 for clarity. As can be seen, after the highlighted criteria: C1.1, C1.8, C2.1 and C2.4, follows a group of criteria formed by *C1.5 Governance*, *C1.2 Gender equality* and *C2.3 Activism* with an importance of between 6 and 8%. The least important criteria are: *C3.2 Communication* and *C3.3 Personal* that have an importance of less of 3%. In general, as introduced, criteria of cluster *3 Resources* are less valued for the anticipation of the responsibility of the project.

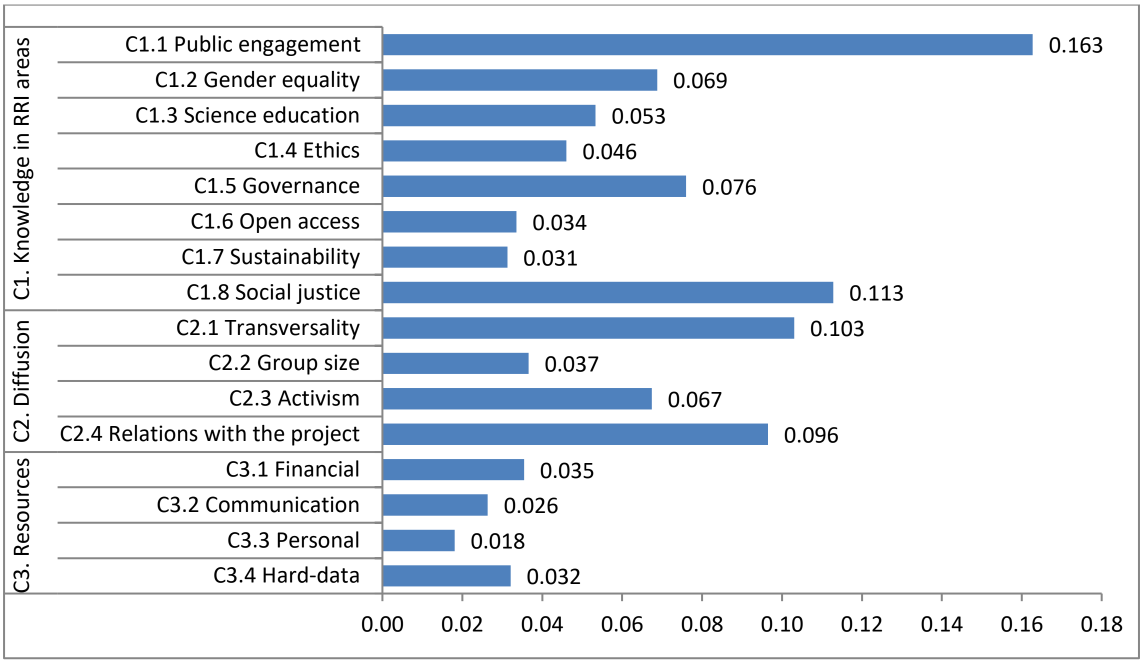

Figure 3.5 Results for the criteria

To end with the discussion of the results for assessment criteria, the case under study has specific characteristics that, together with those of the consortium members, have shaped the most important features to select the influential stakeholders. That criteria related to stakeholder competence and willingness to debate, and their closeness to the research members, are so influential, which does not mean that features like stakeholder group size, activism or possibility to add their own resources to the anticipation of RRI issues may not be more valued by other research teams in other projects, at other development stages.

3.5.3 Stakeholder influence

An overall preference for each stakeholder with regard to all the considered criteria has been obtained. It assesses the relative importance of each stakeholder with regards to the ANP goal. Therefore, the higher the preference, the more influential the stakeholder is. Table 3.5 show the values of the final limit matrixes and the normalised values. As can be seen, on average the most influential stakeholders are: *S4. Developers* (25% of the total weight), *S5. The National Ministry of Economy* (23%) and *S3. Local Tourism Office* (22%). In a second group fall *S1. Users* (18%) and *S2. Business* (11%).

Table 3.5 Limited and Normalized values for the stakeholders

		Expert 1		Expert 2		Expert 3		Aggregated	
		Limit	Normalized	Limit	Normalized	Limit	Normalized	Limit	Normalized
Stakeholders	S1. Users	0,052	0,151	0,068	0,176	0,079	0,231	0,065	0,186
	S2. Business	0,037	0,106	0,062	0,162	0,028	0,081	0,040	0,113
	S3. Local Tourism Office	0,077	0,223	0,090	0,233	0,068	0,198	0,078	0,220
	S4. Developers	0,092	0,267	0,075	0,194	0,097	0,283	0,087	0,248
	S5. The National Ministry of Economy	0,087	0,252	0,090	0,234	0,071	0,208	0,082	0,233
		0,345	**1,000**	**0,385**	**1,000**	**0,343**	**1,000**	**0,353**	**1,000**

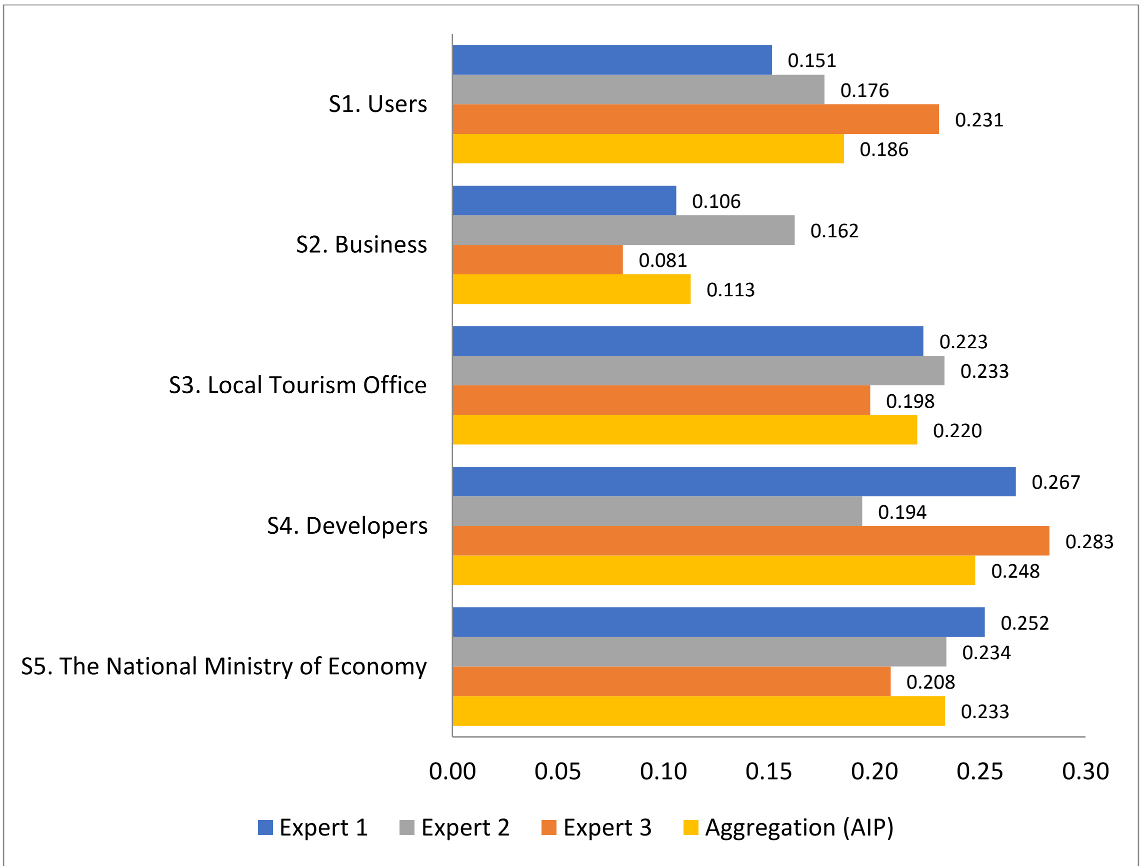

Figure 3.6 Results for the stakeholders

The results also allow us to analyse the experts' individual preferences. Based on the obtained results (Table 3.5 and Figure 3.6), the different experts show some differences in the ranking order of the five stakeholders. For expert 1 the ranking order of stakeholders would distinguish S4 Developers, S5 The National Ministry of Economy, and S3 Local Tourism Office from the rest. For expert 2 only S5 The National Ministry of Economy and S3 Local Tourism Office would be highlighted. And for Expert 3, only S4 Developers and S1 Users would be the most preferred.

The results, besides, allow us to differentiate groups of stakeholders based on their importance. This differentiation is qualitative and open to different interpretations, and here the decision of the project consortium members is shown. Based on the procedure and its learning, and also looking at the differences among stakeholders' final ANP values, three groups were made. It is important to mention that all stakeholders of this classification are influential and ought to be managed. But in a situation of limited resources and some reluctance of the stakeholders to tackle the challenge of RRI, it is advisable to devote more resources: time, people, effort, money, etc. to the most influential ones. And hence the interest to classify them.

The first group was called the most influential one *(S4 Developers, S5 The National Ministry of Economy, and S3 Local Tourism Office*) including those who, according to the experts' judgments are the stakeholders who can contribute more to the anticipation of the responsibility of the project. Therefore, they should be the ones who the consortium should focus on managing.

The second group (*S1 Users*) is called just influential, as they are less clearly preferred at that moment for the RRI analysis. However, Users are key to the project and involved in the research itself in the user-centred design. In fact, their influence on the RRI issues may change as the project evolves into a new phase where the procedure of the application will be further developed and, for example data privacy, offers discrimination, environmental information, or other project decisions will be more relevant. Also, the ranking of stakeholders, or the inclusion of new ones, may be needed as the team follows the RRI self-learning process and moves on to Reflection, Deliberation or Responsiveness (Jack Stilgoe et al., 2013).

Finally, (*S2 Business*), are the least preferred among the influential at the moment. The experts have found the other stakeholders to be preferred for debating the responsibility of the research at its current development phase. Later, when the detailed determination of the app contents demands from Users and Business a closer participation, their role in the responsibility of the project is expected to be clearly more influential.

ANP also allows us to analyse why some of the alternatives are preferred to others. In this case, this analysis shows those stakeholders to be more influential on *C1.1. Public Engagement*, *C1.8. Social Justice* and *C2.4. Relations with the project*, obtained the higher values

3.6 Conclusions

In this chapter a novel application of an MCDM technique to evaluate the stakeholder influences on a project has been provided, which in this case is applied to their contribution to the anticipation of the responsibility of the project and its possible outcomes. By means of the model the global concept of influence is broken down into sixteen criteria, evaluating different aspects that together enable us to define a preference. The preference measures the greater or lesser influence of stakeholders on research responsibility within a framework of RRI. Thus, they can prioritize based on their expected contribution to the anticipation of the issues related to the social desirability of the activity.

Stakeholder management is normally a key activity in research, and particularly so in responsible research. Within stakeholder management, stakeholder analysis is critical for identifying, understanding and proposing strategies for involving them as much as decided. The existing methods of stakeholder analysis can be complemented with the results of the investigation herein presented. The ANP method has shown useful to rank and order the stakeholders, a purpose other methods do not cover, or address very indirectly. Besides, ANP can be adopted and applied to other types of influence assessment.

According to the RRI perspective, as the project develops, a more inclusive stakeholder dialogue will be necessary, including a broader spectrum of stakeholders. For example, in this case study, experts discarded firstly listed stakeholders like S7 Neighborhood associations (they are directly affected or benefited by tourism) and S6 NGO's (interested in the social-environmental impacts of tourism). However, those stakeholders can vary their influence later in the project's development. Or in a following stage of the team's RRI self-learning process: Reflection, Deliberation or Responsiveness.

As regards the results of the case study, the ANP goal was to assess how much stakeholders contribute to the anticipation of the responsibility of the project and the exploitation of its outcomes. Based on that, Expert 1 the project manager and Expert 3 the stakeholder manager give similar evaluations to criteria, highlighting the criterion C2.4. Relations with the project, and C1.1. Public engagement. While Expert 2, the RRI researcher, does not give importance to C2.4., gives importance to C1.1., and gives importance to C1.8. Social justice itself is not really considered by the other experts. The aggregation of the experts' judgments leads to the assignment of the highest importance to criterion C1.1., followed by C1.8., C2.1 and C2.4. And the least importance to C3.3. Personal and C3.2 Communication.

The most influential stakeholder of the case study evaluated is "S4 Developers", based on the ANP goal. For the experts and the chapter author this is understandable as, considering the early stage the project is in, and going through Anticipation in the self-learning process of the project consortium, this stakeholder is key in the usability, inclusivity, energy consumption and other features that will make the greatest social environmental impacts, should the project be finally carried out, and its foreseen app become a success.

The selected experts have found those stakeholders best related to the project, and more able to engage the public in a debate about the project's RRI issues. They are indeed the ones that can contribute the most to the anticipation of those issues.

As recommended by the developer of ANP, once the results are obtained a sensitivity analysis should be carried out in order to demonstrate the robustness of the ranking obtained, particularly in case some alternatives achieve very similar results. This was the case of this chapter, although the sensitivity analysis only gives changes in the order of ANP elements within the identified groups, i.e. the classification of criteria or stakeholders based on their influence. Therefore, the groups of most and least influential criteria and alternatives have the same components, all through the sensitivity analysis.

CHAPTER 4

The design and testing of a tool for anticipatory carbon footprint calculation in research and innovation projects*

[1]This chapter is based on Ligardo-Herrera, I., Gómez-Navarro, T., 2020. The design and testing of a tool for anticipatory carbon footprint measuring in research and innovation projects. Ongoing evaluation.

4.1 Abstract

In most R&I projects the CO_2 generated and its climate change consequences are not considered by researchers. Existing environmental impact assessment tools require great precision and data specialization, which is unknown in the early stages of projects. In general, this is a difficulty for researchers. These tools are mainly designed for the advanced stages of R&I projects where there is more information available and less uncertainty. This chapter presents the design of a novel tool with a user-friendly and didactic interface for anticipatory carbon footprint calculation in R&I projects that allows researchers untrained in environmental impact assessment to estimate the greenhouse gases emissions of their R&I Projects at early stages. We proposed a two-part methodology: (i) Tool designing based on a literature review on carbon footprint tools and open sources databases, and (ii) Tool testing, carried out through a 3-step protocol on some case studies. The results highlight that the designed CO_2 tool works and is useful for helping researchers' decision making by estimating the emissions that their research could generate from its early stages.

4.2 Introduction

Global Warming, and the climate change (CC) it produces, is one of the most global and urgent threats humankind is responsible for (IPCC et al., 2014). Scientific evidence, such as observations and the development of climate models are increasingly strong, and point to a clear human influence on the climate system. Therefore, responsibility has reached all disciplines, including the R&I process. To manage this responsibility, all researchers, even those doing activities where CC is not considered, must have tools. These instruments should be didactic and supported by open databases.

The United Nations Framework Convention on Climate Change (UNFCCC), in its article 1 (CMNUCC, 1992), defines CC and differentiates between CC attributable to human activities that alter atmospheric composition and climate variability attributable to natural causes.

CC is caused by greenhouse gases (GHG) in the atmosphere (Fourier, 1824) including methane (CH4), nitrous oxide (N2O), water vapour (H2O), ozone (O3) and carbon dioxide (CO_2). This last gas is one of the most abundant in the atmosphere (Keeling, 1960). Because of this and its physical properties (Tyndall, 1861), it is attributed to be one of the main causes of CC (Arrhenius, 1896). In this respect and according to (Greenhouse Gas Protocol, 2014) there are direct and indirect GHG emissions, both categorized into three broad scopes: Scope 1: All direct GHG emissions; Scope 2: Indirect GHG emissions; and Scope 3: Other indirect emissions.

R&I have improved our lives in many ways, and it is desirable that they continue to do so. Science and technology have enabled humans to alter ecosystems, the earth's climate by generating emissions, CO_2 emissions among others, and even the building blocks of matter and life itself. Hence, in parallel to the many positive impacts generated for human well-being, sometimes science and technology create new risks and ethical dilemmas, just as they fail to solve the problems, they attempt to solve at the same time stimulating controversy in society.

RRI emerge as a public policy discourse supported by European Commission EU (Owen and Pansera, 2019). RRI has come a long way, efforts to make it operational are bearing more and more fruit. Unfortunately, after 10 years of promotion, the concept of RRI is still quite unknown, poorly institutionalised, considered unclear, and hard to operationalise and evaluate (Christensen et al., 2020). However, many academics and scientists are still betting on the continued relevance of RRI (Gerber et al., 2020a).

In a previous research (Ligardo-Herrera et al., 2018c) an approximation addressing CC and R&I activities related was made with two aspects: first, a set of four general strategies were determined about how to inform researchers on CC prevention: 1. Integration in the core management of research; 2. Open-access databases; 3. Life circle perspective and 4. Stakeholder management (Ligardo-Herrera et al., 2018a). Second, an avenue for future research was identified, concluding that in the context of a bottom-up approach, normative proposals are needed for teams to address CC. Those normative proposals can adapt the proven tools from Corporate Social Responsibility (CSR) and Sustainable Innovation (SI). Hence, new tools are needed, for example, key performance indicators based on open-access databases, as well as ready and easy to understand information to help researchers to integrate CC prevention in their R&I activities. These tools should help to improve the accountability of researchers and, to analyse and foresee impacts that may happen during their research and with future outcomes, including 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 R&I with a life cycle perspective.

As was stated in chapter 1 and 2, this research aligns with the previous aspects and with the substantive frameworks of RRI (Rene Von Schomberg, 2013). For this purpose, environmental impacts must be mainstreamed from the early stages of R&I projects, although there is quite a lot of literature on environmental impact assessment. There are very few studies on assessments in R&I projects whose main characteristics are not environmental impacts, for instance R&I projects from fields such as ICT, food or health.

The environmental impacts assessment of R&I projects should be operationalised. This should be done in a valid way even for untrained researchers on environmental impacts assessment. There are two ways to carry out this assessment. On the one hand, research teams should hire experts in environmental impacts assessment. On the other hand, there must be open-access tools that can replace those experts available.

Existing environmental impact assessment tools require great precision and data specialization, which is unknown in the early stages of R&I projects. In general, this is a barrier for researchers. These tools are mainly designed for the advanced stages of projects where there are more information and less uncertainty. A tool that intuitively and didactically helps researchers to assess the potential environmental impacts from the early stages of their projects is needed. In most R&I projects the CO_2 generated, and the consequent CC are not considered by researchers.

In this chapter, we will focus on the carbon footprint part. Our aim is to propose a new design of a tool that: i) helps researchers with their planned data to estimate from the early stages of their project, when there is a lot of uncertainty about the process and future outcomes of that project, how much CO_2 both process and outcomes of their research will generate, and ii) has a user-friendly and didactic interface that allows researchers to interact with their project, making simulations by changing components of the research design or introducing initiatives such as improvements in energy saving, generation of renewable energy (photovoltaic), reduction of train/plane transportation by having video conference meetings, using very efficient computer equipment and telecommunications, or offsetting emissions by using part of the budget or money earned with the project to encourage the planting of trees or research on CC.

To do this we proposed a two-part methodology: tool designing and tool testing. The results highlight that the novel anticipatory carbon footprint in R&I projects tool designed works, and is useful for helping researchers' decision making. ***The main contribution of this research is to introduce the tool for researchers with evidence that works and allows them to estimate CO_2 emissions in the early stages of R&I projects***. Hence, the research question this chapter seeks to answer is: How can a research team untrained in environmental impact assessment estimate the CO_2 emissions at the early stages of a R&I project that does not specifically address fighting CC?

In the next section (4.3) the two-part methodology is explained. Then (in section 4.4), the Tool is designed and tested on three (3) representative case studies: Case I, an R&I project where outcomes are more important than the process; Case II, where the process is more important than the outcomes; and Case III, where there is a CO_2 emissions balance between the process and the outcomes. Next, the discussion of the results is presented in section 4.5, and finally, the chapter ends with conclusions.

4.3 Method & materials

To answer the research question, a two-part method has been proposed: (i) Tool design and (ii) Tool testing. The first part was based on a literature review on carbon footprint tools and open source databases, and the second part, tool testing, was carried out through a 3-step protocol on some case studies. The research focused on R&I projects. Figure 4.1 illustrates the structure of the method proposed.

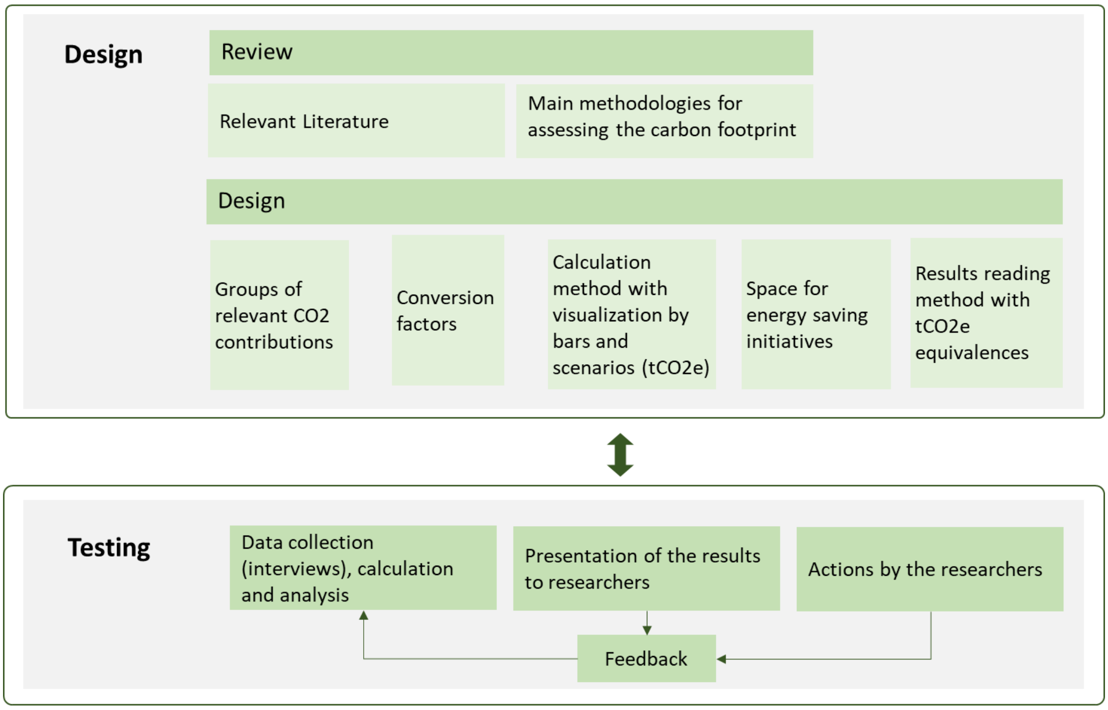

Figure 4.1 Method Proposed

The following segments will show the tool design, how it was tested, and how the data were analysed.

4.3.1 Tool design

Literature review on assessing carbon footprint Tools

The first activity was a review of relevant literature and carbon footprint assessment tools. The purpose was to take advantage of the development already made as a guide for the design of the anticipatory carbon footprint in an R&I Projects Tool. As was described by EC (European Commission, 2013a) and (Ligardo-Herrera et al., 2018c) the main methodologies for assessing the carbon footprint found in the literature are: i) PAS 2050 (The British Standards Institution (BSI), 2011a, 2008); ii) GHG Protocol Product Standard (World Resources Institute and World Business Council for Sustainable Development, 2011); iii) ISO 14064-2:2006 (ISO, 2009); iv) ISO 14040 (ISO, 2006); and more recently this document was included v) ISO14067 – 2018 (ISO, 2018).

Furthermore, we review the interface of many carbon footprint calculators to help us in the didactic component of our design. For a list of the reviewed calculators see Appendix 2.

This activity included the review of other methodologies that, although they do not have the specific aim of carbon footprint assessment, they did have a similar didactic components to the one we wanted to include in our tool. Some of these methodologies can be found in these documents: i) RRI Self-reflection Tool (RRI-Tools Project, 2020); ii) The Responsible Innovation Self-check tool (Tharani et al., 2019); iii) The Product Impact Tool (Dorrestijn, 2017); and iv) the web-based tool "iGEMer's Guide to the Future" (Stemerding et al., 2018).

Design of a tool for anticipatory carbon footprint in R&I Projects

Within a context of R&I projects, the purpose is to design a tool that helps researchers, by providing them information to defining red lines about what to do, or not to, in order to address climate change prevention. Following the proposal of (Strand et al., 2015a) that considers three phases in R&I: outcomes, process and perception. After a previous work by the same authors based on a prioritization of criteria (Gómez-Navarro and Ligardo-Herrera, 2016), we develop the design of our tool with two (2) phases, outcomes and process. We did so in that order, since it was concluded that the research outcomes phase could generally be foreseen as having the greatest potential for environmental impact. The design included the following activities:

1. Simplification of the assessment of the carbon footprint, grouping the features into four (4) major groups of relevant CO_2 contributions, such as, electricity consumption (CO_2 electricity (gr) per kWh) (EEA, 2020), fossil fuel consumption, transportation (travel) and high (or medium) energy content materials and components. See Appendix 3.

2. Designing of conversion factors for calculations. The most common activities of an R&I project were supported by open-access databases and CO_2 conversion pattern databases. The main databases used were: i) Inventory of Carbon & Energy (ICE) Version 2.0 (Hammond and Jones, 2011); ii) Sustainability Disclosure Database (Global Reporting Initiative (GRI), 2017); iii) 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Eggleston et al., 2006); iv) GHG Protocol GHG Emissions Inventories Tools (Greenhouse Gas Protocol, 2003) and v) ELCD European reference Life Cycle Database (European Commission, 2006b). A review of International EPD®System Environmental Product Declaration Database (International EPD® System, 2017), the U.S. Life Cycle Inventory Database (National Renewable Energy Laboratory, 2012) and Exiobase system database (Tukker et al., 2013) was also carried out.

The calculation is given by the following equation:

$$\sum_{i=1}^{i=n} L_i \times CF_i \quad + \quad \sum_{j=1}^{j=m} L_j \times CF_j$$

Where:

L = Load.

CF = Conversion Factors

i = Outcomes

j = Process

This equation calculates data for building different scenarios to work on. In each scenario two (2) corresponding phases, research outcomes (i) and research process (j), have been carried out. Then in each phase all Loads (L) are set. These loads correspond to the types of resources used in a R&I project, such as electricity consumed, fossil fuels, types of transport or materials. All these loads generate GHG emissions and are included in the calculations with their respective conversion factor (CF). Examples of these Loads (L) in a R&I project: use of fuel for transport, type of trips made (car, train, plane), materials used for construction of prototypes, etc., See Appendix 4 – 7.

3. A simple calculation method with visualization by bars and scenarios of the amount of tCO_2e generated by the project for each component was designed. Including measurement parameters and key criteria, based on anticipatory carbon footprint measuring methodologies.

4. A box for allowing users to include energy saving initiatives was designed. Proposals like energy efficiency, use of renewable energy (solar, wind, hydroelectric, etc.,) and CO_2 offset generated that would be considered for the total CO_2 measurement of the project.

5. Results reading method was included. For greater appropriation by the researcher of the project's emissions through tCO_2e equivalences to: i) emissions from cars, cigarettes, etc.; ii) Emissions avoided by led lights, recycling, wind turbines in operation for one year, etc.; or iii) CO_2 sequestered by trees or hectares of forest.

The tool enables the calculation and recording of the direct (Scope 1) and indirect (Scope 2) emissions expressed as in accordance with the Greenhouse Gas (GHG) Protocol, along with part of the indirect emissions (Scope 3) (Greenhouse Gas Protocol, 2014).

The calculations of the tool will be communicated through units of CO_2 equivalent (CO_2e), defined as the universal unit of measurement to indicate the global warming potential (GWP) of each greenhouse gas, expressed in terms of the GWP of one unit of carbon dioxide. It is used to evaluate releasing (or avoiding release of) different GHG against a common basis (Greenhouse Gas Protocol, 2015).

4.3.2 Tool Testing

Before starting the testing stage, initial interviews were conducted with researchers from different R&I projects, in which discussions were held about the initial design of the tool. As a result, an important aspect was determined as a starting point for testing the tool: the criteria to be followed for the selection of projects. See Table 4.1

Table 4.1 Criteria for project selection

Criteria for project selection	A project where it is expected that the research outcomes of the project will generate more CO_2 than what is generated during the implementation phase (research process) of the project.
	A project where it is expected more CO_2 will be generated from the research process than the research outcomes.
	A project in which it is expected that a similar amount (a balance) of CO_2 will be generated from both phases: outcomes and process research.

In all case studies (R&I projects) where the tool was tested, the amount of CO_2e generated during the execution of each project was estimated and scenarios of the possible generation of CO_2e from the project results were built.

Figure 4.1 (proposed methodology), illustrates a 3-step protocol that was designed to test the tool: 1) data collection (interviews), calculation and analysis, 2) Presentation of the results to researchers, and 3) Actions by the researchers. During the application of this protocol, any of these steps could guide us back to part one of the methodology for a re-design of the tool.

More details on tool testing are provided through the application of the case studies in section 4.4.2.

4.4 Results

4.4.1 A tool for anticipatory carbon footprint in R&I projects

The result is the anticipatory carbon footprint measuring for R&I projects Tool, with two (2) phases: i) outcomes and ii) process.

The evaluation starts with phase 1 for the project outcomes, in which with the data provided by the researchers, some scenarios (high, medium or low) of the impact of the results are estimated. Then the conversion factors are applied to calculate the amount of CO_2e generated. This process is repeated with each indicator, whether it is energy consumption, or transportation, or fossil fuel consumption, or components and materials used, and energy saving initiatives making a total sum of phase 1.

Phase 2, which is designed to evaluate the project's research process, repeats the process of the previous phase. This time only two impact scenarios "High" and "As expected" are estimated. Then the amounts of CO_2e calculated in phase 1 and 2 are added up, and a report of the total CO_2e generated by the project is completed. Figure 4.2 illustrates the flow chart of the assessment tool:

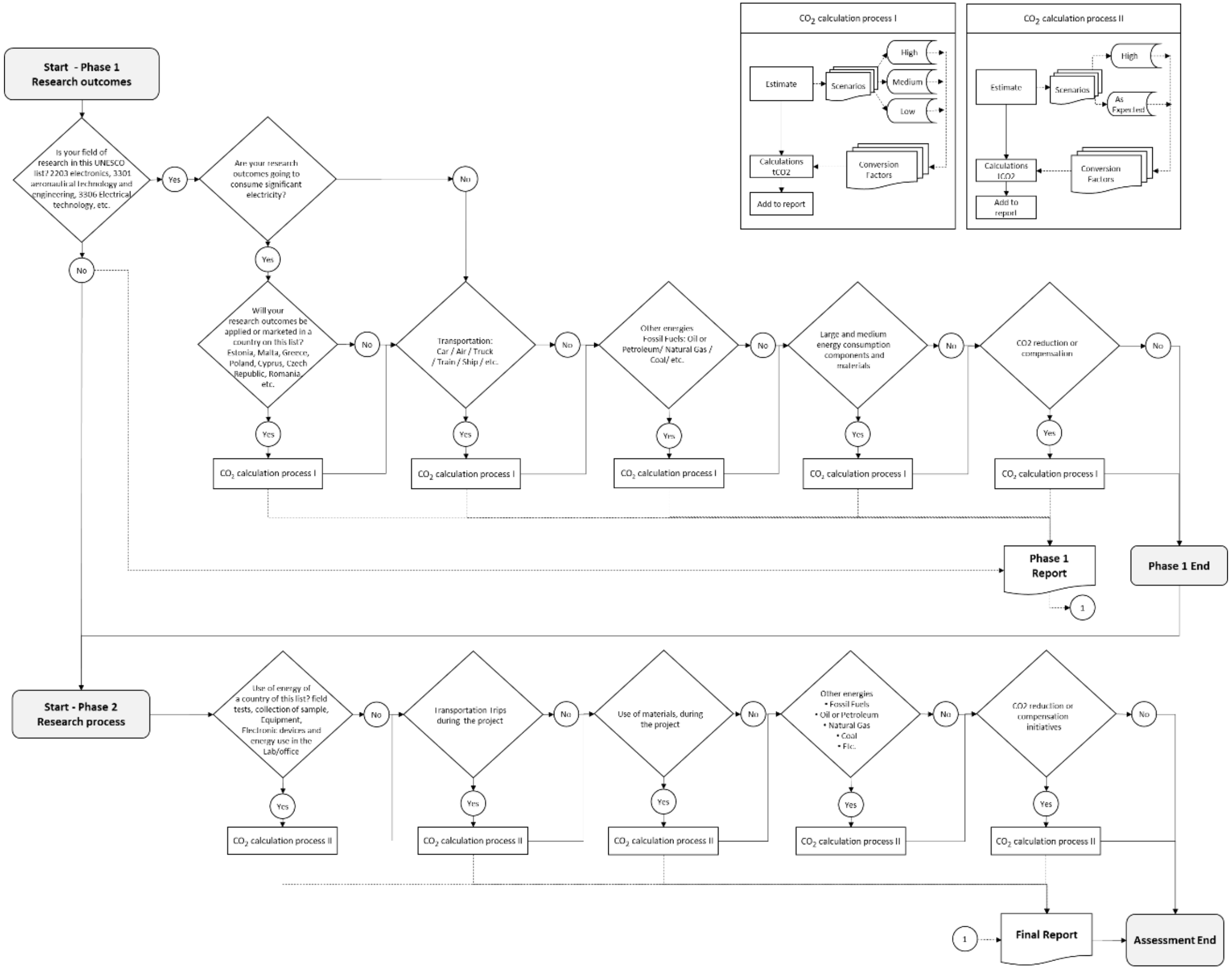

Figure 4.2 Flowchart of the Assessment Tool for R&I Projects

Finally, for better appropriation by the researcher, the algorithm Assessment End's box corresponds to a result reading method designed for the presentation of the results to the researchers in terms of tCO_2e equivalences such as: i) Emissions from cars, cigarettes, etc.; ii) Emissions of tCO_2e avoided by led lights, recycling, wind turbines in operation for one year, etc.; or iii) tCO_2e sequestered by trees or hectares of trees needed to absorb the amount of tCO2e generated from the whole project. This result reading method uses the data based on the calculations from (EPA - United States Environmental Protection Agency, 2008) and (Zafeiridou et al., 2018). A detailed example of calculations is presented in Appendix 8.

4.4.2 Tool testing on case studies: Application of the Tool in research projects

The anticipatory carbon footprint tool has been tested in some R&I projects (Case studies). The first cases were useful for two purposes; on the one hand, to verify the tool in the sense that it allows us to obtain useful results for researchers. On the other hand, they enriched and added details to the final design of the tool, such as small inconsistencies generated, difficulties in the use of the tool, or questions asked to researchers for which they did not have answers. Then, researchers could change and play in real time with the parameters introduced in the tool. Running the case studies by themselves and making the CO_2 assessment in an intuitive way.

Finally, of all the projects in which the tool was tested, three (3) case studies are presented in this work. As they are the most representative of the situations described on criteria selection: i) more CO_2 generated from the project's research outcome, ii) more CO_2 generated from Project's research process, and iii) an expected balance between the project's research outcomes and process. See Table 4.1, in section 4.3.2.

Following the testing protocol designed, see Figure 4.1., the results of these case studies are presented in three steps:

<u>Step 1: Data collection, calculation, and analysis</u>

One of the main purposes of the tool is that it can be used by researchers who are not specialists in environmental impact assessment. For information and data collection, questions were designed in such a way that researchers could easily answer, since they were not questions on environmental impact assessment. Instead, questions were related to the nature of their research, such as the raw materials to be used in the product or process, the means of transport to be used or the energy consumption that could be expected to be used. For example, the tool does not ask researchers how much CO_2 the material "X" they are going to use in their research generates, but rather what amount of material "X" is going to be used in their research. These are typical questions for a researcher managing a project and having to convert available resources into planning, time, money, costs, logistics or movement of materials.

In the first case studies, this information collection was carried out by facilitators in coordination with the researchers. In the last cases, once the tool was more refined, the researchers applied the tool to their projects by themselves.

With the data resulting from the questions and due to a quick calculation design and the didactic component, the tool, allowed the researchers to introduce the data and play with the uncertainties of their projects, since they could, among other aspects, change materials, means of transport or build scenarios of possible results.

It is important to emphasize that this data and information collection is made in the early stages of a research project; in this way the researchers estimate their answers and data by imagining the future developments of their projects. Once the projects reach more advanced stages and once the researchers have more precise information and less uncertainty they can verify and go back over their initial data and predictions to (play with) change details on the tool allowing them to make a more accurate assessment.

The data and information collected in the projects selected as case studies (described below on Table 4.2, Table 4.3 and Table 4.4) are very diverse, such as, raw materials (Case Study I), hours on computer (Case Study II) and the number of computers needed for the system to be put into operation (Case Study III).

<u>Step 2: Presentation of Results to researchers</u>

Case study I: Boat Project

Table 4.2 . Boat Project description

Project title	**Boat Project**	
Aim of the Project	The Boat Project aims to substitute the traditional passenger maritime transport energy supply in the city of Cartagena de Indias (Colombia), by one using more reliable and cheaper fuel, in this case solar power. Rising cost and supply issues have been presented with the traditional alternative (diesel), therefore the purpose is to reduce the operational cost of the maritime transport system and secure the continuous supply of power.	
Research area	Electric Water Transport System	
Constructed Scenarios (with Energy saving initiatives)	Phase 1 - Research Outcomes	High: 22 Boats (50-60 passengers) Medium: 16 Boats Low: 7 Boats
	Phase 2 - Research Process	High: 2 Prototype Boats (12 passengers) As expected: 1 Prototype Boat

Figure 4.3 shows the annual tCO_2e emissions versus different components of the life cycle corresponding to the outcome of the research, in this case an electric boat. In addition, given the interest of the researchers in this project, a diesel boat was also evaluated to determine which could produce more emissions. As can be seen, the greatest environmental impact in both cases corresponds to the use of a power supply for boat navigation (blue bar) producing 137.91tCO_2e for the electric boat and 300.69tCO_2e for the diesel boat. The impact of the solar panels materials is also notable 17.79tCO_2e. For the same functional unit, the total emissions from the diesel boat 305.38tCO_2e are much higher than those from the electric boat 91.36tCO_2e, the difference is more notable taking into account that offsetting renewable energy by solar panels 78.22tCO_2e on the electric boat could compensate for more than a half of the emissions from the consumption of the electric boat.

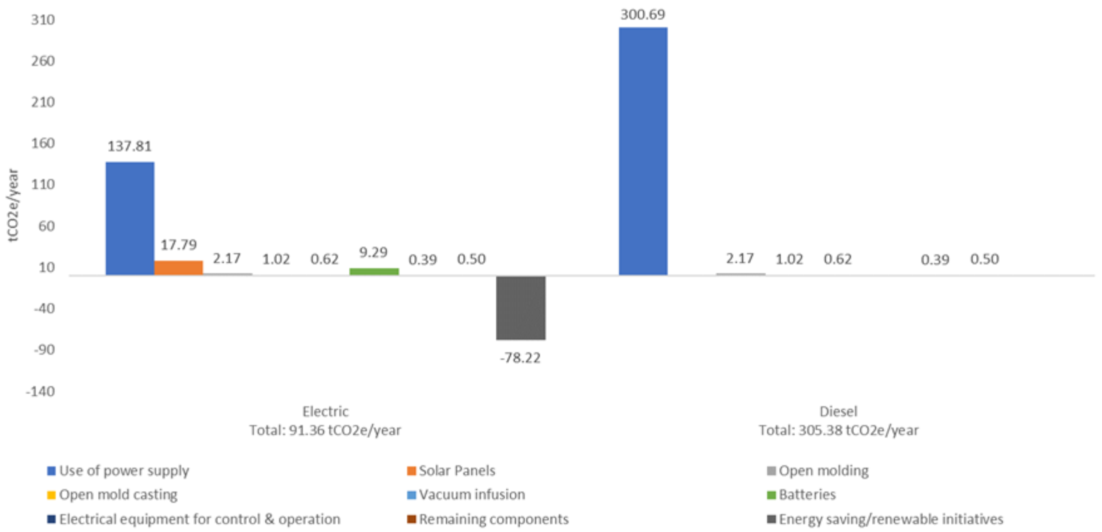

Figure 4.3 Phase 1 Research Outcomes – Scenario High

Figure 4.4 shows the impact of the project process, in which the entire research process (phase 2) has fewer emissions than 1 year of circulation of the boat resulting (phase1) from the project. This is why this project was selected to illustrate the case where the outcomes are much more emissions than the project process. In phase 2, the electric boat produces fewer emissions than the diesel boat 19.62tCO_2e versus 28.97 tCO_2e.

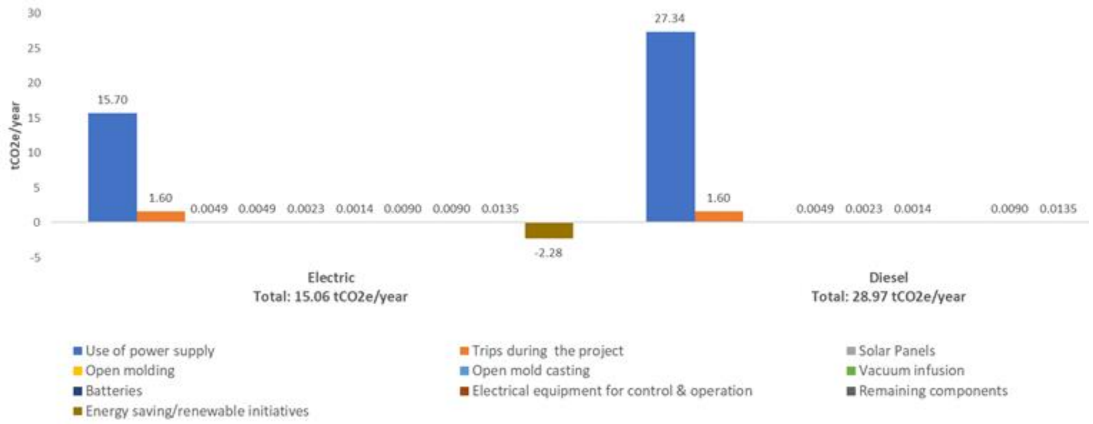

Figure 4.4. Phase 2 Research Process – Scenario High

Looking at the evolution of the phase scenarios, the same trend can be seen where the electric boat emits less CO_2 than the diesel boat, for instance, see Figure 4.5 of Phase 1 – Research outcomes.

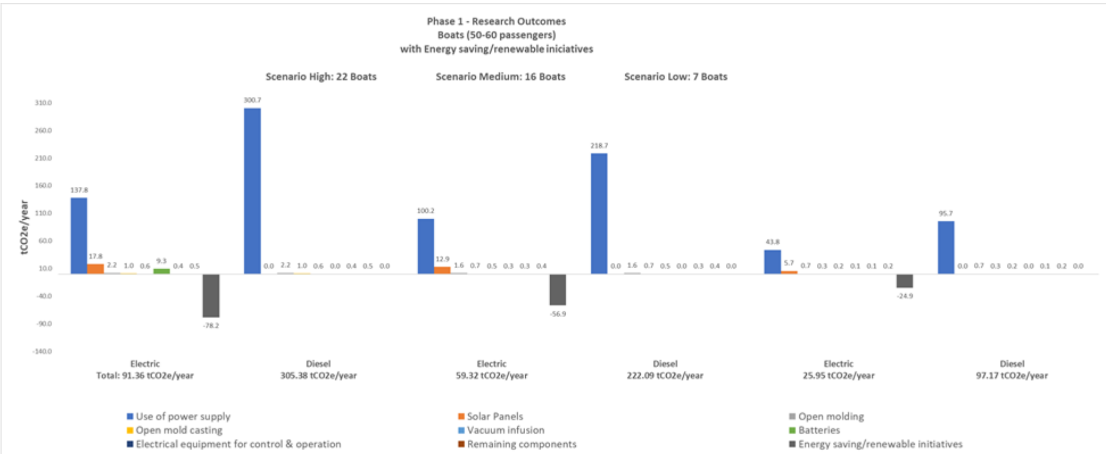

Figure 4.5. Phase 1 Research Outcomes – Scenario High, Medium and Low

Energy-saving initiative

As an energy-saving initiative, this project includes the installation of solar panels on the roof of the prototype 12 passenger and 50-60 passenger electric boats that are expected to be used in the transport system. The panel to be used is the model TALLMAX 340-375W - 72 cells. The tCO_2e per year that would be avoided with the installation of this renewable energy source was calculated taking into account the installed power, the number of panels, the average generation of the panel, the conversion factor based on the tCO_2 emitted per kilowatt-hour in Colombia and the equation described above in section 4.3.1. See the “Energy saving/ renewable initiative” bar in Figure 4.4 and Figure 4.5.

Case study II: Mobile App Project

Table 4.3 Mobile App Project's description

Project title	**Mobile App Project**	
Aims of the Project	The main objective of the Mobile App Project is to develop a real-time recommendation system for dynamic content through push notifications, based on the context of the mobile user and his/her social networks, in order to reduce human interaction with the mobile device and improve the user experience, thus choosing the effectiveness of the recommendations themselves. The nature of the project is to design a mobile app, so the scenarios were designed in terms of downloads.	
Research area	Information and Communication Technologies (ICT)	
Constructed Scenarios	Phase 1 - Research Outcomes	High: 10k app downloaded Medium: 5k app downloaded Low: 1k app downloaded
	Phase 2 - Research Process	"Long" Process: 2 times "As expected" "As expected" Process: "As expected"

As the nature of this project is to design a mobile app. For the outcomes (phase 1) the energy use of the APP was set as the only life cycle component.

Figure 4.6 shows the annual emissions of the estimated scenarios. The annual environmental impact is very low even in the scenario high with 0.03 tCO_2e.

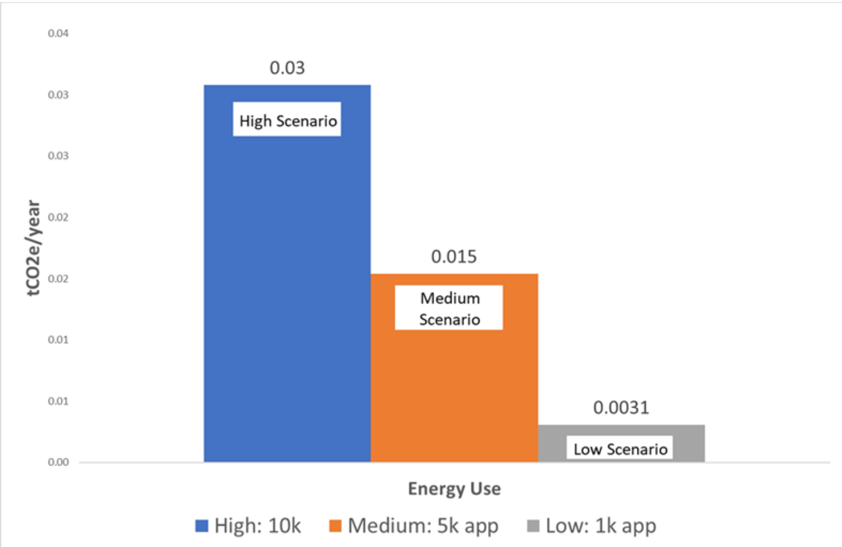

Figure 4.6. Mobile App Project. Phase 1 Research Outcomes.

In this project, the research process (phase 2) represents the greatest environmental impact. A comparison between the research outcomes (Figure 4.6) and the process (Figure 4.7) shows that the annual emissions of the "As expected" scenario are more than 200 times higher than the high scenario of the project outcomes, 6.04tCO_2e versus 0.03tCO_2e.

Figure 4.7 shows the annual tCO_2e emissions versus different components of the life cycle corresponding to “long Process” and “as expected” scenario of the Mobile App Project’s research process. As can be seen, the greatest environmental impact corresponds to energy use by air conditioning system in the office 4.66tCO_2e (grey bar) followed by the energy used 3.08tCO_2e (orange bar) and the material of the computers 2.66tCO_2e (green bar) used during this phase of the project.

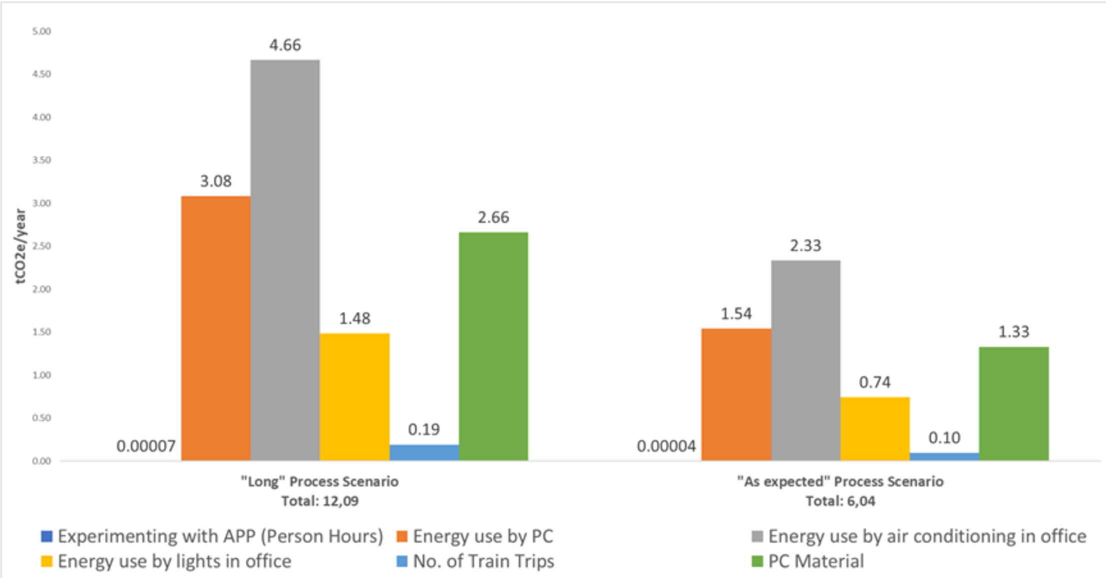

Figure 4.7 Mobile App Project. Phase 2 Research process.

The overall results indicate that efforts to reduce CO_2 emissions in Mobile App Project should be addressed to the research process, in particular to the use of energy for the air conditioning system and personal computers.

Case study III: Sensor Project

Table 4.4 Sensor Project’s description

Project title	**Sensor Project**	
Aims of the Project	The objective of the Sensor project is to develop techniques that allow the use of sensors RGBD in the evaluation of the physical load resulting from the development of a task and optimizing different aspects of the job.	
Research area	Ergonomic assessment of workstations in companies	
Constructed Scenarios	Phase 1 - Research Outcomes	High: For 100 companies Medium: For 10 companies Low: For 1 company
	Phase 2 - Research Process	“Long” Process: 2 times “As expected” “As expected” Process: “As expected”

For the implementation of the ergonomic evaluation system that would be designed in this project, two main components are required, sensors and desktop computers. Taking these components, a life cycle analysis was carried out and impact scenarios were established in terms of the number of companies in which the assessment system could be implemented: scenario High: for 100 companies; scenario Medium: for 10 companies and scenario Low: for 1 company.

For the three set scenarios Table 4.5 shows the annual tCO_2e emissions of the research outcome's life cycle components of this project (phase 1), framed in the use of energy and the materials of the sensors and desktop computers. The greatest environmental impact corresponds by far to the component "PC (for data collection) energy use" with more than $700tCO_2e$, followed by "Sensors energy use" with more than $35tCO_2e$. The emissions generated by the energy use of the components exceed the emissions generated by the component materials.

Table 4.5 Sensor Project. Phase 1 Research Outcomes. Life Cycle's Components

Life cycle's Components	**High Scenario For 100 companies Total tCO_2e: 746,81**	**Medium Scenario For 10 companies Total tCO_2e: 74,68**	**Low Scenario For 1 company Total tCO_2e: 7,47**
Sensors Energy use	35.95104	3.595104	0.3595104
PC (for data collection) Energy use	703.04256	70.304256	7.0304256
Sensor's Material - Plastic	1.0488	0.10488	0.010488
Sensor's Material - heatsink (aluminium)	1.656	0.1656	0.01656
Sensor's Material - Motherboard & sensor Board (Fiberglass and Copper)	0.35616	0.035616	0.0035616
PC (for data collection) Material	4.752	0.4752	0.04752
Total tCO_2e	**746.81**	**74.68**	**7.47**

Figure 4.8 shows that even in the Low scenario, the "energy use" is the largest emitting component, e.g., "PC (for data collection) energy use" accounts for about 150 times more emissions than "PC (for data collection) material", $7.03tCO_2e$ vs $0.05tCO_2e$, or even 20 times more emissions than "Sensor Energy use" with $0.36tCO_2e$.

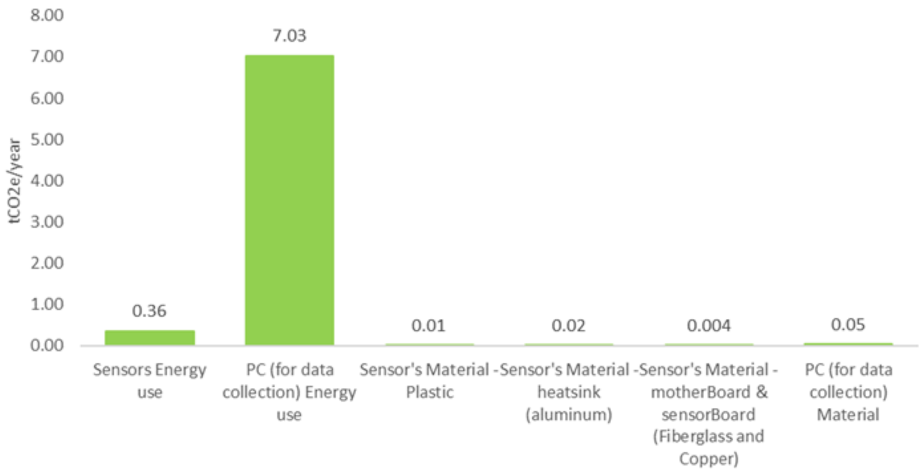

Figure 4.8. Sensor Project. Phase 1 research outcomes. Scenario "Low".

There is a notable difference between the energy used by the components in the research outcomes such Figure 4.9 shows that in the "Medium scenario" (orange bar) the "PC (for data collection) energy use" 70.3tCO_2e represents about twice the amount of emissions than "Sensor energy use" 36tCO_2e in the "High scenario" (blue bar).

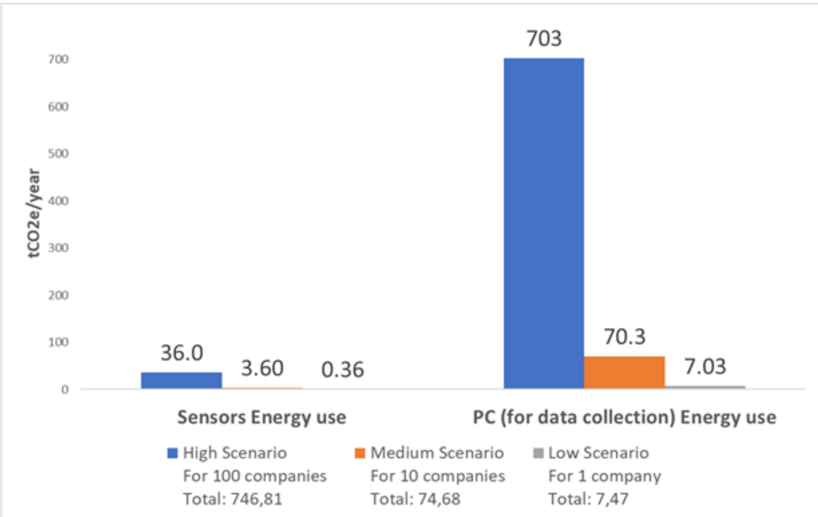

Figure 4.9 Sensor Project. Phase 1 research outcomes. Energy use by components

Table 4.6 shows all the components of the life cycle of the research process (phase 2) of this project for both scenarios: As expected and Long. The same trend of research outcomes (phase 1) can be noticed in the research process where the components of the energy use represent the highest emissions, this time not only by "desktop/laptop PC", but also for air conditioning and lights in the office.

Table 4.6. Sensor Project. Phase 2 Research Process. Life Cycle's Components

Life cycle's Components	**"Long" Process Scenario Total: 13,08**	**"As expected" Scenario Total: 6,54**
Energy use by desktop/laptop PC researchers	3.81	1.90
Energy use by computers for calculations (super PC)	0.09	0.04
Energy use room of computers for calculations (super PC) air conditioning Fans	0.26	0.13
Energy use by air conditioning in the office	2.88	1.44
Energy use by lights in office	1.47	0.73
Energy use by lights in lab	0.37	0.18
No. of train trips	0.89	0.45
Sensor's material - plastic	0.007	0.003
Sensor's material - heatsink (aluminium)	0.011	0.006
Sensor's material - Motherboard & sensor Board (fibreglass and copper)	0.002	0.001
Desktop/laptop PC researchers - Material	2.66	1.33
Computers for Calculations (super PC) Material	0.63	0.31

Taking only the "As expected" scenario as a reference, Table 4.6 shows a relative emissions equilibrium between the energy use components and the rest of the components, for instance, 1.44tCO_2e from "Energy use by air conditioning in office" versus 1.33tCO_2e from "Researcher's desktop/laptop Computers Material".

Step 3: Actions by the researchers

As explained in section 4.3, once the environmental impact assessment is completed with the tool and the final report of results is available, these are presented to the project researchers.

For each project, an amount of tCO_2e/year generated was obtained. For the Boat project, a total of 335tCO_2e/year was obtained by adding up all "High scenario" loads of the option that generated the most emissions, the diesel boat. For the Mobile App project, a total of 6.04 tCO_2e/year was obtained by taking the "As expected" scenario from research process as a reference, since this phase 2 generated far more emissions than the research outcomes (phase 1). Finally, for the Sensor project, a total of 14.01tCO_2e/year was obtained by adding up the "Low" scenario from research outcomes and the "As expected" scenario from research process (phase 2).

For a better appropriation by the project researchers of the dimension of the results (amount of tCO_2e/year), these emissions are presented to the research teams in terms of: i) the number of private vehicles on the road for 1 year, ii) the number of persons smoking for 50 years and iii) the number of tree seedlings grown over 10 years needed to absorb that amount of tCO_2e generated. As shown in Table 4.6. Sensor Project. Phase 2 Research Process. Life Cycle's Components.

	Boat	App	Sensor
tCO_2e	**335**	**6.04**	**14.01**
Private vehicles on the road for 1 year	64	1	3
Persons for 50 years smoking	66	6	3
Trees seedlings grown over 10 years needed to absorb tCO_2e	5,025	95	213

Figure 4.10 tCO_2e Equivalences: Boat Project, App Project, and Sensor Project

Actions by the Boat Project team

In this case, after the presentation of the results, the research team proposed to carry out the following actions on their project:

- Special aerodynamic design that saves energy, lightens the boat, lifts the hull so it rubs less on the water, etc.
- Energy generation with renewable energies like photovoltaic roof or renewable energy supply in ports)
- Use of diesel from waste (such as: tires, oil, energy crops, etc)
- The docking and undocking manoeuvres have been optimized, which are usually very energy-consuming manoeuvres.
- Materials with high energy consumption have been changed for others with a lower consumption (if this is the case, the corresponding materials are changed in the calculation).
- Generative braking system

Actions by Mobile APP and Sensor Project teams

Aware that travel by plane or train generates many CO_2 emissions, for both Mobile App and Sensor project, we noticed that the research teams did a lot of teleworking during the years of the execution of the project (research process – phase 2) as an energy saving initiative.

The team of facilitators of the tool, suggests the following energy-saving actions:

- Photovoltaic power generation on the office/laboratory roof
- To continue the trips by train/airplane, and all the meetings through video conferences.
- To use energy efficient computers and telecommunication equipment.
- To compensate: With the money earned from the project encourage tree planting or funding research work on climate change.

4.5 Discussion

The question we ask in this chapter is how a researcher untrained in environmental impact assessment can estimate the CO_2 Emissions at the early stages of an R&I project that does not specifically address fighting climate change. We have answered that question by designing a tool that through a user-friendly and didactic interface allows researchers committed to the CC challenge, but without enough expertise to tackle it, to interact with their project, to learn from it and estimate environmental impacts in the early stages of the research when there is a lot of uncertainty about the process and future results of the R&I project.

The results confirm that the tool works and is useful in helping researchers in the debate on anticipation and reflection upon the consideration of CO_2 emissions from the early stages of their projects. The tool is aligned with the proposed structure of actions to operationalize climate change prevention in R&I activities by the authors in a previous research (Ligardo-Herrera et al., 2018b), given that it complies with the i) application of the life cycle perspective, ii) the efficient integration of the consideration of CO_2 emissions in the core of the project, iii) the use of open databases and iv) the management of stakeholders. All these strategies were incorporated into the design and testing of the tool presented in this thesis.

As mentioned in section 4.3.1. several tools for carbon footprint assessment were found in the literature and require specialized information from researchers. The tool that has been designed and tested is based on already existing methodologies, but differs in that it is fed by typical project management information (materials, resources, technological alternatives, etc), which any researcher and/or innovator who is not an expert in environmental assessment, has open access.

The three representative case studies not only illustrate that the tool works, but also give us inputs for the design of the tool. For each project, the tool determined which phase of the project and which life cycle component for each phase generated the most CO_2. In the Boat project, the greatest environmental impact corresponds to the emissions from the diesel boat 305.38tCO_2e (phase 1). The impact is more significant taking into account that offsetting renewable energy by solar panels 78.22tCO_2e on the electric boat could compensate for more than half of the emissions from the consumption of the electric boat. In the Mobile App Project, the research process (phase 2) represents the greatest environmental impact. The annual emissions of the "As expected" scenario are more than 200 times higher than the high scenario of the project outcomes, 6.04tCO_2e vs 0.03tCO_2e. Finally, in the Sensor Project, at first glance, it can be said that one of the results is that the medium and high scenarios of the research outcomes (phase 1) outweigh the results of the research process (phase 2) scenarios. However, comparing the "Low" scenario 7.47tCO_2e of research outcomes (phase 1) against the "As expected" scenario 6.54tCO_2e of the research process (phase 2), we noticed a balance that leads the stakeholders involved to put forward improvements for the following research stages in order to reduce CO_2 emissions. Moreover, CO_2 emissions were naturally integrated into the research objectives.

In addition, to place the researcher in the phase of the research that generates the most CO_2 emissions, another important insight that the tool provides is to tell the researchers which component of the life cycle of their project emits the most CO_2. In the case of the Boat Project, it was the use of the power supply with 300.69 tCO_2e. In the case of the Mobile App Project, it was the energy used by the air conditioning in the office with 4.66tCO_2e. Finally, in the case of the Sensor Project, it was the "PC (for data collection) energy use" with 703.03tCO_2e. In this way the tool allows research teams to have a very important clue as to where to focus their efforts (energy use, change of materials, decrease of trips, compensation, etc.,.) to reduce environmental impact. See Table 4.7.

Table 4.7. Overall results of the of the Case Studies

Project (Case Studies)	**Phase of the project that generates the most CO_2**	**Life cycle component that generates the most CO_2**
Boat	Research outcomes (phase 1) and the emissions from the diesel boat	Power supply (300.69 tCO_2e)
Mobile App	Research process (phase 2)	Energy use by air conditioning in the office (4.66tCO_2e)
Sensor	Research outcomes (phase 1) & Research process (phase 2)	"PC (for data collection) energy use" (703.03tCO_2e)

As we mentioned in section 4.3. the case studies were also very useful for the design of the tool, as each project in which the tool was tested provided inputs for improvements that made the design increasingly refined. The 3-step designed test protocol allows the tool to have a dynamic component that constantly improves the design and makes it adaptable to each project.

In the case of the boat Project, rising cost and cuts of supply issues have been presented with the traditional alternative (diesel). Therefore, the proposal is to reduce the operational cost of the maritime transport system and secure the continuous supply of power by a more reliable and cheaper fuel, in this case solar power. So, it was reasonable to think that for cost reasons the Boat Project would include energy saving initiatives, unlike the Mobile App and Sensor projects. However, in practice, the latter projects did include teleworking in the development of their projects, which also has a clear cost component. It is possible that research projects where CO_2 would be expected to be assessed will eventually not be evaluated at all.

Although the issue of climate change has been discussed for many years and is now much more in the mainstream of society, in general when researchers are developing their research objectives, they are not thinking about environmental issues. This means that when researchers are asked about environmental issues, they often find it difficult to give an answer, and when they do give an answer it is usually very speculative. When the tool was applied, researchers found a didactic component that allowed them to address the environmental component in their projects. In addition, the method of reading the results by equivalence, incorporated in the tool, was useful for the researchers for locating themselves within the tool outputs in terms of "tons of CO_2". In this way, researchers were motivated to take action in their projects.

4.6 Conclusion, Limitations and Future Research

Depending on the research area to which the researcher belongs some projects will have more risk than others in terms of the amount of CO_2 generated. For instance, a research project related to energy efficiency field will surely take climate change into account, but a research project related to ICT field probably will not.

The actions taken by the equivalents can be very varied. The tool is intended to lead the actions of the research team towards the component of their research that is generating the most emissions. Researchers can also be oriented towards the compensation.

The tool was designed with the purpose of helping to estimate the environmental impacts in the early stages of a research project when there is a lot of uncertainty about the process and the future outcomes of R&I projects. This assessment can and should be done in the early stages of R&I projects, but not so early. In some cases the researchers needed to advance a little in the development of their projects to later have a clearer forecast about how their research was going to be developed and what their future results could be.

There is a difficulty in thinking about the future. For instance, impacts after 5, 10, 20 years. Many times, the answer from researchers is that they don't know. They will do what they think makes the most sense (make decisions) for their projects and then discuss it with their Stakeholders. The tool allows the creation and testing of scenarios, for instance: a scenario of renewable or polluting energy use, a scenario with or without recycling, a scenario of high or low success in the research results market, of local or worldwide sales, etc.

Certain times the researcher does not make the final decisions, which are made by the project promoter (who generally sees the project from an economic perspective), thus the initiatives of possible reductions of CO_2e emissions need to find a balance with other economic and technical objectives that are not as ambitious as they could be.

CHAPTER 5

General discussion and conclusions

5.1 Introduction

The elaboration of the thesis that you have just read was driven by one of the great challenges that our society is facing, climate change. This is the context in which the RRI arose, an area of research in which for more than 12 years different scientists have been working on the responsibility that research teams should have in society (Timmermans et al., 2017). Recently, there has also been research looking at accountability in the response to challenges such as the COVID-19 pandemic.

The importance of R&I teams as actors for CC adaptation and mitigation goes beyond their actions during the innovation process: there is a risk that when their design of choice decisions scale up in wider contexts (market success), and potential undesirable and unintended outcomes materialise, might be more negative effects than positive ones.

This doctoral thesis, therefore, aims to contribute to filling the gap in terms of calculations tools in R&I projects for the prevention of climate change (Ligardo-Herrera et al., 2018c). It introduces a new tool that helps research teams that are not experts in environmental impact assessment to reflect on the undesired problems that their research may generate, by an anticipatory calculation of the emissions that both the process and the future results of the research would generate.

This chapter presents the general answers to each of the research sub-questions (section 5.2), then, all these results are joined together to respond to the main research question of this PhD thesis (section 5.3), followed by the overview of the main contributions of this dissertation in section 5.4. Finally, the limitations and future research avenues are addressed in section 5.5.

5.2 General discussion of results

RQ1: How does a research team know if its research is responsible for relevant contributions to Climate Change?

To answer the first sub-question, 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, 2009). 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 analysed 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 literature review and the web search returned a variety of tools related to the research question. These findings were grouped into four main strategies or approaches to operationalize addressing CC within RRI (see Figure 2.1). The general strategies are:
1. Efficient integration in the core management of research and innovation.
2. Stakeholder management.
3. Applying a life cycle perspective; and
4. Open-access databases.

These strategies are fully addressed in chapter 2, section 2.5.1. Discussion of these results led to the emergence of two other avenues of research. One avenue (RQ2: second sub-question) on how to assess the influence of stakeholders in a research project within the context of RRI, which is developed in chapter 3, and one avenue (RQ3: third sub-question) on the need for new tools based on open-access databases to help practitioners integrate CC prevention into their R&D, which is developed in chapter 4.

RQ2: How to prioritize stakeholders based on their contribution to the responsibility of a research and innovation project?
The third chapter presents the answer to this question. To solve it, a methodology is put forward based on the combination of two realms: the RRI approach as the framework and the analytic network process (ANP) as the tool. The model has been applied to ongoing research as a case study for the evaluation of the contribution of stakeholders to the accountability of a research project.

Three different analyses have been carried out, in order to present the findings. First, the weights of the clusters have been obtained and compared both for the individuals and for the group. Secondly, criteria have also been analysed for the individuals and for the group. Thirdly, the ranking of the analysed stakeholders has been obtained, which is the final aim of this whole evaluation process.

The results allow us to differentiate groups of stakeholders based on their importance. This differentiation is qualitative and open to different interpretations, and here the decision of the project consortium members is shown. Based on the procedure and its learning, and also looking at the differences among stakeholders' final ANP values, three groups were made: i) the most influential one, ii) the fairly influential, and iii) the least preferred group among the influential ones. It is important to mention that all stakeholders of this classification are influential and ought to be managed. But in a situation of limited resources and some reluctance of the stakeholders to tackle the challenge of RRI, it is advisable to devote more resources: time, people, effort, money, etc. to the most influential ones. And hence the interest to classify them.

Moreover, the ANP also allows us to analyse why some of the alternatives are preferred to others. For instance, in the case study developed, this analysis shows those stakeholders to be more influential on C1.1. Public Engagement, C1.8. Social Justice and C2.4. Relations with the project, obtained the higher values.

RQ3: How can a research team untrained in environmental impact assessment estimate the carbon footprint at the early stages of a research and innovation project that does not specifically address fighting climate change?
In order to answer this third sub-question, two main stages were developed in chapter 4: (i) Tool design and (ii) Tool testing.

Tool design: A tool was designed, that through a friendly and didactic interface allows researchers committed to the CC challenge, but without enough expertise to tackle it, to interact with their project, learn from it and estimate environmental impacts in the early stages of the research when there is a lot of uncertainty about the process and future results of the R&I project. The result it is an anticipatory carbon footprint measuring Tool for R&I projects, with two (2) phases: i) outcomes and ii) process.

The evaluation starts with phase 1 for the project outcomes, in which with the data provided by the researchers, some scenarios (high, medium, or low) of the impact of the results are estimated. Then the conversion factors are applied to calculate the amount of CO_2e generated. This process is repeated with each indicator, whether it is energy consumption, or transportation, or fossil fuel consumption, or components and materials used, and energy saving initiatives making a total sum of phase 1. Phase 2, which is designed to evaluate the project's research process, repeats the process of the previous phase. This time only two impact scenarios "High" and "As expected" are estimated. Then the amounts of CO_2e calculated in phase 1 and 2 are added up, and a report of the total CO_2e generated by the project is completed.

Tool testing: The designed tool was tested, developing three (3) case studies (R&I projects). The first cases were useful for two purposes, on one hand, to verify the tool in the sense that it allows researchers to obtain useful results. On the other hand, they enriched and added details to the final design of the tool, such as small inconsistencies generated, difficulties in the use of the tool, or questions asked to researchers for which they did not have answers. For each project, the tool determined which phase of the project and which life cycle component for each phase generates the most CO_2.

Then, with a refined tool, and given the didactic component incorporated. Researchers could change and play in real time with the parameters introduced in the tool, running the case studies and making the CO_2 assessment of their research projects by themselves in an intuitive way.

The results confirm that the tool works and encourages research teams to the discuss the anticipation and reflection of CO2. The tool is aligned with the structure for operationalization of consideration of CO2 emissions in the early stages of an R&I project, presented in (Ligardo-Herrera et al., 2018c), since: (i) is based on open databases, (ii) follows a life cycle perspective, (iii) integrates carbon footprint management into the core research and (iv) applies stakeholder management. Moreover, as presented in (Ligardo-Herrera et al., 2018c), the tool is also intended for the most important stakeholders in the early stages of the research. In a situation of limited resources and some reluctance of the stakeholders to tackle the challenge of RRI, it is advisable to devote more resources (time, people, effort, money, etc.) to the most influential ones.

As mentioned in chapter 4 several tools for carbon footprint assessment were found in the literature that require specialized information from researchers. The tool that has been designed and tested is based on already existing methodologies, but differs in that it is fed by typical project management information (materials, resources, technological alternatives, etc), which any researcher and/or innovator who is not an expert in environmental assessment has open-access to.

5.3 General conclusions

All these research sub-questions results are used in combination to answer the main question of this doctoral thesis:

How does a research team, while not being specialists, know if its research is responsible for relevant contributions to Climate Change, and how can they include measures to reduce or compensate such contributions (Greenhouse Gas emissions, GHG)?

According to the results described in the previous sections, in order to address their carbon footprint, research teams must effectively involve their project stakeholders and should have open-access tools that allow them to make an anticipatory assessment of their emissions. This should not be an obstacle to the development of the R&I process. The main conclusions in response to the main research question of this thesis will be addressed below:

In reference to addressing Climate Change through 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.

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.

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 what 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.

In reference to assessing stakeholders' contribution to the anticipation of the responsibility of a research project.
A novel application of an MCDM technique to evaluate the stakeholder influences on a project has been provided, which in this case is applied to their contribution to the anticipation of the responsibility of the project and its possible outcomes.

The preference measures the greater or lesser influence of stakeholders on research responsibility within a framework of RRI. Thus, they can prioritize based on their expected contribution to the anticipation of the issues related to the social desirability of the activity.

Stakeholder management is normally a key activity in research, and particularly so in responsible research. Within stakeholder management, stakeholder analysis is critical for identifying, understanding and proposing strategies for involving them as much as decided. The existing methods of stakeholder analysis can be complemented with the results of the investigation herein presented. The ANP method has shown itself useful to rank and order the stakeholders, a purpose other methods do not cover, or address very indirectly. Besides, ANP can be adopted and applied to other types of influence assessment.

According to the RRI perspective, as the project develops, a more inclusive stakeholder dialogue will be necessary, including a broader spectrum of stakeholders.

The selected experts have found those stakeholders best related to the project, and more able to engage the public in a debate about the project's RRI issues. They are indeed the ones that can contribute the most to the anticipation of those issues.

In reference to the design and testing of a tool for the anticipated calculation of the carbon footprint in research and innovation projects.
The carbon footprint of R&I projects is always different in each project. For example, in an environmental project probably the climate change impact component will be considered, but in an ICT project probably not. In general, the field of research to which the project belongs marks a trend towards the consideration or not of the environmental component.

This environmental impact assessment should be made in the early stages of R&I projects. The tool designed and tested in this thesis was developed to help research teams calculate environmental impacts in those early stages of research projects, when there is a lot of uncertainty about the process and future results. However, in some cases, researchers needed to make some progress in the development of their projects in order to have a clearer forecast of how their research is going to be carried out and what their future results might be.

The tool allows for the creation and testing of scenarios, for example: a scenario of renewable or polluting energy use, a scenario of with or without recycling, a scenario of high or low success in the research results market, local or global sales, etc. This is useful to help researchers think about the future. Even to estimate 5, 10, or 20-year impact scenarios.

Initiatives for possible reductions of CO2e emissions in projects are addressed together with other economic and technical objectives to achieve a balance. The problem is that often these other objectives are not as ambitious in environmental terms as they could be. Many times, there are decisions that are made by the project funder (who usually sees the project from an economic perspective) and not by the researcher.

5.4 Main contributions

The main contribution of this PhD thesis is to introduce a new tool, with evidence that works, and encourages the anticipation and reflection of those research teams that are not specialists in environmental sustainability and in particular in climate change prevention. This tool informs the participation of stakeholders, and allows them to make collective decisions in the early stages of an R&I projects by calculating an estimate of CO2e emissions that could be generated, both during the research process and during the exploitation of its outcomes.

Another important contribution is that for a complete operationalization of the anticipation and reflection of R&I teams a four-actions framework for CC prevention in RRI was determined: i) Efficient integration in the core management of research and innovation; ii. Stakeholder management; iii). Applying a life cycle perspective; and iv). Open-access databases.

This four-actions framework has to structure the participation of stakeholders at the early stages of an R&I project. Here is where an important contribution is also made. In order to select the most relevant stakeholders at the early stages, a methodology has been proposed to assess the stakeholders' influence in an R&I project within the context of RRI. The methodology is based on a combination of the multicriteria decision making technique analytic network process and the key areas of responsible research. The method allows ranking and ordering the project's stakeholders based on their influence upon its responsibility. The purpose of such an assessment is to help research teams to more efficiently devote their limited resources to stakeholder management.

5.5 Limitations and future lines of research

We have successfully simulated and built the basis and contents of a robust CO2 calculation tool for research projects. The main lines for future research will be to develop an easy to use, friendly and didactic web-type interface that allows untrained researchers in environmental impact assessment to calculate the CO2 emissions of their project at early stages of the research process and outcomes.

The Ecoinvent database provides us with the conversion factors required for our methodology to work. With other open databases, our methodology would not work, as they do not have the needed conversion factors to make the calculations that would allow us to answer the researchers' questions. A further line of research will be to work on the promotion and/or creation of more open and robust databases, so as not to depend on information found in databases without open access. The trend in the academic and social realm is towards open-access information and data. It is expected that future efforts by the European Union and other public administrations to develop rigorous and complete open databases of life cycle analysis, and will solve the limitation of our tool being based on a database that is not open access.

With the case studies carried out in this thesis, we can say that the tool works, but we will carry out more case studies in the future and we will see what insights we find and thus, be able to work on them. This is another line of research to be worked on in the future. In this way we will be able to guarantee that the tool works for any R&I project where the reduction of the carbon footprint is not addressed from the early stages of the research.

Finally, the databases are still pictures that are updated over time, so in the future we will work on how to make sure that as the data (energy, CO2, materials, etc.,) that serve as inputs for the tool, change, and that the designed and tested tool in this thesis also gets updated.

Conclusions – Spanish version

Conclusiones generales

Los resultados de todas estas sub-preguntas de investigación se utilizan en combinación para responder a la pregunta principal de esta tesis doctoral:

¿Cómo sabe un equipo de investigación, sin ser especialista en evaluación ambiental, si su investigación es responsable de emisiones contribuyentes al cambio climático, y cómo puede incluir medidas para reducir o compensar esas emisiones de gases de efecto invernadero (GEI)?

De acuerdo con los resultados descritos en las secciones anteriores, para abordar la huella de carbono de sus proyectos, los equipos de investigación deben hacer participar eficazmente a los stakeholders en sus proyectos y deben disponer de instrumentos de acceso abierto que les permitan hacer una evaluación anticipada de sus emisiones. Esto no debería ser un obstáculo para el desarrollo del proceso de investigación e innovación. A continuación, se abordan las principales conclusiones en respuesta a la pregunta principal de investigación de esta tesis:

En referencia a abordar el cambio climático a través de la RRI.
Como se había previsto, dado que la sostenibilidad fue incluida como área clave de la RRI para la deseabilidad social de la investigación y la innovación después de las primeras seis áreas, se encontraron pocos proyectos y propuestas que abordaran la sostenibilidad, y el CC en particular. No obstante, se encontraron varios equipos y proyectos de investigación e innovación y sus conclusiones tienen un gran potencial para informar la puesta en marcha de la RRI relacionada con la CC. De esta manera, la mayoría de las conclusiones procedían de los ámbitos de la Responsabilidad Social Empresarial RSE y la Innovación Sostenible.

Las conclusiones del análisis de documentos y la revisión en la web se organizaron en cuatro estrategias principales para la operacionalización de la RRI. Las herramientas propuestas permitirán a los equipos de Investigación e Innovación o a los responsables de la elaboración de las políticas, en primer lugar, tomar conciencia de la relevancia de sus impactos en el CC, en segundo lugar, identificar el qué, cuándo y por qué de esas contribuciones al CC, y por último, integrar en sus procedimientos los medios para abordar el problema.

La mayoría de los autores y profesionales consultados afirman que la RRI será más eficaz y eficiente si se asume voluntariamente en un proceso de abajo hacia arriba. Los encargados de formular políticas y los financiadores de la I + D pueden ser impulsores de la difusión de la RRI, pero en la actualidad las principales barreras son la falta de concienciación y de herramientas adecuadas para aplicar la RRI relacionada con la CC. Esta conclusión puede aplicarse a la RRI en general.

Por lo tanto, si se considera pertinente, la prevención de CC debe incluirse en los objetivos y procedimientos básicos de los equipos de I + D. Esto debe abarcar el ciclo de vida completo de los proyectos de I + D, es decir, se deben evaluar no sólo las actividades de investigación sino también los resultados previstos de I + D. Para ello, se identificaron herramientas para la evaluación del ciclo de vida, bases de datos abiertas y la gestión de los stakeholders. El objetivo es que permitan identificar los indicadores clave de rendimiento que impulsarán las actividades de I + I, supervisar las mejoras y, en una escala más amplia, ayudar a prevenir y educar sobre la CC.

También se encontraron diversas barreras que obstaculizaban la puesta en marcha de la prevención del CC, más allá de la falta de concienciación, de conocimientos técnicos específicos o de herramientas para este fin. Hay dificultades filosóficas y éticas aún no resueltas para aclarar en qué medida se debe asignar a los profesionales de la investigación y la innovación responsabilidades relacionadas con lo que podría suceder en el futuro. Además, se han encontrado problemas de comunicación entre los promotores y financiadores de la investigación y el desarrollo y los profesionales de la investigación y el desarrollo. Muchos de los conceptos, términos, argumentos e incluso indicadores de RRI relacionados con la CC, siguen siendo poco claros para los profesionales de I + I. Otro importante inconveniente es la percepción de una falta general de interés o de educación de los stakeholders en las áreas clave de la RRI, y en particular en la CC.

Respecto a la evaluación de la contribución de los stakeholders a la previsión de la responsabilidad de un proyecto de investigación.
Se ha proporcionado una aplicación novedosa de una técnica de MCDM para evaluar las influencias de los stakeholders en un proyecto. En este caso se aplica a la contribución de los stakeholders en la anticipación de la responsabilidad del proyecto y sus posibles resultados.

La preferencia mide la mayor o menor influencia de los stakeholders en la responsabilidad de la investigación en el marco de la RRI. Así pues, pueden establecer prioridades en función de su contribución prevista a la anticipación de las cuestiones relacionadas con la conveniencia social de la actividad.

La gestión de los stakeholders suele ser una actividad clave en la investigación, y en particular en la investigación responsable. Su análisis es fundamental para identificar, comprender y proponer estrategias para hacerlos participar tanto como se decida. Los métodos existentes de análisis de los stakeholders pueden complementarse con los resultados de la investigación que aquí se presentan. El método ANP ha demostrado ser útil para clasificar y ordenar los stakeholders, un propósito que otros métodos no cubren, o abordan muy indirectamente. Además, el método ANP puede adoptarse y aplicarse a otros tipos de evaluación de la influencia.

Según la perspectiva de la RRI, a medida que se desarrolle el proyecto, será necesario un diálogo más inclusivo entre los stakeholders, que incluya un espectro más amplio de los mismos.

Los expertos seleccionados han considerado que esos stakeholders son los que mejor se relacionan con el proyecto y los que están más capacitados para hacer participar al público en un debate sobre las cuestiones de la RRI en un proyecto. De hecho, son los que más pueden contribuir a la anticipación de esas cuestiones.

Respecto al diseño y testeo de una herramienta para el cálculo anticipado de la huella de carbono en proyectos de investigación e innovación.
La huella de carbono de los proyectos de investigación e innovación es siempre diferente en cada proyecto. Por ejemplo, en un proyecto ambiental probablemente se considerará el componente del impacto del cambio climático, pero en un proyecto del área TIC probablemente no. En general, el campo de investigación al que pertenece el proyecto marca una tendencia a considerar o no el componente ambiental.

Esta evaluación del impacto ambiental debería realizarse en las primeras etapas de los proyectos de investigación e innovación. La herramienta diseñada y probada en esta tesis fue desarrollada para ayudar a los equipos de investigación a calcular los impactos ambientales en esas etapas tempranas de los proyectos de investigación, cuando hay mucha incertidumbre sobre el proceso y los resultados futuros. Sin embargo, en algunos casos, los investigadores necesitaban hacer algunos progresos en el desarrollo de sus proyectos a fin de tener una previsión más clara de cómo se va a llevar a cabo su investigación y cuáles podrían ser sus resultados futuros.

La herramienta permite crear y probar escenarios, por ejemplo: un escenario de uso de energía renovable o contaminante, un escenario de con o sin reciclaje, un escenario de alto o bajo éxito en el mercado de los resultados de la investigación, ventas locales o globales, etc. Esto es útil para ayudar a los investigadores a pensar en el futuro. Incluso para estimar escenarios de impacto a 5, 10 o 20 años.

Las iniciativas para la posible reducción de las emisiones de CO_2e en los proyectos se abordan junto con otros objetivos económicos y técnicos para lograr un equilibrio. El problema es que a menudo estos otros objetivos no son tan ambiciosos en términos ambientales como podrían ser. Muchas veces, hay decisiones que son tomadas por el financiador del proyecto (que normalmente ve el proyecto desde una perspectiva económica) y no por el investigador.

Contribuciones principales

La principal contribución de esta tesis doctoral es introducir una nueva herramienta, con la evidencia de que funciona, y permite la anticipación y la reflexión de los equipos de investigación que no son especialistas en sostenibilidad ambiental y, en particular, en la prevención del cambio climático. Esta herramienta informa la participación de los stakeholders y les permite tomar decisiones colectivas en las primeras etapas de un proyecto de investigación y desarrollo, calculando una estimación de las emisiones de CO2e que podrían generarse, tanto en el proceso de investigación como durante la explotación de sus resultados.

Otra contribución importante es que para una completa operatividad de la anticipación y reflexión de los equipos de investigación e innovación se determinó un marco de cuatro acciones para la prevención de la CC en la RRI: i) Integración eficiente en la gestión básica de la investigación y la innovación; ii) Gestión de las partes interesadas; iii). Aplicación de una perspectiva de ciclo de vida; y iv). Bases de datos de libre acceso.

Este marco de cuatro acciones tiene que estructurar la participación de los stakeholders en las primeras etapas de un proyecto de investigación y desarrollo. Aquí es donde también se hace otra importante contribución. A fin de seleccionar a los stakeholders más pertinentes en las primeras etapas, se ha propuesto una metodología para evaluar la influencia de los stakeholders en un proyecto de investigación e innovación en el contexto de la investigación y la innovación responsables. La metodología se basa en una combinación del proceso analítico en red ANP y las áreas clave de la RRI. El método permite clasificar y ordenar a los stakeholders en el proyecto en función de su influencia en su responsabilidad. El propósito de esa evaluación es ayudar a los equipos de investigación a dedicar más eficazmente sus limitados recursos a la gestión de los stakeholders.

Limitaciones y futuras líneas de investigación

Hemos simulado con éxito y construido la base y el contenido de una robusta herramienta de cálculo de CO2 para proyectos de investigación. Las principales líneas de investigación futuras serán desarrollar una interfaz de tipo web fácil de usar, amigable y didáctica que permita a los investigadores no entrenados en la evaluación del impacto ambiental calcular las emisiones de CO_2 de su proyecto en las primeras etapas del proceso de investigación y sus resultados.

La base de datos de Ecoinvent nos proporciona los factores de conversión necesarios para que nuestra metodología funcione. Con otras bases de datos abiertas, nuestra metodología no funcionaría, ya que no tienen los factores de conversión necesarios para hacer los cálculos que nos permitirían responder a las preguntas de los investigadores. En este sentido, otra línea de investigación será trabajar en la promoción y/o creación de bases de datos abiertas y sólidas, para no depender de la información que se encuentra en bases de datos sin acceso abierto. La tendencia en el ámbito académico y social es hacia la información y los datos de acceso abierto. Se espera que los futuros esfuerzos de la Unión Europea y otras administraciones públicas para desarrollar bases de datos abiertas rigurosas y completas de análisis del ciclo de vida, resuelva la limitación de que nuestra herramienta se base en una base de datos que no sea de acceso abierto.

Con los estudios de casos realizados en esta tesis, podemos afirmar que la herramienta funciona, pero realizaremos más estudios de casos en el futuro y veremos qué conocimientos encontramos y así poder trabajar en ellos. Esta es otra línea de investigación en la que se trabajará. De esta manera podremos garantizar que la herramienta funciona para cualquier proyecto de investigación e innovación en el que no se aborde la reducción de la huella de carbono desde las primeras etapas de la investigación.

Finalmente, las bases de datos son todavía imágenes fijas en tiempo que deben actualizarse, por lo que en el futuro trabajaremos en cómo asegurarnos de que a medida que los datos (energía, CO_2, materiales, etc.,) que sirven como insumos para la herramienta, cambien, la herramienta diseñada y probada en esta tesis también se actualice.

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APPENDICES

Appendix 1*. Data of the 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
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

Project	Sustainability or CC	Methods, etc.	Top-down	Bottom-up	Leader	Web Link	Area	Situation
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
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

Project	Sustainability or CC	Methods, etc.	Top-down	Bottom-up	Leader	Web Link	Area	Situation
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

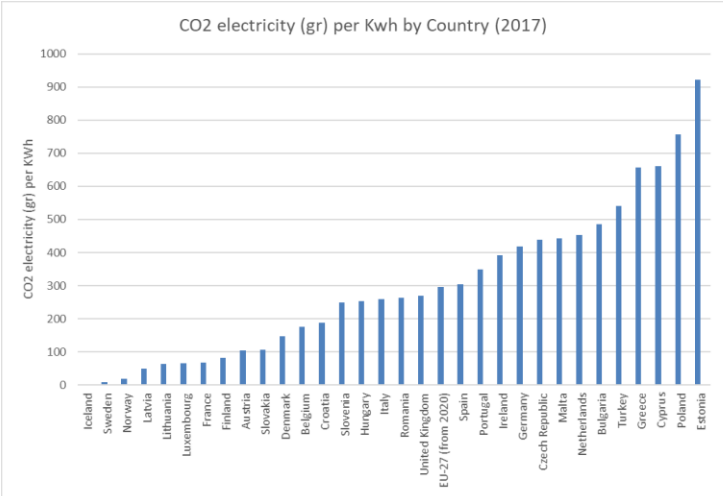
Appendix 2. *Data of the Reviewed Carbon Footprint Calculators*

Calculator Tool	Scope	Release year
Carbon Footprint software developed by Carbon Footprint Ltd (United Kingdom) www.carbonfootprint.com	Individuals Businesses Organisations	2002
Sectoral Decarbonization Approach (SDA) developed by the partners (CDP, WRI, & WWF) https://sciencebasedtargets.org/sbti-tool/	Companies	2019
Environmental footprint calculator developed by WWF https://footprint.wwf.org.uk/#/	Individuals	2002
Greenhouse Gas Equivalencies Calculator developed by EPA (USA) https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator	Businesses Organisations Individuals	2008
EPA's Household Carbon Footprint Calculator developed by EPA (USA) https://www3.epa.gov/carbon-footprint-calculator/	Individuals Households	2008
ClimateCare Calculator developed by Climate Care (United Kingdom) https://climatecare.org/calculator/	Businesses Organisations	2009
Carbon Footprint Calculator (United Kingdom) developed by The Carbon Trust https://gbfcalc.azurewebsites.net/gbf/calc/dataneeds	Businesses Organisations Governments	2017
Australian Greenhouse Calculator developed by EPA Victoria and Education Services Australia Limited (Australia) https://apps.epa.vic.gov.au/AGC/home.html	Individuals	2011
The Carbon Neutral Charitable Fund (CNCF) developed by Carbon Neutral Charitable Fund (Australia) https://cncf.com.au/carbon-calculator/	Businesses Organisations Individuals	2013
Atmosfair Software developed by Atmosfair (Germany) https://www.atmosfair.de/en/	Businesses Organisations Individuals	2005
Carbon Footprint Calculator developed by The Nature Conservancy organization and CoolClimate (USA) https://www.nature.org/en-us/get-involved/how-to-help/carbon-footprint-calculator/	Businesses Organisations Individuals	2015
Conservation International Carbon Footprint Calculator, developed by Conservation International & SC Johnson Company (USA) https://www.conservation.org/carbon-footprint-calculator#/	Individuals	2017
EX-Ante Carbon-balance Tool (EX-ACT)	Agriculture	2011

Calculator Tool	Scope	Release year
developed by FAO (Italy) http://www.fao.org/tc/exact/carbon-balance-tool-ex-act/en/	Forestry Fisheries	
Carbon Footprint Calculator developed by Mossy Earth (United Kingdom) https://mossy.earth/pages/carbon-footprint-calculator	Businesses Organisations Individuals	2019
Greenhouse Gas Protocol tools developed by WRI & WBCSD (USA & Switzerland) https://ghgprotocol.org/calculation-tools	Industries and businesses regardless of sector. Cross-Sectors Specific-Sectors National Cities	2001
Footprint Calculator developed by Global Footprint Network (USA & Switzerland) https://www.footprintnetwork.org/resources/footprint-calculator/	Organisations Cross-Sectors Specific-Sectors National Cities Individuals Industries	2007
Environmental Footprint with GaBi Software developed by Sphera (before ThinkStep) (Germany) http://www.gabi-software.com/international/solutions/product-environmental-footprint/	Businesses Organisations Products	2015
Terrapass Carbon Footprint Calculator developed by Terrapass (USA) https://www.terrapass.com/carbon-footprint-calculator	Businesses Organisations Individuals	2004
Myclimate CO_2 Calculator developed by Foundation myclimate (Switzerland) https://co2.myclimate.org/en/offset_further_emissions	Businesses Organisations Individuals	2006

__Appendix 3__. CO2 electricity (gr) per Kwh by Country

CO2 electricity (gr) per KWh (2017) gCO2/KWh	Country
0.02	Iceland
9.27	Sweden
18.92	Norway
49.16	Latvia
63.69	Lithuania
65.18	Luxembourg
67.23	France
82.79	Finland
103.98	Austria
107.31	Slovakia
147.66	Denmark
176.07	Belgium
187.95	Croatia
248.26	Slovenia
252.96	Hungary
258.80	Italy
262.52	Romania
268.52	United Kingdom
295.74	EU-27 (from 2020)
304.30	Spain
349.78	Portugal
392.53	Ireland
418.82	Germany
437.85	Czech Republic
441.77	Malta
452.63	Netherlands
486.21	Bulgaria
541.43	Turkey
657.31	Greece
660.69	Cyprus
755.72	Poland
922.41	Estonia

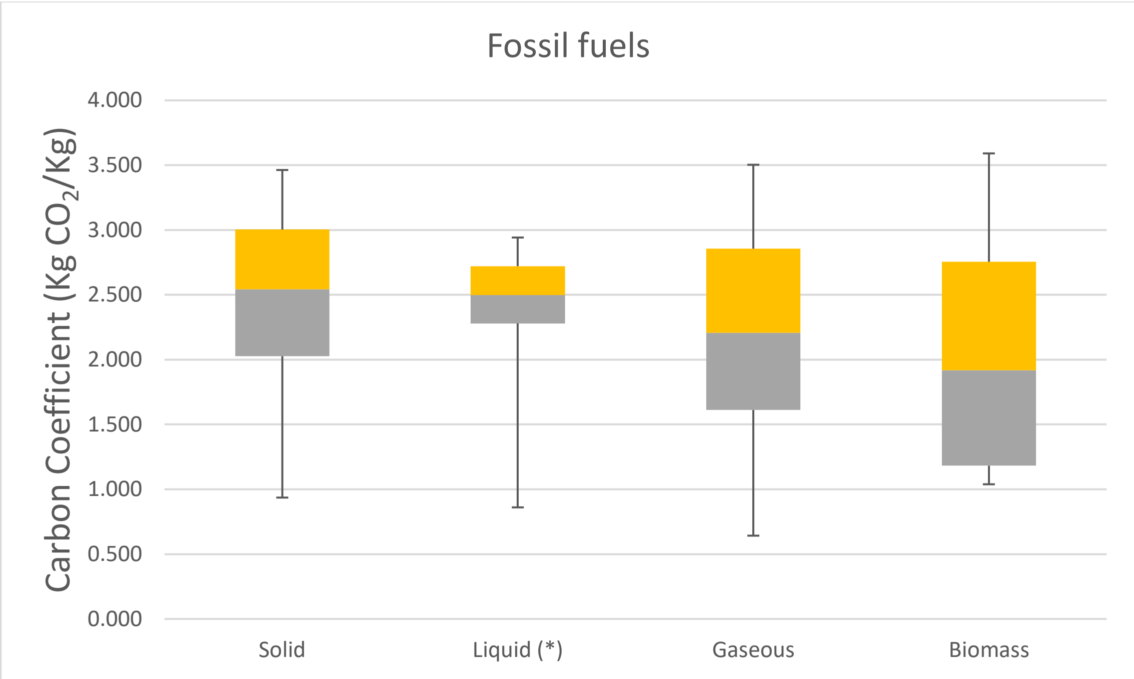


Source: CO2 Intensity of Electricity Generation
https://www.eea.europa.eu/data-and-maps/data/co2-intensity-of-electricity-generation

Appendix 4. *Fossil Fuels*

Carbon Coefficient (Kg CO2/Kg)

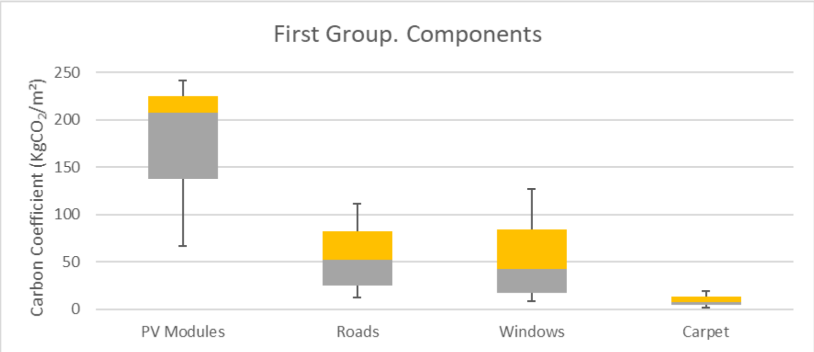
	Solid	Liquid (*)	Gaseous	Biomass
Min	0.936	0.860	0.642	1.039
Q1	1.091	1.419	0.969	0.143
Q2 - Mediana	0.517	0.220	0.596	0.736
Q3	0.459	0.221	0.648	0.836
Max	0.251	0.236	0.132	0.746



Appendix 5. *Large Energy Compo & Materials*

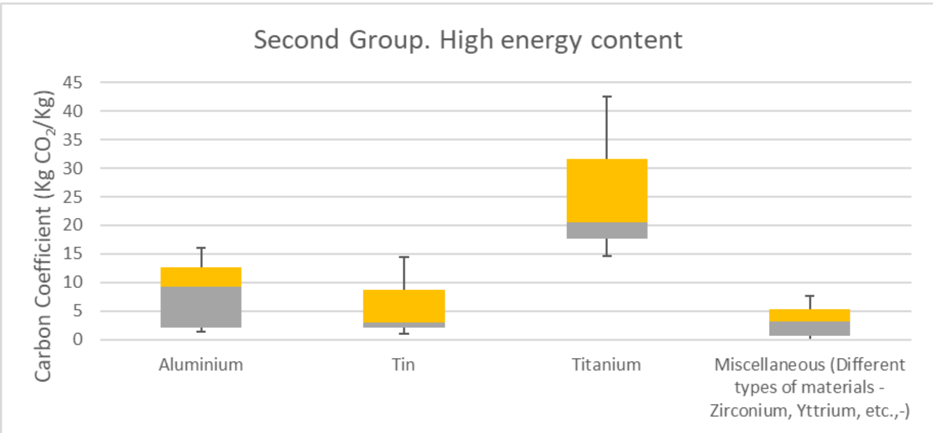
First Group. Components

	PV Modules	**Roads**	**Windows**	**Carpet**
Min	67	12.3	8.33	1.65
Q1	70.5	12.55	9.20	3.4675
Q2 - Mediana	70.5	27.55	25.17	2.1075
Q3	17	29.6	42.01	6.225
Max	17	60	109.03	6.25



Second Group. High energy content

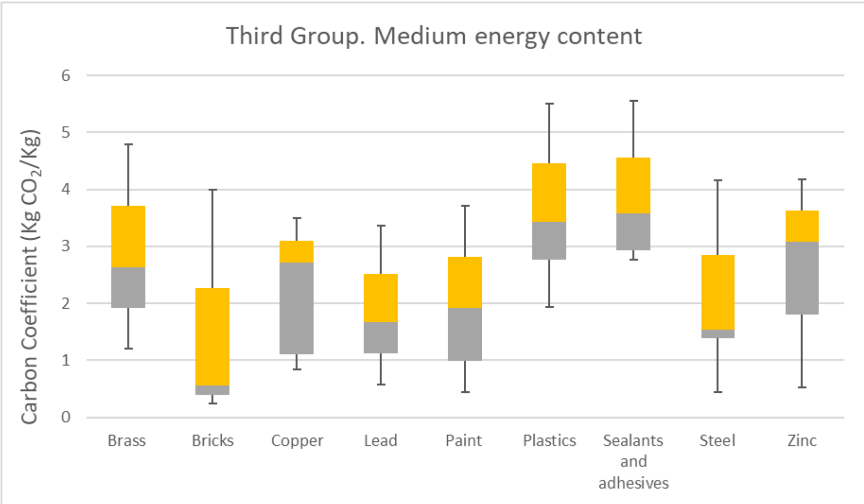
	Aluminium	**Tin**	**Titanium**	**Miscellaneous (Different types of materials -Zirconium, Yttrium, etc.,-)**
Min	1.45	1.04	14.7	0.0008
Q1	0.5925	0.96	2.95	0.7092
Q2 - Mediana	7.1275	0.96	2.95	2.39
Q3	3.4025	5.755	10.95	2.2675
Max	0.5275	5.755	10.95	24.9325



Appendix 6. Medium Energy Materials

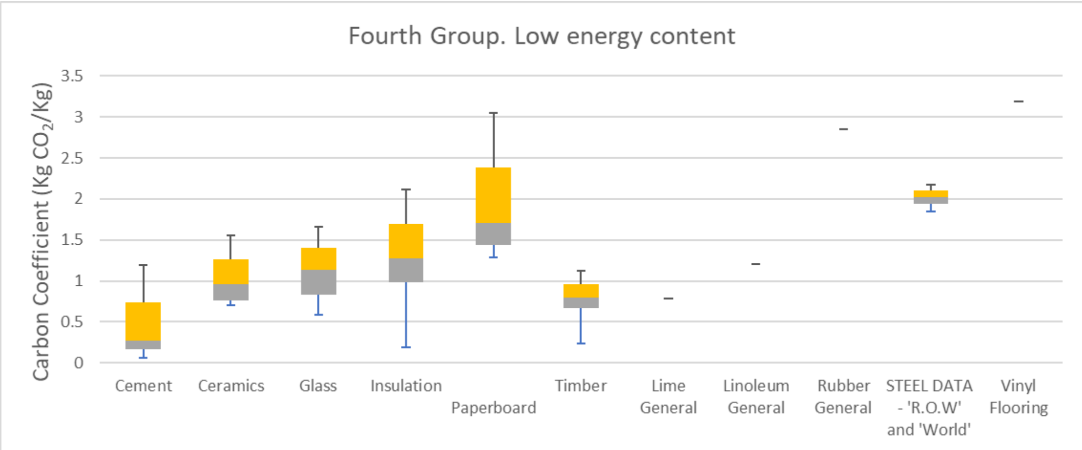
Third Group. Medium energy content

	Brass	Bricks	Copper	Lead	Paint	Plastics	Sealants and adhesives	Steel	Zinc
Min	1.2	0.24	0.84	0.58	0.4369369	1.93	2.76	0.45	0.52
Q1	0.72	0.155	0.26	0.54405	0.5461712	0.8425	0.165	0.935	1.285
Q2 Mediana	0.72	0.155	1.61	0.54405	0.9422973	0.6575	0.66	0.15	1.285
Q3	1.08	1.725	0.39	0.85095	0.8920946	1.035	0.9825	1.31	0.545
Max	1.08	1.725	0.71	0.85095	0.9425	4.675	1.1325	0.425	0.545



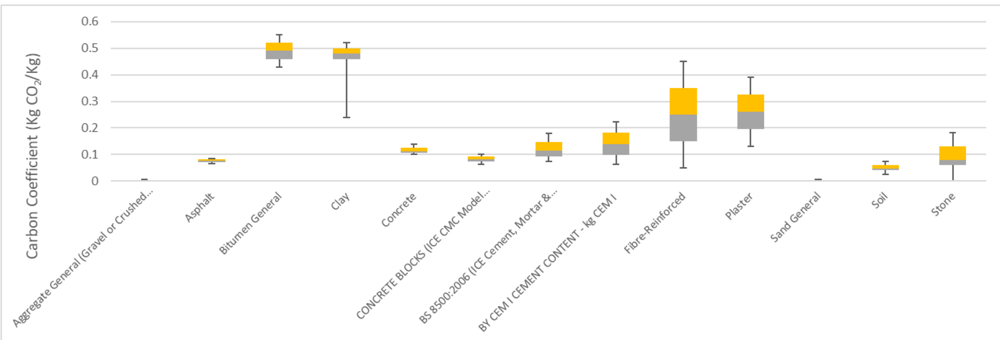
Fourth Group. Low energy content

	Cement	Ceramics	Glass	Insulation	Paper board	Timber	Lime General	Linoleum General	Rubber General	STEEL DATA - 'R.O.W' and 'World'	Vinyl Flooring
Min	0.061	0.7	0.59	0.19	1.29	0.24	0.78	1.21	2.85	1.85	3.19
Q1	0.0995	0.06	0.24	0.79	0.15	0.4275	0	0	0	0.0925	0
Q2 - Mediana	0.11	0.2	0.3	0.3	0.27	0.1325	0	0	0	0.0775	0
Q3	0.462	0.2975	0.2675	0.42	0.67	0.16	0	0	0	0.0775	0
Max	0.5475	0.3525	0.1425	0.21	1.35	0.14	0	0	0	0.2125	0



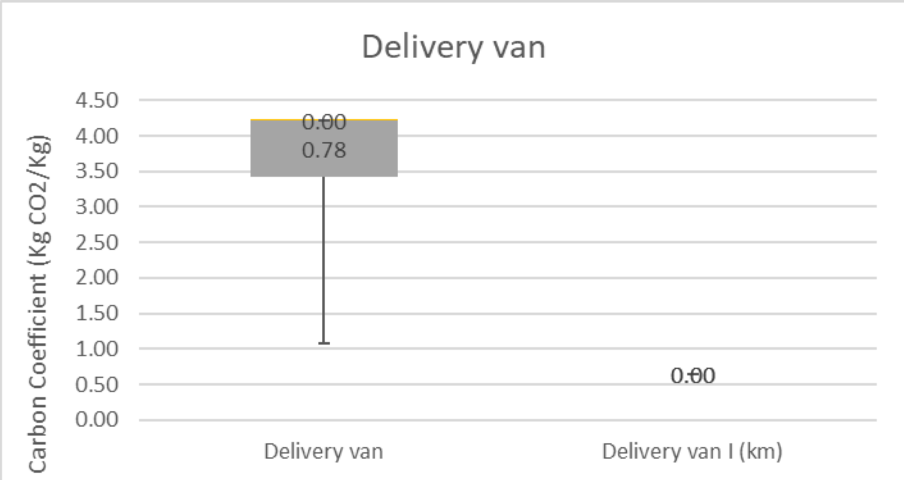
Fifth Group. Very low energy content

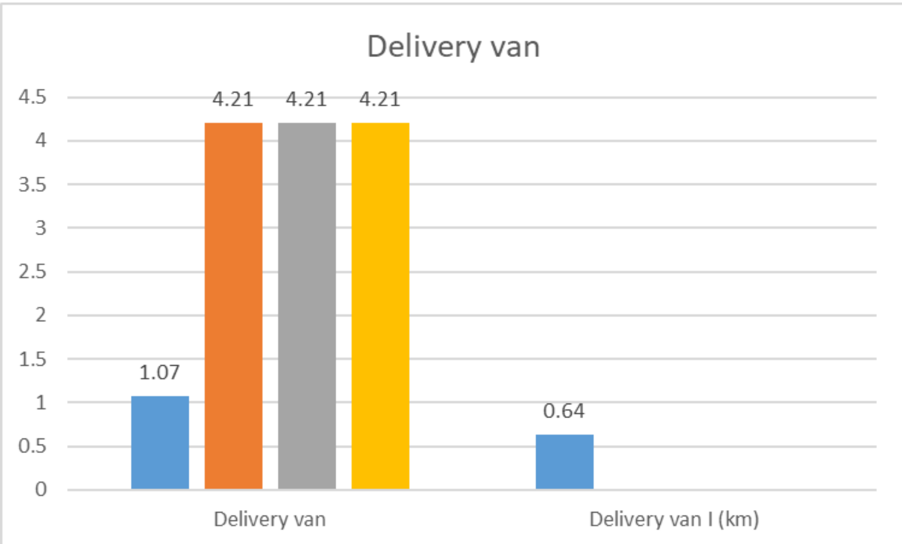
	Aggregate General (Gravel or Crushed Rock)	Asphalt	Bitumen General	Clay	Concrete	CONCRETE BLOCKS (ICE CMC Model Values)	BS 8500:2006 (ICE Cement, Mortar & Concrete Model Calculations)	BY CEM I CEMENT CONTENT - kg CEM I	Fibre-Reinforced	Plaster	Sand General	Soil	Stone
Min	0.0052	0.066	0.43	0.24	0.1	0.063248	0.074	0.064	0.05	0.13	0.0051	0.024	0.002
Q1	0	0.005	0.03	0.22	0.007	0.0111465	0.0195	0.033	0.1	0.065	0	0.017	0.058
Q2 - Mediana	0	0.005	0.03	0.02	0.006	0.0085305	0.0205	0.043	0.1	0.065	0	0.006	0.019
Q3	0	0.005	0.03	0.02	0.013	0.00963	0.03325	0.041	0.1	0.065	0	0.014	0.051
Max	0	0.005	0.03	0.05	0.025	0.014445	0.05875	0.043	0.1	0.065	0	0.023	0.57



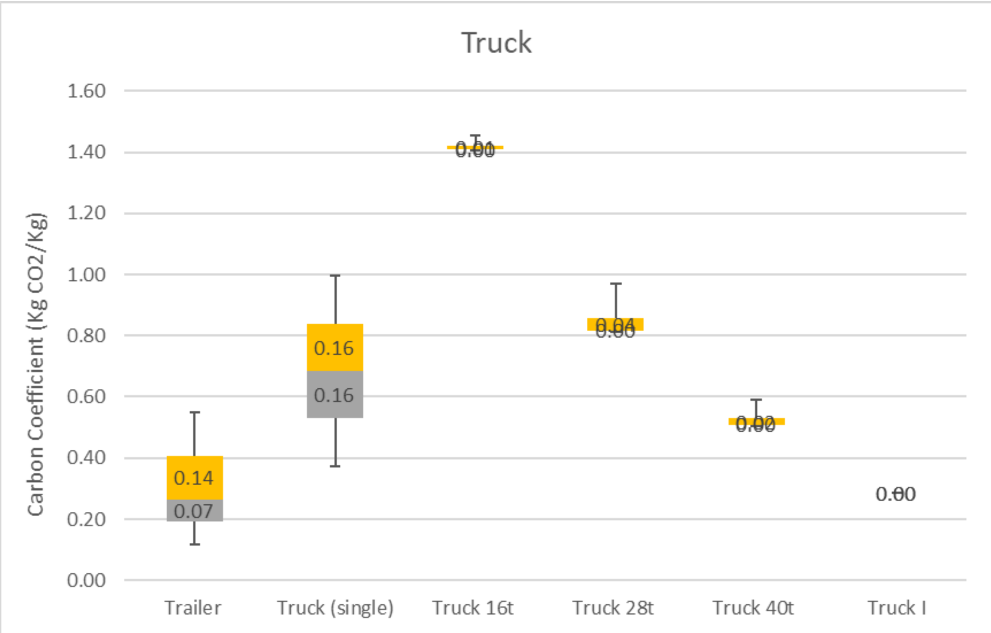
Appendix 7. ***Transport***

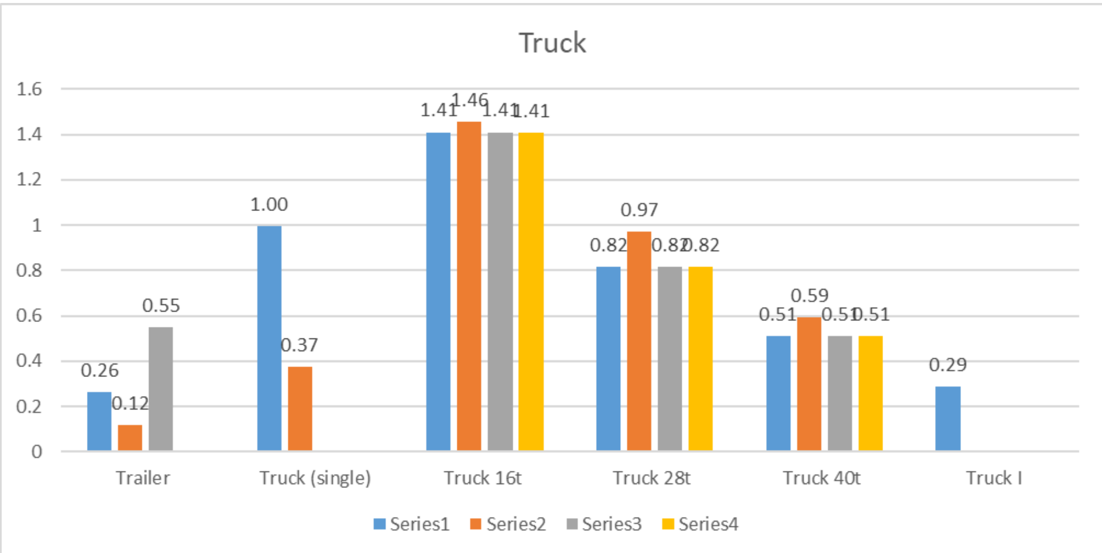
	Delivery van	Delivery van I (km)
Min	1.07	0.64
Q1	2.35	0.00
Q2 - Mediana	0.78	0.00
Q3	0.00	0.00
Max	0.00	0.00



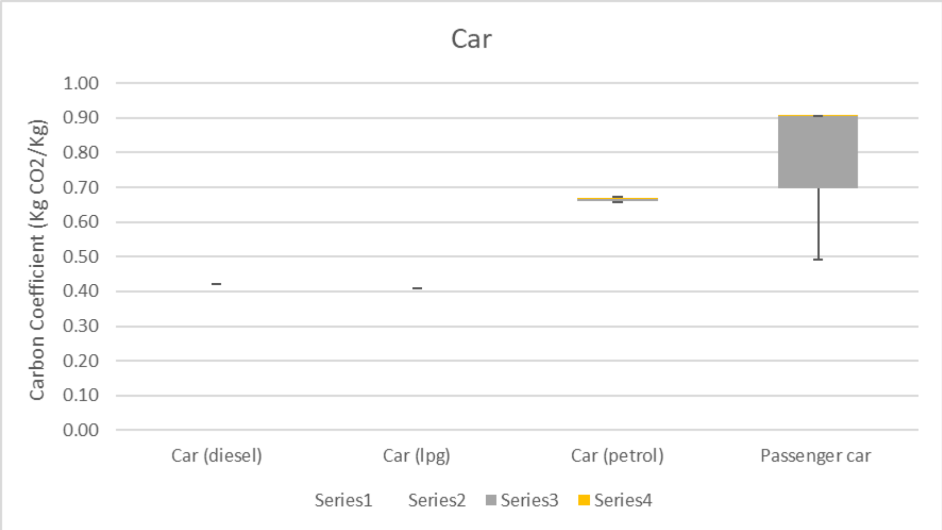


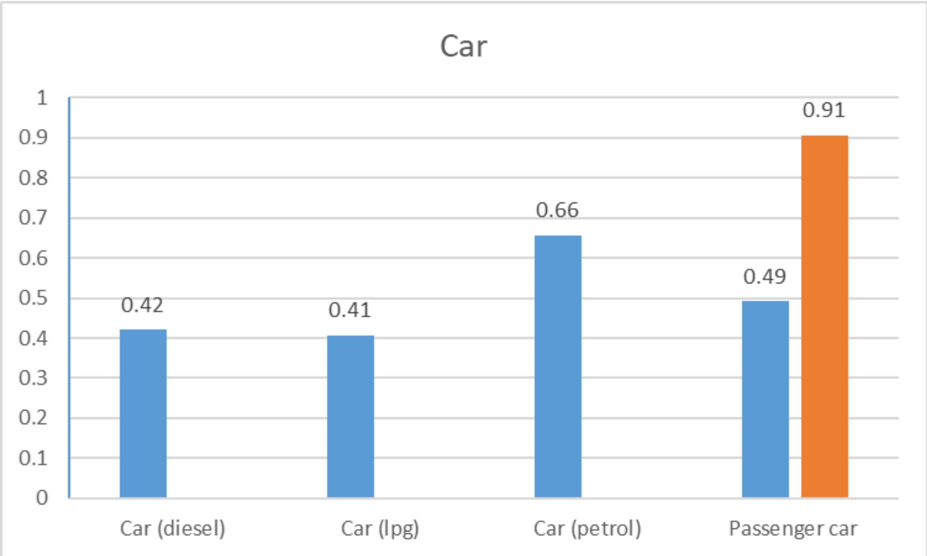
	Trailer	Truck (single)	Truck 16t	Truck 28t	Truck 40t	Truck I
Min	0.12	0.37	1.41	0.82	0.51	0.29
Q1	0.07	0.16	0.00	0.00	0.00	0.00
Q2 - Mediana	0.07	0.16	0.00	0.00	0.00	0.00
Q3	0.14	0.16	0.01	0.04	0.02	0.00
Max	0.14	0.16	0.03	0.12	0.06	0.00



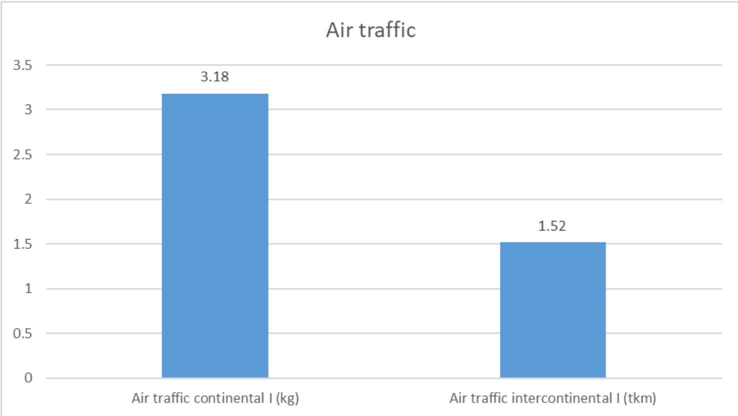


	Car (diesel)	Car (lpg)	Car (petrol)	Passenger car
Min	0.42	0.41	0.66	0.49
Q1	0.00	0.00	0.00	0.21
Q2 - Mediana	0.00	0.00	0.00	0.21
Q3	0.00	0.00	0.00	0.00
Max	0.00	0.00	0.00	0.00

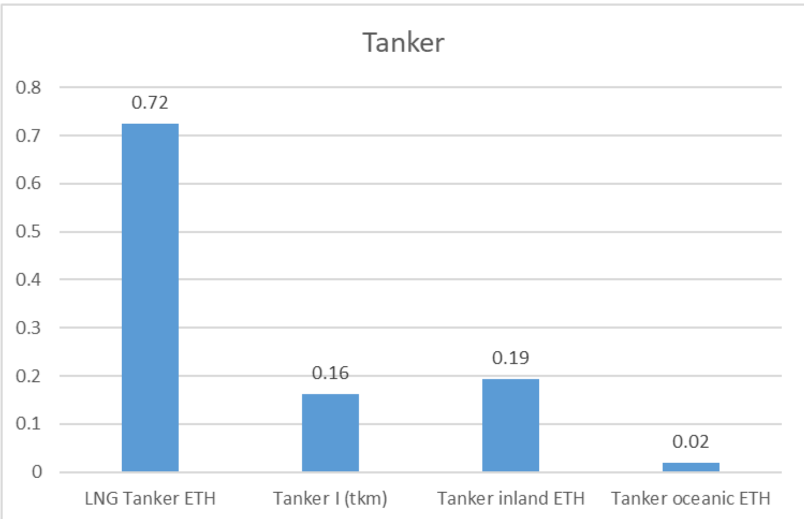




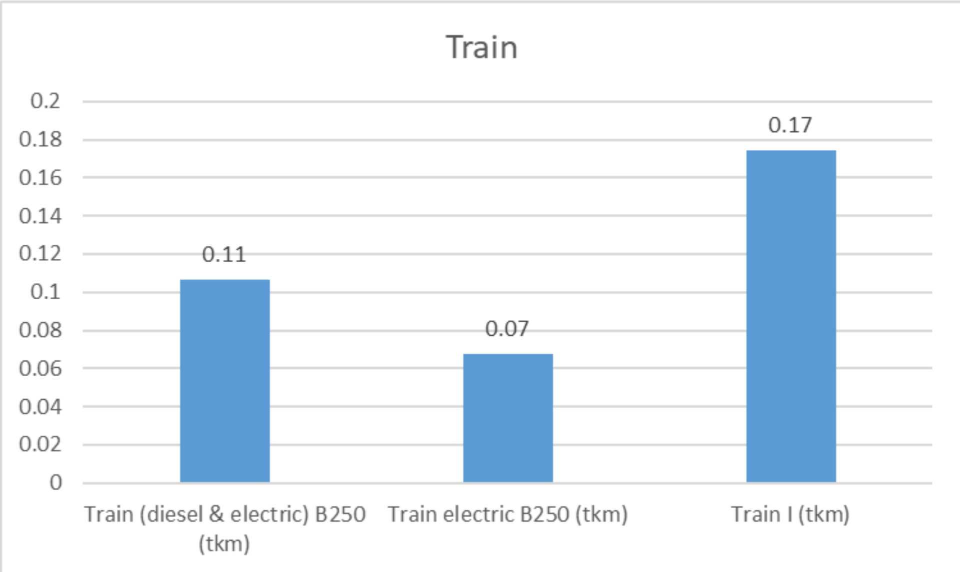
	Air traffic continental I (kg)	Air traffic intercontinental I (tkm)
Min	3.18	1.52
Q1	0.00	0.00
Q2 - Mediana	0.00	0.00
Q3	0.00	0.00
Max	0.00	0.00



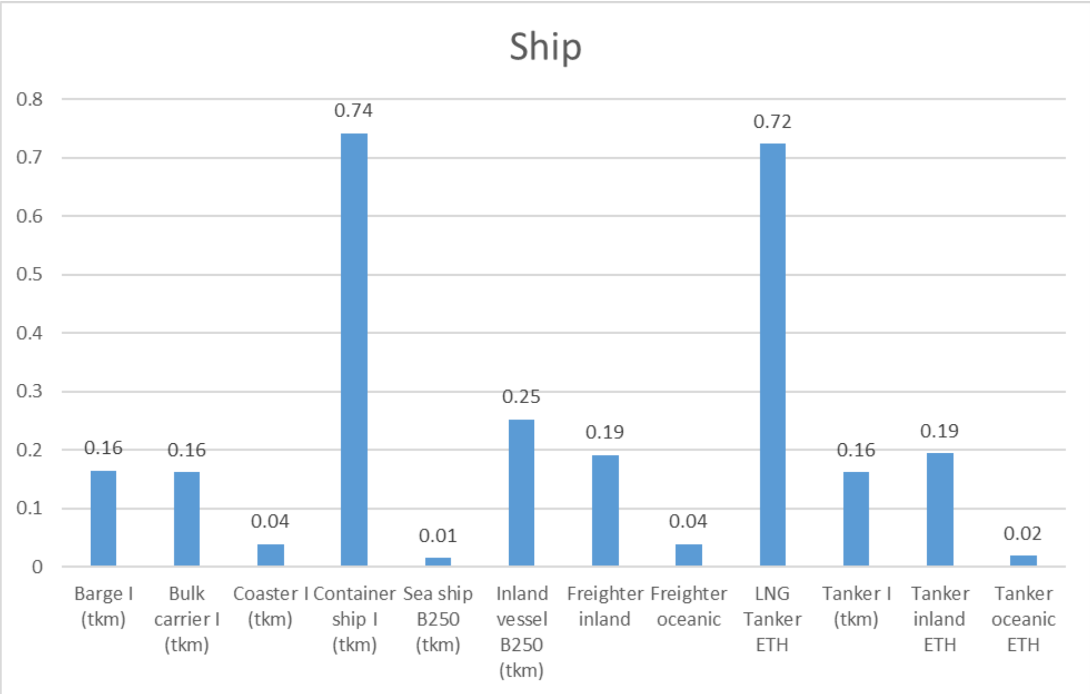
	LNG Tanker ETH	Tanker I (tkm)	Tanker inland ETH	Tanker oceanic ETH
Min	0.72	0.16	0.19	0.02
Q1	0.00	0.00	0.00	0.00
Q2 - Mediana	0.00	0.00	0.00	0.00
Q3	0.00	0.00	0.00	0.00
Max	0.00	0.00	0.00	0.00



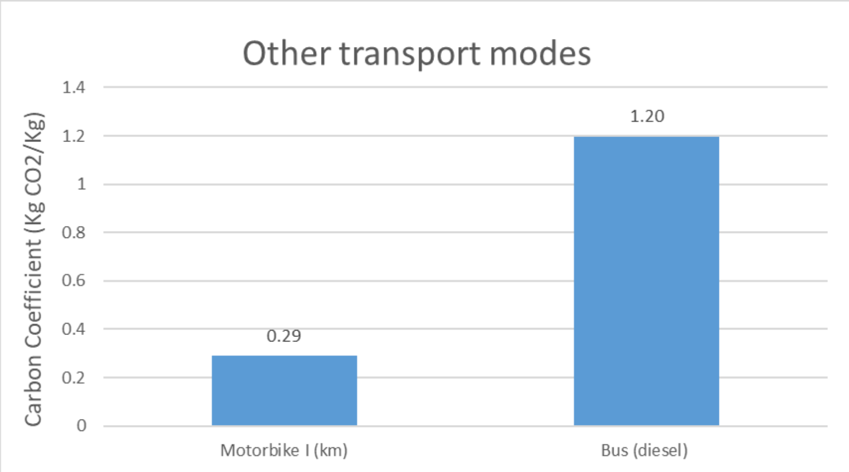
	Train (diesel & electric) B250 (tkm)	Train electric B250 (tkm)	Train I (tkm)	Rail transport ETH
Min	0.11	0.07	0.17	54.10
Q1	0.00	0.00	0.00	0.01
Q2 - Mediana	0.00	0.00	0.00	0.01
Q3	0.00	0.00	0.00	0.01
Max	0.00	0.00	0.00	0.01



	Barge I (tkm)	Bulk carrier I (tkm)	Coaster I (tkm)	Container ship I (tkm)	Sea ship B250 (tkm)	Inland vessel B250 (tkm)	Freighter inland	Freighter oceanic	LNG Tanker ETH	Tanker I (tkm)	Tanker inland ETH	Tanker oceanic ETH
Min	0.16	0.16	0.04	0.7	0.0	0.3	0.19	0.04	0.72	0.16	0.19	0.02
Q1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Q2 - Mediana	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.00	0.00	0.00
Q3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Max	0.00	0.00	0.00	0.00	0.0	0.0	0.00	0.00	0.00	0.00	0.00	0.00



	Bus (diesel)	Motorbike I (km)
Min	0.29	1.20
Q1	0.00	0.00
Q2 - Mediana	0.00	0.00
Q3	0.00	0.00
Max	0.00	0.00



	Units	Q2 - Mediana - CO2e (kg)
Delivery van (km)	Km	4.21
Delivery van I (km)	Km	0.64
Trailer (Tkm)	Tkm	0.26
Truck (single) (Tkm)	Tkm	0.69
Truck 16t (Tkm)	Tkm	1.41
Truck 28t (Tkm)	Tkm	0.82
Truck 40t (Tkm)	Tkm	0.51
Truck I (Tkm)	Tkm	0.29
Car (diesel) (km)	Km	0.42
Car (lpg) (km)	Km	0.41
Car (petrol) (km)	Km	0.67
Passenger car (km)	Km	0.91
Air traffic continental I (kg)	Kg	3.18

	Units	Q2 - Mediana - CO2e (kg)
Air traffic intercontinental I (Tkm)	Tkm	1.52
Barge I (Tkm)	Tkm	0.16
Bulk carrier I (Tkm)	Tkm	0.16
Coaster I (Tkm)	Tkm	0.04
Container ship I (Tkm)	Tkm	0.74
Sea ship B250 (Tkm)	Tkm	0.01
Inland vessel B250 (Tkm)	Tkm	0.25
Freighter inland (Tkm)	Tkm	0.19
Freighter oceanic (Tkm)	Tkm	0.04
LNG Tanker ETH (m3)	m3	0.72
Tanker I (Tkm)	Tkm	0.16
Tanker inland ETH (Tkm)	Tkm	0.19
Tanker oceanic ETH	Tkm	0.02
Rail transport ETH	Tkm	0.14
Train (diesel & electric) B250 (Tkm)	Tkm	0.11
Train electric B250 (Tkm)	Tkm	0.07
Train I (Tkm)	Tkm	0.17
Motorbike I (km)	km	0.29
Bus (diesel)	km	1.20

Appendix 8. *Tool's calculations (tCO2e) Example (Phase 1 and 2)*

Phase 1. Research Outcomes

Research outcomes assessment	**Answer & Possible impact Scenarios**		**Equations and data for tCO2e/year calculations Conversion Factor (CF)**		**Calculations (tCO2/kWh)**
Outcomes 1.) Will your Boats be used in a country on this list?	Yes, Colombia	Use of power supply	Equation:	#ofboats*119kWh/day·boat*250d/year*FC(tCO2e/kWh)	
	High (# of Boats)	22	(CF) Emission of tCO2/kWh in Colombia:	0.00021	137.81
	Medium (# of Boats)	16	Days per year:	250	100.22
	Low (# of Boats)	7	kWh per day:	119	43.85
			Miles/year per boat (Miles/year):	1,345	
		67	Boat power (HP) (67)	20	
			operating hours (h/d)	8	
			HP/kW (https://www.rapidtables.com/convert/power/hp-to-kw.html)	1.341	
			Boat description (kW): 20HP/1,341, 8 hours and 1100 NM	14.91	
Outcomes 4.) Are Boats expected to consume any fossil fuels? -Oil or Petroleum, -Natural Gas, -Coal, -diesel http://ecoscore.be/en/info/ecoscore/co2	Yes, diesel	Use of power supply	Equation: http://ecoscore.be/en/info/ecoscore/co2	Diesel consumption (kg/year)* CF(kgCO2e/kg) /ton 5256.84 litroskg diésel/año * 2.6 KgCO2e/kg /1000	13.7
	High (# of Boats)	22	Diesel consumption (kg/year):	5256.84	300.69
	Medium (# of Boats)	16	CF(kgCO2e/kg)	2.6	218.68
	Low (# of Boats)	7	1 tonne (Kg):	1000	95.67
			days per year	250	
			HP potencia motor diésel (67)	20	
			galllons (Base for calculations)	50	
			hour (typical with 50 gallons)	76	
			h/d servicio	8	
		756.66666667	días	9.5	
			l/gallon	4.54	
			l/76h (con regla de 3 este dato podría ser:756)	227	
			kg/l diésel densidad	0.88	
			kg/d	21.03	

Research outcomes assessment	Answer & Possible impact Scenarios		Equations and data for tCO2e/year calculations Conversion Factor (CF)		Calculations (tCO2/kWh)
Outcomes 5.) Large energy consumption Will any of the material on this list used in the construction of the Boats?	Yes e.g.: Solar Panels (0,3t)		Equation:	Type and quantity of material * CF (kgCO2e/m2SP) / years depreciation ((1,64m2*69SP) * 0,208 tCO2e/m2SP)/30 years	0.8088
	High (# of Boats)	22	Type and quantity of material (t): 69?? (#panels * m2/panel * CF (kgCO2e/m2SP))	24.2651136	17.7944
	Medium (# of Boats)	16	#panels	60	12.9414
	Low (# of Boats)	7	m2/panel	1.94432	5.6619
			CF (kgCO2e/m2SP):	0.208	
			years depreciation:	30	
			Weigth (t) of the material	0.3	
Outcomes 6.) Large energy consumption Will any of the material on this list used in the construction of the Boats?	Yes e.g.: Open molding, rigid composites part, at plant/kg/RNA		Equation:	Type and quantity of material * CF (kgCO2e/Kg mat) / years depreciation (0.4t * 2.2 KgCO2e/kgOM * 1000kgOM/tOM / 1000 tCO2/KgCO2)/30 years	0.0987
	High (# of Boats)	22	Type and quantity of material (t) (No. of Boats * Material (t)) / 12	1.33	2.1707
	Medium (# of Boats)	16	CF (kgCO2e):	2.22	1.5787
	Low (# of Boats)	7	years depreciation:	30	0.6907
			1 tonne (Kg):	1	
			Weigth (t) of the material	0.4	
Outcomes 7.) Large energy consumption Will any of the material on this list used in the construction of the Boats?	Yes e.g.: Open mold casting, rigid composites part, at plant/kg/RNA		Equation:	Type and quantity of material * CF (kgCO2e/Kg mat) / years depreciation (0.4t * 1.04 KgCO2e/kgOMC * 1000kgOMC/tOMC / 1000 tCO2/KgCO2)/30 years	0.0462
	High (# of Boats)	22	Type and quantity of material (t) (No. of Boats * Material (t)) / 12	1.33	1.0169
	Medium (# of Boats)	16	CF (kgCO2e):	1.04	0.7396
	Low (# of Boats)	7	years depreciation:	30	0.3236
			1 tonne (Kg):	1	
			Weigth (t) of the material	0.4	
Outcomes 8.) Medium energy consumption Will any of the material on this list used in the construction of the Boats?	Yes e.g.: Vacuum infusion, rigid composites part, at plant/kg/RNA		Equation:	Type and quantity of material * CF (kgCO2e/Kg mat) / years depreciation (0,3tVa * 0.844 KgCO2e/KgVa * 1000kgVa/tVa / 1000 tCO2e/KgCO2)/30 years	0.0281
	High (# of Boats)	22	Type and quantity of material (t)	1.00	0.6189

Research outcomes assessment	**Answer & Possible impact Scenarios**		**Equations and data for tCO2e/year calculations Conversion Factor (CF)**		**Calculations (tCO2/kWh)**
			(No. of Boats * Material (t)) / 12		
	Medium (# of Boats)	16	CF (kgCO2e):	0.844	0.4501
	Low (# of Boats)	7	years depreciation:	30	0.1969
			1 tonne (Kg):	1	
			Weigth (t) of the material	0.3	
Outcomes 9.) Medium energy consumption Will any of the material on this list used in the construction of the Boats? Will the boats use batteries?	Yes e.g.: Batteries de nueva generación Litio Hierro Fosfato (LiFePO4)		Equation:	Type and quantity of material * CF (kgCO2e/Kg mat) / years depreciation (0,3t * 1.61 KgCO2/KgBatt * 1000kgBatt/tBatt / 1000 tCO2/KgCO2)/30 years	0.4224
	High (# of Boats)	22	Type and quantity of material (t) (No. of Boats * Material (t)) / 12	1.00	9.2928
	Medium (# of Boats)	16	CF (tCO2e/bat): From German's paper	12.672	6.7584
	Low (# of Boats)	7	years depreciation:	30	2.9568
			1 tonne (Kg):		
			Weigth (t) of the material	0.3	
Outcomes 10.) Medium energy consumption Will any of the material on this list used in the construction of the Boats?	Yes e.g.: Electrical equipment for control & operation (regulators, transformers, inverters/chargers, cables, protections etc.)		Equation:	Type and quantity of material * CF (kgCO2e/Kg mat) / years depreciation (0.35t * 1.61 KgCO2/KgBatt * 1000kgBatt/tBatt / 1000 tCO2/KgCO2)/30 years	0.0175
	High (# of Boats)	22	Type and quantity of material (t) (No. of Boats * Material (t)) / 12	1.17	0.3850
	Medium (# of Boats)	16	CF (kgCO2e):	0.45	0.2800
	Low (# of Boats)	7	years depreciation:	30	0.1225
			1 tonne (Kg):	1	
			Weigth (t) of the material	0.35	
Outcomes 10.) Medium energy consumption Will any of the material on this list used in the construction of the Boats?	Yes e.g.: Remaining components to be included (sillas, varandas, vidrios, ventanas, etc.)		Equation:	Type and quantity of material * CF (kgCO2e/Kg mat) / years depreciation (0.45t * 1.04 KgCO2e/kgRest * 1000kgRest/tRest / 1000 tCO2/KgCO2)/30 years	0.0225
	High (# of Boats)	22	Type and quantity of material (t) (No. of Boats * Material (t)) / 12	1.50	0.4950
	Medium (# of Boats)	16	CF (kgCO2e):	0.45	0.3600
	Low (# of Boats)	7	years depreciation:	30	0.1575
			1 tonne (Kg):	1	
			Weigth (t) of the material	0.45	

Research outcomes assessment	**Answer & Possible impact Scenarios**		**Equations and data for tCO2e/year calculations Conversion Factor (CF)**		**Calculations (tCO2/kWh)**
Outcomes 10.) Have you considered some energy saving/renewable initiatives? Will the Boats generates its own energy? How?	Yes, by Solar Panel on the roof		Equation:	(Energy produced by panel (kWh/day)) * (% of energy use) * (No. Days per year) * ((CF) Emission of tCO2/kWh in Colombia):	3.55556
		22	Type of Solar panel	TALLMAX 340-375W and 72 cells	78.22
		16	kWp of the Solar Panel	0.35	56.89
		7	No. of Panels	60	24.89
			Installed potential: kWp * No. of Panels	21.00	
			Average generation (kWh/kWp·day) Colombia Photovoltaic Power Potential https://globalsolaratlas.info/downloads/colombia	4.3	
	35		Energy produced by panel (kWh/day)	90.30	
	17.5		% of energy use	0.75	
	357.5		No. Days per year:	250	
			cada barco tiene de potencia: 20HP/1,341=14,91kW, 8 horas y 1100 NM		
			(CF) Emission of tCO2/kWh in Colombia:	0.00021	

Phase 2 - Research Process

Research Process assessment	Answer & Possible impact Scenarios		Equations and data for tCO$_2$e/year calculations Conversion Factor (CF)		Calculations (tCO$_2$e/kWh
Process 1.) Will the Prototype Boat used energy in a country on this list? Use of Energy of a country of this list? field tests, collection of sample, Equipments, Electronic devices and energy use in the Lab/office to built the Prototype Boat	Yes, Colombia	Use of power supply	Equation:	#ofboats*119kWh/day·boat *250d/year*FC(tCO$_2$e/kWh) + field tests + collection of sample + Equipments + Electronic devices and energy use in the Lab/office to built the Prototype Boat	
	High		(CF) Emission of tCO$_2$/kWh in Colombia:		
			Days per year:		
	As expected		kWh per day:		
			Electronic devices and energy use in the Lab/office to built the Prototype Boat		
			collection of sample		
			field tests		
			Equipments		
Process 2.) Transportation: Trips during the project Ground And Air Trips	Yes, Ground And Air Trips		Equation:	Trips during the project Ground And Air Trips	
	High (# of Boats)		Air Trips (tCO$_2$e/Airtrips) = 10 Trips		
	As expected				
Process 3.) Are Boats expected to consume any fossil fuels? -Oil or Petroleum, -Natural Gas, -Coal, -diesel http://ecoscore.be/en/info/ecoscore/co2	Yes, diesel		Equation:	Diesel consumption (kg/year)* CF(kgCO$_2$e/kg) /ton 5256.84 litroskg diésel/año * 0.2196 KgCO$_2$e/kg /1000	
	High		Diesel consumption (kg/year):		
			CF(kgCO$_2$e/kg)		
	As expected		1 tonne (Kg):		
			days per year		
			HP potencia motor diésel		
			galllons (Base for calculations)		
			hour (typical with 50 gallons)		
			h/d servicio		
			días		
			l/gallon		
			l/76h		
			kg/l diésel densidad		
			kg/d		
Process 4.) Large energy consumption Will any of the material on this list used in the construction of the Boats?	Yes e.g.: Solar Panels		Equation:	Type and quantity of material * CF (kgCO$_2$e/m2SP) / years depreciation ((1,64m2*16SP) * 0,208 tCO$_2$e/m2SP)/30 years	
	High (# of Boats)		Type and quantity of material (t):16?? (#panels * m2/panel * CF (kgCO$_2$e/m2SP))		

Research Process assessment	Answer & Possible impact Scenarios		Equations and data for tCO2e/year calculations Conversion Factor (CF)		Calculations (tCO2e/kWh
			#panels		
			m2/panel		
	As expected		CF (kgCO2e/m2SP):		
			years depreciation:		
			Weigth (t) of the material		
Process 5.) Large energy consumption Will any of the material on this list used in the construction of the Boats?	Yes e.g.: Open molding, rigid composites part, at plant/kg/RNA		Equation:	Type and quantity of material * CF (kgCO2e/Kg mat) / years depreciation (0.4t * 2,2 KgCO2e/kgOM* 1000kgOM/tAOM/ 1000 tCO2/KgCO2)/30 years	#DIV/0!
	High (# of Boats)		Type and quantity of material (t) (No. of Boats * Material (t)) / 12		
			CF (kgCO2e):		
	As expected		years depreciation:		
			1 tonne (Kg):		
			Weigth (t) of the material		
Process 6.) Large energy consumption Will any of the material on this list used in the construction of the Boats?	Yes e.g.: Open mold casting, rigid composites part, at plant/kg/RNA		Equation:	Type and quantity of material * CF (kgCO2e/Kg mat) / years depreciation (0.4t * 1.04 KgCO2e/kgOMC * 1000kgCOM/tOMC/ 1000 tCO2/KgCO2)/30 years	
	High (# of Boats)		Type and quantity of material (t) (No. of Boats * Material (t)) / 12		
			CF (kgCO2e):		
	As expected		years depreciation:		
			1 tonne (Kg):		
			Weigth (t) of the material		
Process 7.) Medium energy consumption Will any of the material on this list used in the construction of the Boats?	Yes e.g.: Vacuum infusion, rigid composites part, at plant/kg/RNA		Equation:	Type and quantity of material * CF (kgCO2e/Kg mat) / years depreciation (0.3t * 0.844 KgCO2/KgVa * 1000kgVa/tVa / 1000 tCO2/KgCO2)/30 years	
	High		Type and quantity of material (t) (No. of Boats * Material (t)) / 12		
			CF (kgCO2e):		
	As expected		years depreciation:		
			1 tonne (Kg):		
			Weigth (t) of the material		

Research Process assessment	Answer & Possible impact Scenarios		Equations and data for tCO2e/year calculations Conversion Factor (CF)		Calculations (tCO2e/kWh
Process 8.) Medium energy consumption Will any of the material on this list used in the construction of the Boats? Will the boats use batteries?	Yes e.g.: Batteries de nueva generación Litio Hierro Fosfato (LiFePO4)		Equation:	Type and quantity of material * CF (kgCO2e/Kg mat) / years depreciation (0.3t * 1.61 KgCO2/KgBatt * 1000kgBatt/tBatt / 1000 tCO2/KgCO2)/30 years	
	High (# of Boats)		Type and quantity of material (t) (No. of Boats * Material (t)) / 12		
			CF (kgCO2e): From German's paper		
	As expected		years depreciation:		
			1 tonne (Kg):		
			Weigth (t) of the material		
Process 9.) Medium energy consumption Will any of the material on this list used in the construction of the Boats?	Yes e.g.:Electrical equipment for control & operation (regulators, transformers, inverters/chargers, cables, protections etc.)		Equation:	Type and quantity of material * CF (kgCO2e/Kg mat) / years depreciation (0.3t * 1.61 KgCO2/KgBatt * 1000kgBatt/tBatt / 1000 tCO2/KgCO2)/30 years	
	High (# of Boats)		Type and quantity of material (t) (No. of Boats * Material (t)) / 12		
			CF (kgCO2e):		
	As expected		years depreciation:		
			1 tonne (Kg):		
			Weigth (t) of the material		
Outcomes 10.) Medium energy consumption Will any of the material on this list used in the construction of the Boats?	Yes e.g.: Remaining components to be included (sillas, varandas, vidrios, ventanas, etc.)		Equation:	Type and quantity of material * CF (kgCO2e/Kg mat) / years depreciation (1.25t * 1.04 KgCO2e/kgRest * 1000kgRest/tRest / 1000 tCO2/KgCO2)/30 years	#DIV/0!
	High (# of Boats)		Type and quantity of material (t) (No. of Boats * Material (t)) / 12		
			CF (kgCO2e):		
	As expected		years depreciation:		
			1 tonne (Kg):		

Research Process assessment	Answer & Possible impact Scenarios		Equations and data for tCO2e/year calculations Conversion Factor (CF)		Calculations (tCO2e/kWh
			Weigth (t) of the material		
Process 9.) Have you considered some energy saving/renewable initiatives? Will the Boats generates its own energy? How?	Yes, by Solar Panel on the roof		Equation:	(Energy produced by panel (kWh/day)) * (% of energy use) * (No. Days per year) * ((CF) Emission of tCO2/kWh in Colombia):	0
	High (# of Boats)		Type of Solar panel		
			kWp of the Solar Panel		
	As expected		No. of Panels		
			Installed potential: kWp * No. of Panels		
			Average generation (kWh/kWp·day) Colombia Photovoltaic Power Potential https://globalsolaratlas.info/downloads/colombia		
			Energy produced by panel (kWh/day)		
			% of energy use		
			No. Days per year:		
			cada barco tiene de potencia: 20HP/1,341=14,91kW, 8 horas y 1100 NM		
			(CF) Emission of tCO2/kWh in Colombia:		