Bridging the Gender Gap in Green Transitions: Women's Role in Renewable Energy and Sustainable Innovation

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Abstract

The shift to the low-carbon economy can be understood as an environmental challenge as well as a socio-economic prospect. Nevertheless, gender inequality reemerges in the fields of renewable energy and sustainable innovation systems limiting the roles of women in climate solutions. Most past research on gender inclusion in clean energy has focused on gender; however, few studies have empirically merged gender and development (GAD) with sustainability transition theory (STT) in explaining systemic processes of exclusion.

The following research is aimed at exploring structural, institutional, and socio-cultural obstacles between women and green technology, renewable-energy entrepreneurship, and STEM-based sustainability innovation in India. A mixed-method (design) methodology was applied on the quantitative data collected relating to 180 women professionals and 15 in-depth interviews with policymakers, engineers, and entrepreneurs. Findings indicate that there are

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significant gender disparities in leadership, capital access and technical positions. Regression analysis revealed that mentorship (0.38, $p < 0.01$) and institutional support (0.42, $p < 0.01$) are relevant in making women more active in terms of innovation.

Combining both GAD and STT, the article suggests a Gender-Inclusive Innovation Ecosystem Model (GIIEM), which shows how gender-responsive structures and agency processes can increase innovation capacity and environmental performance. The results underscore the idea that gender-biased participation in the process of designing, governing, and implementing sustainable energy transitions will not ensure their successful completion. The analysis puts forward a new conceptual and empirical framework of gendered transitions on the auxiliary path, respondent to SDG 5 (Gender Equality) and SDG 13 (Climate Action).

Keywords:
Gender-inclusive innovation, Renewable energy transition, GAD, Sustainability Transition Theory, Empowerment, Climate policy.

1. Introduction

The idea of the transition to sustainable energy systems has become a fundamental part of the development agendas of the international community, specifically in the context of the Paris Agreement and the United Nations Sustainable Development Goals (SDGs). This change is manifested in the increase in the investment flows into renewable energy, clean technologies and innovation systems that facilitate low-carbon development (e.g., International Energy Agency, 2023). Nonetheless, even with the promising nature of the green economy, gender inequalities still continue to deeply permeate it (UN Women, 2022). Females continue to constitute less than one-third of the total renewable-energy labor in the world and experience serious challenges that are connected to skill acquisition, funding, leadership presence and involvement in policy arenas (International Renewable Energy Agency [IRENA], 2023).

The intersection of gender equality (SDG 5) and climate action (SDG 13) thus is a very important but poorly studied nexus in sustainability studies. With the renewable energy shift re-inventing the economic forms and innovation trends, it also provides the occasion to redress the gender historical disparities in technology and governance. However, the possibilities of women are still limited due to institutional, socio-cultural and market-specific barriers (e.g., internalised gender norms, a lack of access to STEM education, access to funding) (Sovacool et al., 2020). By way of illustration, in the area of leadership in energy, women are not represented at all: in the energy industry as a whole, about a quarter of top management positions are occupied by women.

Notably, gender-inclusive innovation is not merely a matter of ethics or fairness: it is the key to successful, equal and sustainable climate changes. The benefits of having diverse teams and inclusive governance are increased innovation, better responsiveness to end-user needs (including the needs of women), and increased institutional legitimacy (e.g., it was demonstrated that gender-diverse teams in energy transition situations improve the results of innovation).

Dimensions of workforce and skills: According to a review of the IRENA and the International Labour Organization (2022), women occupy about a third of the total number of jobs in the renewable energy sector, but the diversity is enormous depending on the technologies and the region. In some sub-sectors like wind energy, women representation is at the lowest level of about 21%. Visualizing Energy+1 The suggestion here is that the move to clean-energy is occurring within a workforce environment that is heavily skewed in terms of gender.

Representation and leadership: Although in some studies the female participation in the renewable sector might be slightly greater than the overall energy sector (e.g., about 32% vs. some 22), leadership positions remain highly dominated by men. Alpha Mundi Foundation+1 Outside of the numbers, women are not represented in technical or administrative positions, but in non-technical, non-administrative positions (skills and leadership chains).

Institutional and market barriers: The most important barrier is access to finance. As an example, a female-dominated firm in the off-grid energy industry will receive less than 13 percent investments in some settings. Additional causes of the gender-based inequality in women access to and advancement on the green-innovation ecosystem are energized Gendered norms and structural conditions (including mobility constraints, caregiving responsibilities, social perceptions of STEM careers).

Innovation, governance and embrace of technology: The case in support of gender-inclusive innovation is convincing: women tend to introduce other angle, problem-formulation and solutions capable of reinforcing technology adoption, user-friendliness design and participative governance. With this awareness, recent studies argue that we just cannot afford to use only half of our human capital, in case the energy transition will be successful. Furthermore, a responsive climate action strategy can improve the adaptive capacity, resilience, and outcome equity (PwC, 2022).

Changing chance: The new green economy is a chance of change to create more inclusionary routes, instead of continuing with past gender inequity. Gender equality, inclusive governance and innovation-system change can be instilled early in the development of renewable energy, that the industry is younger and more dynamic than the old fossil-fuel industry, therefore, there is an opportunity to instill gender equality, inclusive governance and innovation-system change early.

This paper, therefore, is that to make both the climate mitigation and sustainable development objectives simultaneous, there is the need to promote gender inclusive innovation systems in the renewable energy transition. The transition will be ineffective, less equitable and less sustainable unless structural gender difference in skills and leadership, financing and governance are addressed. The rest of this paper discusses how gender-inclusive innovation can be operationalised in the green economy and what obstacles continue to exist, and what policy and institutional options can be used to address them.

2. Review of Literature

2.1 Gender and Sustainable Development

It is well-known that gender equality is one of the essential components of sustainable development (Kabeer, 1994). According to feminist economists and development scholars, the success of sustainable transitions is impossible without breaking down gendered social and institutional frameworks that limit access of women to productive resources, education and decision-making (Rao and Kelleher, 2005). The Gender and Development (GAD) framework emphasizes that development programs should evolve beyond the issue of women participation to the concept of power relationships which contribute to inequality (Cornwall and Rivas, 2015).

Gender is presented as a cross-cutting driver of every sustainability goal in the context of the Sustainable Development Goals (SDGs) specifically SDG 5 (Gender Equality) and SDG 13 (Climate Action) (UN Women, 2022). Empirical evidence has indicated that in cases where women have an active role in environmental governance, there is better equity and sustainability in outcomes (Agarwal, 2010). On the same note, those communities that have greater gender equity have a higher adaptive capacity to climate change (UNDP, 2021).

Therefore, to reach a sustainable state, technological or economic shifts are insufficient, but the social one that is based on gender justice.

2.2 Women in Renewable Energy

Gender is presented as a cross-cutting driver of every sustainability goal in the context of the Sustainable Development Goals (SDGs) specifically SDG 5 (Gender Equality) and SDG 13 (Climate Action) (UN Women, 2022). Empirical evidence has indicated that in cases where women have an active role in environmental governance, there is better equity and sustainability in outcomes (Agarwal, 2010). On the same note, those communities that have greater gender equity have a higher adaptive capacity to climate change (UNDP, 2021). Therefore, to reach a sustainable state, technological or economic shifts are insufficient, but the social one that is based on gender justice.

Women still cannot climb the ladder due to systemic biases in recruitment, pay equity, and promotion practices (UNDP, 2021). Also, women access to finance and professional networks is uneven which limits them to engage in renewable-energy entrepreneurship (OECD, 2022). Occupational segregation is further supported by socio-cultural norms, gender stereotypes about technology, and unpaid care burden (UN Women, 2022). Empirical research points at the fact that the gender diversity within the energy workforce contributes to the improvement of innovation, productivity and environmental performance (Sovacool et al., 2020).

Yet, progress remains slow. As an example, roughly only 19 percent of companies in the renewable-energy sector indicate gender balance in management and fewer than a quarter of technical roles are occupied by females (IRENA, 2023). This underrepresentation is a social imbalance and it is a lost chance of inclusive, creative energy transfer.

2.3 Gendered Innovation Systems

Gendered dynamics influence the creation and distribution of new technologies through innovation ecosystems, networks of institutions, firms, researchers, and policymakers (UNESCO, 2021). Women are still under-represented in STEM education, research and development, and leadership in innovation and do not have as many viewpoints as they need to alter technology on a sustainable level (World Bank, 2023).

The scholars of feminist innovation believe that the involvement of gender into innovation is helpful to become more creative, ethical, and solve the problem in sustainability (Siegenthaler and Lema, 2020). Teams that are gender diverse are linked to the increased innovative performance and the user-focused design results (Nielsen et al., 2018). Nevertheless, the majority of national policies regarding innovation are gender-neutral on paper but gender-blind in reality (Tandon & Pande, 2023). Very few have specific clauses on gender-responsible R&D funding, mentoring networks, or inclusive technology governance (World Bank, 2023).

This control is essential in the system of renewable-energy innovations: without the involvement of women with their experiences and knowledge, the technologies will not meet the needs of various forms of energy (Clancy et al., 2019). The gender-inclusive innovation systems also demand it to institutionalize changes, which is increasing women access to STEM opportunities, entrepreneurship funding, and status in the institutions, which are involved in making innovation policies (UNESCO, 2021).

2.4 Theoretical Gaps

Although there has been an increasing level of acknowledgement on the role of gender issues in sustainability, there are still gaps in theory. The majority of the literature frames the gender inclusion as a social equity issue, without considering it as an instrument of innovation productivity and systems change (Sovacool et al., 2020; OECD, 2022). Gender equality and its connection to the systemic innovation is explicitly present in few models of sustainability-transition theory, which is traditionally based on technological and institutional change and not social power relations (Geels, 2002; Markard et al., 2012).

The aim of this paper is to fill this gap by combining Gender and Development (GAD) Theory (based on structural change and empowerment) and Sustainability Transition Theory (STT) (based on socio-technical regime change). Gender-inclusive innovation is conceptualized in the integrated framework as a normative agenda and a functional requirement to sustainable energy transitions. Integrating gender into innovation systems facilitates equity, as well as fosters sustainability transition effectiveness, legitimacy and resilience.

3. Objectives

This research seeks to explore the role of gender dynamics in determining whether women can participate in renewable energy and sustainable innovation and lead in it. Specifically, it seeks:

1. To Determine main institutional, socio-cultural and policy obstacles to women participation in green economy.

2. To Ship the association amidst gender strength and innovation execution in renewable energy industries.

3. To Recommend a theoretical framework of the Gender-Inclusive Innovation Ecosystem that facilitates fair transitions.

4.Hypotheses

H1: Mentorship significantly enhances women's participation in renewable-energy innovation.

a) Supported by regression coefficient $\beta = 0.38$ ($p < 0.01$).
b) Derived from the GAD framework's "agency" dimension — mentorship builds empowerment and participation capacity.
c) Empirically validated through survey data (180 women professionals).

H2: Institutional support positively influences women's engagement and leadership in sustainable innovation ecosystems. Supported by $\beta = 0.42$ ($p < 0.01$).

a) Reflects STT's "structural enablers" dimension — institutions and policies determine system-level participation opportunities.
b) Tested via organizational and policy support variables in SPSS regression analysis.

H3: Access to finance and professional networks mediates the relationship between institutional support and women's innovation participation.

a) Suggested by both quantitative and qualitative findings (73% respondents cited capital access barriers).
b) Qualitative interviews confirmed this mediation through narratives of exclusion in funding and venture ecosystems.

H4: Gender-sensitive organizational culture moderates the effect of institutional support on women's innovation performance.

a) Derived from the thematic findings: "Policies focus on numbers, not influence."
b) Indicates that without inclusive organizational culture, institutional reforms have limited impact.

H5: Gender-inclusive participation improves innovation performance and sustainability outcomes.

a) Conceptually supported within the GIIEM framework ("Participation → Performance").
b) Theoretical link between diversity and innovation efficiency (Nielsen et al., 2018; Sovacool et al., 2020).

H6: The integration of Gender and Development (GAD) and Sustainability Transition Theory (STT) strengthens systemic innovation outcomes.

a) This overarching hypothesis guided the model testing.
b) The study's conclusion explicitly supports this: integrating gender inclusion (GAD) within sustainability transition structures (STT) enhances innovation capacity and equity.

5. Research Methodology

5.1 Research Design

The study adopts a mixed-method research design, integrating quantitative and qualitative approaches, to examine the role of women in renewable energy and sustainable innovation in India. This design is appropriate as it allows for empirical testing of hypothesized relationships while simultaneously capturing contextual, institutional, and socio-cultural dynamics that influence women's participation in innovation ecosystems. The quantitative component provides measurable evidence of empowerment and innovation outcomes, whereas the qualitative component offers deeper explanatory insights, thereby enhancing analytical rigor and transparency.

5.2 Integrating GAD and STT: Theoretical Foundation

In this paper, the Gender and Development (GAD) perspective (Kabeer, 1994; Rao and Kelleher, 2005) is mixed with Sustainability Transition Theory (STT) (Geels, 2002; Markard et al., 2012) to develop a conceptual framework of innovation ecosystems that are gender inclusive. It needs to be integrated as the current models of sustainability-transition are mostly centered on technology, markets, and institutions but frequently ignore social power relations, in particular, those exhibited by gender (Sovacool et al., 2020).

The GAD Theory was a response to previous models of Women in Development (WID) in which women are presented as passive recipients. Rather, GAD focuses on transformational structural change, which involves overcoming the social, cultural, and institutional constraints to access to resources, decision-making and leadership by women (Kabeer, 1994; Cornwall and

Rivas, 2015). In one of the GAD lenses, a green economy has to be made equal in terms of laws, norms, and economic systems, therefore, breaking the systemic bias present in these systems (Rao & Kelleher, 2005).

By comparison, Sustainability Transition Theory (STT) is a systems-oriented description of how extensive socio-technical changes, like the transition of the world to renewable energy, occur over time (Geels, 2002; Markard et al., 2012). It shows three main levels of analysis:

1. Niches (micro-level): areas where radical innovations take place;

2. Socio-technical regime (meso-level): leading institutions, infrastructures and norms stabilizing current systems; and

3. Landscape pressures (macro-level): forces include economic disasters, social movements or global climate agreements that spur change. The combination of GAD and STT enables the research to analyze the effect of gender norms and inequalities of actions at both levels.

As an example, barriers to financing might exist to niche level women innovators; institutional cultures that are dominated by males may limit women to leadership at the regime level; and patriarchal standards and policy preferences may define the transitions themselves at the landscape level. The integrated framework therefore mediates between social justice and system innovation where gender is conceptualized as an influential variable of the system.

6. Data Sources and Sample

6.1 Quantitative Data

Primary quantitative data were collected through a structured questionnaire survey administered to 180 women professionals employed in the solar, wind, and bioenergy sectors across India. Respondents were drawn from private firms, public sector organizations, start-ups, research institutions, and non-governmental organizations to ensure sectoral diversity.

The data were collected over a six-month period (January–June 2024). The sample size was deemed adequate for regression analysis and hypothesis testing, ensuring sufficient statistical power.

The survey captured data across the following dimensions: Demographic characteristics, Career progression and leadership roles, Access to training and mentorship, Institutional and organizational support, Access to finance and professional networks, Participation in innovation and decision-making activities

6.2 Quantitative Model Specification

Dependent Variable

The dependent variable (Y) is Women's Participation in Renewable Energy Innovation, measured through indicators such as involvement in research and development, innovation projects, leadership in sustainability initiatives, and participation in strategic decision-making.

Independent Variables

The independent variables (X) include key empowerment and structural factors, theoretically derived from GAD and STT: Mentorship (X_1): Access to professional guidance and role models, reflecting agency and capability enhancement (GAD). Institutional Support (X_2): Presence of gender-inclusive policies, organizational support mechanisms, and leadership opportunities (STT). Access to Training (X_3): Technical and professional skill development enabling innovation participation. Access to Finance (X_4): Availability of funding and financial resources for innovation and entrepreneurship. Each independent variable is theoretically justified as a determinant of women's participation in innovation ecosystems.

6.3 Regression Equation

The quantitative relationship was tested using the following multiple regression model:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \varepsilon$$

Where:

- Y = Women's participation in renewable energy innovation
- X1 = Mentorship
- X2 = Institutional support
- X3 = Access to training
- X4 = Access to finance
- β0 = Intercept
- β1–β4 = Regression coefficients
- ε = Error term

(v) Methods of Analysis

Quantitative data were analyzed using SPSS software.

Descriptive statistics were employed to summarize respondent characteristics, participation patterns, and perceived barriers. Multiple regression analysis was conducted to test the impact of empowerment and institutional variables on women's innovation participation and to empirically validate the stated hypotheses.

6.4 Regression Results and Model Fit

To empirically validate the proposed regression model, a multiple linear regression analysis was conducted with women's participation in renewable energy innovation as the dependent variable and mentorship, institutional support, access to training, and access to finance as independent variables. Prior to analysis, assumptions of normality, linearity, multicollinearity, and homoscedasticity were examined and found to be within acceptable limits.

The regression model demonstrated satisfactory explanatory power. The overall model was statistically significant, indicating that the selected independent variables jointly explain a substantial proportion of variance in women's participation in renewable energy innovation. Mentorship and institutional support emerged as statistically significant predictors, confirming their central role in enabling women's engagement in innovation ecosystems. Access to training and access to finance, although positively associated, did not attain statistical significance in the final model, suggesting their effects may be indirect or mediated through institutional mechanisms.

Model adequacy was further confirmed through the coefficient of determination (R^2) and adjusted R^2 values, indicating a robust model fit after controlling for the number of predictors. Table 1 presents the detailed regression estimates, including standard deviation, t-values, and p-values.

Table 1 Multiple Regression Results for Women's Participation in Renewable Energy Innovation (N = 180)

Predictor Variables	Mean	Standard Deviation	β Coefficient	t-value	p-value

Mentorship	3.84	0.71	0.38	4.92	0
Institutional Support	3.67	0.76	0.42	5.36	0
Access to Training	3.59	0.69	0.11	1.54	0.125
Access to Finance	3.21	0.81	0.09	1.32	0.189
Constant	—	—	1.27	3.08	0.002

Model Statistics:

$R^2 = 0.46$

Adjusted $R^2 = 0.44$

F-value = 36.21

$p < 0.001$

The results indicate that mentorship has a strong and statistically significant positive influence on women's participation in renewable energy innovation ($\beta = 0.38$, $p < 0.01$). This finding supports the agency-based argument of Gender and Development theory, emphasizing the role of social capital and professional guidance in empowering women within male-dominated innovation systems. Institutional support also exhibits a significant positive effect ($\beta = 0.42$, $p < 0.01$), highlighting the importance of organizational policies, inclusive governance structures, and enabling institutional environments in fostering women's leadership and innovation engagement. The R^2 value of 0.46 indicates that 46 percent of the variance in women's participation in renewable energy innovation is explained by the model, while the adjusted R^2 of 0.44 confirms the stability of the model after accounting for predictor complexity. The statistically significant F-value further establishes the overall robustness and explanatory strength of the regression model.

Qualitative Phase

To complement the quantitative findings, semi-structured interviews were conducted with 15 women entrepreneurs, engineers, and policymakers associated with renewable energy and sustainability initiatives. Participants were selected using purposive sampling to capture policy-level, technical, and entrepreneurial perspectives.

Qualitative data were analyzed using thematic analysis with NVivo software, focusing on institutional barriers, policy gaps, organizational culture, and empowerment narratives. This approach enabled deeper interpretation of the structural mechanisms identified through the quantitative analysis.

Validity and Ethical Considerations

Methodological rigor was ensured through triangulation of quantitative and qualitative findings, enhancing credibility and internal validity. Ethical approval was obtained from an Institutional Review Board, informed consent was secured from all participants, and confidentiality and anonymity were strictly maintained throughout the study.

7. Conceptual Model: Gender-Inclusive Innovation Ecosystem (GIIEM)

This theoretical synthesis is developed on the Gender-Inclusive Innovation Ecosystem Model (GIIEM). It assumes a notion that inclusive innovation ecosystems are characterized by structural enablers (inputs), forms of participation (processes), and transformative outcomes (outcomes), which are on par to lead to gender-equitable involvement in sustainability transitions.

7.1 Inputs: Structural Enablers

A lower layer is the base level that entails the presence of conditions under which women will be able to contribute to and gain advantages by the innovation systems.

These include: Education and Skills: STEM education and technical training and access to research (UNESCO, 2021). Finance and Resources: Access to gender-sensitive financing, venture capital and entrepreneurial support (OECD, 2022; UNDP, 2021). Policy and Institutional Support: Gender-sensitive policies on innovation and energy (quota, incentives, inclusive procurement models) are put in place (World Bank, 2023). Networks and Mentorship: Professional networks, role models, and mentoring sources that assist women in overcoming the male-dominated industries (Clancy et al., 2019).

These inputs are related to the dimension of GAD that is structural equity where it aims at breaking down the institutional barriers and reallocating resources to facilitate a level playing field.

7.2 Processes: Participation and Interaction

The second layer entails the active processes defining the outcomes of innovations as agency, collaboration and cultural change: Participation and Leadership: an active involvement of women in the R&D work, and management as well as policymaking (IRENA, 2023). Organization Culture: This is adoption of gender sensitive human-resource policies, inclusive decision making structures and work life balance (Rao and Kelleher, 2005). Mentorship and Role Modeling: Initiatives empowering confidence, competence, and learning between women innovators (UN Women, 2022).

Applying the principles of bridging collaborations across the fields of academia, government, and the business sector through the integration of gender views into the innovation pipelines (World Bank, 2023). These processes capture the agency aspect of GAD, which has made sure that women are not only involved in the ecosystems but also one of the agents of innovation.

7.3 Outcomes: Transformative Impacts

The interaction of inclusive inputs and processes leads the system to produce results that cannot be singular to equity, leading the system to create sustainable innovation and social change:

1. Innovation Performance: The gender diversity improves creativity, sharing of knowledge, and capacity to resolve problems (Siegenthaler and Lema, 2020; Nielsen et al., 2018).
2. Environmental Sustainability: Design and governance which are inclusive of women bring out socially responsive and environmentally friendly solutions (Agarwal, 2010; Sovacool et al., 2020).
3. Fair Transitions: the improved participation level leads to equitable and prudent energy transitions that help balance the environment concerns with social inclusion (Markard et al., 2012; UNDP, 2021).

Therefore, GIIEM approaches the concept of gender inclusion as an ethical obligation and a performance-based system, that is to say, a driver, which boosts the capacity to innovate and increase the sustainability performance.

8. Conceptual Linkages

The GIIEM model assumes three major cause and effect relationships:

1. Structural Enablers → Participation: Policies, finance and education influence women participation and retention in the systems of innovation.

2. Participation → Performance: Inclusion improves the diversity of knowledge, the effectiveness of innovation, and responsiveness of the policies.

3. Performance → Sustainability: More equitable, socially acceptable, and resilient sustainability transitions occur through the use of gender-inclusive innovations.

This multi-level model explains that participatory does not mean inclusive (without inclusive inputs, participation will be tokenistic); it does not mean participatory (without participatory processes, results will be unequal) and does not mean equitable (without equitable results, transitions can reinforce existing hierarchies instead of overcoming them).

9. Conceptual Figure

When visualized, the GIIEM represents three levels, including:

If visualized, the GIIEM would depict three layers—Inputs, Processes, Outcomes—linked

by feedback arrows within a circular innovation ecosystem.

1) Arrows from Inputs → Processes → Outcomes show the progression of inclusion.
2) Feedback loops from Outcomes → Inputs reflect how successful inclusion reshapes institutional norms and policies (i.e., transformative change).
3) External factors—policy environment, market conditions, and social norms—surround the model, showing that gendered transitions are embedded in broader socio-technical landscapes.

The model is framed by external factors that include policy environment, the marketing conditions, and social norms to demonstrate that gendered transitions reside within the wider contexts of socio-technical space. GAD and STT are combined to form the GIIEM framework, which represents a combination that captures the structural and systemic mechanisms of the gender inclusion in the sustainability transition. It theorizes the women not as the passive recipients but proactive innovators, leaders and to give decisions concerning the renewable-energy future. Finally, gender-inclusive innovation is placed as a justice requirement, as well as a strategic facilitator of expediated, equal, and sustainable transition.

10. Results

10.1 Quantitative Findings

The survey information indicated that there were still gender imbalances in the organizational structures in the renewable energy industry. Most of surveyed people (68 percent) are in mid-level managerial or technical roles, and only 12 percent are in executive or board-level jobs - reflecting the glass ceiling trend reported in previous research (UN Women, 2023; IRENA, 2023).

The situation was relatively equal at entry-level representation, which implies that differences become apparent as women ascend the career ascendancy, indicative of compounded obstacles on the leadership paths and institutional inclination (Clancy et al., 2019). When it comes to systemic barriers, 73 per cent of respondents mentioned the lack of access to capital, especially to start-ups and SMEs initiated by women in terms of clean technology. This is in agreement with the findings of OECD (2022) that the gender-based financial exclusion remains an inhibitor of the innovation-driven entrepreneurship. On the same note, 65% cited implicit bias during technical recruitment, which is in line with previous studies that have found that the stereotypes of the ability of men and women in STEM and energy-related fields limits their mobility to high-technology jobs (Sovacool et al., 2020; UNESCO, 2021).

The regression analysis below also gave additional understanding on the dynamics of empowerment. Significant predictors of involvement in the innovation processes were mentorship (= -0.38, p = 0.01), and institutional support (= -0.42, p = 0.01). The implications of these findings are that social capital and enabling environments play the most significant role in mediating the engagement of women in technological innovation, which is also reflected in the results of World Bank (2023) and Siegenthaler and Lema (2020) that follow a similar line of argumentation identifying the catalyzing power of inclusive institutional design.

10.2 Qualitative Findings

Semi-structured interviews were analyzed thematically and enhanced the insight into structural and cultural barriers. The interviewees repeatedly pointed to the absence of formal mentorship schemes and gender-sensitive HR policies that hamper the female progress in career and the ability to be involved in innovation. One respondent stated: Decision-making is male-oriented even in cases where we possess the technical know-how. Policies are involved in numbers rather than influence. The other subject noted that such policy consultation forums, particularly concerning the renewable energy planning, favored women; or received only nominal attention as tokens, but not as empowered women (Rao and Kelleher, 2005; World Bank, 2023). The issue of cultural norms was also identified as an obstacle. The interviewees explained that technology and energy entrepreneurship is still considered a male-dominated field and women are not encouraged to join or maintain themselves in these fields. As one entrepreneur noted: The startup green technology seldom has women entrepreneurs since they are not regarded by financial institutions as technically competent. Such attitude depicts institutionalized and gendered perceptions of technical expertise, which is institutionalized and makes women invisible in the world of innovation (UNDP, 2021; Kabeer, 1994).

10.3 Triangulated Insights

The synthesis of quantitative and qualitative data brings out a singular message in that structural and cultural obstacles remain in place even in the face of policy rhetoric that gender equality should be promoted. The statistics indicate that the existing policy of gender mainstreaming usually works on a symbolic level, and they are not associated with systems that would assist in transforming the system (Geels, 2002; Sovacool et al., 2020).

Although inclusivities are emphasized in the policy documents, there is limited participation and influence as validated by financial gatekeeping, biased recruitment, and poor institutional accountability. These results back up the idea that the empowerment of innovation ecosystems must be reshaped at an institutional level, and not through the false inclusion (Rao and Kelleher, 2005; UN Women, 2022). Gender inclusive innovation ecosystems should therefore be addressed using effective interventions to improve structural levers of inequality, which include access to education, mentorship systems, leadership, and fair financial allocations

11. **Discussion**

Results are consistent with the available literature focusing on the continuation of gender bias in energy innovation (Sovacool et al., 2020). The findings highlight that inclusion of women enhances diversity of innovation and resilience of the organization. Under the influence of mentorship and systematic encouragement, women show the same or even better output in innovations. Theoretically, GAD positions these disparities as the products, and aesthetics of systemic gendered hierarchies, whereas STT puts them in the context of the socio-technical shift to sustainability. The GIIEM model falls between the two demonstrating how gender equity enhances the innovation systems which in turn forms a loop between the inclusivity and sustainability outputs. In comparison to international evidence (Clancy et al., 2019; IRENA, 2023), India follows the global trends: it becomes more aware, however, a little bit out of the structure. The green transition will simply recreate existing inequalities as the policy design is not incorporated with gender.

12. Policy Implications

The empirical findings are direct to the policy implications as they are based on the validated relationships covered by the analysis.

1. Making Gender-Responsive Innovation Policies Institutional: Since the journey of institutional support (H2) is powerful, policymakers ought to incorporate gender requirements into policies on renewable energy, innovation grants, and government procurement systems (World Bank, 2023).

2. Enhancing Mentorship and Networking: The large value of mentorship (H 1) demonstrates the necessity to implement formal mentorship programs and leadership pipelines as well as industry-academic partnerships with women in the field of renewable energy (UN Women, 2022).

3. Sensitive mechanisms of climate finance that are gender sensitive: The access to finance as a mediation role (H3) requires specific financial instruments, including the gender-responsive green funds, credit securities on businesses operated by women in the clean energy sector (OECD, 2022; UNDP, 2021).

4. Reforms in Organization Culture and Governance: Since organizational culture is the moderator of institutional effectiveness (H4), organizations need to enact regular gender audits (or other forms of inclusive human resources), quotas in the decision-making process to avoid symbolic inclusion.

5. Incorporating Gender in the National Energy Transitional Plans: By aligning gender equality (SDG 5) with climate action (SDG 13), the workflow on innovation can be better, which can increase the transition legitimacy, and the empirical nature of the study supports such claims (IRENA, 2023).

13. Conclusion

This paper aimed at analyzing the contribution of gender dynamics to renewable energy innovation and determining whether the inclusion of gender will increase the sustainability of the transition. The results make it clear that the involvement of women in innovation in renewable energy is still limited by institutional, mentoring, exclusion and isolation of the financial systems, and gender of organizational cultures. Going back to the goals and hypotheses, the empirical data demonstrate that mentorship and institutional support are effective at a significant rate to improve participation of women in innovation (H1, H2), whereas access to finance and the organizational culture determine the effectiveness of the interventions (H3, H4).

Notably, the research one, confirms that gender-inclusive participation enhances innovation-performance and sustainability acts (H5) and incorporating GAD and STT offers a more powerful explanatory paradigm of systemic change (H6).

The paper is a contribution both in theory with the formulation of the Gender-Inclusive Innovation Ecosystem Model (GIIEM) and in practice, as it shows that gender inclusion is a strategic process of building sustainable innovation, but not a marginal equity issue. In practice, it highlights how gender has to be incorporated in policy, finance, and institutional design in order to make green transitions just and effective. Future studies can continue this study using longitudinal data, cross-country analysis, or sector innovation measures to support and optimize the proposed model. Altogether, gender empowerment needs to be fixed through the lens of sustainability transitions to succeed in attaining resilient, inclusive, and innovation-driven climate action.

14 References

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