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Tackling gender disparities in energy research: a diagnostic tool for equality in research centres

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Abstract

Background In a case study in Spain, the unequal proportion of men and women in a research organization in the energy sector is severe, and long-established dynamics that might determine differences in access to leadership positions and inequalities in research careers are evident. The gender gap in historically masculinized fields, such as energy engineering reflects more than simply the differences in male and female values and personalities. This study seeks to explore the gender gap in energy research centres and to identify barriers that potentially hinder the research careers of women. It proposes the development of a diagnostic tool, based upon indicators, to monitor and evaluate gender roles and inequalities in the management of research centres for identifying and addressing the dynamics and obstacles that hinder women's progress in the energy sector and their potential contribution to the field. This participatory multicriteria-based tool prioritizes the proposed indicators by their influence and importance in the context of energy research and applies it to the monitoring of a specific Spanish energy research centre.

Results The results are threefold: (i) the methodology is adaptable to different research centres; (ii) the analysis of indicators' prioritization could lead to recommendations that should be addressed first; (iii) the diagnostic tool used in this in-depth case study of an energy research centre in Spain allowed results to be achieved in terms of gender dynamics. Two indicators stand out as the most relevant in our analysis: gender diversity in leadership positions and uncomplicated application of work–life balance measures. In this case study, the measurement of the first indicator has drawn unsatisfactory results, and the research of the latter is considered still insufficient. In conclusion, this difference becomes a vicious or negative circle for attracting and retaining more women to the research centre. Despite these results, no gender gap seems to be recognized and thus, no measures are being taken to improve the situation.

Conclusions Comprehensive data and contextualized monitoring are necessary to effectively study and enhance the presence and participation of women in the energy science sector. This approach, combining quantitative and qualitative techniques, is suitable for any research centre that would like to monitor its gender gap, identify potential sources of inequity and address them.

Keywords Gender gap, Equality, Energy research, Research centres, DEMATEL, ANP

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Background

Globally, the limited access to energy disproportionately affects women [1] and highlights the importance of considering gender in discussions about fair energy distribution and its role in development [2–5]. Despite this, the energy sector remains predominantly male-dominated. Not only do women face greater difficulties in accessing energy resources, but they also "continue to be an unrealized potential asset for the development of the energy sector" [6].

Women bring distinct economic and social capitals to the table [7], and lack of gender balance might not only be a matter of fairness and social justice, but could also be detrimental to innovative research. The involvement of women in the field of energy, and particularly in the context of sustainability [6, 8, 9], has been identified as pivotal for addressing emerging future advances, governance structures, and frameworks through which we might tackle the required issues, among others [10]. However, their participation remains limited not only to energy production, but also to the development of alternative consumption and production patterns [7, 11, 12]. This similarly occurs in the production of knowledge within the field where only 15.7 percent of energy scholarship authors have been women [13].

It is widely argued that one of the problems in an area like engineering or energy is the low number of women students. At a macro level, focusing on the case of Spain, where the study case is located, the proportion of women researchers in Spanish universities is 43.67% [14]. However, the main problem lies in the unequal distribution according to career progression, with only 25.6% of women reaching the highest category (full professor) and even more at the study phase. In the field of engineering, for instance, only 9% women are to be found in the highest category. In addition, only 52.4% of women have attained permanent positions in the system [14].

At the meso-level of the university institution examined, 31.98% of the staff are women [15], of which only 30% have attained permanent positions. In the area of engineering, this percentage drops to 21.39% of women researchers with permanent contracts [15]. Regarding the presence of women in public research centres in Spain, only 26.8% of women hold a permanent position working in the field of "natural resources", which includes the energy sector [16]. This figure improves substantially in the initial categories with 57.7% of doctoral students being women [16]. Furthermore, in the case of the Spanish energy sector, only 22.2% of Spain's scientific production on renewable energies in 2022 was led by women researchers [17].

While a significant body of literature and diverse approaches to addressing the scarcity of women in Science, Technology, Engineering and Mathematics (STEM) are available, a notable gap in the case of the energy sector is evident [10, 13, 18]. The presence and participation of women in the field of energy have been studied in boards and management groups of large energy companies [19], in decision-making processes in the renewable energy sector [20] or in energy policymaking [12]. However, to the best of our knowledge, gender roles and inequalities in the management of research energy centres aimed to address the gender gap remain unexplored in the scientific literature, and our study is the first that seeks to specifically address the monitoring of energy research centres.

Monitoring the gender gap in science: contextualization and indicators used at the organizational level

In Europe, gender gap monitoring in science, research and innovation is highly directed by European Union (EU) approaches. Specifically, the Strategic Vision of the European Research Area has set as a goal for 2030 that half of all scientific personnel, in all disciplines and at all levels of the scientific system, should be women. The aim is to break the horizontal and vertical segregation that currently exists in European science, especially in historically masculinized fields like energy [21]. Thus, EU members such as Spain have advanced legislation in this area to achieve the Strategic Vision of the European Research Area.

The indicators used to monitor policies in European reports, such as *She Figures* and their counterpart reports in Spain, tend to focus primarily on providing numbers of men and women. Therefore, despite its relevance, they have scarce information on how gender dynamics work in scientific and innovative working environments, where personnel perform their functions and interact on a daily basis [22–24].

The meso-organizational level is key in the "quality of equality" which means that inclusion is not merely having women but where—in which areas, in which roles—and how are they included [25] is essential; and where—without this information, it is not possible to understand why, for instance, many women leave engineering careers or whether women or other underrepresented collectives in the discipline have a similar wellbeing status.

The organizational level includes crucial issues for equal access and quality such as staff awareness of equality measures, the distribution of tasks and responsibilities, management of projects, recognition, work culture, work–life balance culture, and use of time or personnel selection. At this level, there is a concentration of conditioning factors to accumulate merits in a markedly

meritocratic science system. In this context, which is depicted as neutral and universal within the meritocratic system, it becomes clear that the system is vulnerable to gender dynamics which apparently affects objective processes such as hiring and promotion [26] or the definition of academic excellence [27].

The organizational level is crucial in science development and the lack of indicators may result from intrinsic difficulties in gender monitoring. Monitoring is usually a synonym for quantitative approaches which often tends to focus on public information like how many of each sex are to be found. On the other hand, gender dynamics are difficult to capture without perception and other qualitative indicators [28] which are more difficult to operationalize, and which often require the preparation of surveys or choosing other methods like organizing focus groups to gather primary data. However, the effort can be worthwhile considering that monitoring is not unambiguous in its use and that indicators are not equally relevant. Monitoring can be applied to control policy development, distribute funding, compare organizations, or check the advance of some implemented measures, for instance. Those purposes and the ultimate justification, such as social justice or achieving efficiency, determine institutional logics that affected the final use of monitoring and resulted in different indicator panels which also reflects a different understanding of the issue that is monitored [23].

Measuring gender at the organizational level pursues some primary goals: diagnosis and learning. However, indicators receive their significance from institutional practices [29]. Thus, contextualized monitoring through gathering secondary and primary data, both quantitative and qualitative, is crucial and it becomes essential to go beyond "counting heads" [30] to understand not only the number of women present in energy research centres, but also the dynamics that hinder the development of women's careers in these areas, i.e. the distribution of tasks, management, projects, and recognition. In Europe, gender gap indicators are focused on policy monitoring at the national level, while the organizational level still needs to be developed, which is another challenge to be addressed [23].

Contextualization or context-sensitive monitoring implies a better understanding of different levels as the centre and the research system provides in regards to the conditions of understanding research excellence, access to positions or research funding. This requires expert integration in the monitoring process, to interpret the relevance and cross-influence of the indicators, as is given in more detail in the methods part. Thus, it is crucial to include the context where gendered energy research takes place and to provide a systemic contextualization [12].

We developed a tool based upon performance indicators to monitor and evaluate gender roles and inequalities in research centres. The tool provides feedback to the literature review and quantitative and qualitative inputs at the organizational level which is a sensible step within the overall gender and science context, with a focus on Spain in this case. This perspective also facilitates the integration of the inherent complexity of measuring relational dynamics in organizations, which contributes to the gender gap [31]. The gender gap should be understood as a multi-dimensional concept: people involved, relational dynamics [31], and organizational culture. Therefore, it should be treated as a multi-criteria problem and studied using multi-criteria decision-making methods (MCDM). These methods are highly appreciated for developing monitoring tools [22], for example, the work of [32] where a multi-criteria decision model is used to measure sustainable energy development efficiency [22]. See [33] for more information on MCDM.

We propose a methodology for an in-depth study of research centres investigating energy-related issues. This methodology can be adapted to develop tools to monitor and diagnose different research centres and their specific contexts.

Our proposal will make three contributions to the energy research field: first, by presenting the possible indicators at the organizational level in research centres and a methodology to prioritize them according to the centre's needs; second, by monitoring and presenting results of a specific research centre in the energy field; and third, by including recommendations to address the gender dynamics contributing to indicate gender gaps within the monitored centre.

The rest of the paper is organized as follows: "Methodology" section presents the research methodology and methods employed. "Results" section shows the results and "Discussion" section discusses the implications and is divided into the case of study recommendations and general contributions to the energy field. Finally, "Conclusions" section summarizes the conclusions of the research.

Methodology

The proposed methodological approach of this research is presented in Fig. 1. It is developed through two main stages: the design of the general methodology and the application to a specific energy research centre.

Our diagnostic tool is developed in two stages. The first is generic and useful for any public research organization. The second is specific to a particular research centre in the energy field. In other words, we obtain generic

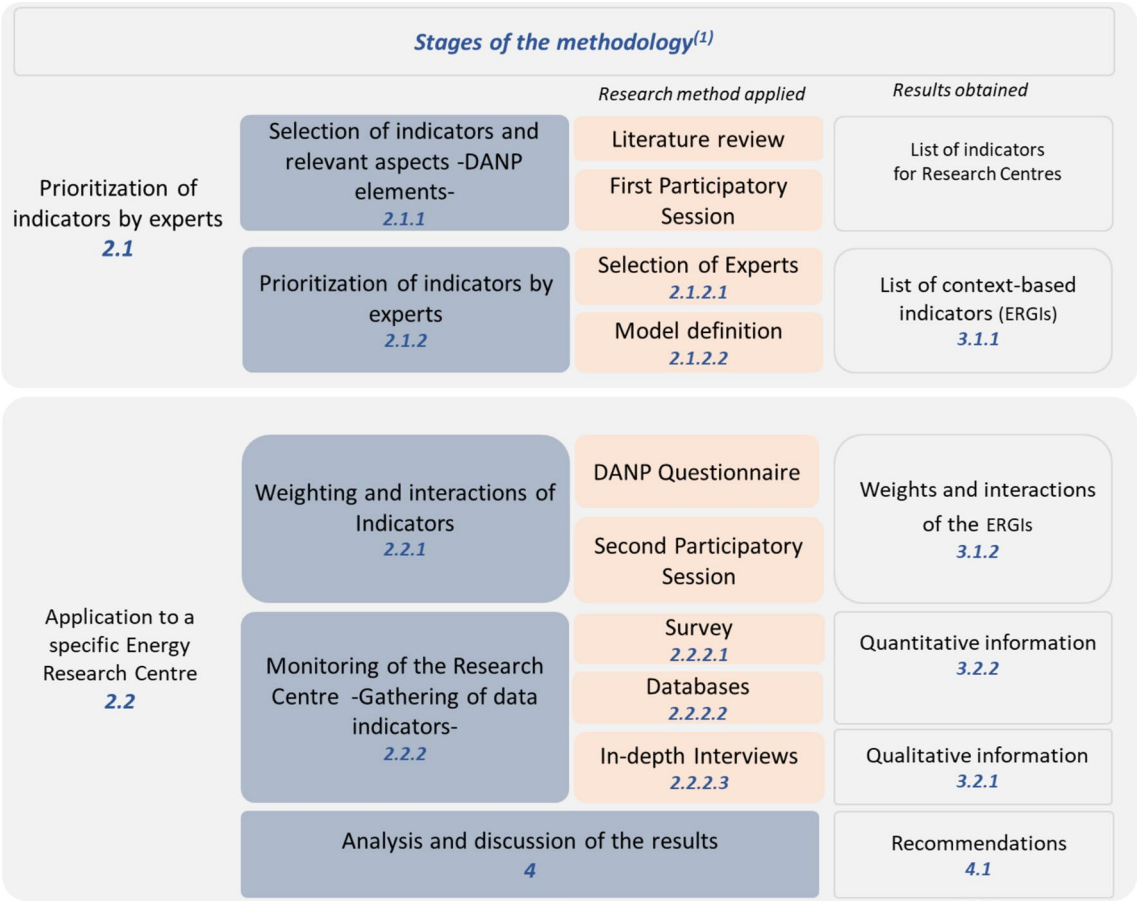

Fig. 1 Methodology diagram. The stages of the methodology correspond to the sections where these tasks are described in the paper

indicators that can be used to measure any organization and we adapt them to the context and then use them to monitor and diagnose a particular Spanish Energy Research Centre.

The goal of the first is to identify all the relevant perspectives and dimensions related to the gender gap and to determine a specific list of performance indicators to monitor and evaluate gender roles and inequalities in research centres. This general methodology employs an integrated MCDM-based approach using a combination of Decision-Making Trial and Evaluation Laboratory (DEMATEL) and Analytic Network Process (ANP) to determine the most influential criteria for the gender gap in research centres. The combination of these two methodologies (DANP) is novel in the context of gender policies and integrates the benefits of both methods. ANP [34] allows us a full analysis of the influence of all the factors that make up a network (see [34] for more information on ANP). In addition, DEMATEL [35] permits a cause and effect analysis of the various network elements involved [36, 37].

The aim of the second is to monitor the performance of a selected Spanish Energy Research Centre (ERC). All the indicators will be measured and analysed according to the results of importance and influence obtained for each.

This stage of the methodology has involved the thorough documentation of the institution itself (bibliometric indicators and other registered numerical indicators), as well as the document analysis of relevant scientific legislation. The analysis of hiring and promotion processes, among other variables, has entailed an in-depth examination of the laws and regulations governing these processes in Spain. A comprehensive study of documentation on Spanish state-level legislation and university organization was conducted to understand the specificities of the case study in the scientific context. A document analysis was carried out to analyse and perform an in-depth study of the chosen case study. Likewise, the content analysis of scientific Spanish legislation [38] and scientific reports [16, 28] have also served methodologically when designing the script of the in-depth interviews.

For methodological reasons, a binary gender system has been assumed in the construction of indicators and in the analysis of results. Nevertheless, in the sociodemographic questions of the questionnaire, the possibility of including other gender identities has been provided. This assumption of the binary system aims to facilitate both the research and the data interpretation. However, the authors are aware of the limitations posed by this binary approach and acknowledge the diverse expressions and identities that may manifest within such contexts.

Finally, some recommendations and guidelines will be addressed to the management team of the research centre in order to target their gender gap.

General methodology

Selection of indicators and relevant aspects

Focusing on the selection of indicators, [22] proposed a list for Research and Innovation purposes from a Responsible Perspective for the Spanish context subsequent to an in-depth review of the existing indicators provided by relevant reports, such as the *Responsible Research and Innovation (RRI) European Expert Group*, the collection of *She Figures* EU reports, or the Spanish version of *She Figures, Científicas en Cifras*. Based on [22] study and previous knowledge, we developed a general, extensive list of indicators that should be considered in the analysis of the gender gap in research centres (Table 1). This preliminary list of indicators is organized into 6 main groups, which are the most common when analysing the gender gap in research centres.

Table 1 List of indicators to be considered in the analysis of the gender gap in research centres

	Preliminary list
Contracts and working conditions	% of women and types of contracts
	% of women with family responsibilities
Labour relations and time use	Average time taken to reach research career milestones
	% of women segregated by age and family responsibilities
	% of women making use of work–life balance policies
	% of women taking maternity leave
	% of women who make use of reduced working hours
	% of women taking paid and unpaid leave
	% of women making use of care leave
Vertical segregation	% of women in low level positions with respect to % in high level positions (glass ceiling)
	% of women principal investigators or team leaders
	% of women according to role distribution (administration, IT, financing, project selection, R&I, …)
	% of women with patents
	% of women as first or last authors of the contribution
	% of women on proposal evaluation panels
	% of women participants in the total number of teams applying for and receiving grants in calls for projects
	Average age of people in the different ranks disaggregated by sex
	% of women in mobility programmes
Visibility and representation	% of women with social media presence and outreach
	% of women belonging to groups of experts
	% of women as keynotes at conferences/workshops
	% of women in awards
Organizational culture	Action protocol in case of sexual harassment
	Gender equality plans in place, with monitoring and impact assessment
	Systems for data collection, analysis and dissemination of statistics
	Transparent workload distribution systems
	Hours of gender training for research team members
Content	% of projects that include gender diversity in their samples/target audience
	Gender mainstreaming in project content
	% of publications with gender-sensitive content, research, or patents

Percentages of women are calculated as nr. women/nr of people, i.e. the percentage of men would be the complementary % up to 100

Prioritization of indicators by experts

The DANP technique is used to evaluate the gender gap criteria (indicators), allowing us to rank these criteria in relation to the objective: evaluate gender roles and inequalities in research centres.

Selection of experts Our methodology considers the inclusion of energy stakeholders, not only gender experts [39], in an interdisciplinary approach that combines experts from social sciences, politics, and engineering for methodological development. This interdisciplinary approach aligns with the underlying debate about the topic in energy studies [40].

The research team includes various types of experts, encompassing those dedicated to gender issues within the Spanish scientific system and engineers specializing in energy. The MCDM technique we use relies heavily on the quality, rather than the quantity, of these experts due to its semi-quantitative and expert-oriented nature [41]. It is vital that the experts display both a comprehensive understanding of the implications of their fields within the context of our case study and a holistic perspective on research centre activities. In order to ensure a comprehensive assessment, our DANP model requires multiple experts on each panel for cross-verification purposes. Our panel, comprised five individuals—one political scientist, one sociologist, and three engineers—was initially chosen to define the DANP model and validate context-based indicators suitable for any research centre. Recognizing the need to integrate the specific dynamics of the energy engineering sector, we expanded our expert panel by including two additional individuals with in-depth knowledge of the field of energy research. With a total of 7 experts, this panel evaluated context-based indicators, weighting them based on their impact on gender equity.

A detailed description of the cross-experience of our 7 experts is shown in Table 2

Table 2 Experts selected

Expert	Type of expertise		
	Scientific field	Gender	Energy
E1	Engineer	x	x
E2	Engineer	x	
E3	Sociologist	x	
E4	Political	x	
E5	Engineer	x	
E6	Engineer		x
E7	Engineer		x

Model definition The ranking model is built upon a network of criteria that have mutual influence. These criteria are derived from a literature review and the context is validated by the panel of 5 experts through a first participatory session.

The relevance of the indicators is heavily affected by the different contexts. The panel evaluates the criteria (indicators) integrating the context. Expert prioritization pinpoints the causal relations and diverse shapes of a specific problem that refuses to be measured.

The objective will be to identify which are important and which are crucial in the specific setting of the energy research centre within both the university and the Spanish research system, considering a panoramic view of the gathered data. This will contribute significantly to an interpretation of the results and the formation of recommendations. The aim is to tailor the general gender gap indicators for research centres (preliminary list) into indicators suitable for monitoring Spanish energy research centres (list of context-based indicators).

For this purpose, we designed a questionnaire that was used to ask the experts individually to elicit their judgements.

Application to a specific Energy Research Centre

Weighting and interactions of indicators

After constructing the model and receiving validation from the experts, the DANP method is applied in five steps:

Step 1: Generation of Direct-Relation Matrix A. Firstly, measuring the relationship between criteria requires the design of a comparison scale on a 0–4 scale:

- 0 (no influence)
- 1 (low influence)
- 2 (medium influence)
- 3 (high influence)
- 4 (very high influence)

Next, experts make pairwise comparisons of the influences between the criteria. Then, the initial data are obtained as the direct-relation matrix. Matrix A is an nxn matrix in which aij denotes the degree to which criterion i affects criterion j.

Step 2: Normalizing the direct-relation matrix. On the basis of direct-relation matrix A, the normalized direct-relation matrix X can be obtained through equations:

$$xij = aij \sum ni = 1aijxij = aij \sum i = 1naij, \tag{1}$$

where a_{ij} is the values of the direct-relation matrix.

Step 3: Obtaining the total-relation matrix: T can be obtained by using (Eq. 5), in which the I is denoted as the identity matrix:

$$T = X(I - X)^{-1}. \tag{2}$$

Step 4: Obtaining the causal diagram of the criteria. Parameters D and Rare obtained for each criterion from matrix T using the following equations:

$$D = \sum ni = 1tijD = \sum i = 1ntij, \tag{3}$$

$$R = \sum nj = 1tijR = \sum j = 1ntij. \tag{4}$$

The cause–effect diagram permits the analysis of the degree of prominence, given by the sum of D and R (horizontal axis), and the degree of cause or effect, given by the subtraction of D and R (vertical axis).

Step 5: Normalizing each column of the T matrix (unweighted) by its sum, we obtain the weighted supermatrix:

$$wij = tij \sum ni = 1tij, \tag{5}$$

where w_{ij} is the values of the weighted supermatrix and t_{ij} is the values of the total-relation matrix.

Step 6: Calculating the limit matrix. In this step, the weighted matrix is multiplied by itself until all its columns become equal, i.e. the values converge, and the process ends. This way, each element's individual influences on the network's other elements are obtained from this limit supermatrix.

The criteria values are extracted from the vector of the limit supermatrix and normalized by the sum to obtain their final weights. In this way, we can obtain the criteria ranking, which will allow us to understand the decision profile of the experts.

After receiving individual assessment results of DANP, each expert validates her/his own results. If the results are unsatisfactory, she/he revises the results of the pairwise comparisons to ensure that the results are coherent with her/his knowledge and overall assessment.

Monitoring of the research centre

Online survey: primary data In addition to the personal interviews, an online survey was designed and circulated to reach as many people as possible within the organization. The study aimed to obtain qualitative and quantitative information to study the gender gap in Energy Research Centres and to identify barriers that potentially hinder the careers of women. Data were gathered through single and multiple choice, and open-ended questions by using Qualtrics software, Version July 2023. Copyright© 2023 Qualtrics. Gender and year of birth were requested for data analysis purposes but no information that would potentially identify the respondent was collected. The survey consisted of 20 questions addressing the level of seniority achieved, the perception of the formal and informal atmosphere of the organization, awareness of the equity plan, use of work–life balance measures, and experience in leading projects.

The survey was sent to the head of the research centre to be internally disseminated by email to all the workers of the institution. Our population is all the researchers who were registered as members of the ERC in May 2023, i.e. 48 people. A total of 36 people answered and, according to their distribution by professional category and gender, it was concluded that the sample was sufficiently representative. The only a priori bias detected was motivation, i.e. the proportion of women in relation to the total number of employees answering the questionnaire is higher than that of men. However, both gender groups are sufficiently represented.

The content validity of the survey was initially tested on a sample of 10 people from diverse academic backgrounds residing in Spain. The survey was adjusted by integrating the feedback received. The data from the pilot are not included in the results.

Databases: secondary data The institutional database and the university's website were consulted for information on the position, professional category, and academic merits (patents, scientific production, projects and other outcomes) of all the members of the research centre.

In-depth interviews: primary data Twelve in-depth interviews (30–60 min long) were conducted with women and men in permanent and non-permanent positions at the centre (12 in total). The interviewees were selected based on a strategic selection of participants to ensure representativeness and to provide diverse and information-rich perspectives on the research topic. The distribution of interviewees corresponds to the structure of the energy engineering field itself, a highly masculine area as seen above.

The aim of the interviews was to obtain information on the perceptions, opinions, and experiences of the centre's staff as regards gender issues from a representative number of individuals of differing professional categories and genders. Following the logic of the dimensions of the indicators, the interview guide was structured into these four blocks (see "Qualitative information" section). The information extracted was transcribed and analysed according to the qualitative content method [42]. The N-VIVO software was used as a tool to support the analysis.

Results

We have divided the analysis of the results into two parts. In the first part, we show the results obtained for the indicators. These results are generic, i.e. they could be useful for monitoring the gender gap in any research centre in the Spanish research system.

Secondly, we present the results of the weighting of the context-based indicators and the monitoring of an energy technology research centre. The results have been obtained by measuring the performance of a particular centre for each of the proposed indicators.

Indicators to monitor the gender gap in research centres in Spain

Model description (Energy Research Gender Indicators)

Once the preliminary list of indicators was obtained (see "Selection of indicators and relevant aspects" section), and based on the context of the research centres, the main indicators were selected for the purposes of monitoring these centres. The final list of indicators, which was drawn up through a second participatory session of scientists with expertise in gender and energy, is shown in Table 3. These selected indicators will be the DANP elements of the network.

This second expert prioritization phase took place during a comprehensive face-to-face session. The experts were convened for a half-day session. The initial session started with the validation of the indicators, which were thoroughly examined and deliberated over to ensure unanimous agreement on the list. Once the indicators were validated, the facilitators (some authors of this paper) elucidated the DANP principles, enhancing the experts' comprehension and facilitating the clarity of the subsequent surveys. After that, each expert addressed his/her surveys individually under the guidance of facilitators. The results of each survey were immediately processed and presented to each of the experts for review. Subsequently, the facilitators aggregated all the individual results using the geometric mean, the consensus judgement according to [41], so as to obtain the group responses.

The criteria are clustered into four categories as shown in Fig. 2: research management and results, staff configuration and structure, work culture, and gender contents in research.

Results obtained for the weights and interactions of the indicators

The context-based indicators already defined must be weighted, obtaining the Energy Research Gender Indicators (ERGIs). For this, we use the DEMATEL technique.

The expanded panel of experts (see Table 2) will then be asked individually to elicit their judgements. To this end, we designed a questionnaire in which they will be asked to rate the intensity of the influence between each pair of criteria from 0 to 4, in which 0 is no influence and 4 is maximum influence. An example of this questionnaire is shown in Fig. 3.

The DANP method prioritizes the selected indicators from the most to the least important for the evaluation of gender issues in the ERC, according to the participating experts.

The final prioritization of indicators for the aggregated group of experts obtained with the DANP technique is shown in Table 4 and Fig. 4.

In Fig. 4, three indicators stand out slightly from the rest. The first is C24: Gender diversity in organizational leadership positions; the second C34: Existence of an equality plan, and the third C11: Gender diversity in research leadership. Two of them are related to the leadership of women.

This graph also shows that indicators related to the organization's own structure, staff configuration and work culture, are more important than indicators related to research outputs when measuring the gender gap in the institution. The use of the DEMATEL technique also allows us to obtain very detailed and relevant information regarding the influences exerted by the indicators on each other. In Table 5, we present the matrix of influences obtained by the set of experts. In this matrix, each cell represents the influence that the indicator in the row exerts on the indicator in the column.

The total relationship matrix presented in Table 5 shows the results in three different levels according to the two obtained thresholds for relevance [21]:

- Threshold 1. Moderate influence: mean + 1 standard deviation (0.209)
- Threshold 2. High influence: mean + 2 standard deviation (0.292)

Grey values are below threshold 1, black values are above threshold 1, and bold values are above threshold 2.

In addition, in the matrix we present the results of the calculations of factors D and R for each indicator (see Eqs. 1–5). Recall that factor D indicates the level of influence exerted by an indicator and factor R represents the level of influence that the indicator receives. In this second level of analysis, we can see that the indicators with the greatest influence are C34 and C24, which coincide with the two indicators that Fig. 3 shows as being the most important. We also observe that the two most influential indicators are C34 and C11. In other words, the

Table 3 Indicators selected to monitor the gender gap in Energy Research Centres

	Indicator	Description	References
C1. Research management and results	C11. Gender diversity in research leadership	Variety of gender profiles as principal investigators (PIs) of projects	[1, 13]
	C12. Mobility actions implemented	Proportion of women who have undertaken placements in relation to the total number of placements undertaken by all staff	[1, 11]
	C13. Participation of women in scientific production	Number of scientific publications co-authored by women in relation to the number of publications of the research institute	[2, 11]
	C14. Participation of women in knowledge transfer	Women's participation in knowledge transfer including formal (patents, entrepreneurship, agreements) and informal (collaboration with associations or others) transfer	[13]
	C15. Leadership in scientific production	Number of scientific publications in which women are first authors in relation to the number of publications of the research institute	[11, 13, 20]
C2. Staff configuration and structure	C21. Vertical segregation	Difference between the number of women and men in management and permanent positions	[1, 13]
	C22. Horizontal segregation	Difference between the number of women and men according to job positions (administration, research, laboratory, etc.)	[1, 13]
	C23. Transparency and equality sensitivity in selection processes	Transparency in selection processes should permeate both the evaluation process itself and the formation of the selection and evaluation committee (e.g., evaluation criteria published in advance). Also, the inclusion of gender specific measures like minimum % of women in the selection committees, active recruitment of women or gender-sensitive language in employment calls	[11]
	C24. Gender diversity in organizational leadership positions	Number of women in positions of responsibility (e.g., affirmative action policies…) in relation to the total number of positions of responsibility	[1, 13]
C3. Work culture	C31.Use of reconciliation measures	Existence of measures for work–life balance, both informal (e.g., non-regulated flexible working hours, non-regulated teleworking, etc.) and formal (e.g., regulated flexible working hours, detailed teleworking, leaves, other)	[4]
	C32. Respectful and inclusive work environment	Perception of a respectful work environment and respectful informal dynamics. This refers to an environment free of sexual, sexist, racist, etc., comments	[1]
	C33. Existence of regulations on conduct in cases of harassment in the workplace	Existence of a protocol for dealing with cases of harassment at work, as well as a specific protocol for dealing with cases of sexual harassment	[1]
	C34. Existence and implementation of an equality plan	Awareness of the existence of the equality plan and perceived impact of its measures	[4]
	C35. Gender-specific training	The existence of gender training in the research centre, including a calendar of courses on gender issues, gender awareness days adapted to different groups, campaigns to disseminate scientific and technological vocations among girls and young women, etc.	[4, 11]
C4. Research Content	C41. Gender in the research content	The existence of research projects that include gender diversity (human or animal), gender perspective to assess the gender impact and gender issues	[4]

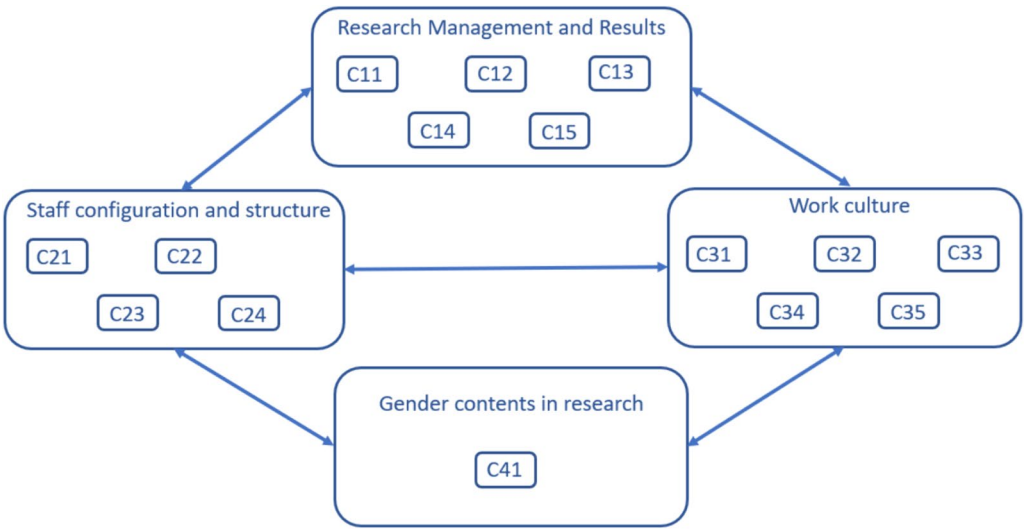

Fig. 2 Overview of the proposed model

		C11	C12	C13	C14	C15	C21	C22	C23	C24	C31	C32	C33	C34	C35	C41
C1. Research management and results	C11. Gender diversity in research leadership		2	3	1	4	3	1	1	3	1	2	1	1	1	3
	C12. Mobility actions implemented	3		2	2	2	3	1	0	2	0	0	0	0	1	1
	C13. Participation of women in scientific production	1	1		2	2	2	2	0	3	0	0	0	0	0	3
	C14. Participation of women in knowledge transfer	1	1	2		2	2	2	0	3	0	0	0	0	0	3
	C15. Leadership of women in scientific production	4	3	3	2		2	2	1	3	1	2	1	1	1	4
C2. Staff configuration and structure	C21. Vertical segregation	3	1	1	1	1		4	4	4	4	4	4	2	4	3
	C22. Horizontal segregation	2	0	3	1	3	3		2	4	3	3	3	1	2	1
	C23. Transparency in selection processes	2	0	2	2	2	3	3		4	2	3	0	0	1	0
	C24. Gender diversity in organizational leadership positions	3	1	1	1	1	4	4	4		4	4	4	2	4	2
C3. Work culture	C31. Facilities for the use of conciliation measures	3	4	3	3	3	1	2	0	2		4	1	1	3	0
	C32. Respectful and inclusive work environment	1	3	3	3	1	2	3	2	4	4		2	2	3	1
	C33. Existence of regulations on cases of harassment in the workplace	0	0	0	0	0	0	1	1	2	0	4		1	2	0
	C34. Existence of an equality plan	2	2	3	3	2	4	4	4	3	4	3	4		3	1
	C35. Gender-specific training	3	0	2	2	3	3	3	2	3	2	4	1	1		4
C4. Research content	C41. Gender content in research (projects and results)	1	0	1	1	1	1	1	0	1	0	0	2	1	3	

Influence	
0	None
1	Very low
2	Low
3	High
4	Very high

Fig. 3 Questionnaire used to weight the influence of context-based indicators

Table 4 Weights obtained by the ERGIs

	Research management and results					**Staff configuration and structure**				**Work culture**					**Research content**
Indicators	C11.	C12.	C13.	C14.	C15.	C21.	C22.	C23.	C24.	C31.	C32.	C33.	C34.	C35.	C41.
Weight	0.094	0.034	0.047	0.033	0.070	0.089	0.064	0.078	0.117	0.084	0.062	0.034	0.109	0.078	0.030

indicators that stand out for their influence on the network coincide with the most important.

We would like to represent this information in a cause-effect diagram; in Fig. 5 we present the *X*-axis, which shows the degree of importance of each indicator ($R+R$) and the *Y*-axis, which shows the degree of cause (positive values) or effect (negative values) of each indicator ($D–R$).

As can be seen in this diagram, the indicators are classified into four quadrants [43]. We may observe that the indicators that appear in quadrant II are: C24, gender diversity in organizational leadership positions and C31, ease-of-use of work–life balance measures. These can be considered key factors and should be taken into account when designing gender actions. Indicator C31 has not appeared until now as it belongs neither to the most influential nor to the most important group. However, the combination of both properties places it in quadrant II, which makes it a relevant factor when measuring the gender gap in research centres. Our

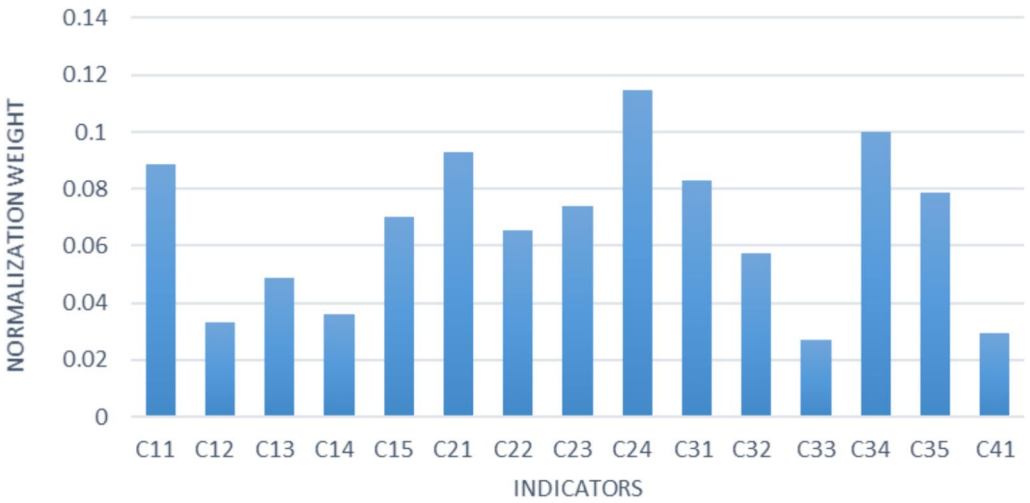

Fig. 4 Prioritization of the indicators

Table 5 Total relationship matrix of criteria

	C11	C12	C13	C14	C15	C21	C22	C23	C24	C31	C32	C33	C34	C35	C41	D
C11	0.18	0.05	0.25	0.16	0.29	0.25	0.16	0.08	0.26	0.14	0.22	0.05	0.04	0.11	0.28	2.4
C12	0.13	0.01	0.13	0.08	0.12	0.12	0.05	0.02	0.09	0.04	0.07	0.01	0.01	0.04	0.09	1.0
C13	0.19	0.04	0.09	0.11	0.20	0.17	0.08	0.03	0.13	0.05	0.07	0.02	0.01	0.06	0.22	1.5
C14	0.12	0.02	0.08	0.04	0.11	0.12	0.07	0.02	0.12	0.04	0.05	0.01	0.01	0.04	0.19	1.1
C15	0.27	0.05	0.22	0.15	0.134	0.21	0.14	0.05	0.20	0.08	0.13	0.03	0.02	0.08	0.27	2.0
C21	0.25	0.04	0.21	0.17	0.23	0.16	0.18	0.10	**0.29**	0.17	0.20	0.05	0.02	0.14	0.25	2.5
C22	0.21	0.03	0.21	0.13	0.21	0.17	0.09	0.07	0.21	0.09	0.15	0.02	0.01	0.08	0.19	1.8
C23	0.24	0.04	0.19	0.14	0.19	0.25	0.22	0.06	0.28	0.13	0.19	0.03	0.02	0.08	0.14	2.0
C24	**0.32**	0.05	0.26	0.21	0.27	**0.31**	0.24	0.15	0.21	0.23	0.27	0.06	0.04	0.15	0.22	2.9
C31	0.28	0.09	0.26	0.22	0.28	0.25	0.18	0.06	0.25	0.09	0.18	0.03	0.02	0.10	0.17	2.3
C32	0.16	0.04	0.18	0.14	0.15	0.13	0.10	0.05	0.16	0.11	0.08	0.03	0.03	0.09	0.13	1.5
C33	0.08	0.01	0.08	0.05	0.07	0.07	0.06	0.03	0.08	0.05	0.10	0.01	0.02	0.04	0.05	0.7
C34	0.25	0.08	0.23	0.18	0.23	0.26	0.21	0.16	0.26	0.22	0.20	0.13	0.02	0.16	0.17	2.6
C35	0.20	0.03	0.19	0.14	0.21	0.17	0.13	0.11	0.19	0.13	0.22	0.05	0.03	0.06	0.25	2.1
C41	0.10	0.01	0.12	0.10	0.10	0.09	0.06	0.02	0.07	0.03	0.05	0.03	0.02	0.08	0.08	1.0
R	2.82	0.54	2.61	1.99	2.67	2.55	1.86	0.95	2.59	1.47	2.04	0.85	0.45	1.34	2.67	0.1

interpretation of these two key factors is that the role of senior researchers is crucial because the fact that there are women in the relevant positions serves as a mirror in which they look for the other women working in the same research centre. In addition, the dynamics can be different when there are women in leadership since it makes clear to the staff in their charge what position they might occupy in the hierarchy of the organization. This result aligned with those from previous studies [30]. In our case study, the effect of the low number of women and the fact that part of the staff is not accustomed to mixed-gendered interactions have been clearly stated during the interviews. We find that women with a clear vision of equality problems in the centre have probably created a safe environment, bearing in mind that the younger women under their command have not perceived the problems they had faced. However, that affects only a few of the research groups

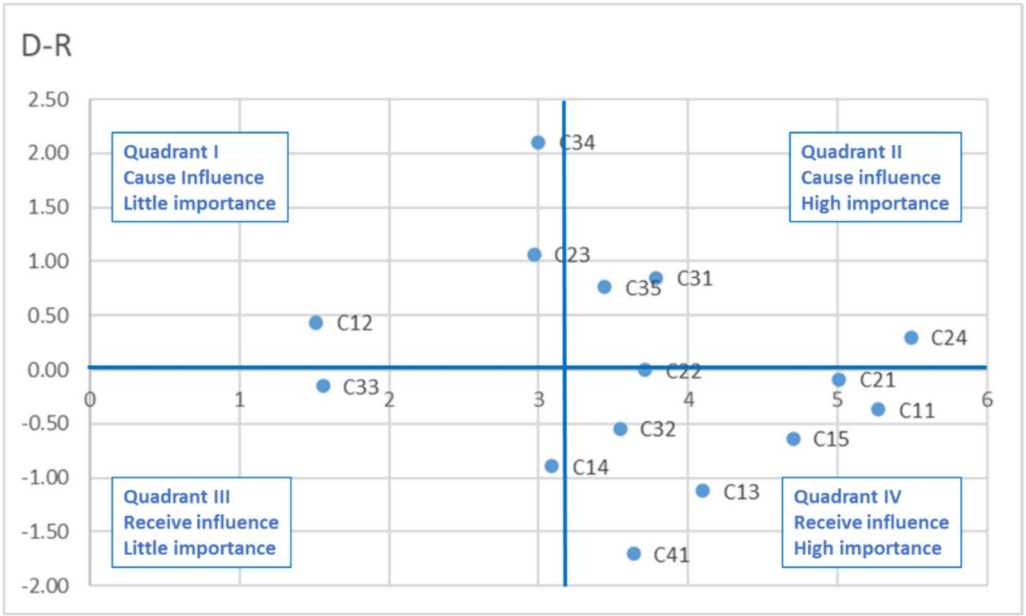

Fig. 5 Cause–effect diagram of the ERGIs

of the centre, groups in which there is a high concentration of female members by the way.

On the other hand, the availability and ease of use of work–life balance measures are considered highly relevant factors that could make the difference when attempting to attract more women to a field as masculine as energy engineering.

Additional conclusions that can be drawn from Fig. 5 are as follows:

These indicators are isolated: *C12, mobility actions carried out*; *C33, existence of regulations on conduct in cases of workplace harassment* and *C14, participation of women in knowledge transfer*. This means that they are less influential on others. For instance, according to the national authorities, mobility or knowledge transfer are relevant requirements for career advancement but have limited impact on other gender aspects, as is the case of sexual harassment regulations, which are highly relevant but not so closely related to others.

C41, gender contents in research appears to be of low influence and not of great importance. Not all research leaves room for gender perspective integration as is the case of some research in the field of energy.

Finally, we would like to re-emphasize those indicators that appear to be very influential but not very important: *C23, transparency in selection processes*; *C35, specific training in gender issues*. These would be indicators that have a strong influence on others, but which would not be so important on their own, i.e. without considering their relationships with the rest. It is necessary to consider them whenever their influence is exerted on important indicators. For instance, transparency in selection processes affects the distribution of staff both vertically and horizontally, whereas the fact that staff are trained in gender issues will make them more aware of these issues and more critical of inequalities.

Results of the monitoring of a research centre in energy engineering

Qualitative information

The three thematic blocks of the information obtained from the personal interviews correspond to the dimensions developed in the Energy Research Gender Indicators (ERGIs): (1) research management and results; (2) staff configuration and structure; (3) working culture; and (4) gender contents in research.

Firstly, as regards research management, a large proportion of the men interviewed stated that the organization, participation, and leadership of research in the centre only respond to meritocratic and hierarchical issues and that gender has no influence whatsoever. A researcher stated "the truth is that we were surprised by your interview because here we do not… here what matters is what matters. (…) women, men, and everything. And the truth is that I believe that no discrimination has ever been made" (I1). However, the women interviewed expressed a more critical attitude towards the management of gender diversity in the centre.

Secondly, the unequal proportion of men and women in the organization is one of the issues most frequently mentioned. It is stated that this is a structural problem of the discipline, which manifests itself as early as undergraduate studies, on which very few women are enrolled, and which is reproduced on the subsequent levels of the scientific career and, therefore, at the centre. Furthermore, they state that in comparison, "there are many women at the entry level, but very few go all the way [to a research career]" (I3). There are no proactive measures to try to reverse the structural inequality in the centre by taking positive discrimination measures in selection processes or by making specific calls to attract more women. The permanent researchers interviewed claim to select members of their group based on their knowledge and specialization, regardless of gender. Furthermore, as will be seen in the quantitative results ("Quantitative information" section), there is a clear gender gap in positions of responsibility, both vertically and horizontally.

Thirdly, as regards the work culture, working hours are flexible, which is seen as positive for both the family and private life of men and women. However, these measures are still insufficient, as one of the interviewees stated: "private life still affects women more in terms of career development (…) motherhood (…) leaves you behind" (I7).

It is also important to highlight the participation dynamics and the atmosphere in the centre. The fact that there is a reduced number of women is influential, insofar as the women feel less involved because they are in a smaller proportion. And "I do have to say that it is still noticeable that men are not used to it. There are very, very few …that will surely affect that men are accustomed to dealing with men" (I7).

Finally, the incorporation of the gender perspective in research, which is seen, in most cases, as something alien to the nature of the work due to its object of study (e.g., fundamental science). In these studies, in which this perspective would have a place, it is considered that "[considering] research questions or the object of our work is more difficult for us because we do not have the skills. What we know how to do, we do not know how it can contribute" (I10).

On the other hand, although most of the interviewees know of the existence of an equality plan and sexual harassment protocols, it is only their existence that is acknowledged, not their content or implications in the centre.

In short, most of the male interviewees' discourse centred around the fact that there is no gender-related problem at the institution, either in the management of research or in the working environment. However, this is not the case for some of the women interviewed who do allude to different problems of gender discrimination, such as "the distribution of tasks and roles in the centre" (I2).

Quantitative information

Primary data results: survey Researchers who indicated they had children (60%) were asked whether they had taken maternity/paternity leave. 100% of the women with children reported taking maternity leave, whereas less than 50% of the men did. This is especially relevant since maternity leave was regarded by some of the researchers as a critical point in the development of a woman's scientific career, leading to them losing advantage compared to their male counterparts. If men took paternity leave as well, the difference would not be so blatant, and the impact would be smaller.

The large majority of respondents (75%) reported not having received any gender equality training (see Fig. 6). The primary source of training for those who did was the university.

Secondary data results: website of the centre and official university database The research outcomes of all ERC staff were thoroughly reviewed and analysed. This examination included several variables, such as the quantity of published papers, papers published as first authors, research projects as PI, contracts obtained, number of contracts in which they participate, and patents. The analysis was focused on the data from 2019–2023, which were later on segregated by gender. The aim was to identify key factors contributing to scientific career advancement.

Table 6 shows the members of the monitored centre classified according to professional categories following the Spanish university system. Notably, there are no women in the highest category.

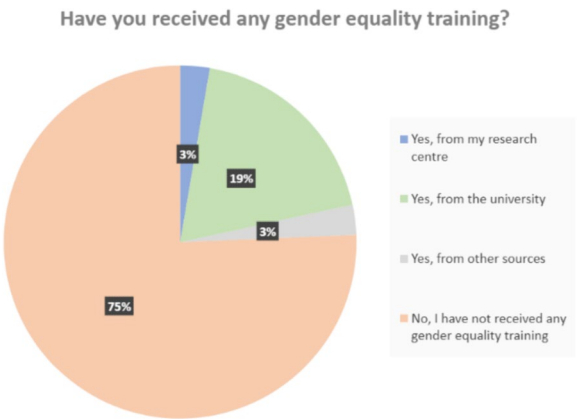

Fig. 6 Gender equality training received

Table 6 List of personnel of the research centre classified according to professional category

Professional category	Men	Women
Full professor	8	0
Associate professor	18	2
Assistant professor II	1	1
Assistant professor I	2	1
Part-time teacher	4	1
Research assistant	15	2

Figures 7 and 8 compare gender distribution in research contracts between private companies and publicly funded R&D projects. A notable difference emerges in leadership roles: senior men predominantly lead contracts with private companies, while senior women tend to lead publicly funded R&D projects. As regards the higher number of women leading public projects (Fig. 7), there could be several reasons for this, such as: (i) networking, (ii) the policy of promoting gender equality and (iii) the differences between the motivations and values of men and women in terms of the impact of their results.

Private contracts lack regulations for PIs, whereas for publicly funded projects, there is a policy promoting gender equality in science that positively evaluates projects led by women. On the other hand, and as far as the higher number of men leading private contracts is concerned (Fig. 8), that could be a question of ease-of-access to advertising venues since, as the information is not open, are obtained through contacts. Again, the dynamics of a male-connected engineering environment may be observed.

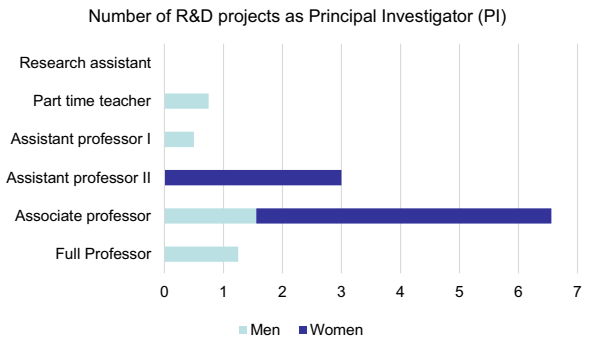

Fig. 7 Principal investigators of publicly funded R&D projects attending to professional tenure and gender

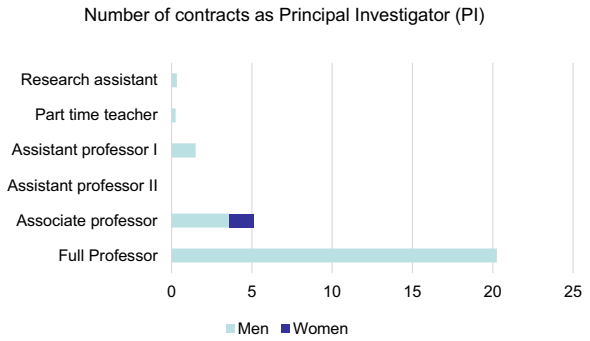

Fig. 8 Principal investigators of private contracts attending to professional tenure and gender

Monitoring of the Research Centre: gathering of data indicators

The results obtained for ERGIs in the monitoring of a Spanish Energy Research Centre as well as the sources from which these results have been collected are shown in Table 7.

As regards the results of the DANP model and the ERGI values obtained for the ERC, we propose some recommendations focusing on key factors that should be considered when designing gender actions in this centre. These key factors will be those indicators that are important or influential, (or those that combine both properties), and whose ERGI values are low or qualitatively deficient for the centre. We propose recommendations for those indicators marked with * in Table 7.

For recommendation purposes, from the total list of 14 indicators we choose those that add up to 50% of the total weight. This prioritization allows us to focus on the most important factors that are likely to have the greatest impact on the outcome and prevents the inclusion of too many recommendations that could lead to excessive complexity and potentially obscure the improvement of the process. Therefore, we will more thoroughly analyse the indicators that add up to 50% of the weighting process according to Fig. 1: C24, C34, C11, C21, and C35.

Discussion

Case study: key indicators and recommendations

As far as the results of the DANP model and the ERGI values obtained for the analysed ERC are concerned, we propose recommendations in the following indicators (marked in Table 7 with *):

C24. Gender diversity in organizational leadership positions

C34. Awareness of the existence of an equality plan

Table 7 Indicator analysis

Indicator	Definition	Result	Data source	Weights of ERGIs	Influential		Needs Recomm
					Yes	No	
C1. Research management and results							
C11. Gender diversity in research leadership	% Women principal investigators of projects	11.1%	Secondary data/ Institutional public data base	8.8		X	*
C12. Mobility actions implemented	% Mobility actions carried out by women	26.7%	Primary data/survey	3.3		X	
C13. Participation of women in scientific production	% Scientific publications written by women	14.7%	Secondary data/ Institutional public data base	4.9		X	
C14. Participation of women in knowledge transfer	% Knowledge transfer agreements and patents developed by women	7.1%	Secondary data/ Institutional public data base	3.6		X	
C15. Leadership in scientific production	% Scientific publications led by women	22%	Secondary data/ Institutional public data base	7.3		X	
C2. Staff configuration and structure							
C21. Vertical segregation	% Women in management positions/ %People in management	0%	Secondary data/ Institutional public data base	9.3		X	*
	% Women in permanent positions/ %People in permanent positions	84%					
C22.Horizontal segregation	% Women in laboratories	0%	Secondary data/ Institutional public data base	6.5		X	
	% Women in administration	100%					
	% Female researchers	16%					
C23. Transparency in selection processes	Transparency in the evaluation process and the evaluation committee	Yes. Regulated by institutional regulations	Primary data/interviews	7.4	X		
C24. Gender diversity in organizational leadership positions	Number of women in leadership positions in relation to the total of leadership positions	There are no women in positions of responsibility	Secondary data/Research Institute Website	11	X		*
C3. Work culture							
C31. Ease-of-use of reconciliation measures	Existence of measures for work–life balance. both formal and informal	Yes. Formal measures regulated by institutional regulations and informal measures at the centre	Primary data/interviews and survey	8.3	X		*
C32. Respectful and inclusive work environment	This refers to an environment free of sexual/ sexist/ racist, etc., comments	Sexist environment (sexist jokes) in informal events	Primary data/interviews and survey	5.8		X	
C33. Existence of regulations on conduct in cases of workplace harassment	Existence of a protocol for dealing with cases of harassment at work. as well as a specific protocol for dealing with cases of sexual harassment	Yes. Regulated by institutional regulations but mostly unknown in the centre	Primary data/interviews	2.7		X	
C34. Existence of an equality plan	Awareness of the existence of the equality plan	Yes. Regulated by institutional regulations. content or implications unknown in the centre	Primary data/interviews	10	X		*

Table 7 (continued)

Indicator	Definition	Result	Data source	Weights of ERGIs	Influential		Needs Recomm
					Yes	No	
C35. Gender-specific training	The existence of gender training in the research centre	There is no gender-specific training	Primary data/survey	7.8	X		*
C4. Research Content							
C41. Gender in research content	Gender perspective in research content. E.g., gender perspective in the sample, gender issues as part of the project, or gender perspective to assess the impact	There is no gender perspective in the content	Primary data/survey	3		X	

* Indicator recommended for improvement

C11. Gender diversity in research leadership—% Women principal investigators of projects
C21. Vertical segregation
C35. Gender-specific training
C31. Ease-of-use of work–life balance measures

The lack of women in organizational leadership positions is pronounced in the case of the study as no women are present in head positions. This indicator (C24) affects multiple dimensions. The insufficient or, in this case, inexistent female representation in high-level positions might dissuade women from joining an organization in which they do not foresee career development. The presence of women in management might be perceived as making panels more approachable or more receptive to the acknowledgement and tackling of gender issues than those that are exclusively male. Additionally, the absence of women in high positions can potentially disincentivize them from entering an institution where gender dynamics might pose a challenge. These arguments also apply to indicators C21: *Vertical segregation* and C11: *Gender diversity in research leadership*. In the case of indicator C11, it is worth highlighting that being the principal investigator of projects is a requirement for any advancement in academic research in the energy sector in Spain. The low proportion of female principal investigators in projects could explain the absence of women in leadership positions. The difficulty they experience in advancing their scientific careers, and consequently accessing management positions, may be a contributing factor.

There is a prevailing belief within the research centre that only meritocracy drives success, dismissing other factors—especially gender—as irrelevant. Despite the evidence, including the low representation of female leaders in the scientific output of the Spanish energy sector [17], many members fail to recognize existing differences or inequalities. Consequently, these indicators could serve as a pivotal tool to raise awareness and challenge expected resistance towards equality measures within specific groups.

Specific training on gender (C35) would address two different aspects identified in this case study. Firstly, it would provide training to those people who recognize that there is a gender gap and are willing to work towards reducing it but do not have the tools or knowledge to address it, either as a power figure or as part of the group. And secondly, it would increase the awareness of those who consider that no gender gap exists, nor that changes should be made to accommodate a more inclusive view. Thus, given its importance, gender training should not be the sole responsibility of the University's Equality Committee, but the research centre should also oversee the proposal and development of activities that promote training in equality to make this as cross-cutting and diverse as possible.

Furthermore, there is a significant lack of awareness regarding the content of the equality plan (C34). The actions taken to circulate this content and make it visible to the staff should be promoted by the management. However, this would require an initial acknowledgment of the gender gap by the heads of the institution.

The availability of work–life balance measures (C31) is identified as a crucial indicator for the career development of women in research. Yet, availability is not enough. The acceptance of such measures by the work environment as well as whether men make use of them are important factors that weigh in women's career development. If men in the institution are making equal use of the measures, women's careers will be less negatively impacted from a competitive point of view when they use them. Besides, it is also a sign that the organizational culture is more sensitive, and that care is not considered a women-only issue.

Furthermore, the ease with which women can make use of the work–life balance measures is considered a highly relevant factor, which leads us to believe that centres not placing obstacles in their way—considering the reasons why they use them—would be an attractive factor for women. Particularly in a field as masculine as energy engineering.

While work–life balance measures are present they are often informal, and the absence of official guidelines gives line managers the discretion to determine the extent, duration, and timing of these measures. Therefore, a change of manager might entail a change of conditions or some uncertainty towards what their rights will be, as some men pointed out in the interviews.

The Gender Perspective in Research Content (C41) was not identified as a relevant indicator, possibly due to the nature of the research. Indeed, for some of the research conducted, gender perspective cannot be applied; for example, in the study of the disposition of photovoltaic cells. However, it was detected that this possibility had often not been considered. Therefore, future research should assess whether its impact may be different for women and whether it is possible to integrate a gender perspective into both the samples and data collection. Several studies have shown that men and women may have different energy consumption patterns due to varying daily routines, responsibilities, and access to resources [44–47]. Taking gender differences into consideration can provide a more comprehensive understanding of the energy needs and these consumption patterns. This is particularly relevant, since women are the primary users of household energy in both developing and industrialized countries [8]. It could also contribute to the

fostering of a broader and fairer approach in policy and technology development; for instance, adapting renewable energy projects to address specific needs of women in rural areas [18, 48], or simply having enough understanding not to create inequalities or perpetuate those already existing.

Finally, a recommendation is addressed to the home institution of the research centre. The centre has no expertise in gender equality, while the equality plans are located at university level. We have identified that some gendered distortions that exist throughout the whole Spanish research system- such as gendered precariousness and the impact of family responsibilities- are not mitigated by centre measures and university measures are equally absent and unrecognized. Considering the effort to be made, the research centre cannot do it alone; for its development, it should have the support of the equality unit of the institution to which it belongs. The centre could greatly benefit from developing a tailored equality plan that considers its unique circumstances as regards the gender gap. While rooted in the general measures of the institution's plan, the centre's plan should incorporate specific aspects that reflect its nuances. This entails integrating measures specifically designed to address and bridge the gender gap within the research centre.

General discussion

To effectively study and enhance the presence and participation of women in the field of energy science, comprehensive data are imperative. Disaggregated data, at least separated into area of knowledge, category, and gender, is vital for both informed decision-making and understanding the reality within research centres, enabling the necessary steps to be taken.

The case study research method carried out aims to provide insights into the workings of a particular process within its context, enabling us to observe the dynamics of the agents and infer explanations. However, it is important to note that this approach is not representative and can only be compared once more cases have been developed [49]. Expanding the research to monitor additional energy research centres would enhance the model and offer deeper insights into the unique dynamics and challenges within this domain. While each centre may present distinct dynamics, this adaptable model is designed to accommodate and integrate these differences. Therefore, this tool can serve both diagnostic and awareness-raising purposes—a conversation starter rooted in data, demonstrating the persistent existence of the gender gap demanding attention and resolution. The presented indicators possess the potential to serve as diagnostic tools for understanding the gender gap within research institutions and for raising awareness. This is particularly crucial in fields such as energy, where according to the cited literature, the gender gap is often overlooked, as we found out in our case study.

We are currently monitoring other research centres using the same general methodology and replicating the specific methodological part of the case study in two additional scientific sectors: applied technologies and biology sciences. The findings in these two case studies reveal similar dynamics in the underrepresentation of women, especially in leadership roles in research and management positions. What may also be observed is how little aware these organizations are of the existing gender gap.

Conclusions

The development of an indicator tool based on DANP not only serves as a proactive approach to the monitoring and evaluation of gender roles and inequalities in research centres but also contributes to interpreting results and forming recommendations. Applied in a case study, this tool is specifically tailored to incorporate findings from literature reviews and both qualitative and quantitative organizational inputs, considering the broader energy, science, and gender context in Spain.

The tool's design considers the complexity of measuring relational dynamics within organizations, recognizing that these dynamics significantly contribute to the gender gap. This perspective helps integrate various dimensions, including the individuals involved, relational dynamics, and organizational culture. The gender gap is portrayed as a multi-dimensional problem, extending beyond mere numerical representation. Using a multi-criteria decision-making method, we assess the impact of the indicators on gender equality in order to address the gender gap in a specific research centre. This method entails the selection and grouping of decision criteria, followed by the analysis of interactions within the network model defined, considering the opinion of energy stakeholders, not only gender experts.

Our context-sensitive methodology reveals specific dynamics. For instance, in the analysed centre, a sexist environment emerges through informal comments, such as jokes; men often underuse available life–work balance measures, and there is a gendered pattern in fund access: women primarily lead publicly funded projects, limiting their diversification due to a more limited access to private funds.

The use of indicators serves as powerful diagnostic tool and catalyst for awareness. They highlight the persistent gender gap, particularly in traditionally male-dominated fields, such as energy engineering, where this gap often goes unrecognized and acts as a catalyst for conversations about the changes required.

It is advisable to expand the research so as to monitor more centres for the purposes of refining the model and better understanding the nuances of the gender gap. An ongoing monitoring would help to identify existing disparities and instigate actions toward gender equality. For this reason, the research would benefit from the monitoring of more energy research centres to further adapt the model and better understand the particularities that this area might include. Our findings, from an in-depth case study, can be discussed in the development of further research avenues on gender and energy. However, each organization is unique and the methodology we propose is designed to fit the specific dynamics of each centre.

Limitations and future research lines

We acknowledge and emphasize the intrinsic limitation of our in-depth case study methodology and encourage further research that can provide additional insights and patterns into the gender dynamics in energy research centres. Our purpose is to follow up with other energy engineering institutes in Spain, as well as to establish comparisons with other geographical contexts, such as with similar studies conducted in Germany [50]. This could provide a broader view and strengthen the applicability of the proposed tool in various contexts. We are currently monitoring several research institutes in differing areas of knowledge, also in Spain, with results that are very similar to those presented in this analysis. We intend to continue this study by applying the proposed methodology and carrying out a comparative study of these institutions.

Moreover, we also want to highlight some other limitations regarding data gathering. We were unable to employ any strategies to mitigate non-response bias in the collection of primary data, such as follow-up contacts or incentives for participation due to confidentiality reasons of the monitored centre. This could have compromised the representativeness of the quantitative results through the survey.

Finally, as regards the interpretation of some of the qualitative results, we know that there is an interpretation bias in the results on paternity leave due to the fact that the length of this leave in Spain has varied greatly over the last 20 years from 4 days to 6 months. Since age was not asked in order to anonymize the responses to the questionnaire, it is not possible to relate the length of leave to whether it was taken or not. Further research could have an impact on this issue, since no data has been available until recently.

Abbreviations

ERC	Energy Research Centre
ANP	Analytic Network Process
DANP	Combination of DEMATEL and ANP (DANP)
DEMATEL	Decision-Making Trial and Evaluation Laboratory
ERGIs	Energy Research Gender Indicators (ERGIs)
EU	European Union
MCDM	Multi-criteria decision methods

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Author contributions

Sara Sánchez-López: writing—original draft, methodology, visualization, data curation. Rocío Poveda-Bautista: conceptualization, methodology, writing—original draft, writing—review & editing, supervision. Carmen Corona-Sobrino: conceptualization, methodology, software, data curation, visualization, writing—original draft, writing review & editing. Paula Otero-Hermida: conceptualization, writing—review & editing, supervision. Mónica García-Melón: methodology, data-curation, writing—review and editing.

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Availability of data and materials

The datasets generated and analysed during the current study are not publicly available due to the need to protect the privacy of study participants but are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Institutional Review Board (or Ethics Committee) of Universitat Politècnica de València (P17_10_01_20, 10 January 2020). The participants provided their written informed consent to participate in this study. The questionnaire and interviews did not collect personally identifiable data, according to Delegación de Protección de Datos, IRB of Universitat Politècnica de València, and national regulations Law 3/2018, 5th of December, Protection of Personal Data and guarantee of digital rights, article 7, published in BOE núm. 294, 06/12/2018, (Reference: BOE-A-2018–16673). The purpose of the study was explained to all the participants at the beginning of the questionnaire and interviews. The participants were also informed that they have the right to leave the questionnaire or interview at any time whenever they feel uncomfortable or do not want to answer any further questions.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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