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TOPICAL REVIEW

Gender vulnerabilities in low carbon energy transitions: a conceptual review

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Abstract

Low carbon energy transitions are of paramount importance to achieve climate goals. These transitions are not only technical and economical, but also deeply social and gendered. In this paper, we reviewed the academic literature to understand: firstly, what gender vulnerabilities have been discussed in the literature and how they have been embedded in structural dynamics. Secondly, what socio-cultural and socio-economic drivers may lead to these gendered vulnerabilities? Based on content analysis, four key themes emerged from this literature survey: *land use change, gender-neutral energy policies, access to resources*, and *green practices, gender, and culture*. These four themes indicate that there are several enabling mechanisms arising from social and structural inequalities, indicative that vulnerabilities ought not to be considered in isolation, but in relationship with others. We also explored dimensions of vulnerability (exposure, sensitivity, adaptative capacity) based on Carley *et al* (2018 *Nat. Energy* **3** 621–7) to contextualise components of vulnerability in relation to gender. The main finding suggests considering further intersectional approaches to low carbon energy transitions, emphasising acknowledging, and lessening societal inequalities.

1. Introduction

Low carbon energy transitions are an essential aspect of carbon mitigation commitments, as noted in the Paris Agreement and supported by the Sustainable Development Goals (especially SDG 5 and 7) (Nick 2003). These low carbon energy transitions could risk marginalising those whose livelihoods and lands are compromised—making it crucial to identify and explore risk factors to alleviate potential vulnerabilities in order to achieve a just energy transition (Sovacool 2021, Tsagkari 2022). Until recently, energy transitions research has expanded into multiple contemporary dimensions, such as techno-economic feasibility (Das *et al* 2018, Bhat *et al* 2019), integration of low carbon technologies (Raven *et al* 2016), developing value chains and business models (Richter 2012), yet neglecting dimensions such as gender and social inequalities (Farla *et al* 2012, Geels *et al* 2017, Chlebna and Mattes 2019). It is therefore necessary to establish which economic sectors, socio-demographic groups, and regions may be most at risk for marginalising vulnerable communities and individuals (Williams and Doyon 2019). More recent low carbon energy transitions literature has begun to consider gender vulnerabilities as a part of their research, indicating that in the past decade academics and practitioners have begun to seriously consider energy transitions as inherently gendered (Fernández-Baldor *et al* 2014, Fernández-Baldor *et al* 2015, Lazoroska *et al* 2021, Tsagkari 2022). This paper draws on recent literature on low carbon energy transitions to identify the gender vulnerabilities that could emerge or are already emerging during the energy transition process.

Most low carbon energy transition (LCET) literature is focused on technological and economic feasibility of energy projects, with gender only recently becoming a category of analysis (Johnson *et al* 2020). However, the literature is now considering

how LCETs impact infrastructures, such as biomass plants and the building of new hydropower plants. Especially in the Global South, local landscapes change to accommodate large-scale energy projects, engendering social inequalities and women's access to resources. Scholars generally overlook gender dimensions in local case studies of new energy systems concerning electricity generation and land-use for transportation biofuels, which exposes new and existing vulnerabilities (Sovacool *et al* 2015, Lieu *et al* 2020). Policy and social inequality studies conclude that there is a noticeable lack of gender representation in the workforce and decision-making concerning low carbon energy projects development and implementation (Boyd 2002, Lieu *et al* 2020, Mang-Benza 2021). Our analysis therefore focuses on considering the potential future of LCETs and its effects on gender vulnerabilities from a system-level perspective. System change is the emergence of new patterns of organisational and system structures (UNDP 2022). We acknowledge the relevance of climate change studies to discerning present-day vulnerabilities (Terry 2009, Djoudi *et al* 2016) and the complex linkages between energy and gender (IRENA 2019, Pueyo and Maestre 2019, Feenstra 2021). This content analysis is concerned with identifying vulnerabilities from when a future transition occurs and what types of gendered vulnerabilities may be revealed from these transitions. Despite the rising amounts of gender analysis in energy, climate change, and energy transitions studies (Pearl-Martinez and Stephens 2016, Clancy and Feenstra 2019), literature on gender and low carbon energy transitions relating to electricity generation, biofuel production, and green policies are currently gaining more scholarly attention, making it a fruitful point of analysis (Johnson *et al* 2020).

In this study, we examine how gender vulnerabilities are analysed in low carbon energy transition literature. An initial 8155 articles were identified, after removing non-peer reviewed articles and initial screening of titles and abstract, articles were selected for the detailed review. We found no papers exist which review literature on gender vulnerabilities and low carbon energy transitions. As stated by (Fernández-Baldor *et al* 2015, Hill *et al* 2017, Ahlborg 2017), there is little emphasis on the formal gender assessment and inclusion of gender-based analysis of how low carbon energy projects and solutions might consider existing injustices and how such vulnerabilities manifest into future potential risks. Our review argues that there is a need to conduct gender-based analysis alongside environmental and social assessments when low carbon energy projects are planned and implemented.

The article is structured in the following manner: section 2 provides definitions for the terminology used throughout the review, section 3 discusses the methodology used to review the literature and research objectives. Section 4 discusses the gendered vulnerabilities observed in literature and their future implications for gender in low carbon energy transitions. Section 5 concludes the review with potential future directions of further studies.

2. Definitions

This conceptual literature review aligns itself with theories on gender and vulnerability, utilising definitions of *vulnerability* and *gender* found in gender and climate change studies. In the sections below, we define the terminology present throughout the review.

2.1. Vulnerability

Vulnerability as a term has numerous definitions dependent upon disciplinary context (Brooks 2003). Within climate change studies, it is used to describe and define different groups negatively impacted by environmental degradation (Brooks 2003). This study utilises the definition of vulnerability according to the Intergovernmental Panel on Climate Change (IPCC). It defines vulnerability as 'the propensity or predisposition to be adversely affected' which 'encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt' (Field *et al* 2014). We utilise Carley *et al*'s (2018) vulnerability assessment framework to assess low carbon energy transition vulnerabilities in relation to gender. They (Carley *et al* 2018) define vulnerability in relation to policy exposure, in this case the IPCC, as 'where and when these policies go into effect (*exposure*); the susceptibility of different communities to the impacts of these policies (*sensitivity*); and the capability of communities to attenuate, cope with or mitigate the negative effects (*adaptive capacity*)'. As the literature surveyed in this paper is not solely based on policies, we expand this definition to include case studies.

2.2. Gender

By *gender* we imply socially constructed differences that translate into inequalities and hierarchies traditionally performed by women and men, whilst acknowledging that gender is a multifaceted and complex term (Johnson *et al* 2019). More recent conceptualizations in the scientific literature fundamentally integrate the wider notion of social equity, which captures the intersectional nature of gender (Stienstra *et al* 2016, Robinson 2019). In our article, we consider the term 'gender vulnerabilities' as encompassing the IPCC definition of vulnerability with an additional emphasis on gender.

2.3. Gender vulnerability

Enarson (2012) argues that 'as a primary factor of social organisation, gender shapes the social worlds within which disaster occur', making gender a vital category of analysis also in low carbon energy transitions. In climate change literature, it is well understood that adverse impacts of climate change disproportionally affect different genders according to their respective vulnerability and adaptive capacity (Freedman 2019). Hence, gender vulnerability is understood as 'the characteristics of a women and men and their situation influencing their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard' (Reid *et al* 2012, McGann *et al* 2016). Climate change is inherently related to disaster risks and risk assessment, as disasters reflect the social divisions which already exist in society. Low carbon energy transitions, which will be impacted by continued and worsened climate change, will need to ensure that the social divisions already existing are not worsened.

3. Literature review methodology

Content analysis is a research method used to identify patterns, themes, and trends in the content and to make inferences by systematically identifying the attributes of the content (Neuendorf 2016, Fell 2017). This method involves coding and categorizing the content, and then using statistical techniques to analyse the results by paying attention to objectivity, reliability, and replicability. (Fell 2017) provides an example by applying it in context of energy services. The sub-sections further provide the details on literature collection for this study, inclusion and exclusion criteria, and some quantitative details of the content.

3.1. Research objectives and search strategy

We conducted a conceptual review that seeks to synthesise the scientific knowledge that can help us better comprehend the essential concepts and arguments. Our research objectives are two-fold: first, how do different articles discuss gender vulnerabilities and, secondly, what types of evidence is utilised to identify gender vulnerabilities related to low-carbon energy transitions. To fulfil these objectives, a search of the literature was conducted in July and in October 2021 using the Scopus database. We also performed searches in December 2022 on Scopus for the years 2021–22 with the same search string. We developed a search string with 'OR' and 'AND' operators. The search string was the combination of the terms (1) low carbon energy transitions (2) gender and (3) vulnerabilities. We aimed for specificity in our searches, aiming to exclude terms not relevant for our focus. For example, we combined 'solar' with 'power', 'photovoltaics', 'PV', 'concentrated' (as in concentrated solar power), 'home system', and 'industry'; to ensure that our searches do not include the related topics outside our research scope. Moreover, we added different qualifiers—such as 'group', 'people,' and 'community', to make our search more inclusive around gender equity issues. Further searches were performed with Scopus were limited to the English-language literature. Table 1 shows the search strings used for the literature review. Additional searches were undertaken to include the terms that were not included in initial search. These terms include green practices, energy justice, injustices, and inequalities.

3.2. Initial screening and eligibility criteria

All the articles gathered in the systemic search were screened for eligibility with title and abstracts, and finally the full text was screened with predefined eligibility criteria (section 3.2.1). The screening was done by the researcher and no software was used. Articles screened on title and abstract are listed in additional file 1. Gender vulnerabilities related to low carbon energy technologies were considered in terms of their influence on education, health, employment, poverty, social and economic class, poverty land ownership, access to resources and markets, which consist of all the major dimensions found in the article screening process.

To analyse the articles selected for review after full text screening, basic information was extracted from each article and put into a coding framework. We utilised content analysis to quantitatively categorize the articles to understand which themes were most frequently occurring. Structured analysis approach was undertaken because we wanted to search for topics which were not the main themes of the papers. Characteristic details of the papers, geographical location, type of energy technology/source or policy and type of impact were assembled in an excel sheet (additional file 2). Figure 1 shows the screening and selection process of articles found in searches. Initially, there were 8155 articles after the searches. After the exclusion of non-peer reviewed and non-English articles, 5401 articles were left. After an initial screening of titles, keywords and abstract, 147 (additional file 1) articles were shortlisted for detailed full-text screening. After full-text screening 65 (additional file 2) articles were selected for review. Articles were shortlisted based on predefined criteria (section 2.2).

3.2.1. Inclusion and exclusion criteria

During the screening of the papers, we used the following exclusion and inclusion criteria to decide which papers fit our search criteria (see figure 1).

Inclusion criteria: (1) Studies of use/adaptation/management of low carbon energy transitions; (2) topics which had an explicit link to gender, vulnerabilities, and new energy systems; (3) only peer-reviewed literature was selected. (4) No restriction regarding country, area, and date of publication.

Exclusion criteria: (1) We filtered out the studies whose primary and/or secondary focus was not

Table 1. Search string.

Database	Date	Search strings
Scopus (title, keywords, abstract) (advance document search option was used)	July and October 2021	((("sustainable energy" OR "low carbon" OR renewable*)) AND ((development OR energy OR power OR electricity OR generation OR industry)) OR ((solar* AND (power OR photovoltaics OR pv OR concentrated OR "home system*" OR industry))) OR ((wind* AND (power OR electricity OR turbine* OR industry))) OR ((geothermal AND (power OR electricity OR industry))) OR (hydropower*) OR ((biomass AND energy) OR bioenergy OR biofuel* OR agrofuel* OR "mini grid*") OR ((geothermal AND (power OR electricity OR industry)))) AND ((transit* OR transform* OR change* OR shift* OR pathway* OR polic* OR strateg*)) AND (("social impact*" OR "social outcome*" OR "socioeconomic* OR vulnerability")) AND ((gender* OR women* OR men OR girl* OR boy*))
Additional searches Scopus (title, keyword, abstract)		(Gender AND just AND energy AND transitions) (Gender AND renewable AND energy inequalities) (Gender AND low AND carbon AND energy AND energy AND justice AND vulnerab*) (Gender AND vulnerab* AND low AND carbon AND transitions)

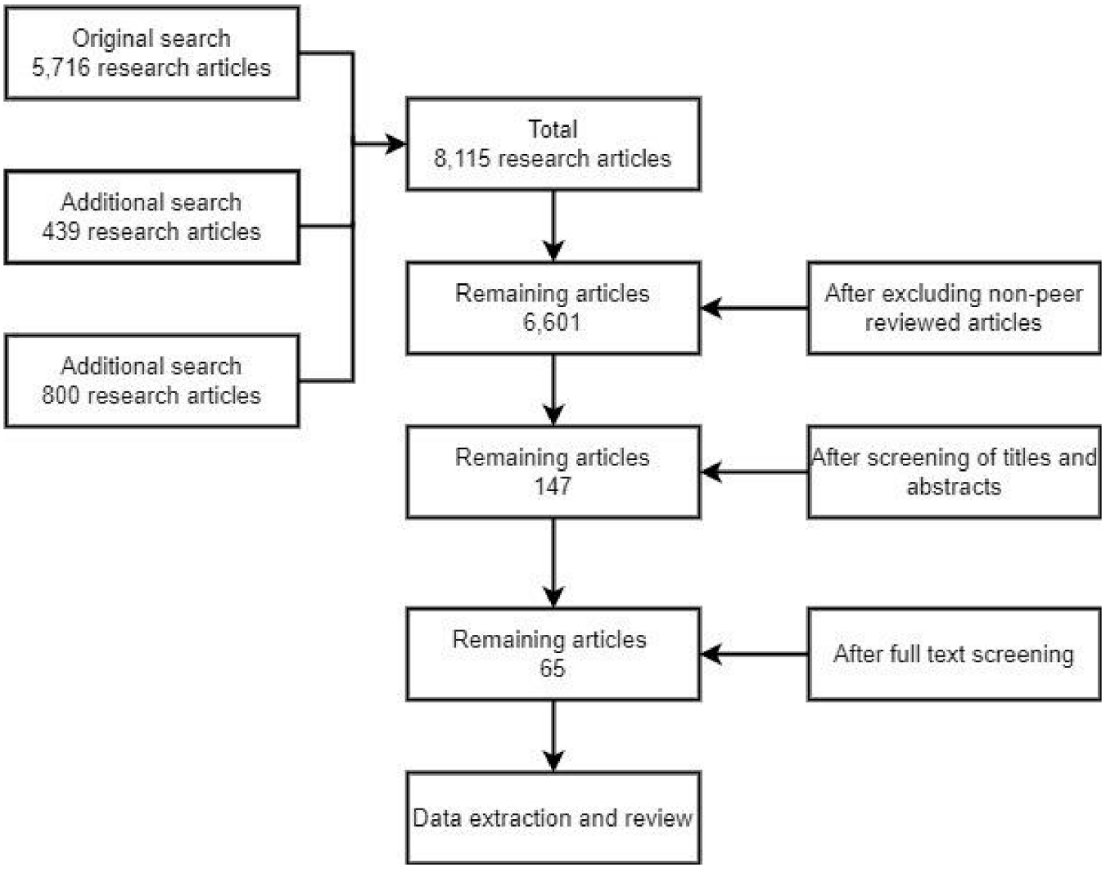

Figure 1. Flow chart diagram of process of articles shortlisting.

the relation between gender and low carbon energy transitions; (2) gendered and non-gendered positive impacts of technology implementation were not analysed as review is focused on vulnerabilities of low carbon transitions; (3) hypothetical studies (computer simulations and modelling studies) and literature reviews were not included as the review is focusing on current and future large-scale energy projects and policies. Focus of this study is to map gendered vulnerabilities emerging from development of structure of low carbon transitions that lacks in modelling studies; (4) studies on the willingness and attitude towards low carbon energy transitions were excluded as they are tangential to system-level studies; (5) studies focusing on technical performance were not included. (6) Non-English-language publications were excluded.

Figure 1 shows the screening process and the numbers of articles at every stage of screening. It should be noted that only 0.8% of the total articles were selected for the full-text review. Papers related to climate change, ecosystem management, and health and food safety appeared in the search terms in large quantities because of their close connection with low-carbon transition themes. Cooking was also a prominent theme, found in 7% of articles surveyed, indicating that this is an important research area in gender and energy research. These papers were excluded from review since they did not focus on vulnerabilities pertaining to LCETs on a system level. Non-peer reviewer literature contains books, book chapters, editorials, letters, conference papers. This literature was mostly related to climate change, environmental sustainability, environmental management, environmental justice, livelihood, and poverty.

3.3. Limitations

It is important to acknowledge the limitations of the approach adopted in this review. Although it was anticipated that the search sample would include a wide range of energy studies, it is not claimed to be representative. Additionally, since all of the searching and screening was done by the first author, it is possible that certain cases were overlooked that another researcher would have identified or interpreted differently. However, given that the shortlisting and screening process in this instance consisted mostly of recording individual words and phrases, very little subjective interpretation was necessary, and it is therefore unlikely that this factor had a significant impact on the conclusions drawn.

Furthermore, it is probable that some works that engage profoundly with the idea of gender vulnerabilities (for example, cookstoves technologies) been excluded from this study since the search terms are more focused on the electricity and systematic level change. We acknowledge that the gender aspects of the clean cooking technologies are so profound and already been studied at an extensive level (Kshirsagar and Kalamkar 2014, Urmee and Gyamfi 2014). Other limitations of this review is the exclusion of grey literature and multiple databases (Dave Singh *et al* 2021). There are several publications on gender and low-carbon transitions in the grey literature, such as reports from non-governmental and international organizations, policy briefs, and position papers from governments. The majority of this work reflects normative methods to gender mainstreaming in energy policy from non-governmental organizations (NGOs) and financial bodies. To be able to critically evaluate and synthesize the main concepts and arguments in examined literature, however, we decided to focus for this review on peer-reviewed academic papers.

4. Results

4.1. Countries and areas

The 65 articles analyse 118 case studies in 48 different countries. In some articles (Behrman *et al* 2012, Terrapon-Pfaff *et al* 2018), there was no mention of a particular country but the geographical areas, so it was not possible to geographically represent these articles with the country scale representation. The majority of the studies analysed the Asian region (15 articles; Terrapon-Pfaff *et al* 2014, Dharmawan *et al* 2020), Africa (15 articles) and North America (13 articles; Winther *et al* 2017, Sovacool *et al* 2020) while 13 articles are related to countries from Global North (Chalifour 2010, Lieu *et al* 2020). Almost all the case studies analysed rural areas with few exceptions (see for example, (Axon and Morrissey 2020, Lieu *et al* 2020, Lazoroska *et al* 2021)).

4.1.1. Energy sources frequency

Figure 2(a) shows the percentage of studies that discussed various LCETs within the literature. Solar energy technologies (PV, thermal, lighting, cooking, and heating) received the most attention with approximately 35% of the literature, followed by biofuels with 34%, and hydropower with approximately 17% of the literature coverage. Increasing land use area for biofuel and hydropower is vital for transitioning to low carbon energy, but the potential impact of other renewable energy (RE) technologies on land use (solar, wind, hydro) remains under-explored. Small-scale decentralised solar energy project case studies are predominantly featured in the articles because solar home system mini-grids and microgrids offer women critical roles in the selling and purchasing of these systems, which is reflected in the literature concerning rural electrification in the Global South (Gray *et al* 2019). Solar technologies are often cheap, small, and inexpensive to install for easy energy access in areas lacking nation grid access (Ulsrud *et al* 2011, Urpelainen 2014, Bhattacharyya *et al* 2019). Wind power projects received little to no attention (mentioned only in two articles (Turkovska *et al* 2021))

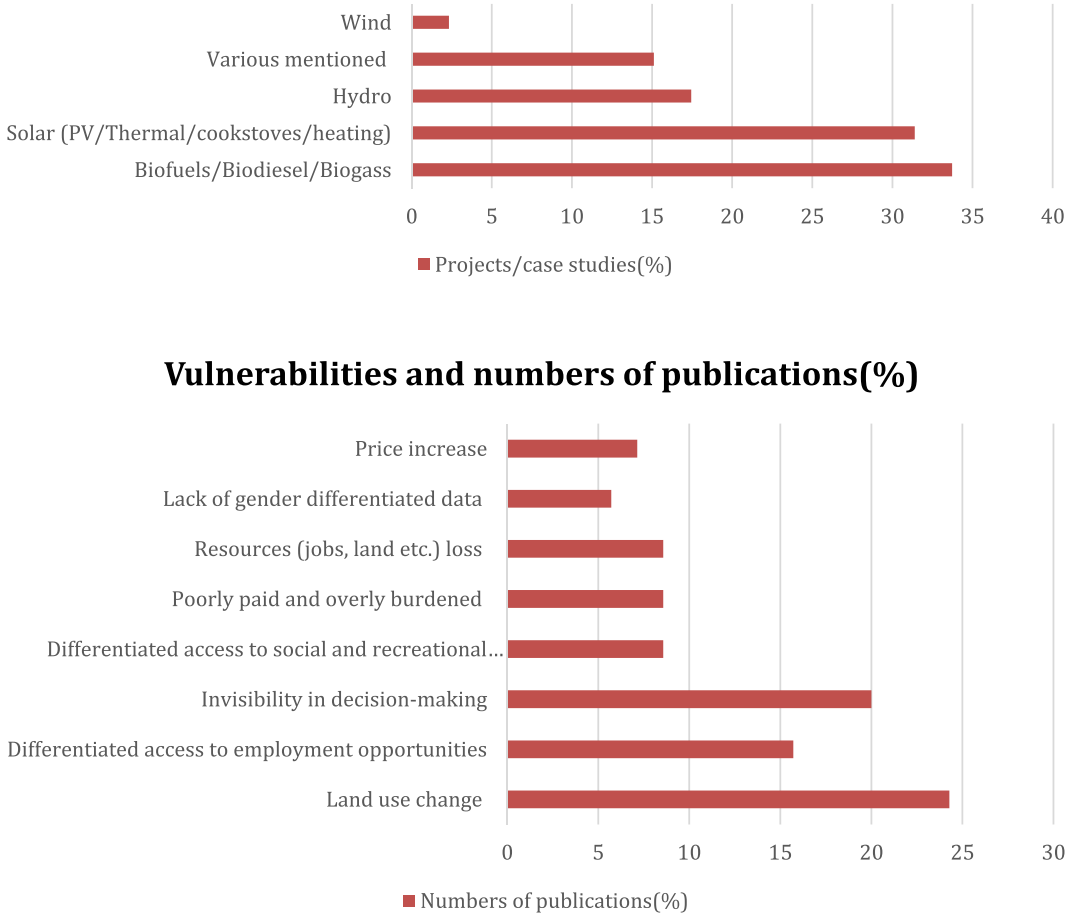

Figure 2. (a) **Technologies and case studies:** Number of case studies that examine each energy technology ('Various mentioned' = carbon taxes, green practice-based policies, electric transportation, household technologies) (b) **Vulnerabilities and number of publications:** Number of publications that address a particular gender vulnerability. (*Note:* percentages are mutually exclusive because one publication may deal with more than one vulnerability).

in review literature. One possible explanation could be the absence of gender analysis in studies related to wind, though the literature is emerging on social impacts of the wind farms (Mueller and Brooks 2020).

Figure 2(b) represents the vulnerabilities covered by the percentage of literature. Land use change related impacts are covered by more than 28% of the literature, whilst the social and economic exclusion and uneven distribution of employment opportunities are covered by more than 18% of the literature. Other negative impacts are job losses, overburden with domestic/household tasks, and price increases. Here, job losses refer to loss of income from the development of energy projects and employment opportunities refers to new opportunities emerge from implementation of low carbon energy projects.

4.2. Previous conceptual work

Main themes emerged from the content analysis of the literature are land, access, resources, practices, and policies in relation with energy and gender (see table 2). In order to categorize these different topics, we merged them in four main themes: *land use change, gender-neutral energy policies, access to resources*, and *green practices as gendered*. These four themes suggest that there are a number of enabling mechanisms arising from social and structural inequalities. This is indicative that vulnerabilities should to be considered not in isolation, but in relationship with others (see figure 3 and table 2). One of the main limitations of rendering the surveyed literature into categories is the overlapping nature of social and structural inequalities which are bolstered especially in the Global South. Pre-existing gender inequalities and social hierarchies may marginalise women's access to land and resources when new energy projects are begun (Gay-Antaki 2016, Tsagkari 2022). This may further exclude women from decision making processes, and this absence from creating carbon market policies and decision-making practices limits women's capacity to gain financial benefits from low carbon energy projects (Gay-Antaki 2016). On a holistic level, low carbon energy projects are predominantly employing men and male know-how, as Science, Technology, Engineering, and

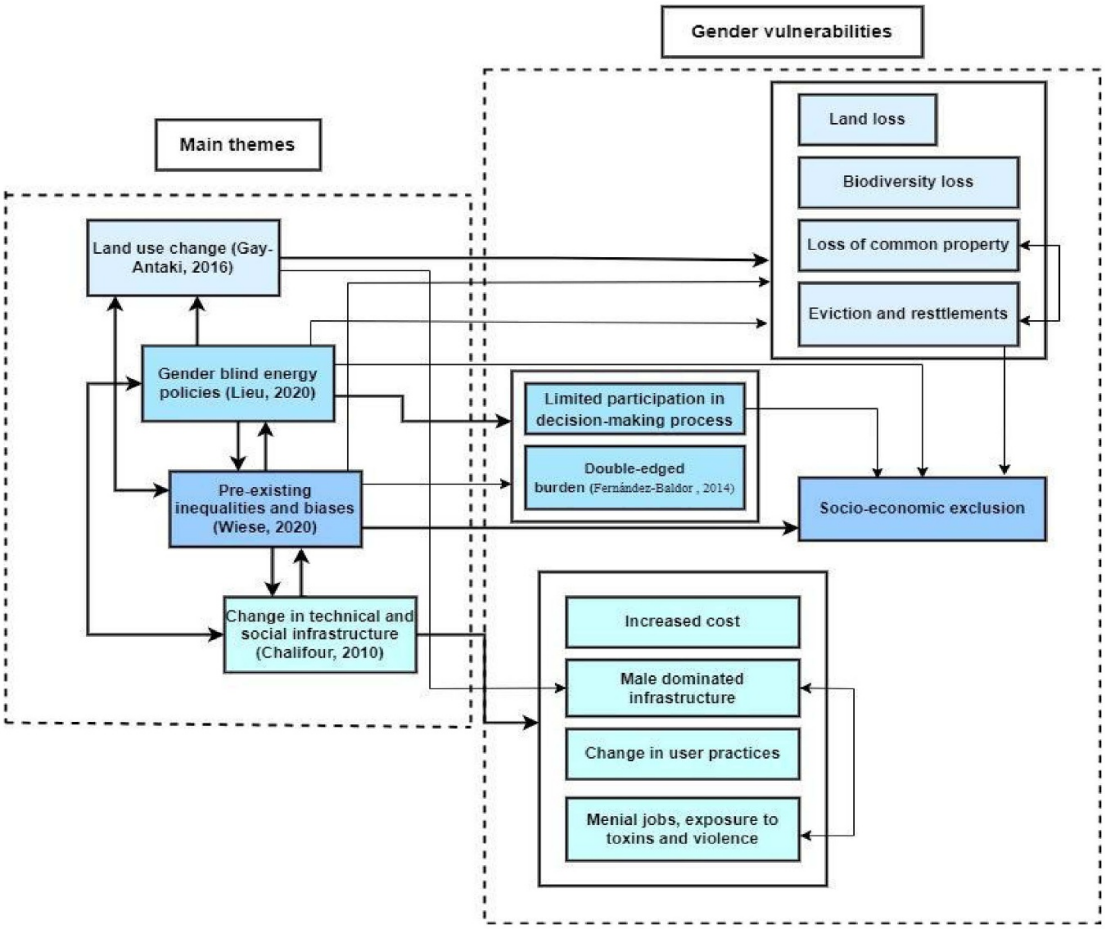

Figure 3. Main four themes colour-coded by theme and their projected gender vulnerabilities.

Mathematics (STEM) related energy sectors and industries continue to be deeply gendered spaces (Boyd 2002). The literature further highlights that energy project planning and execution has often weakened women's abilities to influence or participate in projects, as projects may reinforce existing unequal social hierarchies and reliance on men's technical know-how and skills (Boyd 2002, Lazoroska *et al* 2021, Shrestha *et al* 2021). It is important to consider not just the direct link of vulnerabilities to different enabling mechanisms, but also their complex mutual linkages and relationships. The next section highlights the mechanisms and context by which vulnerability risk factors are expected to arise during low carbon energy transitions.

4.2.1. Land endowment, resettlement, and low carbon energy transitions

Land use change emerged as the dominant topic in reviewed literature, where more than 27% of the reviewed literature concerned this impact. The surveyed literature focused mainly on the Global South, covering loss of land, migrations, and loss of livelihood (Dauvergne and Neville 2010, Hunsberger 2015, Selbmann and Ide 2015, Chigbu *et al* 2019, Bielig *et al* 2022). With the exception of a few papers (Fernández-Baldor *et al* 2014, Hill *et al* 2017, Ahlborg 2017), there was little emphasis on formal gender assessments and inclusion of gender-based analysis of how low carbon energy projects and solutions might consider existing energy injustices and future potential vulnerabilities.

The pattern observed in reviewed literature shows that policies, practices, and projects involving land use change and land deals tend to overlook the interests, rights, and demands of women. As a result, they not only aggravate the pre-existing gendered inequalities, but also limit the available resources, creating gender vulnerabilities (Liu *et al* 2011, Schoneveld *et al* 2011). A common strand in many papers is the focus on changes in forest spaces and common land loss, as these changes could impact men and women differently depending on the existing pattern of responsibilities and control (Corbera *et al* 2007, Dauvergne and Neville 2010, Behrman *et al* 2012, Obidzinski *et al* 2012, Yenneti *et al* 2016, Dharmawan *et al* 2020, Gebreyes *et al* 2020, Stock and Birkenholtz 2020). Some papers (Behrman *et al* 2012, Stock and Birkenholtz 2020) also focus on the differential gender impact of the land enclosure (enclosure of open land that prevents the common grazing and other activities) for low carbon energy

Table 2. Gendered vulnerabilities emerged from different studies and their relevance with the four themes.

Discussed low carbon scenario or outcome/ energy production method	Vulnerabilit(y/ies) emerging from studies	Categorisation of vulnerability	References
Tree plantation and conservation to reduce carbon dioxide levels in Bolivia.	Debate driven by men. Women have menial and low paid jobs. Minimum to no influence in decision making process. Women exclusion from project decision making, implementation and design process. Women reproductive work being used as subsidy. Blindness to gendered resource management.	Inequalities in decision making process. Access to resources and gender division of labour.	(Boyd 2002, Corbera, *et al* 2007, Gay-Antaki 2016)
Biomass plantation and expansion in different countries for biofuels (Indonesia, Ghana, Malaysia, Brazil, Mexico, Zambia, Mozambique, Tanzania).	Loss of available at: resources with the rise of monoculture plantation and forest conversion. Loss of land after resettlements. Exclusion of women from negotiation and consultation process while transferring the land rights during land acquisition process (land deals). Food insecurity (Women usually manage the household food supply). Gender differentiated ability to recover from losses. Changes in farming activities (decreased availability of land). Lower wage and worse working conditions for women. Plantations expansion accompanied by increase in commercial sex cafes. Food crops replaced by cash crops make women vulnerable to resources and land loss.	Access to resources. Land endowment and resettlements.	(Dauvergne and Neville 2010, Vermeulen and Cotula 2010, German *et al* 2011, Schoneveld *et al* 2011, Behrman *et al* 2012, Obidzinski *et al* 2012, Gasparatos *et al* 2013, Popp *et al* 2014, van Eijck *et al* 2014, Chigbu 2019, Dharmawan *et al* 2020)
Nuclear power in France, net metering policy in UK and solar power projects in Germany were developed to address climate change.	In all three cases single mothers were more affected by increase in price.	Green practices are gendered.	(Sovacool *et al* 2019)
Hydropower plant in Lao village and Hongjiang and Wanmipo hydropower stations in Chinawas built to produce clean power and electricity.	Decisions are more influenced by men. Loss of livelihood and resources. High cost of electricity and household's reduced access to land and food.	Land endowment and resettlements. Access to resources. (Land use change, Resettlements and displacements, Water regime change). Men also lost their jobs and forced to work as wage-labourer. Increase in work for women.	(Hill *et al* 2017, Weeratunge *et al* 2014, Gebreyes *et al* 2020, Zhao *et al* 2020)

(Continued.)

Table 2. (Continued.)

Dam construction to produce electricity with low carbon emissions.	Women were pushed to work outside the home because of economic situation but they also have to work at home because of societal norms of division of labour.	Access to resources and gendered division of labour. Land loss. Increase in work for women.	(Aiken and Leigh 2015, Castro-Diaz *et al* 2018, Shrestha *et al* 2019, Aung *et al* 2021, Sikka and Carol 2021)
Micro-hydro power plants Ethiopia were built to generate power	Women challenges, needs and uses were insufficiently addressed. Difficulties in diversifying the income for women and poor men. Gender differentiated access to opportunities and benefits (Education, health etc). Exclusion from decision making spaces at community level.	Inequalities in decision making. Access to resources.	(Wiese 2020)
Renewable energy-based electrification.	Ignoring the gender analysis in project design and implementation. Extra work for women. Men extend their leisure time, but women usually involve themselves in income generation activities like knitting. Lack of participation from women in project related activities due to care giving responsibilities.	Inequalities in power and decision making. Access to resources and gendered division of labour.	(Fernández-Baldor *et al* 2014)
Construction of mega solar energy projects in India to mitigate climate change.	Loss of livelihood (trees, firewood etc) from the land acquisition for solar park. Culture of masculinities in STEM fields. Social and economic exclusion of women. Exclusion from decision making process.	Land use change. Access to resources and gendered division of labour. Inequalities in decision making.	(Yenneti 2016, Terrapon-Pfaff 2019, Stock and Birkenholtz 2020)
Different solar communities and housing association was investigated in link with justice and gender-energy nexus.	Absence (lack of presence) of women in decision making bodies.	Inequalities in decision making process.	(Lazoroska *et al* 2021, Welton and Eisen 2019)
Development of solar projects for clean electricity generation (Morocco, Kenya, some analysis in global south).	No consideration for women employment. Gender blind energy policies.	Access to resources. Inequalities in power and decision making.	(Terrapon-Pfaff *et al* 2014, Terrapon-Pfaff *et al* 2018, Ryser 2019)
Energy production activities at household level in Norway and UK (solar prosumers).	Technology being considered as masculine domain. Less women in STEM fields. Gender and social differentiation neglect in policies.	Access to resources and gendered division of labour. Inequalities in decision making.	(Standal *et al* 2020, Sovacool 2021)
Carbon marketing	Market-oriented development approaches accentuate the existing gender social norms.	Unequal access to resources and embedded patriarchy.	(Lehmann 2019)

(Continued.)

Table 2. (Continued.)

Carbon or environmental taxation policies	Gender analysis is absent from policies. Men travel longer distances and use more fuel. Distributional impact borne more heavily on women than men. Lack of coping strategies because of care giving responsibilities. Unequal division of decision-making power at household level.	Inequalities in power and decision making. Green practices are gendered.	(Chalifour 2010)
Policies about low carbon energy transition.	Dominant male perspective in low-carbon energy transition policies. No gender analysis in energy transition in policies (Kenya). All male expert panel (Spain)-exclusion of diversity.	Inequalities in power and decision making. Gender invisibility in policies. Unequal access to resources and embedded patriarchy.	(Lieu *et al* 2020, Maduekwe and Factor 2021, Tsagkari 2022)
Conceptualization of power in energy transitions.	Already existing power relation predominates. Lack of access to resources for women translates into lack of opportunities.	Unequal access to resources.	(Creutzig *et al* 2015, Ahlborg 2017, Sovacool 2021)
Policies to promote green practices.	No consideration for women in policies designed to promote low-carbon lifestyle.	Green practices are gendered. Differential impact of energy efficiency on women.	(Wang 2016, Kawgan-Kagan 2020)
Mining of minerals to create energy storage batteries	Women marginalised in the community, forced to prostitution to make a wage. Mineral jobs, low wage and health risks.	Green practices are gendered.	(Sovacool *et al* 2019)
Wind power development in Brazil and Mexico was developed to produce renewable electricity.	Social and economic exclusion of women. Decisions are more influenced by men.	Land use change. Unequal access to resources. Inequalities in decision making.	(El Mekaoui *et al* 2020, Turkovska *et al* 2021, Bielig *et al* 2022)

projects. Afforestation or reforestation projects are being implemented as a carbon capture strategy from atmosphere (IEA 2020). An article (Stock and Birkenholtz 2020) explains how the women who depend on forest resource are more likely to be affected by loss of firewood, land for grazing and farming, water and medicinal plants in case of land enclosure for solar energy project. Besides firewood collection, households also depend on many other resources produced by forests like mushrooms, locust bean trees, charcoal production, raw material to make local handicrafts, which also provides a significant proportion of women's cash income. Few studies (Boyd 2002, Corbera *et al* 2007, Gay-Antaki 2016) draw attention to the lack of power in decision-making activities, even though women were primarily responsible for tree plantation in reforestation and management projects. It is evident from literature that there are significant differences in the vulnerabilities and expectations between different genders that may be traced back to social dimensions, such as gender inequalities, traditions, and social roles (Skutsch 2005).

The possibility of increased competition and demand between biofuels and the food sector could perpetuate the food security issue, especially in places where land and resources, such as water, could be diverted to biofuel production which had been previously preserved for staple crops (Popp *et al* 2014, Dauvergne and Neville 2010, (Dompreh *et al* 2021). Schoneveld *et al* explains that changes in existing land use toward monoculture plantations engendered intensive vegetation clearing and the loss of traditional ways of farming and forest resources (Schoneveld *et al* 2011). The change in patterns of power and control likely to result in the marginalisation of women, who not only grow crops for household consumption but to gain additional cash income (Vermeulen and Cotula 2010, Behrman *et al* 2012, Stock and Birkenholtz 2020). Structural

transformation and modernization of the agricultural system owing to the increase in demand for biofuels could lead to insecurity of agricultural commodities, biodiversity loss, differentiated access to resources and increase in food prices. In agricultural production systems found in rural communities, pre-existing gender norms and social hierarchies determine the control over resources, division of labour, and the mechanisms of decision making. These changes could affect women and other vulnerable groups in a number of uncharted ways (Vermeulen and Cotula 2010, Laura *et al* 2011, van Eijck *et al* 2014). Behrman *et al* (2012) draws attention to women's limited access to customary land rights and secure land tenures, emphasising their limited access to nonland inputs, such as fertilisers, pesticides and external services to improve the land and crops conditions. The authors underscore the importance of continued research on gender equitable large-scale land deals (Behrman *et al* 2012). Land related transformations that create opportunities for women may have a positive impact, but if resources are taken away from women, it will negatively impact the welfare of women and their families even if there are financial gains for men (Schoneveld *et al* 2011, van Eijck *et al* 2014). The access to resources and rights represents the ways in which inequalities materialise. The understanding of different resource users and resource managers in relation with different productive spaces and how they are associated with resources is crucial for a just LCT.

Migrations, resettlements, and land loss as a result of low carbon energy projects, alters the fabric of a community by changing the dynamics of the power relations and gender norms. The changing land infrastructure and land deals for LCE projects results in eviction and resettlement of the local population that could have important gendered implications (Obidzinski *et al* 2012, Aiken and Leigh 2015, Hill *et al* 2017, Zhao *et al* 2020). Hill *et al* (2017) examined in a study on Vietnam that migrated communities as a result of low carbon energy projects, settled into the areas that are unsuitable for farming, which forces the migrated population into wage labour or illegal work. These resettlements results into reconstruction of gender relation, culture and livelihood (Lin 2001, Mutopo 2012, Zhao *et al* 2020). Women-headed households also have difficulties in mobilizing labour and material to build houses in resettled areas. Studies by (Mehta 2009, Hill *et al* 2017) argue that following the settlements, a number of gendered impacts were found, such as erosion of women's influence in households, losing the land rights and loss of opportunities as a result of exclusion from official consultations. Furthermore, social norms prevent women from engaging in alternative livelihood options like timber harvesting and wage labouring. Sikka and Carol (2021) draws attention to impacts of displacement on men. They found that in case of migrations of tribal and indigenous people, women were more adaptable, whilst men struggled to reconstruct their lives and renegotiate masculinities upon resettlement.

The concept that the household unit will share the benefits and losses of resettlements equally is flawed (Skinner 2018), as different household members will be affected differently by land loss, resettlement, employment opportunities, and additional assort that accompany the migrations and resettlement. Gender analysis in understanding the vulnerabilities that land use change causes is critical as men and women have different social roles, rights and opportunities. Land use analysis should be more inclusive and should shift focus from agriculture to common land use. Thus, societal and systematic factors play a critical role in determining the degree to which the benefits of the low carbon energy transitions could be reaped by different genders.

4.2.2. Gender inequalities in power and decision making

Exclusion and inequality in decision making processes emerged as the second most debated topic in the reviewed literature, where approximately 17% of the literature directly addressed the gender blindness in LCE policies and project implementation, and around 18% of the studies discussed the disproportionate access to employment opportunities. Although energy policies are often considered gender neutral, in that they benefit all genders equally, the decision makers are predominantly men (Feenstra and Özerol 2021). This influences women's access to social and economic opportunities with pre-existing social norms and gender representation in STEM fields. Although most of the articles are concerned with the Global South, a few articles address the issue from a Global North perspective (Lieu *et al* 2020, Lazoroska *et al* 2021).

Although the importance of gender equality is widely acknowledged in climate mitigation strategies of the Paris Agreement and in SDGs, deep-rooted power dynamics of gender, inequality in resource access, and exclusion from decision making process are making the implementation more challenging (Ahlborg 2017, Zhao *et al* 2020, Buechler *et al* 2020). Many articles indicate that gender blind policies, projects and strategies, alongside local practices and norms, are likely to hinder women's access to energy and produce perpetuate a system largely dominated by men (Boyd 2002, Terrapon-Pfaff *et al* 2014, Ahlborg 2017, Winther *et al* 2018, Shrestha *et al* 2019, Terrapon-Pfaff *et al* 2019, Lieu *et al* 2020, Lazoroska *et al* 2021). Some papers (Boyd 2002, Ahlborg 2017) argue that the reason for limited emphasis on the gender dimension could partly be attributed to the pressures emerging from technical requirements and translation of technical designs into functional system configurations. Consequently, this tends to create

certain sets of ideas about energy consumption and users in which men are doing the productive work and women occupy the household (Winther *et al* 2018, Terrapon-Pfaff *et al* 2019). The analysis of the literature on gender perspectives in energy policy making, highlighted the central need to question why there was an overwhelming absence of not only gendered voices but empowered, gendered and diverse voices in energy transitions. Part of the answer is patriarchal underpinnings of sustainable developments and climate change mitigation agendas. For instance, energy transitions have strong emphasis on techno-economic transition which is dominated by the visions and scenarios largely developed by influential groups—often led by men (Kronsell 2013).

There is an established link between energy justice and policy making, but the discussion of gender in context of low carbon energy transition literature is often limited to sustainable energy poverty, employment and adaptation of efficient and clean energy cookstoves (Terrapon-Pfaff *et al* 2014, Wang 2016, Terrapon-Pfaff et al 2018, 2019, El Mekaoui *et al* 2020). However, in recent literature, gender has been explored from the perspective of power and politics in energy transition (Ahlborg 2017, Lieu *et al* 2020) because the power dynamics between genders can lead to exclusion and inequality in decision making process. The long standing unquestioned social norms, practices and discourses have reinforced unequal power relations between genders in decision-making spaces (Lieu *et al* 2020). Patriarchal approaches toward decision-making and pre-existing inequalities in social infrastructure could limit the potential effectiveness of LCE policies and projects (Boyd 2002). Some studies suggest that women have limited to no stake in decision-making and felt excluded from the processes at national, local and community levels (Boyd 2002, Lieu *et al* 2020, Lazoroska *et al* 2021).

The dilemma of these carbon mitigation policies is to operate through common property whilst upholding the existing unjust and discriminatory decision-making system. Studies shows that neither in the context of project implementation, nor at community level meetings, was there any evidence to improve the socio-political and economic integration of the women in decision-making (Ahlborg 2017, El Mekaoui *et al* 2020). RE programs are usually not gender mainstreamed and do not incorporate plans to address the gender issues in implementation of the projects explicitly (Ahlborg 2017). Many carbon mitigation projects like other development projects focused on some of the women's practical needs, such as, health, education and food production but ignored the strategic needs to empower women, challenge the gender biases and bring greater gender equality (Boyd 2002, Corbera *et al* 2007). This shows the limited capacity of environmental management projects and practices to effect the local structure of non-recognition of the gender needs in carbon mitigation projects (Boyd 2002). Similar pattern of dominance, control, and experienced subordination has been observed in electricity generation and distribution systems which involves the practice. General patterns of the electrification process have a tendency to reproduce the inequalities related to gender and class (Wiese 2020).

Overall, the literature indicates that there is not only a lack of representation of women in decision making processes, but also a lack of consideration of women's needs as energy consumers. Disproportionate representation of gender concerns the question of numbers and capabilities of men, diversity of the visions and actors represented (Lieu *et al* 2020, Wiese 2020). Underrepresentation of one gender accentuates attention towards specific storytellers and their perspectives whilst overlooking how gendered energy transition could be demonstrated. The absence of equal representation of gender, particularly women's needs and demands in decision making processes, perpetuates dominated technical culture, excludes the social and gender perspective, and prioritises the technical expertise and knowledge that lies in the hands of male technical experts (Lieu *et al* 2020). These pitfalls contribute into reinforcing pre-existing inequalities, vulnerabilities and unequal power structures, whilst also indicating that this could be the product of the emerging structure of energy transitions. The narrative constructed around the LCE transitions and climate mitigation actions centre on technological solutions simultaneously reflecting the dominating political and policy agendas.

4.2.3. Unequal access and gender division of labour: embedded patriarchy

Although low carbon energy transitions present alternative financial and community participation opportunities, it was observed in numerous studies that low carbon energy transitions also putting women in disadvantageous positions when it comes to paid jobs, accessing resources, and livelihood survival approaches, therefore creating gender vulnerabilities (Boyd 2002, Creutzig *et al* 2015, Castro-Diaz *et al* 2018, Dharmawan *et al* 2020, Stock and Birkenholtz 2020, Sovacool 2021, Tsagkari 2022).

Modern household electricity and heat use, particularly decentralised solar and bioenergy, are more frequently credited to have a positive influence on gender equality in rural contexts by lowering women's workload, allowing them to use daylight to pursue other activities, such as alternative income opportunities and engaging in community work (Baruah 2017, Terrapon-Pfaff *et al* 2018). Stock and Birkenholtz (2020) conducted a study in an Indian solar park, claim the opposite. The enclosure of land for the solar park has not only increased the time of low

caste women to collect water but also denied their access to firewood. Some researchers (Fernández-Baldor *et al* 2014, Wiese 2020) have examined other ways in which men and women reap the benefits disproportionately from the implementation of low carbon energy technologies. The pattern observed in the literature shows that new energy technologies merely shift the inequalities, rather than eliminate them (Fernández-Baldor *et al* 2015, Lehmann 2019, Stock and Birkenholtz 2020). For example, a study conducted in Peru shows that men extend their leisure time by playing instruments or by watching TV whilst women use their time to increase their family's income by knitting, sewing or in completing other household chores (Fernández-Baldor *et al* 2014). Standal *et al* (2020) argue that the economic, cultural, social and symbolic resources to which individuals have access and different social fields they move within are the important enablers and obstacles to interact with the technologies. Societal differentiation along the gender lines, in which modern technology is perceived a masculine domain, creates a barrier for most women from fully benefited from technologies (Standal *et al* 2020).

The development of the low carbon energy infrastructure to mitigate climate change transforms the resource access, management and control and regional economy. This change translates into gendered inequalities in employment, labour market, and at household level. Many case studies in the reviewed literature show that in climate change mitigation, forestry, and biofuels plantation projects, there is a gendered division of labour: women performing menial tasks whilst men perform more highly-skilled labour (Boyd 2002, Corbera *et al* 2007, Behrman *et al* 2012, Fernández-Baldor *et al* 2014, Gay-Antaki 2016, Axon and Morrissey 2020, Dharmawan *et al* 2020, Sovacool *et al* 2020). In these projects women are increasingly hired as daily waged casual labour and lack the security that comes with permanent contracts. Female workers are mostly involved in collecting mainly weeds and firewood, cleaning and cooking activities, transporting, processing, and trading (Sovacool *et al* 2020).

Poor working conditions, inadequate access to social protection, and unpaid household work have particular implications for vulnerable women. These socio-economic inequalities accentuate gender vulnerabilities due to lack of access to education, mobility, and decision-making spaces (Lazoroska *et al* 2021, Shrestha *et al* 2021). Studies argue that access to electricity alone does not necessarily translate into women's (and men's) economic and political empowerment, such as (Wiese 2020), but rather calls for a need to coordinate energy interventions with other development objectives that target women's empowerment, such as access to credit or education to enhance social equality (Winther *et al* 2017, 2018, Standal *et al* 2020).

4.2.4. Green practices, gender, and culture

The smallest theme of the four analysed the way in which sustainable lifestyle, sustainable consumption policies, and low carbon energy projects underestimate the complexity of everyday life (e.g. Different genders have different roles and so the different energy consumption patterns). The policies, to promote sustainable lifestyle and their implications, usually ignore asymmetric power dynamics in households (Chalifour 2010, Shrestha *et al* 2019, Kawgan-Kagan 2020). These policy interventions to modify individual lifestyles by changing the consumer's choices and attitude increase women's household work and exacerbate gender inequalities (Wang 2016). These plans to promote green practices, which is the practice of creating the structure and habits of consumers that are environmentally responsible, excessively focused on technical and economic dimensions but ignored the social and gender dimensions of change. Policy makers assume that people will be willing to change practices if they are well informed about environmental risks. These policies consider consumption as an individual choice and ignore the fact that individual choices are often affected by the socio-economic position, gender, and culture (Owens *et al* 2004). Wang (2016) argues that gender is invisible in these policies as it might be more difficult for the women to change their behaviour and switch to less carbon intensive transportation because of their caregiving activities related to children or elderly family members.

In addition to the burden of purchasing new equipment, the powers of making decisions about switching to low carbon energy technologies are also gendered; decision making powers in a joint household with male and female members is often disproportionately distributed (Chalifour 2010). Women who work at home have more energy needs during the day, and some may have a partner who might share the cost, but in the case of single parenthood, these costs are difficult to avoid or share—and women are far more often single parents than men (Chalifour 2010, Sovacool *et al* 2019). Moreover, the price increase through carbon taxes related to low carbon energy technologies can have gender differentiated impacts since women make up a disproportionate share of low-income population (Chalifour 2010). Additionally, women's work as caregivers and lack of power over decision-making in relation to energy also restricts their ability to adapt to increased prices (electricity, heating) even in same financial circumstances as men (Chalifour 2010, Sovacool *et al* 2019, Hu 2020).

Another important vulnerability related to low carbon energy mitigation policies is spatial and temporal externalization of harmful impacts, which could have many critical gender implications. A study by (Stock and Birkenholtz 2020) emphasises that low carbon energy projects should be seen as the part of

process of entrenching postcolonial ideas of gender and race within the narrative of nation building and international development interventions. Similarly, a study in Morocco claims that acquisition of land by the government drew on colonial strategies (Ryser 2019). Policies in the Global North to address climate change can deepen the gender injustices and pattern of domination in the Global South.

Low carbon energy transitions necessitate plantation expansion for biofuels and mining camps for mineral extraction, for electric vehicles, heat pumps, and storage technologies. Yet, they are marginalising women and reproducing the patterns of patriarchal control and gender inequalities. These plantation, mining, and RE projects sites were also accompanied by an increase in prostitution (Ryser 2019, Sovacool *et al* 2020). In general, sex workers are among the most vulnerable groups to violence and poverty as most of them are internal migrants and have fewer social connections and support (Behrman *et al* 2012). An increase in prostitution also increases the risk of sexually transmitted diseases in the community. Women in these mining sites, particularly the sex workers, faced the risk of contracting contagious diseases spread by the miners (Sovacool *et al* 2020). Women face the same kind of toxins and chemicals, but perform menial tasks. These toxins, with all other diseases, also put women at abnormally high risks of spontaneous abortions, stillbirths, and premature births (Sovacool *et al* 2020). Although these gendered impacts of mining practices are of paramount importance the research to date on the subject is restricted and there is no in-depth analysis in literature. Women's needs and biological differences are not systematically studied and have been overlooked. The paper by (Dehghani-Sanij *et al* 2019) considers the environmental devastation caused by mineral mining, yet they only briefly discuss the human aspects. Therefore, the links between low carbon energy transitions, gender vulnerabilities, and transition materials require further research.

5. Future research paths

Based on the conceptual review approach, we reviewed 65 peer-reviewed articles, which collectively advances our understanding of the disproportionate distribution of the benefits and burdens of low carbon energy transition and their relation to social and political inequalities for different genders. The low carbon energy transition literature on gender vulnerabilities is limited in scope as identified by the number of relevant articles. Four main themes were emerged from the content analysis of the research papers: *land use change, gender-neutral energy policies, access to resources*, and *green practices, gender and culture* as described in (section 3, figure 3). We have also identified several research gaps in the current literature and directions for future. In LCET research, gender is slowly emerging and little attention has been paid to power, social, and political relations and their synergies.

5.1. Discussion

The analysed literature challenges the prevalent energy system narrative to treat the energy transition as gender neutral, when in practice evidence shows that the distribution of benefits and opportunities for men and women continues to be unequal (Skutsch 2005, Wang 2016, Wiese 2020). Literature also shows how different enablers and potential vulnerabilities are complexly intertwined into each other and in some cases reinforcing one another's impacts. There are pieces of evidence that suggest that if not managed carefully, this energy system change may generate new social justice challenges and vulnerabilities, whilst possibly failing to address the already existing drivers of inequality in the energy market and larger socio-economy (Stock and Birkenholtz 2020, Sovacool *et al* 2020).

Whilst the energy transition literature focuses on the decarbonization of economic activities, it should be emphasized that broader changes in energy distribution and recovery result in new socio-spatial inequalities (Gay-Antaki 2016). Energy policies and decision-making practices are generally considered as technocratic processes and inclusion of gender dimensions is often limited to the electricity access and poverty issues (Clancy and Feenstra 2019, Robinson 2019). Understanding the power inequalities associated with energy transitions can make them a fertile ground to explore justice and equality issues.

Two factors were identified: first, the energy policy and implementation debates are dominated by politics, scientists, and bureaucrats; secondly, sociological thinking is unlikely to produce generalisable conclusions that policy makers favour (see for example, Shove 1998). A technological and/or economic approach limits the range of actors involved and their perspective in the energy transition which could lead to unfair outcomes (Geels *et al* 2017). Advocacy groups argue that the change to clean and low carbon energy resources and technologies should also herald equal employment and work policies for women as well as strong recognition of the women's reproductive roles (IRENA 2019). The gender aspect has not been perceived with the same level of attention by already established stakeholders and politicians regarding the energy transition's economic and technical aspects. Most of the literature on social justice and gender equality regarding LCE transitions is from the field of social science (Williams and Doyon 2019). The main challenge for the future research is how this conceptual thinking should be incorporated and embedded into the quantitative techno-economic debate that dominates the energy policy spheres.

The access to new opportunities that arises from the implementation of the low carbon energy projects are also gendered, as girls and women lack information and resources that might be more prominent in the rural context (Fernández-Baldor *et al* 2015). As Behrman *et al* (2012) observed, women who were responsible for selling crops in the local market have difficulties in reaching the commercial markets because of male dominated infrastructures of the markets and villages are situated away from these markets (Behrman *et al* 2012). Although the access to new large-scale (neo-liberal) markets is an important subject, but there is a lack of critical reflection in literature. There is also a need for gender disaggregated data to raise awareness on gendered implications of energy projects and to identify the remedies for vulnerabilities. Furthermore, it is also a continuous need to further our understanding of women's energy activities and concerns along with the structures that constrain women, particularly in the rural context, from access and use of energy services and participation on the household and community level.

In many countries, women's access to land and productive resources is already tenuous due to gender discriminatory laws and social practices. These pre-existing gender inequalities, disproportionately affect women, particularly rural and indigenous women, to the compounded effects of both climate change and the RE policies and projects implemented on their land and territories to reduce global GHG and diversify the energy system ('Wind farm in Mexico': 2020). The gendered impacts of climate change and the energy responses to address this crisis are often the result of intersectional gender discrimination in land rights, women's and girls' lack of participation in key decision-making processes, as well as their care-giving roles ('Renewable Energy & Gender Justice' 2020). Furthermore, women are overrepresented amongst the world's poor and are often more dependent on land and other natural resources to sustain their livelihoods. To be gender-equal, just, and in harmony with human rights, policies and political frameworks addressing the energy transition should avoid land dispossession for women and other marginalized groups. To ensure a meaningful and just transition, low carbon energy projects must recognise that useful participation of all genders is crucial in the conservation of natural resources and protection of environment.

5.2. Future path: vulnerability and intersectionality

This study aligns itself with theories of gender and vulnerability in climate mitigation literature to analyse the vulnerabilities in literature. Low carbon energy transitions will have implications for notions of gender equality and justice due to their differentiated vulnerability to such change (Fisher and Mohun 2015). Vulnerability is an evasive concept whose definitions varies across disciplines. Growing body of literature is trying to capture the multidimensionality and complexity of the concept (Brooks 2003). The widely used IPCC definitions of vulnerability are in disagreement with one another (Brooks 2003) and this difference further illustrates, whether the vulnerability is determined by the internal characteristic of the system, or if it also depends on the likelihood of the system to experience a particular hazard or probability of particular undesired outcome. Based on the studies analysed, there may be a need for more inclusive definition of gender vulnerability and related terms such as sensitivity, adaptive capacity, adaptation, and risk. A more explicit definition may help researchers, policy makers and NGOs to comprehend the impacts of energy transition on weakest members of the society. In our paper, we understand vulnerability as the integration of the inherited characteristics of the system and probability of occurrence of an event that could result into undesired outcomes.

Whilst the literature on vulnerability assessment of low carbon energy transitions is growing, gender as a component of the vulnerability dimension is missing. The framework of the vulnerability scoping diagram (Coletti *et al* 2013, Carley *et al* 2018) is being widely adopted in literature to analyse the vulnerability of energy transition across its three dimensions (sensitivity, adaptive capacity and exposure) and various components of these dimensions in different geographic locations (Kortetmäki and Järvelä 2021, Raimi *et al* 2022). The absence of gender from assessment frameworks limits the scope of analysis and at the same time make gender invisible in literary discourses. To address the gap, we analysed the identified vulnerabilities according to framework presented in (Carley *et al* 2018). Although (Carley *et al* 2018) focused on one policy and the vulnerability which arose from it, we analysed the vulnerabilities according to the three dimensions (figure 4) (exposure, sensitivity, adaptative capacity) since reviewed literature aimed to address gender in climate mitigation research from contrasting perspectives. Through this grouping exercise, we may see that articles consider specific sectors, but rarely consider gender vulnerability as having spatial dimensions. Although studies deal with sensitivity towards the potential hazards and exposure of the population but little to no attention has been paid to adaptive capacity. Capacity to adapt and respond to change is determined by access to resources and information and that the ability to diversify the livelihood options (Djoudi *et al* 2016, Thomas *et al* 2019). These factors are determined by the social identities and positions where gender is the key element of these identities. Vulnerability also depends on the social and spatial differentiation even within the same gender.

Intersectional approaches consider the impact of policies amalgamated with asymmetric power relation based on identities at various levels. The failure

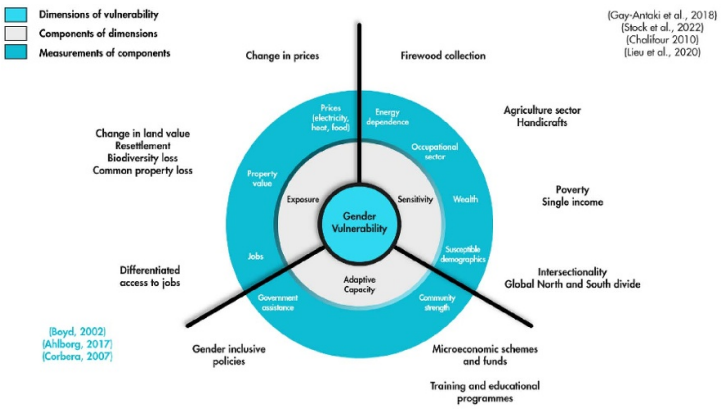

Figure 4. Gender vulnerability scoping diagram based on. Adapted from Carley *et al* (2018), with permission from Springer Nature.

to recognize and consider the complexities in energy interventions could results into short-term success, failed efforts and unplanned consequences (Djoudi *et al* 2016, Smith 2016, Cassese 2019). Although literature on intersectionality, gender, and energy is growing, but conceptualising gendered inequalities and how they interact with inequalities of ethnicity, race, class, and age continues to be critically understudied in low carbon energy transitions literature (Sahrakorpi and Bandi 2021). In the reviewed literature, only one study (Stock and Birkenholtz 2020) addressed that how land enclosure for solar power plant generated the inequalities that cut through gender, caste, and class. Another dimension of energy transition is introduction of technologies, skills, machinery, and policies in developing world. An article (Mollett and Faria 2013) raise the argument that the introduction of low carbon energy technologies should be seen as the part of long historical process of continuing the legacies of postcolonial ideologies of gender and race. To understand the consequences of these processes, new literature must focus on the intersectionality of the social and spatial positioning of people and energy systems.

5.3. Future path: gender inclusive policies, projects and practices

We identified the various gaps that could open new avenues for future research on the relationship between low carbon energy transitions and vulnerabilities. Low carbon energy policies and frameworks often fail to contemplate how changing energy infrastructure and development projects might impact the land and property rights of men and women differently (Burton *et al* 2005). Although, energy policies are assumed to be gender neutral, policy decisions have implications in terms of gender equality, and thus policies intended as gender neutral may turn out to be gender blind in their outputs. Therefore, the process of decision making should consider the roles and responsibilities of different genders (Lazoroska *et al* 2021). Large scale low carbon energy projects rarely adopt any strategy to prevent human rights abuses related to land acquisition, change in electricity generation, and distribution infrastructure (Stock and Birkenholtz 2020, Zhao *et al* 2020). This is a particularly common issue in RE projects (dams, hydro, wind farms, and solar installations) located in rural areas in developing countries where state institutions tend to lack the means and resources to enforce regulations ('Renewable Energy & Human Rights Benchmark' 2020).

Studies often do not critically access the double domination faced by women, a naturalised domination by asymmetric power relation between men and women and from these policies and practices. The role gender plays in green practices is critically understudied, which limits how we may understand vulnerability in the context of green practices (Wang 2016). The gender aspects of energy transitions need to be explored into further work, and the research community needs to put considerable dedication. The dearth of literature highlights more work is required on the differential effects of low carbon energy solutions on men and women, and further rigorous empirical work would be beneficial. Future research ought to incorporate gender-disaggregated data on time use, opportunities for income generation, and prior conditions (such as land ownership) and should examine the change over the course of the project. In addition to incorporating gender aspects, empirical research work and case studies also need to include intersectionality in their analysis by looking at a variety of other factors—including age, marital status, geographical location, and ethnicity. These aspects may impact whether local people will profit from low carbon energy transitions and if some individuals or groups are more likely to benefit than others.

Moreover, the idea that the diffusion of modern technologies and markets in the developing world can optimize production to produce environmental and

social benefits should perhaps be critically re-assessed based on historical and societal realities (Robbins 2004). The development of green revolution technologies took place in developed countries that were later distributed, to increase agricultural production, around the world. Shiva explains how these technologies have resulted in extensive environmental, social and gendered issues (Shiva 2016). Shiva also raised the concerns about the lack of gender discourse in climate mitigation debate (Shiva 1988). She argued that climate mitigation is engaging in the debate lead by men, who are providing technical solutions to ecological problems. Yet, they have little understanding of women's concerns and interests (Boyd 2002). The more general assertion that superior environmental knowledge originates in the Global North for transfer to the Global South is problematic, reproducing as it does authoritarian colonial knowledge relations and *a priori* omitting the environmental practices of indigenous and local communities (Robbins 2004). Therefore, an intersectional perspective on gender, power relations and LCT can bring issues of overlapping inequities to the fore in the analysis of efforts to mitigate climate change through introducing low-carbon energy technologies.

6. Conclusion

This conceptual review analysed how gender vulnerabilities are discussed in low carbon energy transitions literature and what mechanisms may be causing vulnerabilities in the future. Recent trends indicate that gender is becoming a mainstream concern in low carbon energy transition literature. The aim was to map not only the existing literature, but also to provide insights into potential literature gaps and future studies on gender and low carbon energy transitions. Land use change, gender-neutral energy policies, access to resources, and green practices are gendered emerged as the main key themes concerning electricity generation. The studies analysed mainly focused on solar, biofuels, and hydropower as the main technology case studies, with 43 articles focusing on the Global South, 13 articles considered the Global North, and the rest considered global issues. When gender vulnerability was utilised as a tool of analysis, it was heavily featured in papers concerning land use change, differential access to employment, and invisibility in decision making. Through categorisation of the main strands of research, it became apparent that a number of enabling mechanisms from structural and social inequalities were not being addressed by case study projects nor provided adequate focus in the literature. It was also observed that low carbon energy transition projects relating to electricity pay little attention to gendered issues nor provide tools or plans to mitigate potential vulnerabilities. Through employing Carley *et al* (2018) framework to analyse gender vulnerabilities, we presented a number of research areas that are under-researched. The major finding from mapping gender vulnerabilities was that the adaptive capacity, compromises of government assistance and community strength, was often not found within the literature. Therefore, future research ought to consider how low carbon energy transitions are adapted in communities through a gendered dimension. For example, women have little access to the benefits from LCET electricity projects, with local men being offered better employment and waged positions. These results add to the rapidly expanding field of energy research on energy transitions and LCET, indicating the growing importance of the necessity to consider socio-technical systems in addition to the technological or economic dimensions of these transitions.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

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