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Renewable energy research and technologies through responsible research and innovation looking glass: Reflexions, theoretical approaches and contemporary discourses

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HIGHLIGHTS

- Responsible Research and Innovation (RRI) and Open Innovation European strategies.
- RRI policy insights construction.
- RRI dimensions beyond significance.
- Social science frameworks for energy research.
- Operational elements of responsibility in energy research.

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ABSTRACT

The increasing challenges that energy research faces as a priority in most of the global research agendas, are revealed both in terms of social and technical issues. Energy research highlights are set on the development of reliable renewable energy systems and applications; transition to decentralized systems and socio-technical, behavioural and institutional issues combination which requires the integration of both energy and research policies. Global trends in research policies showing an advocacy for responsible approaches are for example Responsible Research and Innovation (RRI) and Open Innovation European strategies which promote the development of social issues as core key of the research and innovation and the definition of the outcomes as the expression of human values such as safety, justice, sustainability and efficiency. The purpose of this article is to present a reflexion regarding to a contextualization of this approach in energy research. Therefore, a range of theoretical backgrounds, meaning making processes, historical approaches, frameworks and contemporary discourses, have been examined. Our aim is to provide a detailed review of existing literature related to the key elements of Responsible Research and Innovation. The innovative contribution is focused in the vision of these key elements applied to energy research, with particular reference to renewables and the outline of the many factors influencing the real field implementation. Results show the existence of a common ground between responsible approaches and many concepts from energy research and social sciences frames. Responsibility as understood in the RRI framework was found not deliberately represented, although, shifts towards responsible approach in social dimension treatment of renewable energy research appeared notable.

1. Introduction

Energy research has been greatly influenced by multidisciplinary efforts towards enhancing and pursuing open, participatory and responsible approaches before this concept become overarching. The integration of philosophy, ethics, communication, economy and politics, shaping energy research and social sciences approaches and the eclectic nature of the energy as a complex socio-technical system, with a combination of a variety of technical aspects and automated processes which includes human behaviour and social factors [1] are some of the examples. Responsibility as a concept, approach and policy [2], permeates today, every scientific discipline and its insights are present in global research and energy policies, reinforced by contemporary discourses regarding to the integration of the social and human dimensions in science, innovation, economy and politics and the search for a new paradigms of governance of science. Examples of this

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integration are the sustainable global challenges development in terms of affordable and clean energy, climate action, responsible consumption, and commitments with renewable energy production. Moreover, this integration is also achieved when policy seeks for strongest partnerships between institutions to achieve those sustainable global challenges, such as gender equality, education and poverty eradication [3] among others.

Responsibility does not correspond to one fixed definition and its scope in policy is still under construction. It comprises a wide umbrella of approaches where, the preference for innovation with the ability to solve social issues, the understanding of progress and advances in terms of social commitments, as well as the management and inclusion of the diversity of stakeholders, are some of its remarkable insights. Responsibility incarnated as research and innovation policy, also comprises a broad spectrum of actions and intentions such as an interdisciplinary integration of topics [4], innovation outcomes reinterpretation as an expression of moral values, intention of broaden the impacts beyond return of investment (ROI) policies [5], and an Impact assessment (IA) process reframing with excellence redefinition both in terms of analytical and social relevance of scientific outcomes [6]. Responsible policies are present as research policies in the European Framework Programme for Research and Innovation *Horizon 2020*, identified as *Responsible Research and Innovation (RRI)*, and as cross-cutting issue in the *Open innovation, Open science, Open to the world* [7] research and innovation strategy of the European Commission [8–11]. At national level, the Dutch Responsible Innovation strategy, now integrated in EU RRI policy and considered one of RRI foundational predecessors [11,12], and the UK Engineering and Physical Sciences Research Council Delivery plan [13] are some examples where responsibility is included as a backbone.

In energy research and policy, many authors agree that the path of responsibility needs to be leaded by social sciences. This is due to its ability, as cross-cutting issue, to highlight its role in solving energy-related challenges regarding social, economic and ecological concerns [14,15]. Social science contribution to the treatment of the non-technical issues has long been recognized, despite critical voices stating that social sciences adapt to technology and not the other way around. Social sciences are accused of being easily amenable to a managerial implementation approach and closely related to a particular technological development [16]. In energy policy, meanwhile, its presence is still marginal [15,17–19], being this concern often justified by the fact that the funding is dominated by techno-economic interests [15] and the prevalence of economics upon other social sciences and humanities. The widespread of social sciences in research policies through early applications to the technical disciplines has not been free from controversy. What is perceived as an expression of interdisciplinarity and responsibility and is accepted as one of the most unanimously recognized early approach of RRI, it is considered by other authors not inclusive and insufficient to encourage policy to transcend from traditional social science topics to tackle neglected issues [18], such as gender and identity. For instance, broadening the spectrum to other disciplines such as philosophy, ethics, anthropology, and culture manifestations is mentioned as a recommendation to transcend from the simple application of the social sciences when it comes to achieving responsibility. Similarly, the moderation in the use of methodologies, such as impact assessment and risk management is recommended in responsible approaches. This is due to the fact that these methodologies are considered top-down, and that adversely neglect the human dimension [17].

It is also subject of discussion of this paper the shift between social dimension approaches related with issues being considered social rather than concerns of society *per se*. Examples such as risk assessment, costs analysis and increase of public acceptance of achievements of science and technologies [20] towards responsibility approach, with the focus in reframing of the process of production of scientific knowledge [21] and how this shift is represented in energy research, are included.

Many factors influence the real field implementation of the responsibility approach. Contextual variation between research fields and research ecosystems are responsible of the insights which modulate societal impact, governance and responsibility. Perhaps it is difficult to apply Responsible approaches and RRI elements as a general research policy to all the practices and disciplines. Other constraints, such as the time for research outcomes to become in applications and contributions of acknowledgment when innovation is in result of a network of interactions between a variety of stakeholders, are some of the many factors influencing the real implementation and the reach of responsibility goals in terms of the insights shown above. Moreover, the interpretation of these insights becomes more complicated, when the considered research fields integrate historically their own societal dimension, governance and responsibility considerations.

The role of researchers also has to be taken into account as factor for implementation: researchers awareness and disaffection, convenience, un-comfortability with social sciences approaches and complexities regarding real practice of the interdisciplinarity, as well as the guarantee of the freedom of individual research activity consideration and the autonomy of the research organizations, are some of the examples.

Energy research and policy have their own interpretation regarding the concept of responsibility, which is present in several aspects of its policy agendas. For example, the concept of responsibility in energy policy is included in the effect of technology outcomes on society, the well-being of the community, the consequences that changes in norms, values and beliefs have on the society, and in the enactment of government as well as policies and regulations [1]. Responsibility as approach can be found, also, in the treatment of social issues and concerns, and in the socio-political impact approaches that are engaged with reframing energy decisions in terms of ethical concerns, such as justice and values [22,23]. It is widely recognized that in the case of renewable energy some projects implementation and assessment follow the bottom-up. This process is guided by the collaboration between relevant stakeholders in terms of the processes and their outcomes and how such processes and outcomes are perceived.

Contextual variation between research fields and research ecosystems are also important. RRI defines key elements, such as engagement and gender, in a generic way, while different scientific disciplines are used to tackle those questions in their specific way. Participation, for example, can be addressed through researcher engagement in policies, evolving citizens through participatory research methods [24], through stakeholders engagement, through social activism, or through citizen science. Moreover, those approaches change over time. Another example is public engagement, which was already present in some social dimension approaches and transcended to RRI. The traditional objective of public engagement was to create *consensus* around *upstream engagement*, which assumes that agreement between diverse *stakeholders* is desirable and possible [25]. Today public engagement considers that stakeholders replace social actors and that a *upstream process* involves methods such as focus groups, citizen juries, and other forums for participatory discussions [6,26]. This is reflected in new models of anticipatory governance [6,27] and Constructive Technology Assessment [28,29] as methods for practical applications in disciplines such as renewable energy research. These models can be considered tools to achieve operational elements of RRI and will be discussed throughout the paper. The importance of the users, as a ramification of participation based in the premise that invention becomes an innovation only if users become a part of the value creation process, is also another example. The integration of the users in RRI and the Open innovation framework is conducted via methods such as *User innovation* in terms of the role of citizens and users in the innovation processes as *distributed* sources of knowledge. In this context, the term *open* is used as a synonym for *user-centred*. Open science, citizen science, and crowdsourcing are also elements of this approach.

Thereby, this paper explores the responsibility understandings of the energy research in terms of the Responsible Research and

Innovation (RRI) European research policy. This is done unpacking the findings regarding to conceptual foundations [2,6,30], operational insights of this policy in terms of the attributes that the innovation needs to fulfil to be consider responsible, and the dimensions to cover. The remaining of this paper starts with an overview of the RRI policy in terms of definitions, key elements and process reformulation; responsibility approach introduction; a revision of the RRI background; and a consideration of RRI contributions and innovations regarding to other Responsible policies or approaches. Following, the paper explores a review of research policy in terms of the responsibility approach, where the social sciences application to the technical disciplines and ethics approaches are introduced as main remarkable backgrounds, followed by an overview of the responsibility insights in energy research and policies. This section highlights social science energy frameworks and the contributions to renewable energy research. The paper is concluded with a discussion of the common ground concepts in terms of responsibility, such as ethical concerns and technological assessment, that social dimension of energy research and policy share with RRI, and the implications originated by the different understanding of shared elements both in research and energy policies together with the conceptualization of the keys such as public engagement, sustainability and social justice.

2. Responsible research and innovation (RRI) policy

2.1. Definition, key elements, and process reformulation

Responsible research and innovation policy was proposed and designed to integrate the main insights of EU policies in terms of challenges, headline targets, and strategies. It is made up by a wide umbrella of branched definitions regarding achievements of more social research outcomes and the reformulation of the research and innovation process. Some examples of definitions are: considering RRI as a process for the creation of an R&I policy driven by the needs of society [8,31]; considering RRI as an approach to address science and technology present and future controversies more efficiently; considering RRI as a mechanism that tackles societal challenges by aligning the values, needs and expectations of all actors involved; and considering RRI as an interactive process governed by the principles of ethical acceptability, sustainability and societal desirability [32].

As theoretical background for RRI policy, Science, technology and society studies (STS) and Technology assessment (TA) are considered the most represented ones [2]. Its policy insights construction [33,34] is embedded in three aspects under the umbrella of the search of governance (Fig. 1). The first one is the search of governance which comprises the development of keys or policy agendas and the consideration of ethical aspects and societal. The second aspect is the statement of research agendas comprising innovative methodologies of innovation such as an *Open innovation*. These are the operational elements to achieve policy objectives. And finally, the third aspect is the adaptation of the Science, technology and innovation (STI) impacts measurement systems to avoid linear approaches, such as the bibliometric impact assessment.

As seen in Fig. 1, a search of a governance comprises the development of the keys and the request to the research and innovation process to be designed in a way that allows the consideration of ethical aspects and societal needs. Therefore, the considered keys are the governance as main objective, that can be separated in (good) governance as principal aim and reinforced key; and in the keys of the public engagement, gender equality, science education, open access, and ethics, as recipes and expression for governance.

Sustainability and social justice are included in RRI as an expression of the policy goals, since they were the backbone of the Europe 2020 strategy in terms of employment, research and development, climate/energy, social inclusion, and poverty reduction [35]. These elements are considered as transversal keys related to gaps between knowledge and policy targets, ethics integration, relationships between researchers and research subjects, and participation of social groups in benefits arising from research. They are also specifically related to the assessment of technologies and applications for the mitigation of climate change.

The consideration of ethical aspects and societal needs in the process dimension is also the core of the search of governance. This is arranged by the inclusion of a set of attributes that research process must comply (anticipation, inclusion, reflexivity, and responsiveness). These attributes were proposed coming from Responsibility approaches such as socio technical integration strategies and the Responsible innovation approach [6,10]. The other element of this process dimension is the engagement with a set of norms or even virtues for practices related with both outcomes and options evaluation. This is done in terms of moral values, including wellbeing, justice, equality, privacy, autonomy, safety, security, sustainability, accountability, democracy, and efficiency [11].

Open innovation is an important concern introduced in RRI policy and being boarded considerably in subsequent proposals such as the Open Innovation European strategy [36]. This approach comprises the open access considerations in terms of the access to research results and the engagement. Here engagement is understood as a participatory and inclusive process to include and embrace, in a determinant role, citizens, underrepresented groups, innovation agents researchers, and policy makers [8]. An example of open innovation are the social innovation strategies, that can be found in the statement of research agendas which combines and includes challenges formulated by policy makers and social agents [37,38]. They are represented by the consideration of a mixture of technological, behavioural and institutional changes concerning the socioeconomic system as a whole and not restricted to the system transformation requirements. The statement of research agendas also includes the removal of top-down governance of R&I in which top-level authorities set the objectives and they implement them through top-down policies and expect them to be achievable and measurable in a linear way.

Finally, the adaptation of the impacts measurement systems can be considered from different approaches. RRI advocates for emphasising the societal impact of scientific publications, moving forward from bibliometric factors towards awareness and understanding of the R&I network context. A broad impacts assessment can be carried out fostering interactions between the most important stakeholders in the network or focussing on short- and medium-term effects.

2.2. Responsibility approach

During the last decade and in parallel with the fast development of emerging technologies, responsibility grew substantially in terms of conceptual frameworks, models and methodologies [2,30,39,40]. The conceptual building blocks of responsibility are rooted in several disciplines, such as applied ethics and moral philosophy, economy, and psychology. These disciplines have been part of science, technology and innovation discourses since early conflicts. For example, the relationship between subject and object appears in first debates related with efforts dealing with ethical, social and moral values [2]. Responsibility early mentions relays in “ordering society” in the emerging professional-industrial society of the 19th century [41]. This early discourse, related to responsible science, shifted to responsible governance [42]. This is represented by the efforts to encompass the social and human dimension with the governance of emerging technologies as the major challenge [6,43], which is also considered one of the foundational issues of RRI policy [30] and the personification of contemporary responsible speech. The societal dimension of technology development and the anticipation of the potential consequences of new technologies [44] and some minority approaches, such as Transdisciplinarity [45–52], are also among the umbrella of this approach.

The contemporary Responsibility approach is still shaped by the

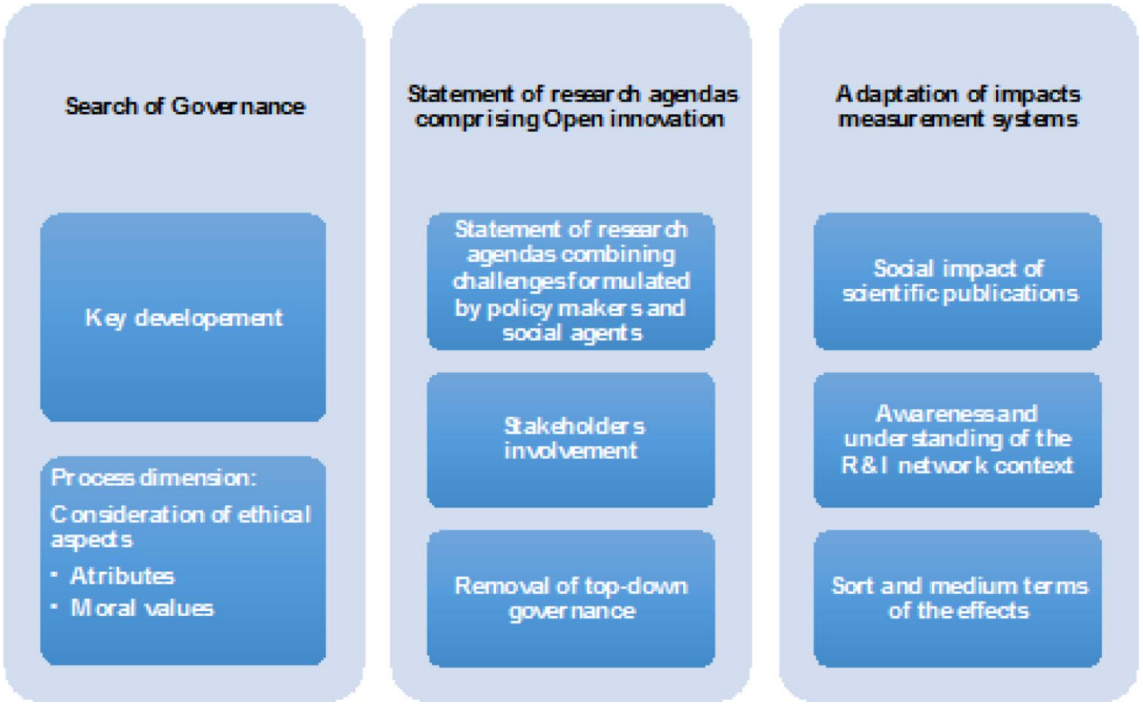

Fig. 1. RRI policy insights construction.

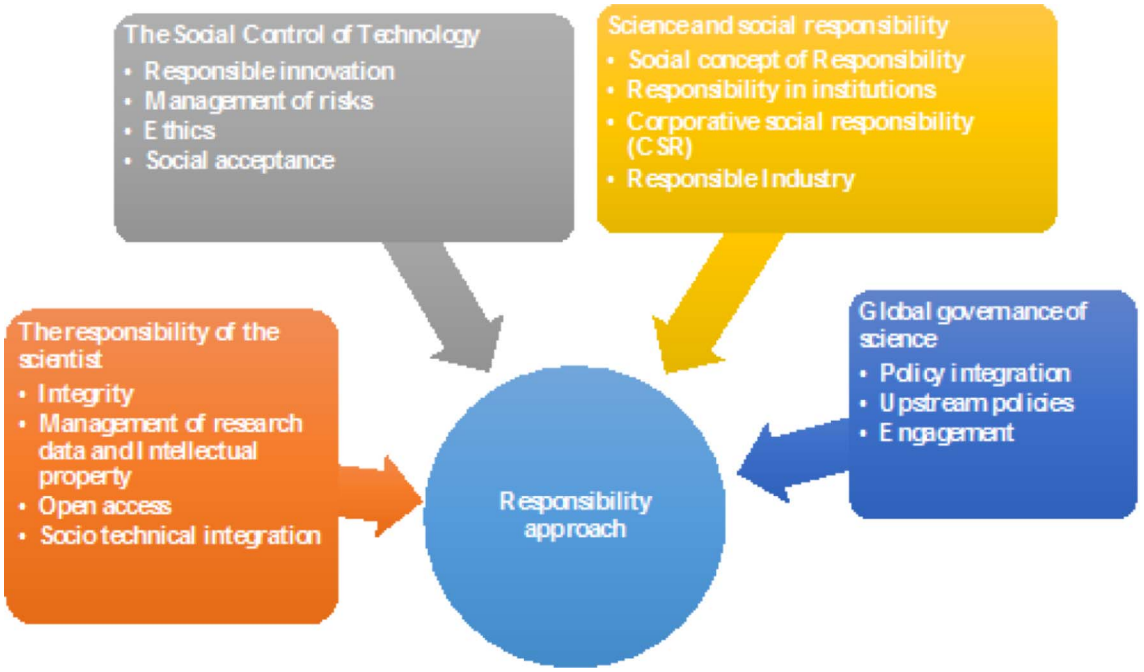

Fig. 2. Outline of the concepts related with the contemporary responsibility approach, considered also branches and relations of RRI.

integration of multidisciplinary methodologies and contexts, as outlined in Fig. 2. Some of the examples are approaches such the responsibility of researchers in terms of behaviour (attributes of the practices) or responsible conduct of research (RCR) [5], the social control of technology [6], the concept of social responsibility, and the governance of research and innovation (Fig. 1).

Underneath these concepts there are concerns which give to this approach high complexity. For example, the researcher responsibility is related with personal and human values on how science is practiced (the freedom of individual research activity consideration and the autonomy of the research organizations). It is also linked with the assessment of the research process; with concerns, ranging from management of the research data and intellectual property, management of the open access, and management of the interdisciplinary collaborations. An example of this responsibility shift related to the social dimension approach is the reinterpretation of the sociotechnical integration in terms of addressing broader societal dimensions of researchers work [53,54].

All the branches related with the reformulation of the research and innovation process, in terms of social values inclusion, ethics, and stakeholder's participation, are located under the Social control of the technology element. Social control of technology encompasses

Table 1
Methods for achieve attributes RRI in terms of background techniques of responsibility approach, related with theoretical concepts, practical objectives, and governance attributes of RRI policy (Adapted from [2,6] and enriched by the authors).

Theoretical concept	Background techniques	Objectives	Related RRI attribute	References
Action of considering the contingency of the products, process and purpose of STI involving systematic thinking for increasing resilience, and revealing new opportunities for innovation	Foresight Upstream public engagement Horizon scanning Constructive Technology assessment Cost-benefit analysis Impact assessment Life-cycle assessment Risk assessment	Identification and appraisal of risks, potential positive and negative impacts of research and innovation	Anticipation	[163–170] [171–173] [13,71,174] [167,175,176] [29,44,177] [61,178] [179] [180] [6] [2]
Multifaceted concept related with the researcher evaluation as an organising principle of science and moral responsibilities	Multidisciplinary Transdisciplinarity Ethical technology assessment Codes of conduct Moratoriums Midstream modulation	Socio-technical integration and interdisciplinarity in research and innovation	Reflexivity	[45,48,52,181–189] [190] [6] [2]
Public and stakeholder's engagement with research and innovation, for the inclusion of new voices in the governance of science and innovation as part of a search for legitimacy	Consensus conferences Citizens' juries Focus groups Science shops Citizen science Participatory research Deliberative mapping Deliberative polling User-centred innovation Open source innovation Participatory innovation Constructive TA Co-evolutionary approaches Backcasting Multi-stakeholder partnerships Participatory agenda setting Upstream engagement Crowdsourcing	Public and stakeholder engagement with research and innovation	Inclusion	[41,58] [191,192] [193–195] [196–199] [6] [2]
Process for assessment products, and outcomes and modulate the process of research in STI in the case where insufficiency of knowledge and control is detected	Regulation Standards Codes of ethics Research integrity Niche management Value-sensitive design Stage-gates Alternative intellectual property regimes	Identification and appraisal of ethical and societal aspects of research and innovation	Responsiveness	[36,200] [12,201] [6] [2]

approaches such as Social acceptance [55] and Responsible Innovation [56,57].

Social responsibility, on the other hand, comprises the responsibility concerns arising from society, institutions and industries interactions. Underneath this concept there is a concern about the present division of moral labour in societies with respect to science, technology and innovation [30,39,58], present in early mention of responsibility, and about how the roles and responsibilities of various actors are attributed. Governance of science comprises the translation from grand social challenges to policy practices. Their integration and development are the core of the RRI policy insights construction as developed in Fig. 1.

2.3. Responsible policies: RRI background

Before the current consolidation of Responsible Research and Innovation (RRI) framework in Europe [2,11,17,18,28,29], policy efforts dealing with ethical and social aspects were managed through approaches such as the EU ethical, legal and social aspects (ELSA) founding initiatives [5,40]. Developed in a context where existing philosophical, bioethical and TA approaches to science and technology were seen as insufficient [40], a contemporary vision regarding to this early policies considers them highly *top-down*, in terms of being developed by science policy makers and governance actors, with no interventions or participation from researchers or citizens, which would be considered a *bottom-up* fashion [26,59].

Responsible Innovation (RI), as a strategy which becomes policy, is also an important antecedent of RRI. In RI, the enhancement of innovation, in terms of moral values, is essential, based in the fact that innovation is never neutral or value laden [25], thus, outcomes needs to be the expression of the mentioned human values [18]. Responsible innovation was present in policies such as the Dutch Responsible Innovation strategy [11,12,60]. The values integration was based in the bioethical principles for experiments with human subjects: non-maleficence, beneficence, respect for autonomy, and justice [61]. It was proposed to predict or anticipate social consequences and to perform moral and regulatory appraisal towards the introduction of new

technologies, where potential social changes, induced by technological development, are considered as social experiments [56,61,62]. Linked with RI as a policy concept, Responsible governance (RG) is also present in early discussions for reframing the pre-existing institutional anchors and strategies such as a top-down, bottom-up, and multi-actor arenas of engagement, especially regarding with actors participation [41].

Values inclusion is part of the ethics (responsible) approaches which RRI conceptual framework also includes. The insights of this ethical approaches can be found in terms of moral values inclusion, ethical technology assessment studies [56,61,63–66], moral acceptability of risks [67], and multidisciplinary approaches to technology assessment [68]. Values inclusion, either through specific frameworks of technology assessment such as a Value sensible design (VSD) [12,69], or through applied ethics and moral philosophy approaches integration, advocating to embrace public values in technology design known as front-loaded ethics and ethics first approaches [70], are important elements of the RRI background which are still present in contemporary Responsible rhetoric. For example, advocacy for ethics being integrated in science and technology processes in the design-phase of innovation trajectories; the essence of the Upstream innovation approach [61,69].

2.4. Operational elements of RRI

The conceptual concerns of RRI are comprised, as mentioned above, by the development of the keys, the inclusion of the attributes, and the revision of the outcomes in terms of moral values. This constitutes the first step of RRI construction in terms of the search of governance, as shown in Fig. 1. It is important to point out that these elements are related with the integration of traditional social concerns, such as the technology assessment and the redefinition of the research and innovation outcomes interpreted as a prevalence of the human dimension upon the socio-technical approach. Regarding the technology assessment heritages in RRI, the relation between attributes and a range of technology assessment background techniques that are present in conceptual frameworks for RRI [2,4,6,10,71] are shown in Table 1.

Those techniques are proposed to achieve the operational elements of RRI [2,6] in order to arrange the actions such as considering the contingency of the outcomes of STI and identifying the potential negative impacts of research. These methods serve as a starting point, not only for the real practice of RRI policy, but to analyse its presence in renewable energy research.

2.5. Contributions and extension of RRI

As many scholars [30,39,40,72], we wonder what differences RRI from previous policies. This is due to the fact that RRI methods for the real field implementation and operational elements (Table 1), transformed currently in an element of research policy, coexist with policy instruments such as normative codes of conduct, standards, certifications, and accreditations. They run alongside with expert reports, traditional and contemporary technology assessments methods strategic roadmaps [6], as well as traditional impact assessment methods and reviled top-down policy structures. This impression is reinforced by the fact that RRI is often considered a forward-looking view of responsibility built on insights from STS [6] or the latest manifestation of a sequence of policy-oriented debates concerned with the interaction between science and society [73] still focused in issues such as *who* shapes research agendas and *how* the best knowledge and technology might be governed [2].

But, RRI brings two remarkable innovations concerning policy. The first one is that ethical aspects of new technologies are no longer seen as a constraint, but as a stimulus [8]. For this reason, RRI policy is built upon the strength of the ethical considerations and its fundamental role for the reformulation of the innovation process. And the second one is the consideration of the innovation process from research and development to production and distribution, engaging policy to address economic growth and socio-economic challenges [40]. One example is the importance of economic growth and openness regarding innovation in Europe. This motivated, in 2016, a series of initiatives proposed by the Research and Innovation General Directorate, such as a new strategy of *Open Innovation, Open Science and Open to the World* [7], which does not represent a new policy initiative or funding programme as such, but that is a way to reinforce existing programmes, such as Horizon 2020 (where RRI policy is located) and the European Research Area [36]. As a framework, this strategy comprises insights of Responsible Research and Innovation such as public engagement, open science and participation, and it also includes the idea that a specific innovation should not be longer seen as the result of predefined and isolated activity, but rather as the outcome of a complex co-creation process. This process involves knowledge flows across the entire economic and social environment that encompasses businesses, academia, financial institutions, public authorities, or citizens. Open innovation considers collaborations which combine elements such as users, the innovation eco-system, etc. as an alternative to linear or bilateral transactions [74].

If RRI is used as a new tool for funding prioritization or for research impact evaluation, it is necessary to consider that RRI advocates for fundamental changes in the way research is conducted.

3. Responsibility insights in energy research and policies

3.1. Approaching responsibility in energy research

Since energy supply was considered a fundamental prerequisite for the functioning of society [69], its development as a technology has always been filled with social issues, often considered a non-technical barrier. Barriers are divided in technological and non-technological ones [75–77] and in cost [78,79] and non-cost or social barriers [77,80]. Moreover, policies are explicitly designed to promote and stimulate barriers overcoming [80]. The integration of energy correlations and social and political impacts was carried out mostly with the application of social sciences in energy research. Energy correlates the social dimension with the other related concepts, shaping *the complexity of the energy systems* [81]. These concepts appeared in early 1960s and are examples of concerns regarding socio-technical topics located under the umbrella of the *Energy and Society* approach. This approach comprises economy and value, quality of life and development of human beings, ethical and moral aspects of energy, environmental consequences, and energy futures. Renewable energy systems themselves were considered as an element within a social dimension embodied with social evolution of energy, energy geography and energy decision-making and policies [82], included also in many disciplines, from ecological economics to activism.

Ethics and moral philosophy dealing with moral aspects are also disciplines present in early approaches. Depletion of energy resources from others, uneven distribution and resources abundance morality, markets morality, and the use of energy against others were some of the most remarkable approaches within the ethical environmental impact assessment approaches [83]. Values inclusion insights, as part of the responsible approach, can found in energy research in applied ethics integration, including values segmentation in terms of *public values*, defined by economists, and *technology values*, emerging form the outcomes of thereof technology in contrast with moral or *human values* [69]. Another example is this integration of public, technology and human values and the necessity of a modulation of the process due to the fact that moral values are not included inside the energy socio-technical system (which is characterized by a long-term dynamic interplay between technology and societal behaviour). Moral values emerging as an outcome of the expansion and adaptation to heterogeneous activities and technical and social developments in and around the energy system also underneath from this approach [69].

Values are also included in contemporary energy research and

projects in terms of the accommodation of diverse needs and conflicts among stakeholders. These values were developed based on the insights of Science and technology studies (STS). Important approaches to this aspect were the management of the diversity of stakeholders/social actors, and avoiding pitfalls in the introduction of new technologies in society, taking into account that society is alarmed and worried about its risky aspects of new technologies [62,84]. Moreover, in terms of responsible energy policies, the development of renewable energy is a fundamental issue of values and individual choices [85]. Such choices include concerns such as the consequences of the changes of regulations, values, and beliefs on human population [1], approaches to reframe energy decisions, and policies considering ethical elements such as justice and values [22,23].

Contemporary elements of the responsibility approach found in the energy literature are the acceptance of energy systems, the relationship with landscape, consumption and behaviour issues, equity and justice, energy education and knowledge, innovation and research process reframing, and institutional frameworks assessment. But recently, others have shift towards being part of the responsibility approach, including economics approaches more related with the idea of efficiency, cost benefits, circular economy, energy savings, and consumption moving from energy economics towards social and behavioural approaches [86,87]. The major forces considered as those revolutionizing modern energy systems are the behavioural dimension and the transformation of information and communication technologies. The first ones is an element of the decision-making processes and is reinforced by the challenge of addressing global climate change [88], and the second one is the factor leading to systems such as smart grids and to the transition from consumers to prosumers [89,90].

3.2. Operational elements of responsibility in energy research

The operational elements of RRI and thus the methods for achieve them, share intentions and goals with techniques applied in the social science approach of energy research (such as TA). On the other hand, in the case of RRI attributes of Reflexivity and Responsiveness, impact and risk management approaches, in terms of identification and appraisal of the risks and impact of the research and innovation, accomplish the objective of socio-technical integration and interdisciplinarity. Moreover, examples of the RRI inclusion attribute are applied ethical technology assessment, engagement of multi-stakeholders, Backasting, and user-centred innovation and identification. A review of the literature regarding the operational elements mentioned in the previous sections and related with energy research is show in Table 2 [2,6].

A process to review energy socio-technical topics for renewable energy research under the looking-glass of RRI attributes shows that anticipation is related to energy research with issues such as a techno-economic feasibility and topics such as pricing selection, forecasting, feasibility and renewable energy markets, as well as efficiency and costs-benefits [91–93]. Consumption topics appear to be related to reflexivity and inclusion, with the participation of the behavioural sciences approach and the participation of topics such as consumers acceptance, sustainability and energy future [87]. In the case of renewable energy research, this behavioural point of view has been reinforced since the challenge of addressing global climate change is taking place in global research agendas [89,90]. The introduction of social acceptance of renewable energy and its deployment in communities and in developing countries may be related with the attributes inclusion and responsiveness in terms of elements such as local value added and employment and environmental and economic growth [88], as show in (Table 2).

3.3. Contribution of social sciences in energy policy: a responsibility insight

3.3.1. Background

As mentioned, energy research is being greatly influenced by social sciences, despite an undervaluation of its influence in policy [15,18] and the reported prevalence of economics over other social sciences. Early approaches of energy research and policy, with important social sciences contribution and responsibility insights, can be found in approaches such as demand side management and ecological economics. One of the first approaches was proposed by Lovins [92], the so-called *soft energy path*, as an alternative future where energy efficiency and appropriate renewable energy sources steadily replace a centralized energy system based on fossil and nuclear fuels. This early framework reveals the importance of an economy based in renewable energy. It also defines energy as a *service* rather than an *end* or a *product*, showing anticipatory advertence of conflicts between process and outcomes in the results of the innovation and knowledge generation.

The theoretical approach known as *soft path* was settled as an alternative to the *supply-demand* management model, and was developed as a methodology to build desirable future scenarios, from the future back to the present via *Backcasting*. It is considered the first use of the Backcasting technique in the energy field. It is also remarkable as first example of balancing process and outcomes with big emphasis on economic efficiency, environmental protection, and alternative governance.

A contribution from the ecological economics discipline, with renewable energy as the expression of the social dimension, is also represented by the *Human-Scale Development approach* (H-SD). H-SD is a critic review regarding the mainstreaming presence of economics in energy studies [15,47,93,94]. This framework proposes a re-conceptualization from a systemic use-value-centred perspective towards human necessities and satisfactions, where economy, technology and research are devoted to serve human needs [93]. In the H-SD approach, the resources consumption and distributional justice are reframed in terms of ecological limitations measured with a new unit, *ecoson* (ecological person) unit. Ecoson is defined as the amount of resources consumed by one person to achieve a good quality of life. Ecosons were based in clothing, housing and food requirements and were used mainly to express the inequality and unsustainability present in traditional energy policy proposals [95].

A revision of responsibility as a concept in energy policy shows different approaches. Responsibility concerns in terms of *responsible choices made on the basis of expectable consequences* versus responsibility understood as a responsibility to assume the effects. Also, a recognition of the importance of *people-centric* approaches for energy use, and responsibility as element of the social justice [83]. The presence of these approaches to achieve certain objectives does not necessarily imply subscribing responsible research policies, although responsibility insights are found.

3.3.2. Social science research on the long-term energy options framework

The core of this integrative framework for energy research [16] is the relevance of social science research application to energy policy, and it is considered essential in order to tackle the upcoming energy challenges in a sustainable way [15,96,97]. It classifies the global energy-related problems in four categories: security and access, climate change and other environmental impacts, economic and social development, and knowledge management.

This framework was undertaken to examine which R&D initiatives were most needed and fruitful and how to relate and structure the social science research field. Arranged by a request from the European Fusion Development Agency [98], the framework advocates for the integration of social sciences and humanities to advice public acceptance of new technologies and to support the market introduction of new technologies through specific promotion mechanisms.

The framework considers the central functions of social-science energy research in three attributes: reflection, analysis, and design or realization. Reflection is understood in terms of societal functions, their possibilities and limitations, and their responsibilities. Analysis is engaged with the identification of trends and challenges (through the

Table 2
Methods to achieve attributes of RRI in terms of Background techniques of the responsibility approach related with theoretical concepts, practical objectives and governance attributes of RRI policy found in energy research literature (Adapted from [2,6] and enriched by the authors).

Theoretical concept	Background techniques	Objective	Related RRI attribute	References
Action to consider the contingency of the product, process and purpose of STI involving systematic thinking for increasing resilience and for revealing new opportunities for innovation	Foresight Horizon scanning Upstream public engagement Constructive technology assessment Cost-benefit analysis Impact assessment Life-cycle assessment Risk assessment Risk management	Identification and appraisal of risks, potential positive and negative impacts of research and innovation	Anticipation	[1,19,117,131,172,174,202–204] [19,69,86,89,107,114,117,126,131,205–208] [145,209–214] [6] [2]
Multifaceted concept related with the researcher evaluation as an organising principle of science and moral responsibilities	Multidisciplinary Transdisciplinarity Ethical technology assessment Codes of conduct Moratoriums Midstream modulation	Socio-technical integration and interdisciplinarity in research and innovation	Reflexivity	[15,16,18,156,209,215,216] [6] [2]
Public and stakeholder engagement with research and innovation, for the inclusion of new voices in the governance of science and innovation as part of a search for legitimacy	Consensus conferences Citizens' juries Focus groups Science shops Citizen science Participatory research Deliberative mapping Deliberative polling Open innovation User-centred innovation Open source innovation Participatory innovation Anticipatory governance Constructive TA Co-evolutionary approaches Participatory foresight Backcasting Multi-stakeholder partnerships Participatory agenda setting Participatory TA Public/Stakeholders advisory Upstream engagement Crowdsourcing	Public and stakeholder engagement with research and innovation	Inclusion	[150,157,217] [91,156,218,219] [107,210] [155,220–223] [90,116,145,156,224] [225] [2,6]
Process for the assessment of products and outcomes, and to modulate the process of research in STI in the case where insufficiency of knowledge and control is detected	Regulation Standards Codes of conduct Codes of ethics Moratoriums Research integrity Niche management Value-sensitive design Moratoriums Stage-gates Alternative intellectual property regimes	Identification and appraisal of ethical and societal aspects of research and innovation	Responsiveness	[69] [6] [2]

description and understanding of the basic societal mechanisms related to the energy system and actors at all levels). Finally, design or realization is understood as elaboration and support to the implementation of realizable and forward-looking measures and strategies aimed at reaching ecological, economic, and societal/social sustainability (the concept of social sustainability and its correlation with RRI is addressed in following sections).

Although this framework was based in energy policy improvements due to the positive influence of the social sciences, it includes some recommendations that can be considered under the responsible approach. For example, in terms of social science integration and as a methodological responsible approach for energy research with practical recommendations for researchers.

This framework includes also the construction of energy research agendas with the focus on ethical considerations, ethnographic analysis, related developments of political and social changes, and policy recommendations derived from gender-specific changes or individual needs. Examples of the responsible approach of this framework are concepts of trans- and interdisciplinary energy research, the inclusion of ethical topics such as justice when it comes from the evaluation of

Table 3
Building blocks of long-term energy options social science framework. Based on [15,97].

Global energy-related problems	Levels of discourse	
Security and access	Level 1: Pre-analytical approach to topics	Energy behaviour Paradoxes of energy efficiency
Climate change and other environmental impacts	Level 2: Specific research questions and participation	Climate change and energy systems Energy visions
Economic and social development	Level 3: Research period conducted by experts	Policy measures to limit energy use Investment behaviour of house owners with respect to their buildings energy use Socio-technical infrastructure design Sustainability assessment Commercialization of new renewable energy technologies
Knowledge management	Level 4: Research results assessment by multidisciplinary participation of researchers	Involvement of end-consumers The construction and practice of energy markets

emissions, and the economic approach being broadened by other disciplines via a cross-disciplinary methodology [15].

To structure a research agenda for social science energy research in a way meaningful to and adaptable by the scientific communities, the framework proposes three levels of discourse, in parallel with an interaction level where researchers meet practitioners and end-users [16] (Table 3).

3.3.3. Energy justice framework

The core of the energy justice framework proposed by Sovacool et al. [22,23] are the pending consequences of climate change and the structures of the global energy system as central contemporary justice issues, with implications in human dimension and concern such as happiness, welfare, freedom and equity. The framework background is based in several efforts to integrate, redefine and reveal the value of social sciences in energy research [17,18,88,99–101] and to contribute with an integration of new social issues such as depletion of resources, energy poverty as well as excess of energy arising from waste. The energy justice framework is focused in five contemporary energy problems: nuclear waste, involuntary resettlement of populations due to the energy infrastructures, energy pollution, energy poverty, and climate change. The framework is built in a series of conceptual considerations, framed in principles such as availability, affordability, due process, transparency and accountability, sustainability, inter- and intra-generational equity, and responsibility [22].

In this framework, social justice expressions in energy research are related to concepts of distributional and procedural justice (also related with governance), policy and ethics. Examples of distributional justice in renewable energy technologies are the observed perception of environmental and social impacts (such as noise, visual impacts, and land and habitat loss). Some studies also connected distributional fairness and its perception with the extent to which procedural justice is seen to be done, through transparent and open decisions making. Early mentions to energy justice can found in the energy research and policy literature [102,103].

Under this framework, responsibility is understood as a responsibility to assume the effects of today energy system and as a recognition of the importance of *people-centric* approaches of energy use. The effects of today energy system are related to the minimization of the environmental degradation and climate change, and the responsibility of today generations to protect future human and non-human beings. *People-centric* approaches are defined as historical and future shifts in energy practices, sources of variation in energy-use patterns, and effective mechanisms for transforming how people, organizations and societies use energy. Responsibility is also seen as an element of social justice, included in the concepts of individualism and universality (which shape the approach of *cosmopolitan justice*), in terms to achieve a meaningful global change specifically in energy behaviours and attitudes. The use of the energy justice framework as an analytical tool is focused in the connections between energy justice and energy policy and technology. This is achieved through eight philosophical concepts: *virtue, utility, human rights, procedural justice, welfare, freedom, posterity*, and *responsibility*. These concepts are proposed for the reframing process of traditional social issues. An example of this process is represented by the “efficiency”, which is reframed in terms of the human dimension, not as an economic or technical issue, but one of virtue. Another example is the concern of *externalities*, considered human rights abuses. This framework proposed energy problems as justice concerns For example, energy poverty and fossil fuel pollution considered as human rights abuse [22], or climate change considered as a moral issue concerning responsibility, or involuntary resettlement of populations considered as a violation of procedural justice.

The energy justice framework can be used as an analytical tool as well as a decision-making tool, therefore the definition of a series of principles is needed to guide energy decisions [22], as shown in Table 4. These principles can be considered operational elements to

Table 4
Energy justice principles. Based on [22,23].

Energy justice framework principles	Description of the principles
Availability	Ability to guarantee enough energy resources when needed, transcending to concerns related to security of supply, sufficiency, and reliability
Affordability	Stable and equitable settlement of prices
Due process	Ensuring the participation of stakeholder in the energy policy making process
Accountability and transparency	Access to information and central element of promoting *good governance*
Sustainability	The duty of states to ensure the sustainable use of natural resources
Intergenerational equity	Ensure the present people to have a right to access energy services fairly
Intragenerational equity	Integration of the present and future generations regarding to energy
Responsibility	– Responsibility of governments to minimize environmental degradation – Responsibility of industrialized countries responsible for climate change to assume the problem (polluter pays principle) – Responsibility of current generations to protect future ones – - Responsibility of humans to recognize the intrinsic value of non- human species

Table 5
Overview of the RRI keys definition.

RRI key elements	Description of intentions
Governance	Searching for acceptable and desirable futures, robust and adaptable to the unpredictable developments of R&I
Public engagement	Promoting to all societal actors work together in order to align outcomes, values, needs and expectations
Science education	Enhancing the education process to better equip citizens with the necessary knowledge and skills
Gender equality	Promoting, ensuring and considering always gender dimension in decision –making process
Ethics	Fostering research integrity and ethical acceptability of scientific and technological developments
Open access	Fostering accessibility and ownership of scientific information
Social justice	• R&I and social justice connections: – The role of science and technology education and technological developments – The consideration of ethical issues and values in the design, development and implementation of new technologies • Social justice and research activities connections: – Relationship between the researchers and the research subjects – Participation of social groups in benefits arising from research
Sustainability	• R&I and sustainability connections: – Knowledge gap between the headline targets for inclusive and sustainable growth • Sustainability and research activities connections: – Technologies or applications for mitigation or adaptation against climate change – Monitoring of ecosystem services and their effect on human well-being

achieve the goals or key elements to develop the policies.

The approach of social justice in energy projects development and in energy research and policies is carried out from different perspectives, although the experiences can be transferred between them.

4. Responsible research and innovation assessment for energy research

4.1. RRI dimensions beyond significance

As mentioned before, the division of the RRI keys separating governance, as an overarching principle, gender equality, science education, open access, engagement and ethics, and including sustainability and social justice as more general policy goals, allows finding the elements of energy research and applications in terms of responsibility [35]. An overview of the RRI keys definition is show in Table 5. Governance seeks the active participation of all relevant stakeholders in developing a monitoring policy. Within public engagement, the efforts are separated between policies, regulation and frameworks.

Sustainability and social justice, in terms of RRI and as a main goal of European research policies, are understood as an inherent attribute of the research process, in terms of what extent does a research field, a research programme or an RRI initiative contribute to sustainable growth and social justice and to sustainability (Table 5).

Also in the context of research activities, social justice can be considered from two perspectives: the relationship between the researcher and the research subject; and the participation of social groups in benefits arising from research. The concept lays over the impact of research and its effect on social justice/inclusion in terms of the access and affordability of products and services developed as a result of R&I activities for different social groups. It also covers the steps to extend the impact of research to a larger population or to minimise potential unintended negative consequences in relation to social justice [104].

4.2. Key dimensions for energy research

An understanding of energy research in terms of the RRI dimensions [4,6] shows correspondences with other responsible approach insights, although new perspectives, such as the duty to assume the effects and the participation of stakeholders needs, are also included. Trends in responsibility in energy projects development and in energy research and policies are carried out from different perspectives. Experiences can be transferred from research to policy and from policy to projects planning.

As mentioned before, the presence of RRI dimensions to achieve certain objectives does not necessarily imply subscribing responsible research policies, due to the fact that, RRI policy is defined within Europe 2020 strategy.

Another consideration is related with two factors. The first one is that sustainability and social justice as dimensions, which deserve a special treatment in the case of energy research and renewable energy, are common elements in RRI and energy policy. The second factor is the presence of intensive interrelations between the dimensions both on terms of policy and of research process.

4.3. Science education

The relevance of ensuring energy education at all levels is an issue globally recognized. Revising science education [105], the aspects found were energy education [106], renewable energy education [106–109], as the treatment of various topics and issues related to renewable energy resources and technologies (as an independent subject or correlated with social acceptance [86]), energy poverty [110,111], consumption behaviour [112,113], and communication and diffusion. On the other hand, energy education devoted to promote public awareness, to the development of consumer confidence, as well as related with training experts, and educational efforts addressed to training policy analysts, advisors, and future customers were found [106]. Regarding the responsible approach within science education, where public, policy makers and innovators are engaged, the inclusion of efforts to increase policy makers awareness and to educate common public about energy and climate change (to expose them to the state of the art of renewable energy technologies [114]) was also reported, however general efforts are still focused in the generation of potential users [115–117]. No references regarding to RRI science education considerations, in terms of including this dimension in the reformulation of the research process, in energy research, and in policy were found.

In case of community energy projects assessment, the education of inhabitants (particularly women) in the use and management of renewable technologies, and the education of communities and indigenous populations was also reported in the literature [107,118]. Science education regarding energy research was found deeply linked with the public acceptance dimension. Public awareness campaigns and demonstration exhibitions related to renewable energy technologies and appropriate institutional initiatives to communicate renewable energy goodness were found [119]. References on stakeholders involvement, employment, and educational resources as an approach of open science within education were found [120]. Also, outmodedness regarding how scientists and engineers receive scientific education and the need of reformulation of the programs being used was also reported [121].

4.4. Public engagement

An example of responsible approach is public participation, in terms of how public commit with renewable energy projects results [69,122]. Traditionally, public engagement was based on the communication researchers to citizens [90]. A more contemporary view is the involvement of citizens, as a core element for energy production and savings, to take part on the changing energy system with involved stakeholders [89].

The early consideration of acceptance, as a externality of the energy sector, distinguish between socio-political (public and policy actors), community (procedural and distributional justice and trust actors), and market acceptance (consumers and investment sectors) [85]. Community acceptance is the only consideration that is directly related to the responsibility approach. It engages with the contemporary idea of participation in terms of specific acceptance to manage local stakeholders relations, particularly residents and local authorities. An example is the different interests between the energy provider (utility) and the owner of the site/land [70,123–126].

The community acceptance approach is engaged almost exclusively with energy projects development, although it is also connected with the integration of participatory decision making processes and good governance concerns. Bidwell et al. [90] proposed the fundamental questions to modulate this participation in energy decisions in terms of four factors. Those factors are *the scope of the problem* (how the problem is defined determines what issues or topics will be discussed, the types of information and analysis required, and which interests should participate in the decision process), *the purpose of participation* (for example, devoted to incorporating diverse voices), *degree and time of inclusion* (who should be included and during which period of time), and *the allocation of decision authority* (in terms of who makes the final decision, even in a participatory process) [127,128]. This acceptance aspect can be considered under the umbrella of the RRI approach on terms of the reformulation of the process and the inclusion of different stakeholders. It also fits in the idea of the definition of a series of attributes that research and innovation needs to fulfil. And it also contains elements of distributive and procedural justice as factors affecting community acceptance [129].

The acceptance process with the innovative inclusion of considering the *do-it-yourself* market [130] and the adoption of renewable energy systems at home [131], including the behavioural theory to understand the consumer perspective, are also considered to develop energy policy interventions [132]. This vision of participation is engaged with the concepts of social/circular economy and social enterprises [133] in terms of bringing better outcomes through localized problem identification, reduction of project costs, improvement of maintenance and allocative efficiency, and prospective self-reliance [134].

Public engagement associated with technology reflecting values and management of stakeholders expectations in the case of engagement in energy projects development has been approached with conceptual frameworks based on multiple European case studies on public engagement with renewable energy projects [135]. Walker et al. [136] developed a descriptive conceptual framework to advance how engagement results from the interaction between project developers and public stakeholders will be developed.

4.5. Social justice

Justice concerns presented a big growth in the last years, both in energy policy and in energy research areas [137], with examples such as distributional issues in energy matters, with a body of work on 'energy justice' [22,23] and procedural justice concerns [22,23,69,103,138–142].

To advance social justice in terms of responsible approach for the energy field, a number of factors must be taken into account. First, as mentioned above, the approach of social justice in energy projects development and in energy research and policies is carried out from different perspectives, although the experiences can be transferred between them.

Second, RRI policy defines social justice together with sustainability in terms of general policy level [143]. Both dimensions speak to the political guidelines for the EU Commission, which present an agenda for jobs and growth that has a clear eye for fairness and democratic change, however, *justice* does not resemble with *social justice* in terms of responsibility approach. The energy justice framework [22,23,103] engages with the responsible approach, especially when reframing energy global challenges through a set of philosophical aspects, which when are not observed lead to the violation of social justice. This approach can be found in the foundational concepts of RRI, regarding the ethical assessment of technologies [56,61], and in the reframing of the research and innovation process taking into account the consequences of these outcomes. Energy justice set of philosophical principles have their correspondence with the moral values approach that supports and embodies technology proposed in Responsible Innovation and later on adapted in RRI. Also, social justice as dimension shows interlinks with other RRI dimensions, such as public participation and the inclusion of the decision-making process in the governance. These concepts reveal a chance of certain integration between those energy policy proposals and RRI research policy.

Finally, the third factor covers the fact that there is a general approach of justice in energy research not engaged with the responsible approach. Different theories have been formulated to approach justice concerns in energy research in contrast with the responsible approach. Some examples are social justice in terms of fairness in the distribution of goods and advantages [144], the warranty that all citizens are able to meet their basic needs, people capabilities in terms of justice [23,137], as well as the marginal mention of socio-technical evolution towards a decentralized energy system (DES) leading to a socially inclusive, community-led energy planning [145,146]. Both the basic need approach (warranty that all citizens are able to meet their basic needs) and the capabilities approach (people capabilities in terms of justice) are partial approaches to the distributional justice theory. However, formulations of distributional justice have been developed beyond that traditionally consideration of social justice [137]. The explicit connection with the distributional justice theory and the renewable energy development appears relatively weak, with intuitive notions of (un) fairness and (in)equity [129,137]. Examples to distributional justice in renewable energy technologies are, for example, the observed perception of environmental and social impacts (such as noise, visual impacts, and land and habitat loss) [67,147], and renewable energy projects contributing to achieving economic development and climate change targets at regional, national and international level [137].

4.6. Gender equality

In terms of RRI policy, the inclusion of gender as a research topic in energy research projects is the only consideration towards transcending traditional socio-technical approaches towards responsible ones [18]. Gender issues are also represented in the marginal participation of women in energy policy, in contrast with their importance as producers and managers of community resource systems, their higher exposure to pollutants, as well as gender overlook in terms of citizen participation in renewable energy systems [18,148–150]. Mainstreaming gender perspective with concerns such as equal opportunities, parity and glass ceilings, is also a core issue in the reformulation of research policies which permeates scientific disciplines.

A revision of gender studies in terms of energy research shows new trends. The first one is ecofeminism, in terms of connection between the exploitation and degradation of the natural resources and the subordination and oppression of women [151]. The second one are relational ethics associated with gendered differences in the moral decision-making process [148,152]. Examples of research policies that include

the gender perspective and a gendered treatment of the topics are new research agendas (including eliminating indoor air pollution [18,148], and the contribution to discussion of community energy management [153,154]) and developing a legal framework explicitly covering and the increasing women representation in energy research [148].

4.7. Ethics

The ethics dimension covers both epistemic and moral considerations. The moral considerations are covered by the inclusion of values and moral obligations. Responsibility in this terms is defined as the duty with respect to certain moral obligations [61]. Epistemic considerations are related with conceptual approaches of anticipation, reflexion, inclusion, and responsiveness, expressed with the identification and appraisal of ethical and societal aspects of research and innovation [2,6].

Before RRI policy development and deployment, multiple efforts to apply alternative technology assessments and ethical impact assessments were subscribed under the umbrella of applied ethics. Similarly, to other dimensions (social justice), a distinction between the application in energy projects and in energy research needs to be considered. In energy projects, different techniques subscribed under the umbrella of applied ethics can be found. Those are constructive technology assessments and co-construction [118,155] and value sensible design [69], where the moral considerations are reflected. Moral inclusion can also be found in community energy based projects, based in moral economy and social enterprise concepts, including alternative approaches to economic development related with ethics (such as the ethic of livelihood, in terms of granting the right to sustenance to each and every member of the community, and sustainability in terms of social retrieving an social outcomes) [133,156,157]. Regarding the ethical aspects of energy research and policy, an important contribution is found on the different frameworks of energy justice mentioned above [22].

4.8. Governance

Marginal mention to governance appears in the energy justice frameworks defined above [22]. However, the practical application coming from existing methodologies such as anticipatory governance, constructive governance and other forms of technological enhancement can be found in literature (Table 2).

4.9. Open access

Marginal considerations regarding open science and open access in terms of energy research and policies can be found in the literature. Although, concerns regarding public stakeholder engagement for the inclusion of new voices [2,6] and alternative systems to stablish collaborations linked with public engagement (such as a crowdfunding [158]) can be found.

4.10. Sustainability

Energy studies and renewable research generally subscribe sustainability in terms of development that meets the needs of the present without compromising the ability of future generations to meet their own needs [159]. Contemporary approaches in energy research reinforce the sustainability dimension in terms of clean, reliable, and affordable (sustainable) energy, and link it critically with achieving inclusive, low-emissions growth and development [22]. Sustainable energy can influence human progress, creating jobs and economic competitiveness, can empower women, can lead to new global markets for goods and services, can alter regional energy trades, and can help ensuring that environmental impacts of economic development are minimized [160–162].

Under the umbrella of sustainability in energy research, a concept such as social sustainability [55] is included. Traditional sustainability considerations are linked with three dimensions: ecological, economic, and social sustainability [161], shifting in contemporary discourses, from a focus on economic development to a new view of sustainable development. Social acceptance has been recognized as one basic ingredient of social sustainability, taking into account that for a technical system to be deemed socially sustainable it should enjoy wider social acceptance. The integration of these functions allows to perceive societal, political, economic (e.g. globalization), ecological (e.g. climate change), and technological developments significant for the energy sector. They also include the society basic attitudes towards specific issues such as risk, insecurity, trust, rationality, change, and tradition.

Social acceptance and social sustainability scope are still under construction and changing. They include social impacts, social aspects, and social indicators. Other definitions of social sustainability are related to the continuation of society in the future, implying the continuation of its social values, social identities, social relationships, and social institutions [160]; with the social requirements for long-term development and with concerns regarding with environmental and cultural integration of societies.

Social sustainability can be linked with RRI through its definition related to the fairness in distribution and opportunity, and adequate provision of social services (including health and education, gender equity, and political accountability and participation), and through the component of social acceptance.

5. Conclusions

An overall consideration shows that renewable energy research does not seem very influenced by the RRI approach when considered globally. However when each dimension is observed separately, finding more correspondences is possible. The RRI dimensions of science education, gender, governance, sustainability, ethics, open access, engagement, and social justice have been treated in renewable energy research in varying levels, emphasizing engagement, education, sustainability, and social justice. Several interconnections between RRI and evolved and traditional social inputs from energy research heritage were also found in the literature review process, moreover, correlations between RRI dimensions in energy policy were found focused on the relationship with technology. Education, public engagement, gender and public participation, and new paradigms such as energy justice, are some of the most remarkable elements where correlations are notable. For example, in the case of sustainability and social justice dimensions, both can be located under the umbrella of the seeking for *good governance* in terms of the right to all people to have access to high-quality information about energy and the environment. Therefore, information, accountability, and transparency become central elements for promoting *good governance* throughout a variety of sectors.

A review of the social sciences energy policy frameworks in terms of RRI elements yields the following results. First, the application of social sciences to the technical disciplines is perceived as an expression of responsible approach. It is still one of the most unanimously recognized interpretation and the contributions of social sciences in the development of energy policies for the inclusion of divergent voices and topics such as *Energy justice framework* is notable. Second, although the same terms are used in the RRI discourse and in social sciences frameworks, the concepts and contexts embodied are not exactly the same. This effect is especially notable in responsibility considerations bias, found when attributes of the research process of RRI considerations and Responsibility in terms of the consequences of environmental degradation, responsibility for climate change and the recognition of values are compared. An example of this bias is the social justice and sustainability considerations, to pursue fairness in the distribution of goods and advantages achievement. Interestingly, social justice and sustainability are endorsed in RRI as elements for transversal objectives of specific EU policies and dedicated in social sciences frameworks for

energy. Despite of this difference in the meaning of the concepts, correlations can be found. One example of these correlations are ethics dimensions, like in the case of Energy justice and RRI framework. However, this relation can be explained due to the sharing of theoretical background and contemporary trends towards responsibility affecting most of the approaches.

The third factor is related with the presence of the operational elements related with the use of technology assessment methods for the re-interpretation of the attributes that research process needs to fulfil for being considered responsible. As mentioned above, in the RRI approach, attributes are considered fundamental vectors to archive the reformulation of research and innovation. They are also considered elements to achieve the transversal objectives of specific EU policies. Attributes of anticipation and reflexion can be achieved with the application of technology assessments and participatory research among others, as mentioned in the operational description of the RRI policy. These methods are also widely being used in energy policy. In the case of energy research, attributes and operational elements are considered an extension of socio-technical topics. In the RRI attributes translation to energy research, for example, anticipation is related to issues such as a techno-economic feasibility and topics such as pricing selection, forecasting, feasibility and renewable energy markets, as well as efficiency and costs-benefits. Consumption topics appear to be related to reflexivity and inclusion, with the participation of the behavioural sciences approach and the participation of topics such as consumer acceptance, sustainability and energy futures. In the case of renewable energy research, this behavioural point of view has been reinforced since the challenge of addressing global climate change. It can therefore be concluded that for the reviewed elements, attributes are related with topics and subtopics of specific research and not related with the reformulation of the research and innovation process, and the operational elements are related with socio-technical considerations to approach the topics.

Technology assessment methods are also related with the understanding of the dimensions. For example, the ethics dimension is related with these methods due to the application of social sciences approaches in energy research and policy. Under the umbrella of applied ethics in energy research, approaches and methods such as constructive technology assessments, co-construction, and value sensible design, where the moral considerations are reflected, can be found. Moral inclusion can also be found in community energy based projects, based in moral economy and social enterprise concepts, including alternative approaches to economic development related with ethics.

Another significant conclusion is the evolution of the responsibility approach and the shift towards responsibility detected in other approaches. The ethics dimension treatment is an example of the shift towards responsibility. In the case of energy research, ethical frameworks have been detected, transitioning from their use (trying to predict or anticipate social consequences and as a basis for moral and regulatory appraisal) towards their use for the introduction of new technologies. Another example of responsible shift becoming a trend is represented in analytical approaches such as top-down and bottom-up considerations, as well as upstream/downstream/mainstream considerations. The distinction between top-down and bottom-up technical approaches in energy innovation and energy research attends to distinct manners in which these two types of models treat the adoption of technologies, the decision-making of economic agents, and how markets and economic institutions actually operate. Participatory bottom-up approaches in renewables and energy studies are generally related with systems that ensure people participation at multiple stages of the process, starting from project selection by capturing people needs/desires and studying the existing practice to understand its importance in the local context.

In responsible approaches, both top-down and bottom-up synergies are related with the introduction of policies, with top-down referring to initiatives coming from policy makers and governance spheres, and bottom-up with the inclusion of represented researchers as well as involved stakeholders. Responsible rhetoric converts this analytical approach considering bottom-up policies as responsible, inclusive and participatory, and considering RRI to strength and foster this way instead of top-down.

Responsibility approach has been evolving from encompassing socially considered aspects of disciplines towards more specific approaches. Therefore, the multifaceted nature of responsible approach seems to be taking the place in the case of social dimension treatment of the energy research and policy, as a natural and contemporary evolution of approaches. However, in renewable energy research, as well as in the general energy studies field, contemporary discourses coexist with traditional socio-technical approaches and it is difficult to separate the effects of the temporal evolution of the methodological approaches from deliberate responsible trends due to the social footprint of the discipline. Despite the strong social dimension of renewable energy research, the integration of RRI can trigger misunderstandings in the definition of the terms, and approximations, obstructing the translation into practice. Likewise, the integration may be possible due to the fact that both, socio-technical dimension and responsible approaches, share the same theoretical background.

Responsibility does not correspond to one fixed definition and its scope in policy is still under construction. This allows for a certain amount of flexibility in terms of implementation. However, actions labelled as such can have a less effective influence when compared to efforts framed within a more targeted focused framework.

Contextual variation between research fields and research ecosystems must also be taken into account in any development and implementation of a responsibility approach. Specific strategies need to be developed to apply Responsible approaches and RRI elements, always taking into account the particularities of Energy research and policy. This means incorporating elements such as the effect of technology outcomes on society, the well-being of the community, the consequences that changes in norms, values and beliefs have on the society, and the enactment of government as well as policies and regulations.

The role of researchers also needs to be taken into account as factor in any implementation: researchers awareness and disaffection, convenience, a lack of familiarity with social sciences approaches and the complexities of interdisciplinarity in real practice, as well as the autonomy of the individual investigator's activity and that of the research institution. Other constraints, such as the time lag between the research outcomes and final applications and the extra effort in acknowledging contributions when innovation is the result of a network of interactions between a variety of stakeholders, also affect both researchers and stakeholders. In this sense, raising awareness among researchers about the policies of responsibility and seeking their direct participation in the design of tools for implementation can considerably increase their support in taking part in such implementation. A number of innovative strategies such as focus groups, citizen juries, and other forums for participatory discussions and new models of anticipatory governance and Constructive Technology Assessment for renewable energy research, will, when incorporated in the research practice, greatly enhance the successful integration of responsible policies.

Moreover, the design of these responsibility goals can sometimes be framed in a broad spectrum of expectations and suggested good practice such as the interdisciplinary integration of topics, innovation outcomes reinterpreted as an expression of moral values, the aim to broad research impacts beyond traditional R&D outcomes or the redefinition of excellence in terms of analytical and social relevance of scientific outcomes. This means that in some ways, the impact of responsibility actions can be relegated to a series of good intentions without actual materializing into specific actions. Future progress trends for responsibility ought to include implementation toolkits and pilot experiences to be able to easily move from policy to practice. Also they should be accompanied by a series of institutional changes to make it progress from intentionality to firm commitment.

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