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Social sciences and nuclear energy practitioners: Exploring Spanish perceptions and expectations of interdisciplinary work in a transdisciplinary world

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ABSTRACT

The challenges of energy transitions, as reflected in current energy-sector research agendas, call for greater multi-, inter-, and transdisciplinarity, with particular emphasis on greater contribution from the social sciences. While recommendations abound on how to strengthen the role of the social sciences in energy-sector research, there is little empirical evidence on how the attitudes of energy-sector professionals might facilitate or constrain such interaction. This article helps to fill the gap by presenting the results of an exploratory survey into how nuclear-sector professionals in Spain perceive the potential role of the social sciences in this sector. The large majority of the respondents had little experience of collaboration with social scientists, and the tradition of inter-disciplinarity remains weak in this sector. For many professionals, enhancing public acceptance of nuclear energy is the main potential function of the social sciences. Although the road towards true interdisciplinarity is still long, the surveyed Spanish professionals showed true interest in greater openness, dialogue, and inclusion of the social sciences, and believed in the possibility of breaking the structural inertia that they saw as one of the obstacles to cross-disciplinary collaboration in the sector. According to the surveyed professionals, social scientists could play a useful role as organisers of deliberative interdisciplinary processes. However, the portrayal by some of the surveyed professionals of social scientists as biased and anti-nuclear calls for self-reflection among social science scholars. Future research should expand the number of countries analysed, and could usefully explore cross-country differences in the opinions of nuclear-sector professionals, by applying representative sampling methods.

1. Introduction: a new role for social sciences in energy research, practice, and policy: from multi-, through inter- to transdisciplinary work

The key European research agendas as well as energy and climate policies and strategies increasingly call for multi- and interdisciplinarity, with special attention to the expected contribution from the social sciences and humanities. Arguably, the sought-for energy transitions that would profoundly transform our societies require even transdisciplinarity, that is, crossing boundaries between academia, practitioners, various types of stakeholders, and the civil society. The quest for multi-, inter- and transdisciplinarity is manifested in key policy documents that underpin European energy and climate policy, such as the European Climate Pact [1], the European Green Deal (EC COM/2019/630), and the new EU Strategy on Adaptation to Climate Change (EC COM/2021/18). In the efforts to foster transdisciplinary collaboration, the interaction between the engineering, natural, and social sciences is vital. Diverse EU Horizon 2020 and Horizon Europe funding calls in the area of energy transitions indeed not only urge projects to employ participatory and deliberative practices but explicitly advocate the inclusion of social science and humanities scholars also in technically oriented research projects. Literature on the role of the social sciences in the energy sector argues that social scientists - whether in academia, government, or the private sector - could play a useful role in ensuring the inclusiveness and the methodological robustness of the deliberative and participatory processes, carrying out research and experimentation

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on behavioural, social, and cultural change across Europe, and ensuring that the projects apply state-of-the-art methodologies that respect ethical standards [2]. Multi-, inter-, and transdisciplinary networks of experts, researchers, practitioners, and civil society organisations are therefore likely to constitute a key pillar of energy research in the years to come. Initiatives such as the Net4Society network, an international network of national contact points to promote successful integration of social sciences and humanities research throughout Horizon 2020, further illustrate this trend [3].

Various terminologies have been used in the literature and practice to describe different types of "integrated research" [4], that is, forms of research that involve multiple disciplines and sometimes actors and approaches beyond academia. We rely on the typology presented by Stock and Burton in 2011 [4], which classifies the forms of integrated research as a three-pronged hierarchy, from multidisciplinarity through interdisciplinarity to transdisciplinarity. This article examines the opportunities of and obstacles to multi- and interdisciplinary work, considering these as essential albeit alone insufficient preconditions for transdisciplinarity.

Multidisciplinarity, the least ambitious type of integrative research, entails collaboration whereby researchers share knowledge and compare results but make no attempt to cross disciplinary boundaries or generate new integrative knowledge. Such research can be problem-oriented, but usually not to the same extent as inter- and transdisciplinary research. Interdisciplinary research addresses specific 'real world' system problems and hence compels scholars from a range of disciplines to cross disciplinary boundaries and create new knowledge. The degree of integration and cooperation are greater than in multidisciplinary research, and the projects may allow the existing knowledge to be examined from the perspective of a neighbouring discipline. Stock and Burton [4] distinguish between 'big' and 'small' interdisciplinarity, with the former characterised by collaboration between distant disciplines, and the 'small' version engaging sub-disciplines that are relatively similar with each other.

Transdisciplinarity is the most advanced type of integrated research, as it includes also non-academic participants in research. At the most general level, transdisciplinarity can be defined as a critical, self-reflexive and knowledge-oriented joint effort by the academic community and a broader range of actors in society, in the pursuit of solutions to pressing societal problems and associated scientific challenges [5,6]. It seeks to generate mutual learning, and produce transformative knowledge that is transferable both to scientific and societal practice. It requires intensive exchange between knowledge producers and users throughout the entire research process [6,7]. Arguably, addressing today's pressing and existential problems facing society requires transdisciplinarity, which would help to integrate a multitude of communities of knowledge, ensure the theoretical consistency and practical viability of solutions, and strengthen the legitimacy, ownership, and accountability for problems and solutions [6–8].

While there is a general understanding on the meaning and potential virtues of multi-, inter-, and transdisciplinarity, implementing these in practice is hampered by a host of difficulties. These include resistance from within the academic and expert communities, but also sometimes profoundly distinct epistemological and methodological approaches adopted by the social, natural, and engineering sciences, respectively. Differences concern aspects such as quantification, interpretation, explanation, understanding, reductionism, normative and positive analysis, and the criteria of scientific objectivity [9]. Most of the scientific literature on multi-, inter- and transdisciplinarity has thus far taken a normative approach, suggesting what should be done, whereas there is a dearth of literature on the actual practice of disciplinary integration and on the preconditions for such integration.

This article helps to fill this gap by providing empirical evidence concerning the opportunities for and resistance to cross-disciplinary work in the nuclear energy sector. Although by no means the only sector vital for energy transitions, it is a fruitful target for the exploration of the challenges of inter- and transdisciplinarity, characterised as it is by a highly science- and engineering-oriented identity and tradition, as well as by polarised views and strongly-held values. The article examines the perceptions and expectations expressed by practitioners and engineering scholars in the Spanish nuclear sector concerning multi- and interdisciplinary work that would involve scholars from the humanities and social sciences. By examining these findings in the light of the normative recommendations from the existing literature, the article identifies and analyses challenges and opportunities for multi-, inter- and transdisciplinarity in the energy sector, and thus contributes to theoretical and conceptual development in social science energy research.

Several encouraging examples of attempts at integrative work in Spain can be mentioned. These include active Spanish participation in EU-funded inter- and transdisciplinary research projects such as COWAM, COWAM 2, CIP, and HoNESt, in international networks such as SHARE (focused on interdisciplinary research on ionising radiation), and in numerous committees and working groups dedicated to integrative work under the OECD Nuclear Energy Agency. Noteworthy are also public engagement consultancy work by firms such as Merience, and interdisciplinary work at CIEMAT - a government research organisation focusing on energy and environment and the associated technologies. However, to our knowledge, ours is the first empirical exploration into the views and experience of Spanish nuclear-sector experts on multi- and interdisciplinarity.

The next section reviews the existing literature concerning the challenges, opportunities, and needs for multi- and interdisciplinary work in the energy sector. Section 2 presents the data and methods, while Section 3 details the results of the empirical surveys of the views of Spanish nuclear practitioners regarding social sciences and their potential contribution to the practitioners' daily work. In particular, we explored Spanish nuclear professionals' views on four topics: the nature and degree of interaction between the nuclear sector and the social sciences today; the expectations regarding the potential contribution of social sciences to nuclear research and practice; the obstacles to greater integration of social science knowledge into the nuclear sector; and suggestions for potential options and pathways for stimulating transdisciplinarity in the nuclear sector research and practice in Spain.

Section 4 discusses these views and expectations in the light of the key recommendations in the existing literature summarised in Section 1.1. Section 5 concludes and suggests topics for future research on how to overcome the barriers to multi- and interdisciplinary work in the energy sector in general, and in Spain in particular.

1.1. Integrative research and practice in the energy sector: where are we now?

The social sciences and humanities scholars in the energy sector have widely endorsed the objectives of inter-, multi-, and transdisciplinarity, and have sought to develop new approaches to research and policy relating to both demand and supply of energy [10,11]. A general consensus, which provides a basic normative foundation for the very existence of this journal, prevails on the notion that a sustainable energy future is possible only if it integrates insights from both the physical and the social sciences [2,12], and gives proper consideration to the social dimensions of energy transitions [13].

This call for a stronger role of the social sciences is not limited to research. Social scientists can also play a vital role in the practical energy policy and management work, whether in government agencies, industry, or civil society organisations. Within these organisations, social scientists may contribute, for instance, to better management practices by participating in risk assessments, and to the development of stakeholder engagement approaches and methods [10]. Social scientists can also function as agents of change, by spurring self-reflection and questioning of established norms and practices. Findings from research within the energy-related social sciences and humanities (energy-SSH)

are therefore fundamental for efforts to identify opportunities and challenges facing energy policy [14].

As Schuitema and Sintov [15] argue, "interdisciplinary energy research (and policy), in which social sciences play an equitable role on par with 'hard' sciences, is much needed to create a sustainable, secure and affordable energy future." Energy research needs social science and should "intentionally, systematically, and institutionally be more problem-oriented, interdisciplinary, socially inclusive, and heterogeneous" [8]. This broad consensus is reflected also in the growing number of articles, reviews, and journals dedicated to the topic, as the rapid growth of this journal demonstrates. Furthermore, the established social science and energy-sector journals increasingly publish work on such topics.

It is less clear how far we have advanced in our efforts towards such integration. How and to what extent has this consensus translated into concrete integrative practices, institutions, and knowledge? A look at the recent social science research on energy provides tentative insights.

The very first observation is that most research and policy efforts have focused on multi- or interdisciplinary work, whereas literature on transdisciplinarity is virtually absent. Interdisciplinarity is therefore pointed out as the main challenge for the integration of social sciences research in energy research. This existing literature has identified a number of gaps in the current knowledge:

- There are very few case studies analysing practical experiences of multi- and interdisciplinary work [16,17].
- There are very few systematic empirical studies on the status of multi-, inter-, and transdisciplinary work. A systematic analysis of 262 articles addressing the integration of disciplines from 2009 to mid-2019 concluded that less than a third of the studies employed comparative or mixed methods. More than a third of the articles (35 %) had neither a research design nor a methods section [18].
- In the absence of strong empirical evidence, most articles provide conceptual and methodological reflections on the role of the social sciences in energy research. Themes addressed include:
  - specific areas of energy research in which social sciences could best contribute;
  - methodological challenges and solutions [18];
  - the means of adequately incorporating the social science contributions [10];
  - the key actors, methods, topics of research, barriers, and prospects [19].

The existing literature has come up with a number of normative recommendations on how to bring social scientists into energy research, improve the understanding of the social sciences among energy-sector actors, and advance integrative work:

- Social sciences should provide *analytical tools* (theories and methods) to promote understanding of the human and social adaptations that energy transitions require, rather than encouraging, let alone forcing, individuals to accept top-down energy policies or technologies [e.g., 14,17,20].
- Social sciences should focus on methods and *processes* rather than on the envisaged or promised outcomes [e.g., 11,14,17,21].
- Social sciences should develop more robust *research designs*: methods in general and mixed methods in particular require more attention [e.g., 10,11,16].
- Social sciences should be involved *from the very beginning of research projects*, in defining and exploring problems, and framing the research questions, instead of being integrated only at the latter stages, when technical choices have already been made [e.g., 2,14,22].
- Social sciences should foster *inclusiveness*, by promoting reflection on who should be involved in doing what, and by integrating knowledge and expertise from lay citizens, community leaders, local groups, and the like [e.g., 6,11,14,16].
- The (public and private*) funding schemes* should devote more resources to social sciences and multi-, inter-, and transdisciplinary research. The limited funding that is currently available for interdisciplinary research is not equally distributed across disciplines [e.g., 11,14–16,20–23].
- The *evaluation criteria* applied by funders should be revised to give due credit to scientifically rigorous and high-quality multi-, inter-, and transdisciplinary research [e.g., 15,16,20–22].
- *Research agendas* should encompass research on energy behaviour and energy demand, alongside the traditional supply-focused research [e.g., 10,14,15].
- *Publication processes*, including the scientific quality criteria and peer review, should better account for *the specificities of multi-*, *inter-*, and *transdisciplinary research* [e.g., 11,15].
- *New research paths* should be pursued in areas such as socio-ethical aspects, justice, identity & politics, imaginaries, public engagement, and governance [e.g., 10,22].
- *Case studies* to better understand the challenges and opportunities for cross-disciplinary dialogues should be conducted [e.g., 16,17].
- Social sciences should help to promote *reflexivity*, a key component of Responsible Research and Innovation (RRI) [e.g., 17].
- Efforts should be made to develop *shared concepts and language*, *so as to foster mutual understanding* among disciplines [e.g., 8,16,17].

In summary, the social sciences are acknowledged as an essential contributor to energy research, and a variety of (preliminary) conceptual and methodological means for moving in this direction have been proposed. However, the road towards truly integrative work in energy research is still long. We need to better understand the dynamics, drivers, and barriers for multi- and interdisciplinary research in this field. This could lay the bases also for more integrative work between practitioners and social scientists, that is, for transdisciplinarity. The following section presents the findings from a study that sought to identify the opportunities and barriers that the prevailing perceptions among nuclear-sector professionals in Spain pose for the integration of social science and humanities scholars in this sector.

2. Material and methods

To explore the perceptions and expectations of the Spanish nuclear-sector professionals in relation to the social sciences and their potential contribution to the development of the nuclear sector, two on-line questionnaires were conducted between May and September 2020.

2.1. The sample

The participants were recruited through email invitations targeted to professionals in the Spanish nuclear sector. A total of 129 responses were obtained (73 in the first survey and 56 in the second). Five responses were excluded due to missing values for the key variables. Of those who responded to the first questionnaire, 28 % also participated in the second one. Table 1 presents the sociodemographic profile of the participants.

The mean age of the respondents was 40 years, with almost half of the participants in the age group of 18–35 years. The percentage of women was relatively low (15 %), reflecting the gender imbalance in the nuclear sector in general. Most (73 %) of the respondents hold an engineering degree. Diverse work positions were represented, with 29 % being directors, 29 % technicians or consultants, 16 % managers, 16 % teachers, and 10 % holding other types of positions.

The CEIDEN Platform (Spanish Platform of Nuclear Fission Energy) and the association "Jóvenes Nucleares" (the Spanish Youth Nuclear Society) helped to recruit participants by sending email invitations to their members.

CEIDEN is the Spanish organisation established to coordinate the

Table 1
Sociodemographic profile of the sample.

$N = 124$	Mean/%
Age	40
18–35	46 %
36–50	30 %
+50	24 %
Gender (female)	15 %
Years in the field	12
Degree	
Engineering	73 %
Natural sciences	21 %
Social sciences	6 %
Job position	
Director	29 %
Manager/responsible	16 %
Technician/consultant	29 %
Teacher	16 %
Others	10 %

efforts and needs of nuclear fission energy research and development. Its main functions are to design and implement joint projects, and to elaborate common positions concerning national and international commitments and proposals in the field of nuclear fission R&D. CEIDEN's membership encompasses all actors and entities involved in the R&D of nuclear fission in Spain. It has more than 100 members from 11 subsectors such as utilities, fuel cycle companies, engineering, service companies, R&D institutions, universities, and authorities.

"Jóvenes Nucleares" is a subsection of the Spanish Nuclear Society. Its main objective is to disseminate knowledge about nuclear energy, by highlighting its contribution to societal wellbeing. The organisation has approximately 1300 members. It spreads information via social media, lectures and courses at schools and universities, conferences and debates, participation in international events related to nuclear industry and research, and by organising educational visits to nuclear facilities.

Given that the data were collected via convenience sampling, the results cannot be taken as representative of the entire nuclear sector in Spain. Our research was indeed exploratory, and not aimed at producing generalisable findings. Nevertheless, we believe that because two large institutions in the sector were involved, the results give a relatively good approximation of the prevailing views among the Spanish nuclear-sector professionals.

2.2. Questionnaires

The first questionnaire was exploratory, consisting mostly of open-ended questions. It included two sections. The first provided information about the purpose of the study and introduced the overarching question of the study: 'How could the social sciences contribute to the development of the nuclear sector?' A very short description of the social sciences and its disciplines was presented, followed by a brief explanation of the potential interest that such disciplines could present for the nuclear sector.

The second section comprised seven questions on participants' knowledge of social science research in the nuclear field; direct and indirect experiences and perceptions with social science research; expectations regarding the social sciences and their role in the future of the nuclear sector; and views on the main challenges and opportunities in efforts to overcome such obstacles.

Four nuclear-sector experts revised the first version of the questionnaire and proposed some changes. As a result of this review, a text was added at the beginning of the final version to ensure anonymity and confidentiality of the data, a couple of questions were deleted, and two others were reformulated.

To design the second questionnaire we drew exclusively on the findings of the first questionnaire. It contained mainly close-ended questions with Likert response scale (agreement from 0 to 7), so as to enable quantitative analysis. The first section explained the objective of the survey. The second section presented eight questions concerning the same topics as in the first questionnaire.

It is worth noting that in our questions we did not explicitly distinguish between multi-, inter-, and transdisciplinarity but inquired more generally about approaches and attitudes concerning the integration of the social sciences into nuclear-sector work.

The lists of questions used in the two surveys are presented in Annexes A and B, as supplementary material.

2.3. Procedure and analysis

Participants were recruited via an email invitation distributed via the CEIDEN Platform and sent to all members of the association "Jóvenes Nucleares". In addition, snowball sampling was used by inviting participants to forward the survey link to other potentially interested colleagues in the nuclear sector.

Data was collected using the Lime Survey Software. The first on-line survey took place between May and June 2020, while the second lasted from July to September 2020. Confidentiality of the data was guaranteed to participants and the questionnaires asked neither the names nor professional affiliations of the respondents.

Data from the first questionnaire was analysed qualitatively, using the MAXQDA software. A thematic qualitative analysis [24] was carried out. First, all comments expressed by the participants were classified into thematic categories, generated inductively on the basis of an initial analysis of the responses. Second, we reread all the comments to detect patterns, nuances, and narratives within each category.

Data of the second questionnaire were analysed quantitatively by means of descriptive analysis (means, standard deviations, and percentages) using the IBM SPSS Statistics 27 software.

3. Results

To introduce the reader to the overall Spanish context, we first present the participants' views on the current relationships between the nuclear sector and the Spanish society (3.1).

The subsequent description of the results is then organised around the four main objectives of the study. The first sought to identify the nature and degree of interaction between the nuclear sector and the social sciences today (3.2). The second focused on the expectations of the Spanish nuclear sector professionals regarding the potential contribution of the social sciences to nuclear research and practice (3.3). The third reviewed the obstacles identified by the respondents to greater integration of social science knowledge into the nuclear sector (3.4). The fourth section drew on the questionnaires to elaborate pathways and options on how to stimulate transdisciplinary approaches in the nuclear sector research and practice in Spain (3.5).

In each section, we first describe the results of the quantitative survey, and then provide direct quotes from the qualitative questionnaire, in order to describe and illustrate the findings in more detail.

3.1. Perceptions concerning the relationships between the nuclear sector and the Spanish society

As for the current relations between the nuclear sector and the Spanish society, the statement that generated most agreement was that these relations are difficult due to the serious lack of knowledge about nuclear energy among the Spanish citizens (6.2 out of 7). The relationships were also perceived as relatively hostile and tense due to the ill-informed image of the sector conveyed by the media (5.3 out of 7). The respondents showed less agreement with the statement that the relations are distant because society is not interested in nuclear energy (3.5 out of 7), or because the nuclear sector is too technical, complex, and difficult to communicate (3.4 out of 7).

Notably, when the relationship was seen as difficult and/or hostile,

the reasons were attributed to society or the media, rather than to the characteristics of the nuclear sector (see Table 2). Concerns about how issues concerning nuclear energy are communicated were also frequent.

This general view of the relationships of the nuclear sector with society helps to place in context the more detailed key findings of our study, presented next.

3.2. Interaction between social scientists and nuclear- sector professionals: current state and evolution

The very first, and remarkable, finding is the limited experience that the Spanish nuclear professionals participating in the study have had with the social sciences and social scientists. Only 16 % of those surveyed have ever participated in a nuclear project that would have included social scientists. Of those who had, the majority considered that this collaboration had been positive or very positive. Only one respondent referred to a rather bad experience, and another described the experience as somewhat complicated.

Among those who had not participated in collaborative projects with social scientists, 35 % were aware of collaborative projects. In this sense, projects on the history of nuclear energy, man-machine reliability, perception and acceptance of nuclear energy, and safety were mentioned. Likewise, 40 % affirmed that they were aware of the existence of social studies on nuclear energy, but the examples they provided were unclear and unspecific. In summary, most participants did not have practical experience of working with the social sciences nor did they have a clear idea of what such collaboration could entail.

We found statistically significant differences between participants from CEIDEN and "Jóvenes Nucleares" in terms of interaction with social scientists. For all three questions - participation in nuclear projects that include social scientists ($p = .014$), awareness of collaborative projects ($p = .008$), and awareness of social studies about nuclear energy ($p = .025$) - the percentages were higher for respondents from CEIDEN than for those from "Jóvenes Nucleares".

When asked about the evolution of the relationship between the nuclear sector and the social sciences over time, most respondents stated that the relationship was stable (59 %) while 25 % perceived that it was improving (Fig. 1).

3.3. Expectations of the Spanish nuclear sector regarding the social sciences and their potential contribution to nuclear research and practice

As illustrated in Table 3, when asked about the potential contribution of social sciences to nuclear research and practice, respondents clearly agreed with four of the five proposed statements, with mean scores of 5 and 6 (out of 7) and low standard deviations. Nevertheless, the idea that the social sciences can help to improve the internal organisation of the nuclear sector received less support, with a lower mean (3.8) and a higher SD, indicating greater divergence of responses.

Table 2
How do you consider the relations between the nuclear sector and society in Spain today?

	Mean (0–7)	SD
Relationships are difficult: due to serious lack of citizens' knowledge about nuclear energy	6.2	1.2
Relations are hostile and tense: because the media's view is sectarian and ill-informed	5.3	1.8
Relationships are positive: particularly in the area of nuclear installations, thanks to the significant information efforts made	4.3	1.6
Relationships are hostile and tense: because society is suspicious, emotional and fearful	4.1	2.1
Relationships are non-existent or distant: because the nuclear sector has preferred to remain unnoticed and isolated	4.1	2.1
Relationships are difficult: because the nuclear sector is very technical and complex, difficult to communicate	3.6	1.8
Relationships are non-existent and/or distant: because society is not interested in nuclear energy	3.4	1.8

The expectations among the surveyed experts concerning the potential contribution of the social sciences to work in the nuclear sector can be presented under four distinct discourses briefly outline in the following.

a) 'Influencing the society' discourse

'Influencing the society' was the most widely present discourse. From the participants' point of view, the main potential function of the social sciences is to help improve the public image of the nuclear sector (5.9 out of 7), mainly through communication strategies to correct mistaken perceptions and false beliefs that prevail among the public. The broad support for the statement that the social sciences can help to understand how society perceives nuclear energy likewise reflects this discourse (5.8 out of 7).

The responses aligned with this discourse include those that emphasised the need for information, communication, and improvement of the sector's image, which would help enhance the social acceptance of nuclear energy. This reasoning reflects the 'deficit model' of public knowledge, based on the assumption that the public holds insufficient or inaccurate information of the technology [25] – in this case overestimating the risks and underestimating the benefits of nuclear energy.

> "*They can serve as a link with society, helping to improve public knowledge about this technology, and all its (good) implications for the economy, the society, health, etc.*"
>
> (Member of CEIDEN)

> "*[The social sciences can promote] a real societal understanding of what nuclear energy represents in the world today and for the future.*"
>
> (Jóvenes Nucleares)

Responses within this discourse underlined better and more precise communication as key to improving public knowledge about the technology. The social sciences could help communicate the contribution of nuclear energy to sustainability, and its benefits to society.

Ultimately, this discourse was underpinned by the assumption that disseminating information about the benefits of nuclear energy will lead to improved awareness and knowledge, greater social acceptance, and lesser public opposition to nuclear energy. Furthermore, it was assumed that this would require destigmatising nuclear energy, strengthening confidence, and reducing fears, to increase public, social, and market acceptance.

> "*It could try to destigmatise everything that has to do with nuclear energy, bringing it closer to the wider public*"
>
> (Jóvenes Nucleares)

> "*To facilitate public support, political support, investments, research efforts and ultimately the presence of the sector within the national strategic plan.*"
>
> (Jóvenes Nucleares)

b) 'Being influenced by society' discourse

The second prominent discourse considered that social sciences could help the nuclear sector to strategically adapt itself to societal needs. Thus, the social sciences could generate new discourses, promote reflection on the social construction of knowledge, on social values, traditions, and beliefs, identify new social demands, etc. We named this discourse as '(the nuclear sector) being influenced by society'.

This discourse sees as the main contribution of the social sciences

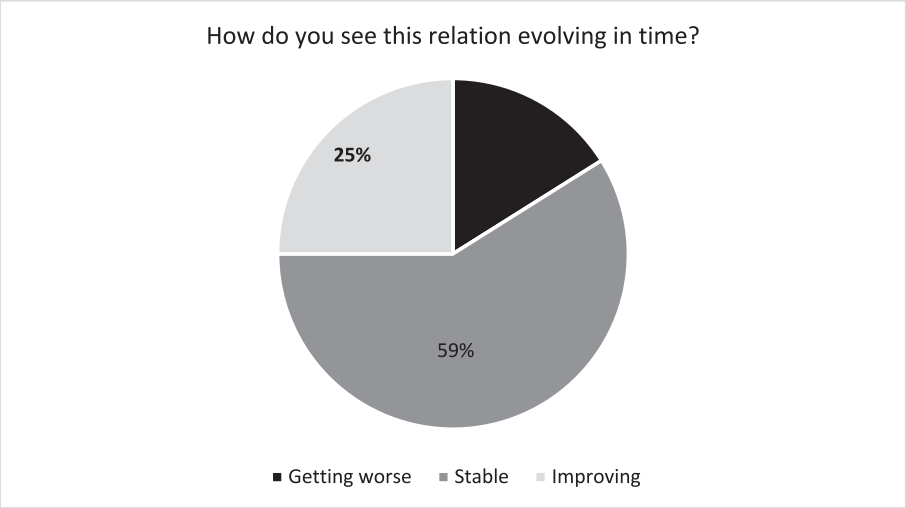

Fig. 1. Perception of the evolution of the relations between the social sciences and the nuclear sector (% of agreement).

Table 3
How could the social sciences contribute to the nuclear sector in Spain?

	Mean (0 a 7)	SD
Improve the public image of the sector	5.9	1.4
Understand how society perceives the nuclear sector	5.8	1.2
Share knowledge and facilitate dialogue	5.7	1.3
Provide information on the extent of and conditions for public acceptance of nuclear technology	5.1	1.6
Improve the internal organisation of the sector (security, human reliability, …)	3.9	2.0

that of 'sharing knowledge and facilitating dialogue with society' (5.7 out of 7), and 'understanding to what extent *and under what conditions* the public is willing to accept nuclear technology' (5.1 out of 7) (see Table 3). While the first discourse was based on the assumption that by better understanding society, the nuclear sector could more efficiently promote nuclear energy ('influencing the society'), in this second discourse, this greater understanding would help the sector to better adapt to society's needs ('being influenced by society').

Some quotes expressed by the participants serve as an illustration:

"*The research methods typical of the social sciences, the combination of qualitative and quantitative analysis, thick data analysis or ethnographic and 'net-nographic' tools, studies… can promote reflection on the social construction of knowledge, values and traditions among individuals and groups of society*."

(Member of CEIDEN)

"*The ability to establish a dialogue with society where new lines of technological development are valued, learning from the needs*."

(Member of CEIDEN)

The social sciences were also considered useful in helping to identify, through economic, social and environmental impact studies, the effects of decision-making in the nuclear sector on society, and to modify future decisions, if needed.

In addition, the social sciences were seen as a useful provider of long-term strategic analysis (in the context of energy transitions), which allows the sector to adapt to new future societal scenarios.

"*In a global perspective, the role of nuclear energy is being redefined in a context of the energy transition and this requires research groups that have a capacity for strategic analysis*."

(Member of CEIDEN)

Some participants highlighted the need to address complexity, including spaces for dialogue with society. For example, the social sciences could help to strengthen collaboration (between groups, individuals, agencies, and institutions), to facilitate agreement among decision-makers, and, ultimately, to help learn about the stakeholders' needs, clarify positions and concepts (risk, security of supply, etc.), and enhance knowledge exchange between the academia and society at large.

"*The difficulty is in decision-making, and this will not take place without consensual political agreements that have the support and participation of the population*."

(Member of CEIDEN)

"*I also think that it could offer a very enriching space for dialogue, softening the polarised positions that we are facing today*."

(Jóvenes Nucleares)

c) 'Internal reforms in the nuclear sector' discourse

The potential contribution of social sciences towards objectives such as safety, human reliability and the motivation of professionals were perceived as the least important of the mentioned possible contributions from the social sciences (3.9 out of 7) (Table 3).

A minority did conceive the social sciences as useful in helping to shape new forms of organisation within the nuclear sector, as well as to create new ways to motivate its professionals. From this perspective, the social sciences could contribute to improving organisational aspects, safety (human reliability), emergency plans, communication, training, and change management.

"*New forms of organisation, operation and motivation among professionals in the nuclear sector*"

(Member of CEIDEN)

"*Improved safety (human reliability) and emergency plans*."

(Member of CEIDEN)

"*Ideas to improve processes, facility design safety, long-term environmental benefits…*"

(Jóvenes Nucleares)

The respondents also included three professionals trained in the social sciences, namely in history, economics and law. Unsurprisingly, they highly valued the participation of social scientists in nuclear

projects. All three regularly participate in projects in the nuclear sector (one providing support for technical analysis, the second for communication, and the third for the management of organisational change). They stressed the role of the social sciences in managing the often-conflictual relations with the public, but also in improving the internal functioning of nuclear-sector organisations. For them, the main obstacles preventing the integration of the social sciences into nuclear-sector projects are the lack of people trained in interdisciplinarity, and the lack of experts with worldviews grounded in both "hard" and social sciences. They considered that the high degree of regulatory complexity makes changes difficult in this sector. These obstacles could be reduced by fostering crossbreeding and creating mixed professional profiles, which would help to "decompartmentalise" knowledge. Interestingly, unlike the other respondents, these three social-science professionals stressed the need for interdisciplinarity (mainly calling for social science training for engineers) and changes in the management culture of nuclear-sector organisations.

d) 'Absence or denial' discourse

Finally, some participants either said they did not know what role the social sciences could play in the nuclear sector, or considered that their impact could be negative (as instruments of manipulation). This vision reflects the idea that the social sciences carry an intrinsic bias and lack the rigor required in nuclear projects.

"*Honestly, I am not very clear about what the social sciences do*"
(Member of CEIDEN)

"*If there are not objective and unbiased studies, they can do a lot of damage by disseminating anti-nuclear propaganda in a covert manner*."
(Member of CEIDEN)

3.4. Obstacles to the integration of the social sciences in nuclear projects

In the quantitative survey, views concerning the obstacles to better collaboration between the nuclear sector and the social sciences revealed ambivalence, with most scores hovering around 3 (neither agree nor disagree), while the highest mean scores remained below 5 (Table 4). This indicates that none of the proposed options was perceived, on average, as a substantial obstacle to the integration of the social sciences into nuclear-sector projects.

The obstacles that received the highest scores were the lack of well-known social scientists (mean = 4.8), a supposed ideological anti-nuclear bias among social scientists (mean = 4.7), and the lack of familiarity and understanding of the nuclear sector among social scientists (mean = 4.6). Again, it is important to stress that none of these obstacles were perceived, on average, as highly significant.

Table 4
Perceived obstacles for the social sciences to be integrated into nuclear projects.

	Mean (0 a 7)	SD
A certain anti-nuclear ideological bias prevails among social scientists.	4.7	1.9
Social science professionals do not know or understand the nuclear sector and therefore tend to misunderstand it.	4.6	2.0
Nuclear technicians and social scientists work with very different logics, cultures and even languages.	3.8	1.8
The nuclear sector is highly regulated and subject to confidentiality. It is not easy to change the way it works.	3.5	1.7
The social sciences are perceived to constitute an unstructured, and therefore unreliable, body of knowledge	3.3	2.1
There is a lack of funding for the integration of non-technical aspects into nuclear projects	3.3	2.0
The social sciences could expose weaknesses in the sector and call nuclear projects into question.	2.6	2.1

In this context, the social sciences were perceived to be radical, often averse to nuclear energy, and tending to misinterpret nuclear issues. As such, the social sciences were considered potentially dangerous and even manipulative. The social sciences would thus contribute little to the nuclear sector but would instead bring many potential problems.

"*Social scientists often come from anti-nuclear backgrounds. They tend to have radical views against nuclear energy*"
(Member of CEIDEN)

"*Lack of understanding or misinterpretation of nuclear energy by social science professionals*"
(Jóvenes Nucleares)

"*Nuclear practitioners do not see the social sciences as essential, capable of bringing great added value to the nuclear sector*"
(Member of CEIDEN)

Several participants also mentioned epistemological obstacles: the social sciences on the one hand and the natural and engineering sciences on the other were seen to embody different and to a certain extent mutually incompatible worldviews (mean = 3.8), representing distinct cultures and each employing their own language.

"*[Main barrier] The difference in languages used by these distinct disciplines*."
(Jóvenes Nucleares)

"*The obstacle is the same as always: experts in "hard sciences" and "soft sciences" have two ways of seeing the world. Technicians distrust the social sciences and they are partially right in doing so. Technical projects are dominated by an Apollonian rationality. Thus, scientific uncertainty is acknowledged, but the aspiration is to manage it rationally. When such technical projects get closer to implementation, they face a social reality "contaminated" by the uncertain, changing, poorly predictable, and demagogic conceptualisations put forward by social scientists*."
(Member of CEIDEN)

Thus, for some participants the nuclear sector itself is an obstacle, often reluctant to accept contributions that are not strictly technical. In fact, some respondents argued that the nuclear sector is quite reluctant to change, governed by very strict regulations that prevent rapid changes in management, organisation, and structures.

"*Well, I would say the main obstacle is the nuclear-sector community itself. I think they do not fully perceive the potential of this integration, limiting themselves to the eminently technical aspects of their work*."
(Jóvenes Nucleares)

"*The unwillingness of the sector to open up to society*"
(Jóvenes Nucleares)

"*It is a historical and cultural issue. Nuclear is a highly regulated sector for safety and reliability reasons, and this implies a conservative and highly technical culture, where changes in management are difficult*."
(Member of CEIDEN)

The respondents also stressed the lack of a tradition that would value collaborative work. Multi- or interdisciplinary (or transdisciplinary) work between professionals is lacking. In the absence of meeting forums and traditions of interdisciplinarity, hardly any professionals are prepared to work together, across disciplinary boundaries. If this is true for collaboration across the diverse engineering and natural sciences within the nuclear sector, it is even more so for collaboration with the social sciences. Moreover, the participants pointed at the serious gaps in the requisite technical knowledge among social scientists as an obstacle to meaningful collaboration.

"*Lack of collaboration, direct contact, or meeting forums*."
(Jóvenes Nucleares)

"*Professionals with a good understanding of the role of the nuclear sector in society are needed*."

(Member of CEIDEN)

"*Lack of knowledge within the social sciences about nuclear energy*."

(Jóvenes Nucleares)

The respondents also mentioned obstacles related to funding (mean = 3.3). The financing structures do not facilitate integration across disciplines, and the nuclear-sector financing entities do not show sufficient interest in the integration of the social sciences, especially in the current context, when the sector faces an uncertain future.

"*As they are non-technical issues, they remain at the margins in R&D projects funded by the nuclear sector. Given the current scarcity of resources in the nuclear sector, it is necessary to prioritise activities*."

(Member of CEIDEN)

The proposition that the social sciences could make weaknesses in the sector visible and thereby endanger nuclear projects received the lowest degree of support among the surveyed participants (mean = 2.6).

3.5. Paths towards stimulating transdisciplinary approaches in nuclear-sector research and practice in Spain

As for the means of overcoming the obstacles to greater integration of the social sciences in the nuclear-sector work, the respondents suggested that promoting the establishment of interdisciplinary teams was indispensable. In the quantitative survey, the propositions of 'forming multidisciplinary teams that integrate social scientists' (34 %) and 'generating spaces for dialogue and meetings' (27 %) were the most preferred options (Fig. 2), followed by 'integrating social scientists into nuclear projects' (23 %).

The respondents supported the idea of setting up large-scale multi- or interdisciplinary projects, but considered that for this to happen, well-known social scientists would be needed, to arouse the interest of professionals in the nuclear sector. Currently, there are no such well-known social scientists, many respondents argued.

The respondents suggested that to overcome the current-day obstacles, social scientists could be trained jointly with nuclear sector professionals. However, this joint training was seen mainly as a means of training the social scientists. The objective would be to address the alleged problems of lacking knowledge and understanding of the nuclear sector among social science professionals, who tend to misinterpret fundamental facts. By contrast, our qualitative survey data did not suggest that the respondents would see a corresponding need for training among nuclear professionals, designed to improve their knowledge and understanding of the social sciences.

"*The nuclear sector, although highly technical, must have a wide range of multidisciplinary professionals, including those from the social sciences*"

(Jóvenes Nucleares)

"*Integrating social scientists in some of our projects, promoting fluid interaction between both groups*"

(Member of CEIDEN)

The respondents also argued that the social sciences should better demonstrate their value and usefulness, and should seek greater scientific rigor.

"*The social sciences have to make an effort to improve their ability to face the very conservative nuclear sector*"

(Member of CEIDEN)

"*The nuclear sector is dominated by professionals from highly technical backgrounds. If the social sciences can show that their contribution is relevant to a project in the nuclear sector, then I don't think there is any impediment. However, it is the task of the social sciences to affirm their position within such an engineering-dominated sector*."

(Jóvenes Nucleares)

Some considered that there were no obstacles to the integration of the social sciences in the nuclear sector, as demonstrated by the existence of multi- and interdisciplinary projects. Research projects address to an increasing extent social aspects. This was described as requiring commitment, effort, and desire to learn, but was seen as already happening in some ongoing projects.

"*They have already begun to do so. Getting out of inbreeding (…) is a truly important step (…) I would start by asking if this question is the right one, as there are no obstacles to overcome. It is not about winning a race by pushing the others aside…. As consultants (…) we always design projects focused on people: that is the key. It is so simple that it is hard to*

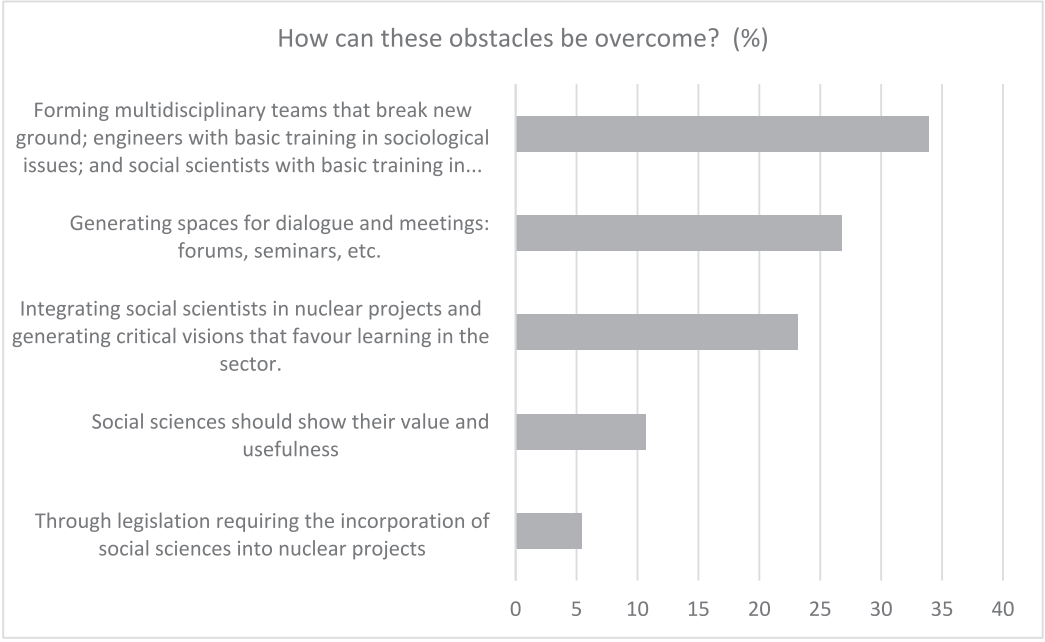

Fig. 2. Perceived ways to overcome the obstacles for the integration of the social sciences in the nuclear sector.

believe. There is an African proverb that if you want to get there fast, walk alone, but if you want to go far, walk together."

(Member of CEIDEN)

"*(…) TV series such as Chernobyl, Twitter characters like 'Operador nuclear', as well as science communicators and organisations such as Jóvenes Nucleares are doing a good job, as they open the nuclear field to discussion and dialectics that may stimulate anthropologists, historians, economists, philosophers…*"

(Jóvenes Nucleares)

"*I do not perceive great obstacles. There is more and more of a culture of integrating societal visions and issues related to human behaviour in nuclear-sector projects*"

(Member of CEIDEN)

Finally, participants were asked about the specific areas in which the contribution of the social sciences would be the most needed or recommended. Education and training clearly stood out as being seen as the sector that could benefit the most from the social sciences. This preference could be linked to the 'influencing the society' discourse.

The management of radioactive waste was also mentioned as a potential field in which greater contribution from the social sciences would be beneficial (Fig. 3).

4. Discussion

This article contributes to the incipient field of research on the integration of social science knowledge into the work of the largely engineering-dominated nuclear sector. Most of the scientific literature in this area has thus far taken a normative approach, providing recommendations on what should be done, whereas very little empirical analysis has been done on practical experience. Our analysis provides an exploration into the perceptions of professionals in the Spanish nuclear sector concerning the role of the social sciences, and identifies challenges and opportunities for the multi- or interdisciplinary integration of the social sciences in nuclear energy research and practice.

The very first and remarkable finding was the very low level of interaction between social scientists and the nuclear professionals participating in our study (only 16 % had ever participated in a nuclear project with social scientists). Our exploratory analysis suggests that there is still plenty of potential for improving integrative nuclear energy research and practice in Spain. Most of the surveyed nuclear professionals acknowledged the social sciences as a relevant contributor to nuclear energy research and practice (Table 3).

As far as the specific potential contributions of social sciences are concerned (Fig. 3), we identified four types of discourses, which we in the following explore in the light of the normative recommendations from earlier research, presented in Section 2, and summarised below in Figs. 4–7.

The most common proposal was to use the social sciences to increase the public acceptance of nuclear power. Moreover, some respondents consider that the public tends to reject nuclear power because it lacks adequate knowledge of the technology. To address these problems, our respondents suggest improved design and implementation of communication and information strategies. This rationale is underpinned by the above-mentioned and today largely discredited 'deficit model', which holds that if provided correct facts, citizens would behave reasonably and accept the technology [26]. The reasoning is at odds with the recommendations found in the literature concerning the role of the social sciences in the energy sector. These recommendations highlight the need to focus on methods and processes rather than on specific expected outcomes and contents of nuclear energy projects and policies. The social sciences should provide analytical tools, not promote the social acceptance of projects and policies elaborated by technical experts (Fig. 4).

A less widely endorsed but significant discourse conceived of the social sciences as a tool for reflection and inclusiveness (Fig. 5). They could enhance and improve the interaction between groups, individuals, agencies, and institutions, facilitate political agreement and decision-making, and ultimately, help the nuclear sector better understand stakeholders' needs.

The third discourse suggested that the social sciences could contribute to the design of organisational structures in the nuclear sector, and motivate professionals in the nuclear field to work towards improving the organisation, management, and practices within the sector (Fig. 3).

Finally, the fourth discourse took a negative view, considering that the social sciences cannot and should not play a role in nuclear projects, as they could introduce an ideological bias and undermine the scientific rigour of these projects. This discourse was founded on the perception that the social sciences are excessively radical and manipulative, and therefore potentially harmful for the sector.

As far as the obstacles to collaborative work were concerned (Table 4), the respondents underlined the institutional inertia of the nuclear sector itself (described as highly regulated and resistant to change). This finding hence illustrated the reflective potential of the

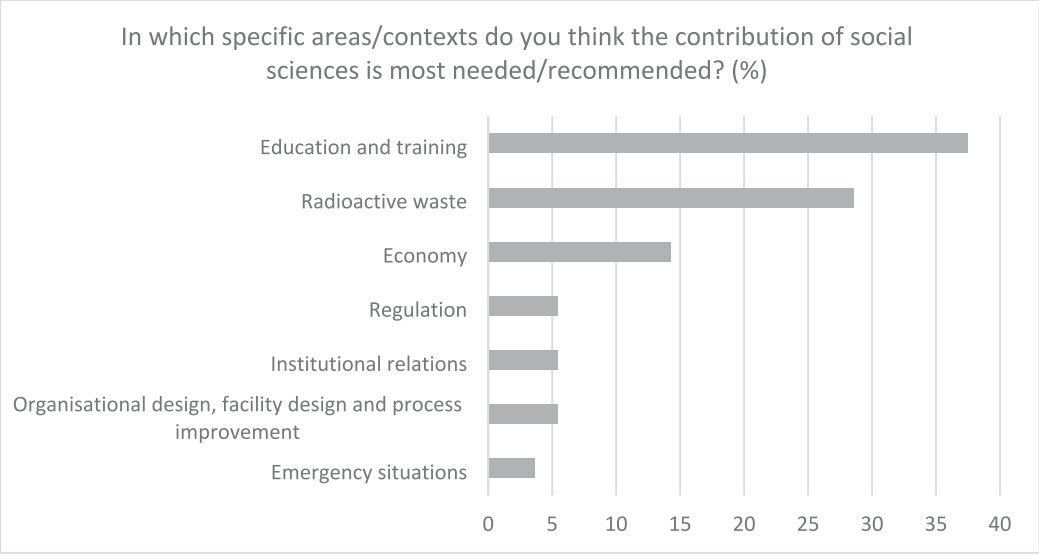

Fig. 3. Areas in which the contribution of social science could be of more interest.

Normative recommendations to advance integrative work

- ✓ *Social sciences should focus on methods & processes rather than on envisaged or promised outcomes.*
- ✓ *Social sciences should provide analytical tools (theories and methods) to promote understanding of the human and social adaptations required by energy transitions, rather than forcing or even encouraging individuals to accept policies or technologies imposed upon them in a top-down manner.*

Fig. 4. Normative recommendations: methods, processes, analytical tools [e.g., 11,14,17,20,21].

Normative recommendations to advance integrative work

- ✓ *Social sciences should foster inclusiveness by promoting reflection…*
- ✓ *New research paths should be pursued in areas such as socio-ethical aspects, justice, identity & politics…*

Fig. 5. Normative recommendations: inclusiveness, reflection, socio-ethical, justice… [e.g., 6,10,11,14,16,17,22].

Normative recommendations to advance integrative work

- ✓ *Development of a shared language and mutual understanding among disciplines.*

Fig. 6. Normative recommendations: shared language and mutual understanding [e.g., 8,16,17].

Normative recommendations to advance integrative work

- ✓ *'Funding schemes should devote more resources to collaborative research.*
- ✓ *The evaluation criteria should be revised to better account for collaborative research.*

Fig. 7. Normative recommendations: funding schemes and evaluation criteria [e.g., 14–16,20–23].

social sciences.

Further obstacles mentioned included the different epistemologies and mutually incompatible worldviews of the social and the natural science disciplines. This reasoning fits rather well with the recommendations found in the literature concerning the need to develop a shared language and a mutual understanding among disciplines. (Fig. 6). In addition, this observation is in line with Horlick-Jones' [27] notion of the 'signature' of a technology, entailing the idea that the ways in which people make sense of a technology are shaped not only by the prevailing social and cultural environments but also by the inherent characteristics of the technology in question.

The respondents also evoked the lack of a tradition in interdisciplinary collaboration. To foster the emergence of such a collaborative culture at the individual level, institutional changes would be needed, the respondents argued. For example, some considered that interdisciplinary integration would require proactiveness and anticipation on the part of projects and funding agencies alike (Fig. 7).

However, and importantly, in the light of our quantitative data, none of these obstacles appeared as insurmountable (Fig. 2). According to the respondents, these obstacles could be overcome by the establishment of multi- or interdisciplinary spaces that would facilitate collaboration, help participants to know each other and learn together, and thereby pave the way for more effective integration. At the moment, establishing such collaborative spaces seems difficult, especially due to the inertia of the institutional structures in the nuclear sector.

5. Conclusions

This article explored the perceptions and expectations of the Spanish nuclear professionals regarding the social sciences and their potential contribution to nuclear energy research. We then compared these perceptions and expectations with what "should be happening" according to earlier social science research. Our final aim was to identify the degree to which the attitudes and perceptions of nuclear-sector professionals might facilitate or prevent the implementation of such recommendations in practice. This comparison provided the basis for both our observation that there is still a strong potential for integration in the Spanish nuclear sector, and for the identification of future research topics and areas.

The findings from our research are relatively well aligned with the key message in the social science literature on energy - a conviction which we share - that the social sciences indeed are vital in obtaining a deeper understanding of the human and social adaptations required for energy transitions. However, our results also show that at least in Spain, the road ahead is still long, and challenges many. In the absence of a tradition of interdisciplinary integration, nuclear-sector professionals

have little experience of interaction with the social sciences and social scientists. They tend to perceive the social sciences as merely a tool for enhancing the public acceptance of nuclear energy at best, and as an enemy characterised by biased opinions and worldviews hostile to nuclear energy at worst.

Even if based on the largely discredited deficit model of public understanding of science [e.g. 25], and on probably excessive suspicion concerning the true motives of social scientists, these perceptions merit attention, introspection, and humbleness on the part of the social science energy research community. Obviously, given their training and education, social scientists often lack detailed knowledge in engineering and natural sciences. Moreover, according to our rather long personal experience from the field, some social scientists certainly are highly sceptical towards nuclear energy and the "nuclear community". Under such circumstances, it is understandable that nuclear professionals may hesitate to engage in dialogue with social scientists.

However, our research likewise points to opportunities for greater collaboration in the near future. Despite its limitations - notably the tendency to consider the public and stakeholders only at the later stages of planning, as "accepters" or "rejecters" of proposals designed by experts [28] - research on social acceptance and acceptability could help move towards more genuine multi- and interdisciplinarity. More inclusive and deliberative approaches, such as the Social Licence to Operate [29] and the Ownership of Societal Projects [30] could help to advance in this direction. Alongside a certain scepticism towards social sciences, we could detect among the nuclear-sector professionals a true interest in greater openness, dialogue, and inclusion of the social sciences, as well as a recognition of structural inertia within the nuclear sector. Hence, an opportunity and even a degree of demand for social science expertise exists among the professionals in the field, who see that the social sciences could help to break the institutional inertia. Yet, much more needs to be done, for instance, to move from an exclusive emphasis on the desired outcomes (e.g., promotion of specific energy technologies or projects) towards an approach that pays greater attention to improved planning and policymaking processes, early involvement of the social sciences in research designs, inclusiveness, reflexivity, shared language, and mutual understanding among disciplines.

Gender equity would also require further attention. Women only accounted for 15 % of our respondents. Future research should explore the reasons behind this imbalance and identify mechanisms for enhancing the contribution of women in the Spanish nuclear sector, thus paving the way for integrative work [31].

The Spanish nuclear sector continues its efforts towards incorporating the social sciences in its work. Working groups on the social aspects of nuclear energy and radiological protection have been created within both the Spanish Technological Platform for Nuclear Fission (CEIDEN) and the Spanish Platform for Research in Radiological Protection (PEPRI). Moreover, the latest research programme funded by the Spanish nuclear safety authority encompassed social sciences and humanities. Nevertheless, our evidence suggests that the interaction between social scientists and nuclear sector professionals remains fragmented. Given that there is still a limited understanding among the nuclear professionals of the potential contribution of the social sciences, moving towards multidisciplinarity appears as a step forward. This would involve getting to know each other, learning together, and laying the bases for closer interaction.

Future research efforts could usefully focus on practical work: increasing awareness and promoting reflection on the ways to overcome the barriers and thus taking advantage of the opportunities identified in this preliminary study. Potential means for advancing towards this end include deliberative and reflective engagement methods and processes involving social scientists and nuclear practitioners. One such tried and tested method consists of reconvened focus groups, whereby the same focus groups meet at regular intervals, to promote reflection [e.g., 32,33]. Another possibility could be to conduct case studies in the Spanish nuclear institutions. The unavoidable limitations of our exploratory study, notably our methodological choice of convenience sampling, point towards further research opportunities. Furthermore, the small sample size did not enable cross-tabulations. Similar opinion and attitude surveys could be conducted, applying methods of representative sampling and ideally from a comparative cross-country perspective, among social scientists working in public and private sector organisations in the nuclear sector. Given the scarce knowledge by our participants of the potential roles of the social sciences, and the fact that our questionnaire provided only very brief information on the social sciences to participants, future research could integrate more detailed background information and even employ methods such as deliberative polling. All these measures could facilitate efforts at moving towards inter- and transdisciplinarity.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.erss.2023.102970.

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