



REVIEW ARTICLE



<https://doi.org/10.1057/s41599-022-01266-6>

OPEN

# Synergies and trade-offs between climate change adaptation options and gender equality: a review of the global literature

Joyashree Roy <sup>1,2</sup>, Anjal Prakash <sup>3✉</sup>, Shreya Some <sup>1,2,4</sup>, Chandni Singh <sup>5</sup>, Rachel Bezner Kerr <sup>6</sup>, Martina Angela Caretta <sup>7</sup>, Cecilia Conde <sup>8</sup>, Marta Rivera Ferre <sup>9</sup>, Corinne Schuster-Wallace <sup>10</sup>, Maria Cristina Tirado-von der Pahlen <sup>11</sup>, Edmond Totin <sup>12</sup>, Sumit Vij <sup>13</sup>, Emily Baker <sup>6</sup>, Graeme Dean <sup>14</sup>, Emily Hillenbrand <sup>6</sup>, Alison Irvine <sup>10</sup>, Farjana Islam <sup>15</sup>, Katriona McGlade <sup>16</sup>, Hanson Nyantakyi-Frimpong <sup>17</sup>, Federica Ravera <sup>14</sup>, Alcade Segnon <sup>18</sup>, Divya Solomon <sup>19</sup> & Indrakshi Tandon <sup>20</sup>

Climate change impacts are being felt across sectors in all regions of the world, and adaptation projects are being implemented to reduce climate risks and existing vulnerabilities. Climate adaptation actions also have significant synergies and tradeoffs with the Sustainable Development Goals (SDGs), including SDG 5 on gender equality. Questions are increasingly being raised about the gendered and climate justice implications of different adaptation options. This paper investigates if reported climate change adaptation actions are contributing to advancing the goal of gender equality (SDG 5) or not. It focuses on linkages between individual targets of SDG 5 and climate change adaptation actions for nine major sectors where transformative climate actions are envisaged. The assessment is based on evidence of adaptation actions documented in 319 relevant research publications published during 2014–2020. Positive links to nine targets under SDG 5 are found in adaptation actions that are consciously designed to advance gender equality. However, in four sectors—ocean and coastal ecosystems; mountain ecosystems; poverty, livelihood, sustainable development; and industrial system transitions, we find more negative links than positive links. For adaptation actions to have positive impacts on gender equality, gender-focused targets must be intentionally brought in at the prioritisation, designing, planning, and implementation stages. An SDG 5+ approach, which takes into consideration intersectionality and gender aspects beyond women alone, can help adaptation actions move towards meeting gender equality and other climate justice goals. This reflexive approach is especially critical now, as we approach the mid-point in the timeline for achieving the SDGs.

A full list of author affiliations appears at the end of the paper.

## Introduction

Climate change adaptation actions that also advance sustainable development goals (SDGs) have the potential to reduce exposure to climate risks and social vulnerability and enhance human wellbeing (Zhenmin and Espinosa, 2019; IPCC, 2022). Gender inequality inherited from historical, socio-economic developmental processes and entrenched social norms are a major factor exacerbating vulnerability to climate change impacts across sectors and regions (Vij et al., 2017; Jerneck, 2018; Sultana, 2018; Partey et al., 2020; Ampaire et al., 2020; Rao et al., 2019). Synergistic links between adaptation actions and gender equality can enable inclusive development for gender-transformative climate action (Resurreccion et al., 2019) and inclusive development that 'leaves no one behind' (Agarwal, 2018). Here, gender transformative change refers to 'transforming' systems that perpetuate inequality and addressing broader structural inequalities in relation to gender and other intersectional issues (Prakash et al., 2022a; Tschakert and Machado, 2012; Singh et al., 2021).

For this paper, we understand gender to be socially constructed roles, identities and behaviours of men, boys, women and girls and non-binary people, which affect people's actions, power, and resources and vary over place and time. We define gender equity in the context of climate change as 'equity between women and men about their rights, resources and opportunities (IPCC, 2019, p. 685). Evaluating climate actions through an SDG lens is attracting the attention of assessment reports within the larger research community (McCullum et al., 2018; Roy et al., 2018; Hoegh-Guldberg et al., 2019; Honegger et al., 2020; Creutzig et al., 2020; Solomon et al., 2021). Specifically, SDG 5 and its targets aim to achieve gender equality and empower all women and girls (United Nations [UN], 2015a). However, information concerning the linkages between adaptation options and gender equality is sparse (Ngigi et al., 2017; Bryan et al., 2018). These two papers provide evidence from household-level field-based studies in parts of Africa to show what is missing in adaptation programmes that prevents them from being gender-responsive. This study provides an assessment based on studies from various parts of the world to get a global perspective.

Further, adaptation actions are socially differentiated and constructed (Few et al., 2017; Carr and Thompson, 2014) and are strongly gendered. Thus, understanding links with SDG 5 becomes critical to ensuring that adaptation actions do not perpetuate or worsen prevalent gender inequalities (Bhattarai, 2020). Vulnerability increases when gender inequality intersects with other dimensions of social difference such as income, ethnicity, religion, and age (Carr and Thompson, 2014; Kaijser and Kronsell, 2014; Sultana, 2014; Perez et al., 2015; Goodrich et al., 2019; Rao et al., 2019; Resurrección et al., 2019). Addressing this requires a mechanism through which adaptation actions can be tracked and linked with SDG 5 and intersectionality to ensure synergistic solutions (Andrijevic et al., 2020).

In this paper, we ask two key questions—(1) do climate change adaptation options implemented through various projects in various contexts advance or hinder gender equality? (2) Are the targets under SDG 5 (Gender Equality) sufficient to track the gender responsiveness of adaptation actions? Overall, we find that current adaptation options implemented and undertaken across contexts, countries, and sectors generate positive as well as negative impacts on different targets under SDG 5. We also argue that the targets defined under SDG 5 (United Nations, 2015a) are inadequate to capture multidimensional and intersectional outcomes of adaptation (for example, the targets focus on women alone and do not consider intersections with age, ethnicity, or livelihoods). Adaptation actions that are gender-sensitive from the planning and design phase tend to advance gender equality

targets more effectively, highlighting the need for proactive gender-sensitive adaptation planning. For some sectors, there are more negative outcomes of adaptation actions observed than positive outcomes, demonstrating an immediate need to examine how adaptation actions in these sectors can be aligned with gender equality goals. This would help forefront gender-responsive tradeoffs and generate actions in the right directions before structural injustices are magnified.

## Methods

This paper is based on a rapid review of relevant literature for adaptation to climate change (Sharpe et al., 2017; Liem et al., 2021) using keyword and string-based searches (Supplementary Material 1, section 1.2), coordinated through in-person and virtual meetings. Adaptation actions across nine sectors were examined, following the Intergovernmental Panel on Climate Change (IPCC) Working Group II sector classification. The nine sectors are [1] terrestrial and freshwater ecosystems; [2] ocean and coastal ecosystems; [3] mountain ecosystems; [4] food and fibre and other ecosystem products; [5] water and sanitation; [6] poverty, livelihoods, and sustainable development; [7] cities, settlements, and key infrastructures; [8] health, well-being, and changing community structure; and [9] industrial system transition. Further, four broad adaptation options are categorised as behavioural/cultural; ecosystem-based; technological/infrastructure; and institutional (Table 1; also see Supplementary Material 1, section 1.1 and Supplementary Material 2 for details).

Starting in May 2020, sectoral experts searched sector-specific climate adaptation literature published between 2014 and 2020. The choice of 2014 is purposeful: pre-2014 literature is considered and assessed in the IPCC's Fifth Assessment Report published in 2014, and this cutoff coincides with the SDGs declaration in 2015. Literature searches were conducted using two literature databases—Scopus and Web of Science (Core Collection). A subsequent focused search was undertaken in Scopus, Web of Science (Core Collection), and Google Scholar, as experts found that many relevant studies were not identified in the initial broader query search. Internal cross-checking occurred across authors after each step to ensure consistency across and within sectors. Over 17,739 peer-reviewed publications and reports from intergovernmental agencies were identified through titles using keywords in the first round of search. After reading of abstracts and then followed by full-text scans, finally, 319 publications were selected that report outcomes of climate adaptation on gender (Supplementary Materials 2 and 3). Articles were screened for relevance based on expert critical appraisal, and relevant themes were extracted and coded using each of the nine SDG 5 targets (see Supplementary Material 2 for details).

**Assessment methodology.** Following similar assessments (Roy et al., 2018; Hoegh-Guldberg et al., 2019), the linkages between adaptation options and SDG 5 targets are classified into synergies (positive impacts or co-benefits; denoted by '+') and trade-offs (negative impacts; denoted by '-'). The magnitude of the score (Supplementary Material 4—Table S4.1), irrespective of the sign, indicates the strength of interlinkage. A 7-point SDG-interaction (-3 to +3) score (Nilsson et al., 2016) was used to explore the nature and degree of linkage between identified climate adaptation options and SDG 5 targets. The highest positive score, '+3', was assigned when evidence in the literature suggested that implementing an adaptation option would achieve gender targets. If implemented adaptation options were demonstrated to help achieve gender targets, then '+2' was assigned. A score of '+1' was assigned when evidence showed that implementing the adaptation option may achieve a specific gender target. The

**Table 1 Sectors descriptions and adaptation options by adaptation category.**

Sectors	Adaptation category	Ecosystem-based (E)	Behavioural/cultural (B)	Technological/infrastructural (T)	Institutional (I)
Terrestrial & freshwater ecosystem = t		Et1: Integrated watershed management; Et2: Ecosystem restoration (woodland restoration); Et3: Sustainable aquaculture; Et4: Ecosystem restoration; Et5: Reduced deforestation and forest degradation; Afforestation, Reforestation; Forest conservation and forest restoration; Et6: Biodiversity management/conservation X—Ecosystem restoration (grassland restoration) X—Management of invasive species/encroachment X—Restoration and reduced conversion of peatlands X—Reduced landslides and natural hazards (e.g. natural barriers, terraces) Eo1: Coral reef conservation & mangrove restoration; Eo2: Sustainable aquaculture. X—Restoration and reduced conversion of coastal wetlands	X—Avoiding pollution including acidification (water quality improvement)		It1: Community-based natural resource management
Ocean & coastal ecosystem = o			Bm1: Livelihood diversification and financial measures; Bm2: Mobility; Bf1: Reduced crop, post-harvest, food losses, and waste; Bf2: Livelihood diversification. X—Dietary change	To1: Coastal defence and hardening	Io1: Biodiversity conservation, protection (e.g., Marine Protected Areas);
Mountain ecosystem = m		Em1: Watershed management; Em2: Ecosystem management, conservation and restoration; Em3: (agro) Biodiversity management/conservation;	Bm1: Livelihood diversification and financial measures; Bm2: Mobility;	Tm1: Reduced landslides and natural hazards	Im1: Community-based natural resource management;
Food, fibre & other ecosystems products = f		Ef1: Crop diversification; Ef2: Agroforestry; Ef3: Mixed crop-livestock; Ef4: Conservation farming practices (no soil disturbance; crop rotation, mulching); Ef5: Water conservation and efficiency; Ef6: Agroecology. X—improved soil management	Bf1: Reduced crop, post-harvest, food losses, and waste; Bf2: Livelihood diversification. X—Dietary change	X—Plant cultivar improvements or livestock species breeding, X—Improved food processing and retailing, X—Improved irrigation efficiency and use	If1: Community-based adaptation; If2: Formal institutional capacity-building (e.g., agri extension, credit services, marketing facilities); If3: Regional & local food systems strengthening, short food circuits; If4: Climate Information Services, including weather index insurance products; If5- Social network institutional support (e.g., social support groups); If6: Local seeds strengthen (e.g., community seed banks)
Water & sanitation = w		Ew1: Increasing supply (e.g. rooftop rainwater harvesting, protecting urban wetlands); Ew2: Ecosystem restoration —nature-based solutions;	Bw1: Water and sanitation approaches; Bw2: Natural Disasters;	Tw1: Flood management through infrastructural measures and buildings and early warning systems, Tw2—Storage Strategies, Tw3—WaSH Infrastructure X—infrastructure, technology, and climate service delivery for improving living conditions	
Poverty, livelihood & SD = p		X—Ecosystem-based service for improving livelihoods	Bp1: Livelihood diversification; Bp2: Human migration, relocation, retreat; Bp3: Economic incentives during disasters. X—Unemployment cash benefits X—Special support schemes for people with disabilities X—Storage strategies Bht: Indigenous knowledge; Bh2: Human migration;	X—infrastructure, technology, and climate service delivery for improving living conditions	Ip1: Post-disaster social safety nets X—Risk insurance X—Indigenous knowledge
Health, well-being, and changing communities' structure = h		Eh1: Ecosystem-based approaches for health and well-being;	Bht: Indigenous knowledge; Bh2: Human migration;	Th1: Disaster risk management, Th2: Climate services, Th3: Infrastructure and health	Ih1: Risk-sharing and spreading insurance and credit programmes; Ih2: Education and learning; Ih3: Population health and health systems; Ih4: Social safety nets & social protection; Ih5: Integrated climate change adaptation policies; Ih6: Community-based climate adaptation
Cities, settlements & key infrastructures = c		Ec1: Green infrastructure, nature-based solutions;	Bc1: Awareness about climate risks; awareness and uptake of disaster management protocols	Tc1: Heat-related adaptation (passive cooling in buildings, cool roofs, etc.); Tc2: Relocating/refurbishing the critical infrastructure	Ic1: Sustainable land-use & urban planning
Industrial system transition = i		X—Industrial site selection	Bil: Dialogue with the actors on the supply chain;	X—Automation/industrial ecology/circular economy	Iil: Industrial health safety, cooling of workspace

X—no literature found. Source: Authors compilation from the review of 319 publications.

negative score ‘−3’ was assigned if the implementation of an adaptation option made it impossible to achieve a particular gender target. A score of ‘−2’ was assigned if implementing an adaptation option act against the achievement of a gender target, while ‘−1’ was assigned if implementing an adaptation option may limit the achievement of a gender target. The score (0) was assigned to adaptation options with no reported impact on a particular gender target. These scores were assigned based on consensus among sectoral experts.

For each SDG 5 target and adaptation option, the assessment also judged the amount of evidence and degree of agreement among the literature based on consensus among sectoral experts (high or >75% agreement; medium or >50% but <75% agreement; low or <50% agreement), and level of confidence (very high, high, medium, low, very low), based on a 5-star rating system (Supplementary Material 4—Table S4.2). The interaction scores, while helpful in assessing the linkages between adaptation options and SDG 5 targets, are not immediately useful to policy or decision-makers, given that synergies and trade-offs are dependent on socio-economic contexts, the timing of assessment, and the stage of adaptation action. Therefore, we developed the net interaction score (i.e., net of synergies and trade-offs). The net SDG-interaction scores for each sector ( $NS_k$ ) and various SDG 5 targets were calculated using Eq. (1). For details, see Supplementary Material 4.3.

$$NS_k = \sum_k \left[ \frac{Z_j}{P_k} \times \sum_j \left\{ \left( \frac{L_i}{T_j} \right) \times \left( \frac{\sum_i f_i S_i}{L_i} \right) \right\} \right] \quad (1)$$

where  $i$  denotes  $i$ th SDG 5 target,  $j$  denotes the  $j$ th adaptation option category, and  $k$  denotes the  $k$ th sector.  $S$  = Interaction Score (as given in Supplementary Material 4 Table S4.1).  $f_i$  = Number of publications with positive or negative outcomes for  $i$ th SDG 5 target.  $L_i = (\sum_i f_i)$  = Total number of publications mentioning  $i$ th SDG 5 target.  $T_j = (\sum_i L_i)$  = Total number of publications in  $i$ th SDG 5 target for  $j$ th adaptation option.  $Z_j$  = Total number of publications for  $j$ th adaptation option (one publication counted once only).  $P_k$  = total publications for  $k$ th sector.  $\left( \frac{\sum_i f_i S_i}{L_i} \right)$  is the weighted average of positive or negative outcomes for  $i$ th SDG 5 target. Therefore, it also captures the agreement among the publications.

Note that in the case of some SDG 5 targets, the literature is classified as either only synergistic (positive outcomes) or with only trade-offs (negative outcomes), in which case, according to Eq. 1,  $\left( \frac{\sum_i f_i S_i}{L_i} \right) = S_i$ , as  $f_i$  and  $L_i$  have the same values. The total number of publications (literature base) may also be very limited, which would give rise to misleading net score, as it will be a higher score compared to other targets.

We use  $\frac{Z_j}{T_j}$  as a weight in Eq. (1). This serves two purposes: (i) addresses the drawback of misleading net score and (ii) makes the scores of an adaptation option across SDG 5 targets comparable.  $\frac{L_i}{T_j}$  basically, captures the degree of evidence for a particular SDG 5 target, given an adaptation option  $j$

Similarly, to compare net scores across adaptation options,  $\frac{Z_j}{P_k}$  is used as a weight.  $\frac{Z_j}{P_k}$  captures the degree of evidence for a particular adaptation option, given a sector  $k$ .

Note that,  $T_j \neq Z_j$ , as one publication can be repeated in several SDG 5 targets

Sensitivity checks for  $NS_k$  show that net scores are sensitive to: (1) the number of publications (2) publications with positive or negative outcomes  $f_i$ , and, (3) the magnitude of the strength of the SDG interaction score  $S_i$  (for details see Supplementary Material 4.4). As more publications/literature come up documenting

synergies and tradeoffs, the conclusion will need to be revisited in the light of the new information.

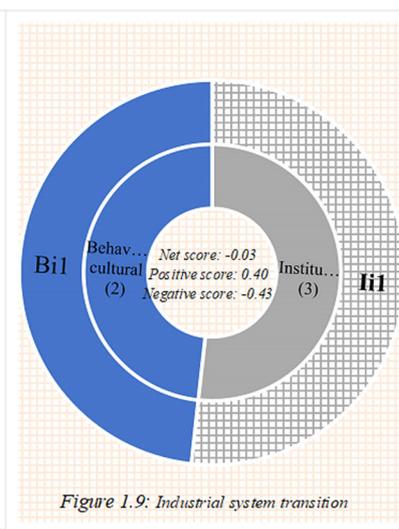
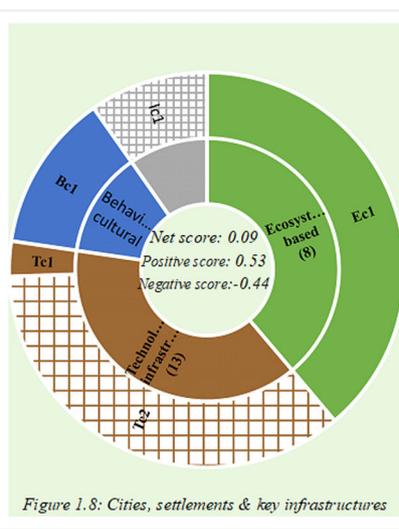
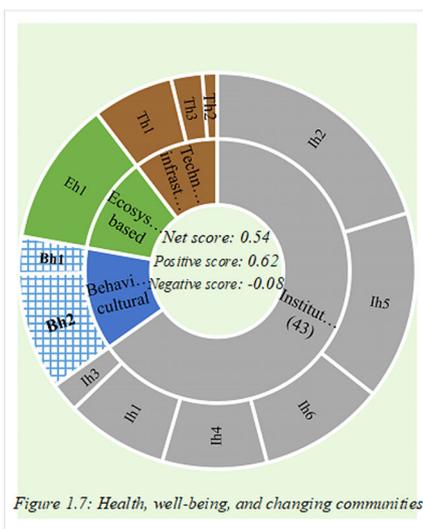
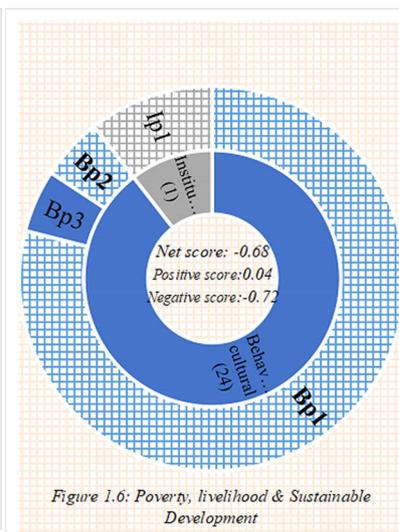
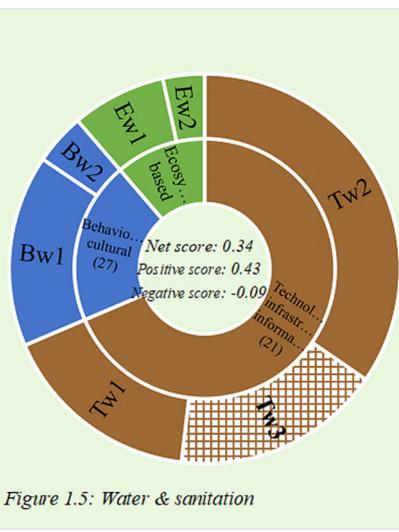
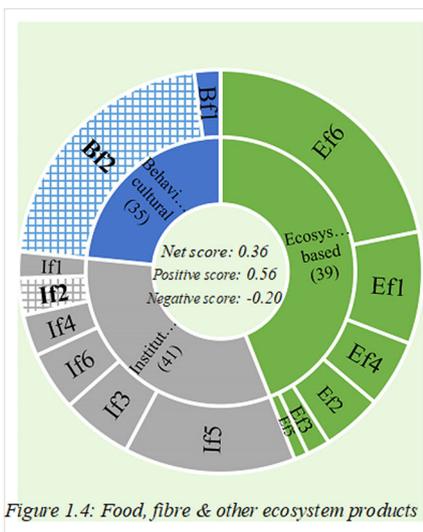
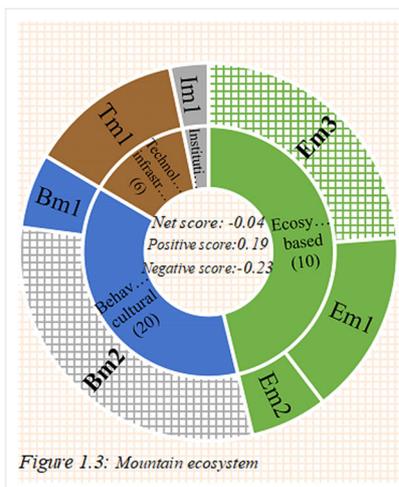
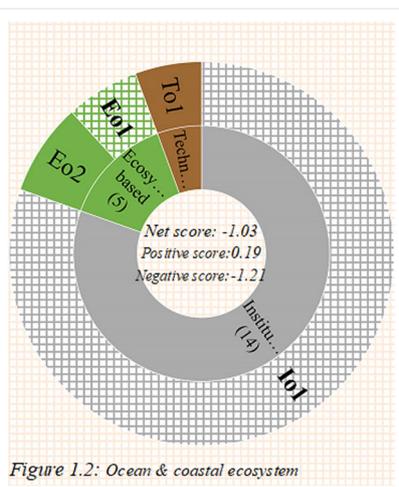
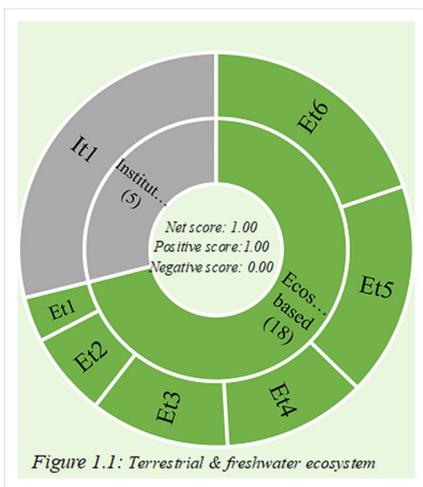
**Limitations of the study.** This study uses only two literature databases (Scopus and Web of Science-Core Collection) and focused on literature written in English only. Though the research was largely based on peer-reviewed articles, we did not completely exclude grey literature. As a rapid review, this could be our limitation. The assessment was constrained by the limited framing of SDG 5, which focuses only on women, ignoring relational and intersectional aspects of gender-based inequities. Thus, power differential and reciprocal relationships of cooperation and conflict between men and women, and interactions of gender with other forms of inequity, such as race or socio-economic status, were not fully captured. This study does not aim at critiquing the targets and indicators of SDG 5 (for targets see United Nations, 2015a; for indicators see United Nations, 2020) themselves as that can be a study in its own right and is beyond the scope of this work. This study used a scoring approach to arrive at a comparative assessment frame based on qualitative links between components. Also, this study provides an aggregated assessment to examine linkages between climate adaptation and gender equality. The study assesses the adaptation option and how it impacts gender equality outcomes but does not claim to cover the changes in gendered power relations, or how gender relations are organised and structured across places, generations, ethnicities, religions, classes, etc. Instead, this study is envisioned as a review to map the synergistic and conflicting links between implemented adaptation actions and SDG 5 in various parts globally, which can be used to inform more granular assessments.

**Results**

The 319 publications that were assessed include quantitative and qualitative case studies, regional assessments, and meta-reviews. Of the nine sectors examined, five sectors (terrestrial and freshwater ecosystems; food and fibre; water and sanitation; health wellbeing and changing communities; and cities, settlements, and key infrastructures) show overall positive links (i.e., positive net score) with SDG 5. For example, in terrestrial and freshwater ecosystems, ecosystem-based adaptation actions have the strongest positive links with all the SDG 5 targets (Fig. 1). Behavioural and institutional adaptation has more negative links to SDG 5, but the degree of impact varies across sectors.

**Terrestrial and freshwater ecosystems (positive net interaction score) (Fig. 1.1 and Supplementary Material 2).**

Positive interactions are generated through the establishment of women’s groups, training and knowledge sharing, and engagement in adaptation actions. These women’s groups have led to community-based adaptation with increased women’s participation (Leone, 2019) (target 5.5), income generation, and local leadership (Yang et al., 2018) (targets 5.1, 5.5, and 5.a). In Bangladesh, for example, women are successfully earning from freshwater aquaculture through adaptation projects focused on training and capacity building (Choudhury et al., 2017) (target 5.b). In turn, this is garnering the women involved greater respect, and increased voice in household decision-making, and a greater ability to control pond resources. In parallel, men have more confidence in giving trained women responsibilities, listening to their views, and permitting autonomy in pond management (Choudhury et al., 2017) (target 5.5). However, women’s engagement in any new technology is dependent on the incorporation of gendered approaches (Scarborough et al., 2017) (target 5.1) and failure in aquaculture hampers a woman’s



reputation and future chances for permission to innovate (Choudhury et al., 2017).

Some negative links to SDG 5 are associated with adaptation actions in ecosystem services and ecosystem restoration. For example, payment for ecosystem services based on property size as a forest protection measure reduces women’s income compared to men (Schwartz, 2017) (target 5.a). Forest conservation/

reforestation programmes, including the Clean Development Mechanism (CDM) and Reforestation and REDD+, as well as forest sequestration programmes, can overlook potential increases in women’s workloads (target 5.4). Further, restricted rules of REDD+, do not always include the traditional economic activities of local communities (Benjaminsen and Kaarhus, 2018) (target 5. a) hampering women’s income-generating options.

**Fig. 1 Adaptation actions and SDG 5 linkages across sectors.** [Note (1) The inner circle is the net score (sum of positive and negative scores) that reflects the strength of the link between adaptation options and the nine SDG 5 targets\* within each sector. The higher the score, the stronger the link. The magnitude of net scores is not comparable across sectors, but signs are comparable. (2) The middle circle depicts the four broad categories of adaptive actions. The numbers in parenthesis show the selected number of publications (Supplementary Material 2 and Table 1). Further, the sectors are colour-coded as follows: **Ecosystem based** (green), **Behavioural/ cultural** (blue), **Technological/ infrastructural** (brown), **Institutional** (grey). (3) The outer circle identifies the total number of individual adaptation options in each adaptive action category (Table 1). The size of the slice in the outer ring shows the relative contribution of the individual option (whether positive or negative). (4) Solid colours denote positive net score; hatching denotes the negative net score; for abbreviations, please see the details in Table 1]. \*Briefly, the different targets for all women and girls everywhere are: (for details please see United Nations, 2020). Target 5.1 Ending all forms of discrimination, Target 5.2 Eliminating all forms of violence, Target 5.3 Eliminating all harmful practices, Target 5.4 Recognising unpaid care and domestic work, Target 5.5 Ensuring full and effective participation and equal opportunities for leadership, Target 5.6 Ensuring universal access to sexual and reproductive health, Target 5.a Undertaking reforms to give equal rights to economic resources, Target 5.b Enhancing the use of enabling technology to promote empowerment and Target 5.c Adopting and strengthening sound policies and enforceable legislation for gender equality and empowerment.

**Ocean and coastal ecosystems (more negative than positive score/negative net interaction score) (Fig. 1.2 and Supplementary Material 2).** The predominantly negative scores reflect the lack of gender-focused approaches in formal adaptation activities. For example, most commercial-scale aquaculture projects exclude women or are gender-blind in countries where many women are engaged in sustainable aquaculture practices (Galapaththi et al., 2020; Prakash et al., 2022b) (targets 5.1, 5.4). In mangrove restoration projects in Pangani Magharibi, Tanzania, women's participation is limited by a lack of access to information about adaptation projects (Omukuti, 2020) (targets 5.5, 5.a). Marine Protected Areas (MPAs) tend to reproduce existing gender disparities in leadership and power (target 5.1) as women are less likely to participate in MPA governance in many countries, including Kenya, Tanzania, Madagascar, Indonesia, and the Philippines. This often results in women seeking non-fishing sources of income to support their families (Call and Sellers, 2019) (targets 5.5, 5.a). Conversely, in the Pacific islands, women are taking the lead and undertaking a range of local-scale adaptation actions that are based on innovation as well as building on traditional and local knowledge, for example, Yap women are planting palm in flooded traditional food growing taro patches and getting coastal protection and materials for building homes. In Papua New Guinea, taro, cassava, and yam are now grown in recycled rice bags. Older women are passing on traditional knowledge to younger ones for the preservation of knowledge (McLeod et al., 2018) leading to opportunities for a new generation to lead (target 5.5).

**Mountain ecosystems (more negative than positive score/negative net interaction score) (Fig. 1.3 and Supplementary Material 2).** Negative links are predominantly due to women's disproportionate access to financial resources and productive land that create biases towards adaptation actions involving men (target 5.a) (Wangui and Smuker, 2018). Moreover, new technologies and information systems are adopted differentially by women and men largely due to differential, gendered access and control over household assets. For example, women felt less empowered to use irrigation assets in agriculture when ownership is controlled by men (Wangui and Smuker, 2018) (target 5.a). Inaccessibility to mobile phone ownership and formal knowledge and information systems, including early warning systems, increases women's exposure to risk (e.g., during disasters), and adversely impacts their capacity to respond to climate impacts (Jin et al., 2016; Bhadwal et al., 2019) (target 5.b). However, women in Uttarakhand, India, found local knowledge to be more effective than formal weather forecast communications (Ravera et al., 2019) (target 5.5). On the positive, environmental constraints due to changing climate have pushed women into new roles, domains, and spaces leading to increased skills and capacities (Goodrich et al., 2019) (targets 5.4, 5.5). Adaptive actions in conservation and recycling to reduce

water scarcity can serve to strengthen women's leadership roles (Su et al., 2017) (targets 5.4, 5.a) in mountain ecosystems.

**Food, fibre, and other ecosystem products (more positive than negative score/positive net interaction score) (Fig. 1.4 and Supplementary Material 2).** Positive links are generated through adaptation actions such as strengthening artisanal activities, livelihood diversification, networks, access to information, socially sensitive training programmes, and valuing traditional knowledge. For example, artisanal and fruit value chains have been identified as offering greater income opportunities for women than more traditional agroforestry in timber, rubber, and cacao value chains (Gumucio et al., 2018) (targets 5.5; 5.a). Diversification across crops and animals in the farm system tended to increase women's control over consumption and marketing (Yiridomoh et al., 2020) (target 5.5). Positive links were often tied to access to information—in Vietnam, women farmers who received the information were able to increase agricultural production and diversify products (Huyer, 2016) (target 5.b). Access to climate information services connected women to new opportunities and can increase agriculture incomes, enhancing women's resilience (target 5.b). Further, agroecological training that included social dimensions has been demonstrated to improve gender equality outcomes, generate more equitable household workloads, and enhance educational opportunities for girls (Briggs et al., 2019) (targets 5.4; 5.5). In Malawi, households where farmers discussed agroecological farming with their spouses, a significant increase in food security and nutrition was observed (Bezner Kerr et al., 2019). Farmers' networks also enhance women's leadership opportunities and autonomy (Sylvester and Little, 2020) (target 5.5). In the Alpine region, farm women possess rich traditional wisdom in handling high-quality food products. Not only have they led the movement to localise food systems, but they have also established and operated Climate Smart Agricultural practices, farm stores, herbal medicines, traditional grain varieties, and introduced culinary practices (Oedl-Wieser, 2017) (target 5.5).

Despite these positive links, conservation-focused agricultural programmes have had mixed effects, with some evidence of increasing women's roles in decision-making and leadership (e.g., in Malawi) (Maher et al., 2015) (targets 5.4, 5.5), but also increasing women's workloads where the rate of male migration is high (e.g., Ha Tinh and Thai Binh provinces in Vietnam) (target 5.4). Women also face barriers including low-income levels, lack of skills in deciphering climate information, and limited access to mobile phones (Drewry et al., 2019) (targets 5.a, 5.b).

**Water and sanitation (mainly positive score/positive net interaction score) (Fig. 1.5 and Supplementary Material 2).** In urban settings, positive links are predominant because women and men are responding to water scarcity through adaptation

actions such as small rainwater harvesting systems and storage tanks, greywater recycling systems, and fog water collection. Even if not gender-responsive in design, given the major role of women and girls in water fetching in many countries, these adaptation actions often reduced their physical and time burdens, increasing time to be spent on other activities such as schooling for girl children (Lucier and Qadir, 2018) (targets 5.1, 5.4). For these reasons, improved water and sanitation facilities have been shown to increase school enrolment as well as a reduction in school dropout rates for girls (Pouramin et al., 2020) (target 5.c). Long-term benefits are significant, as higher education for women is correlated with reduced incidence of diarrhoea mainly due to an increase in awareness (United Nations, 2018) (target 5.c).

Despite these positive links, there is a notable gap in recognition of menstrual hygiene management—lack of access to adequate hygiene and sanitation facilities often restricts women and girls from fully participating in the job place or regularly attending school (UN, 2015b) (target 5.5). Further, when infrastructure developed to respond to natural disasters considers gender-specific needs, such as sanitation facilities, this can create security and safety for women and girls and foster empowerment (WaterAid, 2017) (targets 5.1, 5.4, 5.6, 5.b). Unfortunately, in the absence of infrastructure to reduce water scarcity and improve access to sanitation and hygiene facilities, maladaptation can occur. For example, women may travel further distances to collect water. But adapting in this way, women's domestic burden increases, and their safety is put at risk, including exposure to violence and sexual assault (United Nations, 2018) (target 5.2).

**Poverty, livelihoods, and sustainable development (more negative than positive score/negative net interaction score) (Fig. 1.6 and Supplementary Material 2).** Negative links are predominant as livelihood diversification and capacity building are sometimes poorly articulated with gender equality. Some livelihood strategies have been better aligned with women's engagement, such as homestay-based ecotourism and fruit farming that presents promising and innovative adaptation actions that are being taken up by women (Van Aelst and Holvoet, 2018) (target 5.5). However, continuing patriarchal institutions and structural discrimination result in women's lower access to services and economic resources, including less control over income, fewer productive assets, lack of property rights, less access to credit, irrigation assets, climate information and seeds. This has led to reduced adaptation options for women's farm-related work (Buechler, 2016) (target 5.1). Further, unanticipated events and actions can have adverse impacts on women. For example, women are paid lower wages compared to men in off-farm adaptive action projects (Bedelian and Ogutu, 2017) (target 5.1), while crop failure due to climate events force women to sell off their assets to generate income for their families (Masson et al., 2019) (target 5.4). Larger numbers of people engaging in migration as an adaptation action also have negative impacts on women, often leading to additional work burdens and precarious work contexts with low pay and poor living conditions in new locations (Evertsen and van der Geest, 2020) (target 5.4). For example, when women care workers from the global south enter global care chains, they leave a care gap in the places they are migrating from, adding additional burdens to those [women and girls] who stay behind (Clark and Bettini, 2017) (target 5.4). Finally, a feminist political economy interpretation of disaster recovery across four empirical case studies from the United States, Thailand, Philippines, and New Zealand, shows that methods of 'enclosure, exclusion, encroachment, and entrenchment can distort disaster-relief and post-disaster safety nets, to

maintain or exacerbate gender, class, and ethnic disparities' (Sovacool et al., 2018, p. 244) (target 5.1).

**Health, well-being, and changing community structures (more positive than negative score/positive net interaction score) (Fig. 1.7 and Supplementary Material 2).** Positive links are predominant because adaptation evidence points to improved women's physical and mental health and reduced mortality. For example, actions that enhance participation in land-based activities and interaction with community members helped in sustaining mental health and well-being in Indigenous communities, regardless of gender (MacDonald et al., 2015) (target 5.2). Maternal education significantly reduced the risk of child undernutrition in post-flooding events or post-drought situations (Davenport et al., 2017) (target 5.1). More generally, climate change policies that address mitigation and adaptation together can improve women's well-being and mental health, through mechanisms such as increased access to green spaces, reduced air pollution, increased use of bicycles, and access to transport. However, while few policies have a little indirect or direct impact on people's well-being, resource-poor and low socio-economic status individuals and communities may not be able to take advantage, meaning that the intersection of different vulnerabilities should be considered (James et al., 2016) (target 5.c). For example, the effects of disease and disability amplify vulnerability and gender inequity (Osamor and Grady, 2016) (targets 5.1, 5.4). Often, women also have less access to credit or insurance for climate change adaptation practices, including post-disaster relief (Hossain and Zaman, 2018) (targets 5.1, 5.a).

**Cities, settlements, and key infrastructures (more positive than negative score/positive net interaction score) (Fig. 1.8 and Supplementary Material 2).** Overall, several urban adaptation options report positive links between women's participation and gender equality (Solomon et al., 2021). For example, green infrastructure options are enabling women's participation in planning and decision-making processes by expanding their social and economic capital and enhancing household food security (Barnes and Bendixsen, 2017) (Target 5.5). Urban agriculture allows women to gain social and economic empowerment (Olivier and Heineken, 2017) (target 5.5). Well-designed and inclusive transit-oriented development that considers women's specific needs can ensure freedom of movement and security in public spaces (Milan and Creutzig, 2017) (target 5.a). Similarly, bottom-up awareness-building programmes can address gender-specific concerns and promote positive impacts on women's livelihoods and well-being as well as expanding their participation in socio-economic, physical, and political spaces, leading to long-term empowerment outcomes (Mustafa et al., 2015) (target 5.b).

However, some adaptation actions are negatively linked with SDG 5 targets. For example, public infrastructure-based adaptations to heat stress that do not explicitly consider gender in policy design are limited in their accessibility to women. Current urban policies around climate resilience often do not recognise structural gendered barriers to participation, such as inadequate recognition of women's unpaid work, insufficient workforce participation, and their critical role in decision-making (Jabeen and Guy, 2015) (target 5.c). This gender-blind approach can translate into additional work burdens and inequities for women. Further, post-disaster relocation can force women to accept lesser pay for the same job as compared to men, while women's time poverty reduces access to social networks and opportunities to participate in formal employment (Sunikka-Blank et al., 2019) (target 5.4).

**Industrial system transition (more negative than positive score/negative net interaction score) (Fig. 1.9 and Supplementary Material 2).** The literature on adaptive actions in industrial systems is extremely limited, signalling a knowledge gap. Those that exist tend to demonstrate negative links with SDG 5. For example, there are many organisations such as women's groups and NGOs that work with migrant populations in the informal sector. In this context, there is an urgent need for legislation to regulate working conditions, wage structure, and welfare measures for women workers (Dehury and Dehury, 2017) (target 5.c). More specifically, climate impacts such as heat waves indicate a need for increasing awareness about adaptive actions (Varghese et al., 2019) (targets 5.1, 5.a). Women's self-help groups and NGOs could play a bridging role to increase communications and information-sharing between workers and their employers (Dehury and Dehury, 2017) (targets 5.b, 5.c).

### **Discussion: Leveraging adaptation actions to achieve gender equality**

We assessed the outcomes of adaptation actions by looking into the qualitative links with gender equality using SDG 5 and its targets. From a review of 319 publications, we find that currently reported adaptation has positive and negative outcomes for gender equality, but some sectors tend to have large knowledge gaps (e.g., adaptation in industries) while some have more negative outcomes of SDG 5 (e.g., ocean and coastal ecosystem, mountain ecosystem, poverty livelihood, etc.). We also found that the current set of SDG 5 targets is unable to capture dimensions of gender equality and intersectionality comprehensively. Therefore, we revisited the SDG framework and identified an additional 29 gender-related targets across 11 other SDGs (Fig. 2). We argue that studies using the SDG framework will gain from the use of this expanded list of gender-related targets, which we call SDG 5+. The Sixteen Plus Forum (2021) and Roy et al. (2021) use similar logic to derive a comprehensive list of targets to mobilise actions around peace, justice, inclusiveness and international cooperation respectively that are not limited to SDG 16 and SDG 17 targets alone.

The SDG 5+ suite of targets helps in addressing many trade-offs (negative links) identified in earlier sections. For example, a study of adaptation options for Indian farming communities found that gender intersects with caste, age and wealth by mediating priorities and power differences when implementing adaptation options (Ravera et al., 2016; Rao et al., 2019).

Various actions enabled gender equity, albeit in context-specific ways, with explicit attention to gender and other social inequities in programme design as a key factor. Enabling active participation in programmes of marginalised groups, including low-income, Indigenous people, and other groups that experience discrimination, was another important feature of many adaptation programmes. Addressing structural inequities in policies, regulations, and programmes was important enabling condition for ensuring gender equity and adaptation targets. Designing inclusive decision-making processes to actively engage women and other marginalised groups was another strategy for ensuring gender and other social equity gains in adaptation programmes and policies.

Using the findings from this review and consideration of the SDG 5+ suite of targets, a roadmap emerges for addressing many of the trade-offs identified. Embedding gender considerations and facilitating women's participation in project design and implementation along with inclusive policies, training, information access, planning, and monitoring can reduce or even eliminate negative links (Table 2). For instance, changes in project design and management of mangrove conservation programmes across

multiple countries could facilitate information access to women, thereby enabling their participation in focus group discussions (Barrero-Amórtegui and Maldonado, 2021). Gender-transformative project design in adaptive marine protection activities can also prevent income loss to women by loosening movement restrictions in the collection of marine products (Rohe et al., 2018). Forest user groups with higher proportions of women in executive committees have been demonstrated to engage more in environmental concerns and include equity considerations in their rules of operation (Clair, 2016).

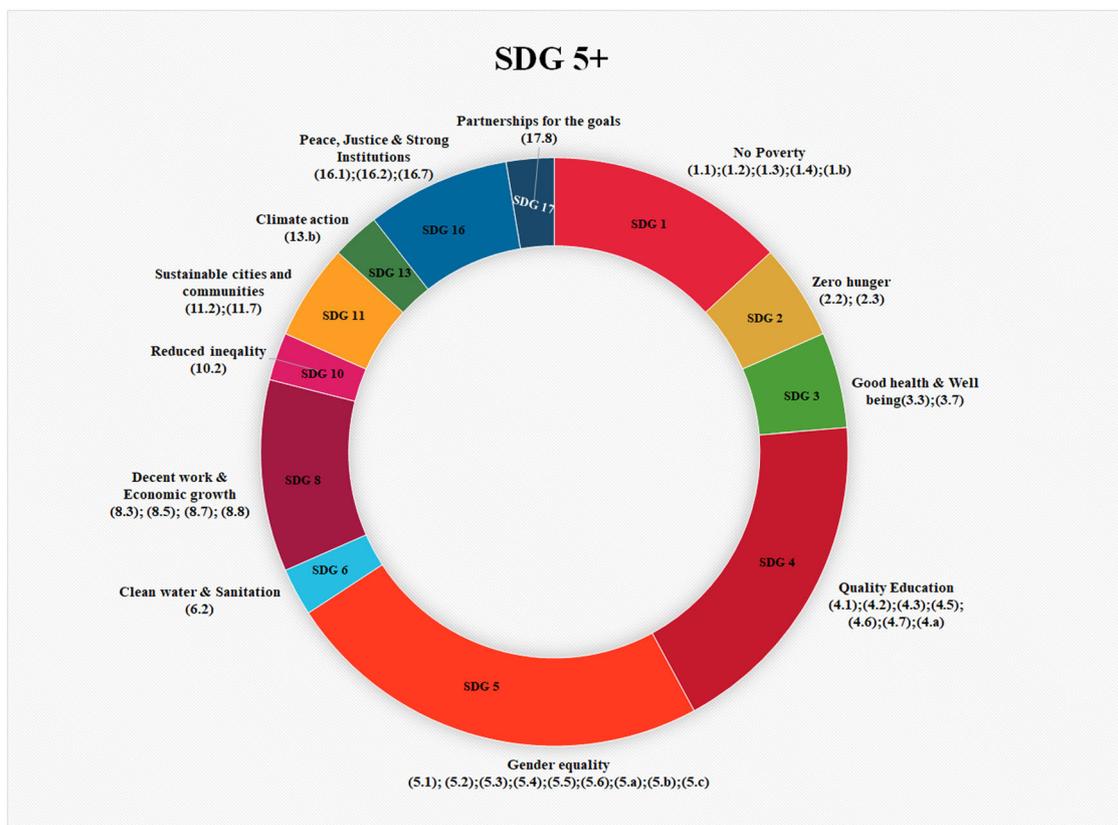
All sectoral adaptation actions need the engagement of local bodies and communities with strong vertical links to national institutions supported by international cooperation to scale up success stories (e.g., Singh et al., 2021 in sub-national adaptation planning in India; Mersha and van Laerhoven, 2018, in Ethiopia). In achieving this, some adaptation options will require further research to understand local specificities and social norms as well as their implications. Indeed, this assessment demonstrates that there is a need for both academic and action research as well as for policymaking and financing communities to focus on climate change adaptation and gender equality synergistically across sectors to avoid more damaging social impacts through adaptation.

Adaptation in some sectors and regions, such as natural ecosystems, already demonstrates positive synergies with gender equality compared to other categories such as industrial system transition, that continue to be gender blind. Further, it is important to highlight in adaptation programmes/projects the relevance of working with and supporting women's associations and consideration of women's agency (Rao, 2017; Rao et al., 2019; Palliwoda et al., 2017). Consideration of racial inequities and other forms of marginalisation is also important. Indigenous women can have an important role in supporting, teaching, and adapting traditional knowledge to adaptive actions. Bringing together women growing up in diverse cultural and social environments and age groups helps in intergenerational knowledge transfer (Lemke and Delormier, 2017; Magni, 2017).

### **Conclusion**

This study undertook a rapid review of the climate change adaptation literature to examine the positive, negative, and/or neutral outcomes of ongoing adaptation interventions on gender equality (operationalized through the Sustainable Development Goal 5 on Gender Equality). The adaptation projects assessed are distributed across nine sectors: [1] terrestrial and freshwater ecosystems; [2] ocean and coastal ecosystems; [3] mountain ecosystems; [4] food and fibre and other ecosystem products; [5] water and sanitation; [6] poverty, livelihoods, and sustainable development; [7] cities, settlements, and key infrastructures; [8] health, well-being, and changing community structure; and [9] industrial system transition. The final assessment presented here draws on 319 peer-reviewed articles. This rapid review is not put forth as a comprehensive assessment of all ongoing adaptations but provides an overview of what is known about adaptation outcomes for gender equality, and where significant knowledge gaps remain.

Our assessment confirms that current adaptations aiming to reduce exposure, risks, and vulnerabilities to climate change do not automatically enhance gender equality. Structural inequalities resulting from historical marginalisation (e.g., based on geography, caste, or ethnicity), and social norms around gendered work, are exacerbating unequal outcomes for the most vulnerable. Thus, without an explicit focus on gender equality and transformative change at project formulation, design, implementation, and monitoring stages, adaptation projects run the risk of reproducing existing gender disparities. While many projects do not explicitly discuss whether they intended to achieve gender



**Fig. 2 List of targets across all SDGs that contribute to SDG 5 referred here as SDG 5+.** [Note Figure: Colour codes of the slices are the same as the SDG-icon colour codes. In the brackets, the numbers represent SDG 1-SDG 17 and alphabets associated with the numbers represent targets<sup>a</sup> under each SDG. The size of the slice is proportionate to the relative numbers of targets with a gender dimension within a given SDG. <sup>a</sup>The targets, in short, are about: SDG 1: Eradicating extreme poverty (1.1; 1.2), Implementing nationally appropriate social protection systems (1.3), Ensuring equal rights to economic resources and basic services (1.4), creating sound policy frameworks for gender-sensitive development strategies (1.b). SDG 2: Ending all forms of malnutrition (2.2), Doubling the agricultural productivity and incomes of small-scale food producers (2.3). SDG 3: Ending epidemics and communicable diseases (3.3), ensuring universal access to sexual and reproductive healthcare services (3.7). SDG 4: Ensuring children complete free, equitable and quality primary and secondary education (4.1), ensuring access to quality early childhood development care and pre-primary education (4.2), ensuring affordable and quality technical, vocational and tertiary education, including university (4.3), eliminating gender disparities in education (4.5), ensuring that all youth achieve literacy and numeracy (4.6), ensuring that all learners acquire the knowledge and skills needed to promote sustainable development (4.7), building and upgrading education facilities (4. a). SDG 5: see caption of Fig. 1. SDG 6: Achieving access to adequate and equitable sanitation and hygiene (6.2). SDG 8: Promoting development-oriented policies that support productive activities (8.3), achieving full and productive employment and decent work (8.5), taking immediate and effective measures to eradicate forced labour, end modern slavery and human trafficking (8.7), protecting labour rights and promoting safe and secure working environments (8.8). SDG 10: Empowering and promoting the social, economic and political inclusion (10.2). SDG 11: Providing access to safe, affordable, accessible and sustainable transport systems (11.2), providing universal access to safe, inclusive and accessible, green and public spaces (11.7). SDG 13: Promoting mechanisms for raising capacity for effective climate change-related planning and management (13.b). SDG 16: Significantly reduce all forms of violence and related death rates (16.1), ending abuse, exploitation, trafficking (16.2), ensuring responsive, inclusive, participatory and representative decision-making at all levels (16.7). SDG 17: Enhancing capacity-building support to developing countries (17.18) (for details see Supplementary Material 5 and United Nations, 2015a, 2020)].

equality, this assessment demonstrates how adaptation actions can have intended and unintended synergies (positive impacts) and trade-offs (negative consequences) for SDG 5.

This study identified various policy actions and priorities from case studies that can reduce and even eliminate some of the trade-offs that adaptation can have on gender equality. These include gender-sensitive project design and careful choice of awareness-building instruments such as gender-targeted dissemination of climate information; creation of women’s networks, direct engagement of women in decision-making; and wherever applicable, female leadership in adaptation projects. In practice, these mean equitable access to finance and insurance, inclusive ownership of assets that build adaptive capacities (e.g., irrigation equipment or food rations), investing in maternal health education or urban infrastructure that promotes safe

transit systems, etc. Training programmes that are socially sensitive, integrate local knowledge held by older women, and focus on skill-building have more positive outcomes for gender equality. Legislations and policies on wage structures that transcend social norms, carefully anticipating and monitoring if adaptation interventions are disproportionately increasing women’s workloads, and paying attention to disproportionate burdens on women such as in post-disaster relief distribution or relocation also help in reducing inequity. Investing in appropriately designed adaptation actions will not only enable women to become resilient in the long run but stimulate economic activity and employment in the near term (Gurung and Bisht, 2014). This conclusion becomes relevant, especially for post-COVID19 recovery (Sultana, 2021) where each country is designing recovery paths with stimulus packages.

**Table 2 Policy and action priorities in adaptation projects to enhance gender equality.**

Objectives	Possible policy and action priorities (also see Supplementary Material 2)
Enhance women’s participation, leadership, and share in the power structure in ecosystem-based (e.g., biodiversity conservation, protection, natural resource management, agroecology) and community-based adaptation activities.	<ul style="list-style-type: none"> <li>● Targeted information dissemination to enhance participation of marginalised groups including women, girls, and intersecting categories (e.g., income, ethnicity) in adaptation activities related to focused group discussions.</li> <li>● Address gender and other intersecting inequities when introducing any adaptation option.</li> <li>● Create a women’s group to foster networking among women.</li> <li>● Organise workshops for leadership building for marginalised women and groups.</li> <li>● Revise decision-making structures to explicitly address inclusivity, transparency, and accountability along with gender, ethnicity, class, and other social categories of marginalisation.</li> </ul>
Inclusion of women in livelihood diversification projects	<ul style="list-style-type: none"> <li>● Provide institutional support as the enabling environment to support resilience building for women and not just as beneficiaries, e.g., provide extension services like improving cash crop growing skills and technology training</li> </ul>
Increase women’s participation in urban planning	<ul style="list-style-type: none"> <li>● Frame and implement urban policies that recognise and address structural barriers to women’s participation, such as recognition of women’s unpaid work, participation, and leadership promotion in decision-making.</li> </ul>
Enhance women’s recognition in climate-resilient infrastructure interventions	<ul style="list-style-type: none"> <li>● Design climate-resilient infrastructure interventions explicitly focusing on gendered differences in needs and the spaces that they inhabit, e.g., by designing women-centric evacuation shelters</li> </ul>
Reduce disadvantages to women from increased migration (including pre/post-disaster)	<ul style="list-style-type: none"> <li>● Provide social safety nets and ensure marginalised women’s participation in off-farm adaptation activities.</li> <li>● Facilitate social networking among women in the community so that they can help each other when needed.</li> <li>● Empower the use of local and traditional knowledge.</li> <li>● Provide sanitation facilities and women’s safety at the migration site</li> <li>● Connect to livelihood diversification actions</li> </ul>
Reduce vulnerability and enhance the adaptive capacities of women-headed households	<ul style="list-style-type: none"> <li>● Invest in women and girls’ education and work towards their empowerment.</li> <li>● Increase accessibility of women to reasonable credit facilities.</li> <li>● Increase access to the market through programmes or schemes that provide social security.</li> </ul>
Enhance women’s access to improved WaSH (water supply, sanitation, and hygiene) infrastructure	<ul style="list-style-type: none"> <li>● Expand early warning systems to reach women</li> <li>● Plan and provide climate-resilient WaSH facilities with menstrual hygiene management for women in workplaces, public places, educational institutions, and emergency shelters</li> </ul>
Enhance access to training, information, technology, and resources for new adaptation projects	<ul style="list-style-type: none"> <li>● Develop an explicit focus on women in multilateral funding agencies to ensure women’s participation.</li> <li>● Establish knowledge and information delivery channels that design and deliver relevant and context-specific climate information/seasonal forecasts that respond to the specific needs of rural and marginalised women.</li> <li>● Enhance the capacity of women to be able to understand and respond to climate advisories</li> </ul>
Enhance women’s access to climate insurance products	<ul style="list-style-type: none"> <li>● Adopt legislation that promotes equitable access to resources at both national and subnational levels, regardless of social norms</li> </ul>
Improve women’s working conditions in all sectors: organised, unorganised, formal, and informal	<ul style="list-style-type: none"> <li>● Plan and implement legislation for regulating welfare measures targeting women in the labour force, e.g., working conditions and wage structure</li> </ul>
Enhance, advocate and encourage the sharing of Indigenous and local knowledge from older women to younger generations	<ul style="list-style-type: none"> <li>● Organise knowledge-sharing workshops that respect and recognise different sources of knowledge</li> </ul>

Source: Authors’ compilation from the 319 papers used in the review.

Evidence from four sectors: ocean and coastal ecosystems; mountain ecosystems; poverty, livelihood, and sustainable development; and industrial system transitions shows more negative than positive links between adaptation interventions and gender equity outcomes. This strengthens our argument that every adaptation project does not necessarily contribute to gender equality and unless it is designed to be sensitive and responsive to existing intersectionality, inequities, and their drivers, adaptation cannot hope to be gender transformative. While this conclusion reiterates feminist scholarship on exacerbating gendered vulnerability, it does highlight how business as usual adaptation continues to dominate the adaptation landscape. This strengthens

calls for all climate action to have early and intentional gender mainstreaming.

Based on these findings, we suggest an additional course correction for SDG 5 through the implementation of an SDG 5+ approach. First, there is a need for adaptation practice communities to focus on how to incorporate gender equality within climate change adaptation projects. Second, it is important to revisit and redesign development projects and climate change responsive projects to accommodate context specificities that go beyond the one-size-fits-all type of strategy to effectively address women’s differential needs and unequal relations and circumstances (Huynh and Resurreccion, 2014; Sultana, 2014; Rao et al.,

2019, Prakash et al., 2022a). Third, there is a need to reduce existing structural injustices and make sure that adaptation options are gender-responsive (Singh et al., 2021) and power-sensitive (Vij et al., 2021). Fourth, policies need to incorporate gender concerns in adaptation priority design, planning, and implementation, along with an understanding of the intersectionality, i.e., how gender is mediated by other social vulnerabilities, such as income and ethnicity, women's health, and well-being need to be a standard practice. Continuous monitoring, database preparation, or updating the one prepared here will also provide almost real-time provision for course correction.

### Data availability

All data generated or analysed during this study are included in this published article and its five supplementary materials [Supplementary Material (SM) 1: Categorisation of Sectors/Regions and Adaptation Categories and Search terms and search results; Supplementary Material (SM) 2: Sector-wise adaptation options and SDG 5 targets mapping; Supplementary Material (SM) 3: Sector-wise unique list of references (Count-319); Supplementary Material (SM) 4: SDG-interaction score and Confidence level assessment; Supplementary Material (SM) 5: SDG 5+ targets].

Received: 22 March 2021; Accepted: 13 July 2022;

Published online: 01 August 2022

### References

- Agarwal B (2018) Gender equality, food security and the sustainable development goals. *Curr Opin Environ Sustain* 34:26–32
- Ampaire EL, Acosta M, Huyer S, Kigonya R, Muchunguzi P, Muna R, Jassogne L (2020) Gender in climate change, agriculture, and natural resource policies: insights from East Africa. *Clim Change* 158(1):43–60
- Andrijevic M, Cuaresma JC, Lissner T, Thomas A, Schleussner CF (2020) Overcoming gender inequality for climate resilient development. *Nat Commun* 11(1):1–8
- Barnes KL, Bendixsen CG (2017) “When this breaks down, it’s black gold”: race and gender in agricultural health and safety. *J Agromed* 22(1):56–65
- Barrero-Amórtegui Y, Maldonado JH (2021) Gender composition of management groups in a conservation agreement framework: experimental evidence for mangrove use in the Colombian Pacific. *World Dev* 142:105449
- Bedelian C, Ogutu JO (2017) Trade-offs for climate-resilient pastoral livelihoods in wildlife conservancies in the Mara ecosystem, Kenya. *Pastoralism* 7:2–22
- Benjaminson G, Kaarhus R (2018) Commodification of forest carbon: REDD+ and socially embedded forest practices in Zanzibar. *Geoforum* 93:48–56
- Bezner Kerr R, Hickey C, Lupafya E, Dakishoni L (2019) Repairing rifts or reproducing inequalities? Agroecology, food sovereignty, and gender justice in Malawi. *J Peasant Stud* 46(7):1499–1518
- Bhadwal S, Sharma G, Gorti G, Sen SM (2019) Livelihoods, gender and climate change in the Eastern Himalayas. *Environ Dev* 31:68–77
- Bhattarai B (2020) How do gender relations shape a community’s ability to adapt to climate change? Insights from Nepal’s community forestry. *Clim Dev* 12(10):876–887
- Briggs L, Krasny M, Stedman RC (2019) Exploring youth development through an environmental education program for rural indigenous women. *J Environ Educ* 50(1):37–51. <https://doi.org/10.1080/00958964.2018.1502137>
- Bryan E, Bernier Q, Espinal M, Ringler C (2018) Making climate change adaptation programmes in sub-Saharan Africa more gender responsive: insights from implementing organizations on the barriers and opportunities. *Clim Dev* 10(5):417–431
- Buechler S (2016) Gendered vulnerabilities and grassroots adaptation initiatives in home gardens and small orchards in Northwest Mexico. *Ambio* 45:S322–S334
- Call M, Sellers S (2019) How does gendered vulnerability shape the adoption and impact of sustainable livelihood interventions in an era of global climate change? *Environ Res Lett* 14(8):083005
- Carr ER, Thompson MC (2014) Gender and climate change adaptation in agrarian settings: current thinking, new directions, and research frontiers. *Geogr Compass* 8(3):182–197
- Choudhury A, McDougall C, Rajaratnam S (2017). Women’s empowerment in aquaculture. Two case studies from Bangladesh. FAO <http://www.fao.org/3/a-i7512e.pdf>
- Clair PCS (2016) Community forest management, gender and fuelwood collection in rural Nepal. *J Forest Econ* 24:52–71
- Clark N, Bettini G (2017) ‘Floods’ of migrants, flows of care: between climate displacement and global care chains. *Soc Res* 65(2\_suppl):36–54
- Creutzig F, Callaghan MW, Ramakrishnan A, Javaid A, Niamir L, Müller-Hansen F ... Wilson C (2020) Reviewing the scope and thematic focus of 100,000 publications on energy consumption, services and social aspects of climate change: a big data approach to demand-side mitigation. *Environ Res Lett*. 16(3):033001
- Davenport F, Grace K, Funk C, Shukla S (2017) Child health outcomes in sub-Saharan Africa: a comparison of changes in climate and socio-economic factors. *Glob Environ Change* 46:72–87
- Dehury RK, DeHuRy P (2017) A review of measures against increasing temperature and climate change for the safeguard of workers in India. *J Clin Diagn Res* 11:10
- Drewry JL, Shutske JM, Trechter D, Luck BD, Pitman L (2019) Assessment of digital technology adoption and access barriers among crop, dairy and livestock producers in Wisconsin. *Comput Electron Agric* 165:104960
- Evertsen KF, van der Geest K (2020) Gender, environment and migration in Bangladesh. *Clim Dev* 12(1):12–22
- Few R, Morchain D, Spear D et al. (2017) Transformation, adaptation and development: relating concepts to practice. *Palgrave Commun* 3:17092. <https://doi.org/10.1057/palcomms.2017.92>
- Galappaththi EK, Ford JD, Bennett EM (2020) Climate change and adaptation to social-ecological change: the case of indigenous people and culture-based fisheries in Sri Lanka. *Clim Change* 162(2):279–300. <https://doi.org/10.1007/s10584-020-02716-3>
- Goodrich CG, Prakash A, Udas PB (2019) Gendered vulnerability and adaptation in Hindu-Kush Himalayas: research insights. *Environ Dev* 31:1–8
- Gumucio T, Alves MDA, Orentlicher N, Hernández Ceballos MC (2018) Analysis of gender research on forest, tree and agroforestry value chains in Latin America. *For Trees Livelihoods* 27(2):69–85
- Gurung DD, Bisht S (2014) Women’s empowerment at the frontline of adaptation: emerging issues, adaptive practices, and priorities in Nepal. ICIMOD Working Paper (2014/3)
- Hoegh-Guldberg O et al. (2019) The ocean as a solution to climate change: five opportunities for action. Report. World Resources Institute, Washington, DC
- Honegger M, Michaelowa A, Roy J (2020) Potential implications of carbon dioxide removal for the sustainable development goals. *Clim Policy* 1–21. <https://doi.org/10.1080/14693062.2020.1843388>
- Hossain KM, Zaman F (2018) Unravelling coastal people’s adaptation to salinity: evidence from Bangladesh. *Int J Environ Sustain Dev* 17:70–92
- Huyer S (2016) Closing the gender gap in agriculture. *Gend Technol Dev* 20(2):105–116. <https://doi.org/10.1177/0971852416643872>
- Huynh PT, Resurreccion BP (2014) Women’s differentiated vulnerability and adaptations to climate-related agricultural water scarcity in rural Central Vietnam. *Clim Dev* 6(3):226–237
- IPCC (2019) Annex I: Glossary [Weyer NM (ed)]. In: Pörtner H-O, Roberts DC, Masson-Delmotte V, Zhai P, Tignor M, Poloczanska E, Mintenbeck K, Alegría A, Nicolai M, Okem A, Petzold J, Rama B, Weyer NM (eds) IPCC special report on the ocean and cryosphere in a changing climate. IPCC, pp. 677–702 <https://www.ipcc.ch/srocc/chapter/glossary/>. Accessed 25 Jun 2021
- IPCC (2022) Summary for policymakers [Pörtner H-O, Roberts DC, Poloczanska ES, Mintenbeck K, Tignor M, Alegría A, Craig M, Langsdorf S, Lösschke S, Möller V, Okem A (eds)]. In: *Climate Change 2022: impacts, adaptation, and vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Pörtner H-O, Roberts DC, Tignor M, Poloczanska ES, Mintenbeck K, Alegría A, Craig M, Langsdorf S, Lösschke S, Möller V, Okem A, Rama B (eds)]. Cambridge University Press (in press)
- Jabeen H, Guy S (2015) Fluid engagements: responding to the co-evolution of poverty and climate change in Dhaka, Bangladesh. *Habitat Int* 47:307–314
- James P, Hart JE, Banay RF, Laden F (2016) Exposure to greenness and mortality in a nationwide prospective cohort study of women. *Environ Health Perspect* 124:1344–1352
- Jerneck A (2018) What about gender in climate change? Twelve feminist lessons from development. *Sustainability* 10(3):627
- Jin J, Wang W, Wang X (2016) Adapting agriculture to the drought hazard in rural China: household strategies and determinants. *Nat Hazards* 82(3):1609–1619
- Kaijser A, Kronsell A (2014) Climate change through the lens of intersectionality. *Environ Politics* 23(3):417–433
- Lemke S, Delormier T (2017) Indigenous peoples’ food systems, nutrition, and gender: conceptual and methodological considerations. *Matern Child Nutr* 13:e12499

- Leone M (2019) Women as decision makers in community forest management: Evidence from Nepal. *J Dev Econ* 138:180–191
- Liem A, Natari RB, Jimmy, Hall BJ (2021) Digital health applications in mental health care for immigrants and refugees: a rapid review. *Telemed e-Health* 27(1):3–16
- Lucier KJ, Qadir M (2018) Gender and community mainstreaming in fog water collection systems. *Water* 10(10):1472. <https://doi.org/10.3390/w10101472>
- MacDonald JP, Willox AC, Ford JD, Shiwak I, Wood M, Government RIC, IMHACC Team (2015) Protective factors for mental health and well-being in a changing climate: perspectives from Inuit youth in Nunatsiavut, Labrador. *Soc Sci Med* 141:133–141
- Magni G (2017) Indigenous knowledge and implications for the sustainable development agenda. *Eur J Educ* 52(4):437–447
- Maher J, Wagstaff P, O'Brien J (2015) Empowering women through conservation agriculture: rhetoric or reality? Evidence from Malawi. In: Chan C, Fantle-Lepczyk J (eds) *Conservation agriculture in subsistence farming: case studies from South Asia and beyond*. CABI, Oxfordshire, pp. 226–238
- Masson VL, Benoudji C, Reyes SS, Bernard G (2019) How violence against women and girls undermines resilience to climate risks in Chad. *Disasters* 43:3
- McCollum DL, Echeverri LG, Busch S, Pachauri S, Parkinson S, Rogelj J, Riahi K (2018) Connecting the sustainable development goals by their energy interlinkages. *Environ Res Lett* 13(3):033006
- Mcleod E, Arora-Jonsson S, Masuda YJ, Bruton-Adams M, Emaurois CO, Gorong B, Whitford L (2018) Raising the voices of Pacific Island women to inform climate adaptation policies. *Mar Policy* 93:178–185
- Mersha AA, van Laerhoven F (2018) The interplay between planned and autonomous adaptation in response to climate change: Insights from rural Ethiopia. *World Development* 107:87–97. <https://doi.org/10.1016/j.worlddev.2018.03.001>
- Milan BF, Creutzig F (2017) Lifting peripheral fortunes: upgrading transit improves spatial, income and gender equity in Medellín. *Cities* 70:122–134
- Mustafa D, Gioli G, Qazi S, Waraich R, Rehman A, Zahoor R (2015) Gendering flood early warning systems: the case of Pakistan. *Environ Hazards* 14(4):312–328
- Ngigi MW, Mueller U, Birner R (2017) Gender differences in climate change adaptation strategies and participation in group-based approaches: an intra-household analysis from rural Kenya. *Ecol Econ* 138:99–108
- Nilsson M, Griggs D, Visbeck M (2016) Policy: map the interactions between Sustainable Development Goals. *Nature* 534(7607):320–22. <https://doi.org/10.1038/534320a>
- Oedl-Wieser T (2017) Women as drivers for the sustainable and social inclusive development in mountain regions—the case of the Austrian Alps. *Eur Countrys* 9(4):808–821
- Olivier DW, Heineken L (2017) Beyond food security: women's experiences of urban agriculture in Cape Town. *Agric Hum Values* 34(3):743–755
- Omukuti J (2020) Challenging the obsession with local level institutions in country ownership of climate change adaptation. *Land Use Policy* 94:104525
- Osamor PE, Grady C (2016) Women's autonomy in health care decision-making in developing countries: a synthesis of the literature. *Int J Women's Health* 8:191
- Palliwoda J, Kowarik I, von der Lippe M (2017) Human-biodiversity interactions in urban parks: the species level matters. *Landsc Urban Plan* 157:394–406
- Partey ST, Dakorah AD, Zougmore RB, Ouédraogo M, Nyasimi M, Nikoi GK, Huyer S (2020) Gender and climate risk management: evidence of climate information use in Ghana. *Clim Change* 158(1):61–75
- Perez C, Jones EM, Kristjansson P, Cramer L, Thornton PK, Förch W, Barahona CA (2015) How resilient are farming households and communities to a changing climate in Africa? A gender-based perspective. *Glob Environ Change* 34:95–107
- Pouramin P, Nagabhatla N, Miletto M (2020) A systematic review of water and gender interlinkages: assessing the intersection with health. *Front Water* 2:6. <https://doi.org/10.3389/frwa.2020.00006>
- Prakash A, McGlade K, Roxy MK, Roy J, Some S, Rao N (2022b) Climate adaptation interventions in coastal areas: a rapid review of social and gender dimensions. *Front Clim* 4:785212. <https://doi.org/10.3389/fclim.2022.785212>
- Prakash et al. (2022a) Gender, climate justice and transformative pathways. Cross chapter box. In: Schipper ELF, Revil A, Preston BL, Carr ER, Eriksen SH, Fernandez-Carril LR, Glavovic B, Hilmi NJM, Ley D, Mukerji R, Muylaert de Araujo MS, Perez R, Rose SK, Singh PK (eds) *Climate resilient development pathways. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Pörtner H-O, Roberts DC, Tignor M, Poloczanska ES, Mintenbeck K, Alegria A, Craig M, Langsdorf S, Lösche S, Möller V, Okem A, Rama B (eds)]. Cambridge University Press. pp. 57–63, Chapter 18 (in press)
- Rao N (2017) Assets, agency and legitimacy: towards a relational understanding of gender equality policy and practice. *World Dev* 95:43–54
- Rao N, Lawson ET, Raditloane WN, Solomon D, Angula MN (2019) Gendered vulnerabilities to climate change: insights from the semi-arid regions of Africa and Asia. *Clim Dev* 11:14–26
- Rao N, Mishra A, Prakash A, Singh C, Qaisrani A, Poonacha P, Bedelian C (2019) A qualitative comparative analysis of women's agency and adaptive capacity in climate change hotspots in Asia and Africa. *Nat Clim Change* 9(12):964–971
- Ravera F, Martín-López B, Pascual U, Drucker A (2016) The diversity of gendered adaptation strategies to climate change of Indian farmers: a feminist intersectional approach. *Ambio* 45:335–351. <https://doi.org/10.1007/s13280-016-0833-2>
- Ravera F, Reyes-García V, Pascual U, Drucker AG, Tarrasón D, Bellon MR (2019) Gendered agrobiodiversity management and adaptation to climate change: differentiated strategies in two marginal rural areas of India. *Agric Hum Values* 36(3):455–474
- Resurrección BP, Goodrich CG, Song Y, Bastola A, Prakash A, Joshi D ... Shah SA (2019) In the shadows of the Himalayan mountains: persistent gender and social exclusion in development. In: Wester P et al. (eds.) *The Hindu Kush Himalaya assessment*. Springer, Cham, pp. 491–516
- Rohe J, Schlüter A, Ferse SC (2018) A gender lens on women's harvesting activities and interactions with local marine governance in a South Pacific fishing community. *Marit Stud* 17(2):155–162
- Roy J, Das N, Some S (2021) India must use SDG framework to strengthen developmental diplomacy. In: Chakrabarty M, Suri N (Eds.) *A 2030 vision for India's economic diplomacy*. Observer Research Foundation and Global Policy Journal, New Delhi. <https://www.orfonline.org/expert-speak/india-must-use-sdg-framework-strengthen-developmental-diplomacy/?amp>
- Roy J, Tschakert P, Waisman H, Abdul Halim S, Antwi-Agyei P, Dasgupta P, Hayward B, Kanninen M, Liverman D, Okereke C, Pinho PF, Riahi K, Suarez Rodriguez AG (2018) Sustainable development, poverty eradication and reducing inequalities. In: Masson-Delmotte V, Zhai P, Pörtner H-O, Roberts D, Skea J, Shukla PR, Pirani A, Moufouma-Okia W, Péan C, Pidcock R, Connors S, Matthews JBR, Chen Y, Zhou X, Gomis MI, Lonnoy E, Maycock T, Tignor M, Waterfield T (eds) *Global warming of 1.5 °C. An IPCC Special Report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*. IPCC
- Scarborough WJ, Risman BJ, Meola C (2017) Women's-group fishponds in Bangladesh: using gender structure theory to examine changes in the gender asset gap. *Socius* 3:2378023117700419
- Schwartz GJ (2017) The role of women in payment for environmental services programs in Osa, Costa Rica. *Gend Place Cult* 24(6):890–910
- Sharpe EE, Karasouli E, Meyer C (2017) Examining factors of engagement with digital interventions for weight management: a rapid review. *JMIR Res Protoc* 6(10):e205
- Singh C, Solomon D, Rao N (2021) How does climate change adaptation policy in India consider gender? An analysis of 28 state action plans. *Clim Policy* 21(7):958–975. <https://doi.org/10.1080/14693062.2021.1953434>
- Sixteen Plus Forum (2021) WFUNA—World Federation of United Nations Associations. Sixteen Plus Forum <https://wfuna.org/sixteenplusforum>
- Solomon DS, Singh C, Islam F (2021) Examining the outcomes of urban adaptation interventions on gender equality using SDG 5. *Clim Dev* 13(9):830–841. <https://doi.org/10.1080/17565529.2021.1939643>
- Solomon DS, Singh C, Islam F (2021) Examining the outcomes of urban adaptation interventions on gender equality using SDG 5. *Clim Dev* 1–12. <https://doi.org/10.1080/17565529.2021.1939643>
- Sovacool BK, Tan-Mullins M, Abrahamse W (2018) Bloated bodies and broken bricks: power, ecology, and inequality in the political economy of natural disaster recovery. *World Dev* 110:243–255
- Su Y, Bisht S, Wilkes A, Pradhan NS, Zou Y, Liu S, Hyde K (2017) Gendered responses to drought in Yunnan Province, China. *Mountain Res Dev* 37(1):24–34
- Sultana F (2014) Gendering climate change: geographical insights. *Prof Geogr* 66(3):372–381. <https://doi.org/10.1080/00330124.2013.821730>
- Sultana F (2021) Climate change, COVID-19, and the co-production of injustices: a feminist reading of overlapping crises. *Soc Cult Geogr* 22:447–460. <https://doi.org/10.1080/14649365.2021.1910994>
- Sultana F (2018) Gender and water in a changing climate: challenges and opportunities. In: Fröhlich C et al. (eds) *Water security across the gender divide*. Springer, Cham, pp. 17–33
- Sunikka-Blank M, Bardhan R, Haque AN (2019) Gender, domestic energy and design of inclusive low-income habitats: a case of slum rehabilitation housing in Mumbai, India. *Energy Res Soc Sci* 49:53–67
- Sylvester O, Little M (2020) I came all this way to receive training, am I really going to be taught by a woman? Factors that support and hinder women's participation in agroecology in Costa Rica. *Agroecol Sustain Food Syst* 45:1–24

- Tschakert P, Machado M (2012) Gender justice and rights in climate change adaptation: opportunities and pitfalls. *Eth Soc Welf* 6(3):275–289. <https://doi.org/10.1080/17496535.2012.704929>
- United Nations (2015a) Transforming our world: the 2030 agenda for Sustainable Development. United Nations General Assembly Resolution A/RES/70/1. <https://undocs.org/A/RES/70/1>
- United Nations (2015b) Eliminating discrimination and inequities in access to water and sanitation. United Nations <https://www.unwater.org/publications/eliminating-discrimination-inequalities-access-water-sanitation/>
- United Nations (2020). Global indicator framework for the Sustainable Development Goals and targets of the 2030 agenda for Sustainable Development. United Nations <https://unstats.un.org/sdgs/indicators/indicators-list/>
- United Nations (2018) Sustainable Development Goal 6 synthesis report on water and sanitation. United Nations New York, New York, [https://www.unwater.org/publication\\_categories/sdg-6-synthesis-report-2018-on-water-and-sanitation/](https://www.unwater.org/publication_categories/sdg-6-synthesis-report-2018-on-water-and-sanitation/)
- Van Aelst K, Holvoet N (2018) Climate change adaptation in the Morogoro Region of Tanzania: women's decision-making participation in small-scale farm households. *Clim Dev* 10(6):495–508
- Varghese BM, Hansen A, Nitschke M, Nairn J, Hanson-Easey S, Bi P, Pisaniello D (2019) Heatwave and work-related injuries and illnesses in Adelaide, Australia: a case-crossover analysis using the Excess Heat Factor (EHF) as a universal heatwave index. *Int Arch Occup Environ Health* 92(2):263–272. <https://doi.org/10.1007/s00420-018-1376-6>
- Vij et al. (2021) 'Power-sensitive design principles' for climate change adaptation policy-making in South Asia. *Earth Syst Gov* 9:100109
- Vij S, Moors E, Ahmad B, Arfanuzzaman M, Bhadwal S, Biesbroek R, Wester P (2017) Climate adaptation approaches and key policy characteristics: cases from South Asia. *Sci Policy* 78:58–65
- Wangui EE, Smucker TA (2018) Gendered opportunities and constraints to scaling up: a case study of spontaneous adaptation in a pastoralist community in Mwangi District, Tanzania. *Clim Dev* 10(4):369–376
- Yang F, Paudel KP, Cheng R, Qiu L, Zhuang T, Zeng W (2018) Acculturation of rural households participating in a clean development mechanism forest carbon sequestration program: A survey of Yi ethnic areas in Liangshan, China. *J For Econ* 32:135–145
- Yiridomoh GY, Appiah DO, Owusu V, Bonye SZ (2020) Women smallholder farmers off-farm adaptation strategies to climate variability in rural Savannah, Ghana. *GeoJournal* 86:2367–2385
- WaterAid (2017) Water, sanitation and hygiene: a pathway to realizing gender equality and the empowerment of women and girls. WaterAid, London
- Zhenmin L, Espinosa P (2019) Tackling climate change to accelerate sustainable development. *Nat Clim Change* 9(7):494–496

### Author contributions

Contributed to the conception or design of the work: JR, AP, SS, RBK, MAC, CC, MRF, CS, CS-W, MCT-vP, ET, SV; Contributed to literature review, collection of data, preliminary analysis: JR, AP, SS, RBK, MC, CC, MRF, CS, CS-W, MCT-vP, ET, SV, EB, GD, EH, AI, FI, KMG, HN-F, FR, AS, DS, IT; Contributed to final analysis and interpretation

of data, formulation of Eq. (1) and preparation of figures for the work: JR, SS Drafting the work or revising it critically for important intellectual content: JR, AP, SS, RBK, MC, CC, MRF, CS, CS-W, MCT-vP, ET, SV. Final approval of the version to be published: JR, AP, SS, RBK, MC, CC, MRF, CS, CS-W, MCT-vP, ET, SV Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved: JR, AP, SS, RBK, MC, CC, MRF, CS, CS-W, MCT-vP, ET, SV, EB, GD, EH, AI, FI, KMG, HNF, FR, AS, DS, IT.

### Ethical approval

This article does not contain any studies with human participants performed by any of the authors.

### Informed consent

This article does not contain any studies with human participants performed by any of the authors.

### Competing interests

The authors declare no competing interests.

### Additional information

**Supplementary information** The online version contains supplementary material available at <https://doi.org/10.1057/s41599-022-01266-6>.

**Correspondence** and requests for materials should be addressed to Anjal Prakash.

**Reprints and permission information** is available at <http://www.nature.com/reprints>

**Publisher's note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.



**Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this license, visit <http://creativecommons.org/licenses/by/4.0/>.

© The Author(s) 2022

<sup>1</sup>Asian Institute of Technology, Pathum Thani, Thailand. <sup>2</sup>Jadavpur University, Kolkata, India. <sup>3</sup>Bharti Institute of Public Policy, Indian School of Business, Hyderabad, India. <sup>4</sup>Ahmedabad University, Ahmedabad, India. <sup>5</sup>School of Environment and Sustainability, Indian Institute of Human Settlements, Bangalore, India. <sup>6</sup>Cornell University, New York, USA. <sup>7</sup>Lund University, Lund, Sweden. <sup>8</sup>The National Autonomous University of Mexico (UNAM), Mexico, Mexico. <sup>9</sup>INGENIO (CSIC-Universitat Politècnica de València), Valencia, Spain. <sup>10</sup>University of Saskatchewan, Saskatchewan, Canada. <sup>11</sup>University of California, Los Angeles, USA. <sup>12</sup>Ecole de Foresterie Tropicale, Université Nationale d'Agriculture du Bénin, Cotonou, Benin. <sup>13</sup>Institute for Environmental Sciences, University of Geneva, Geneva, Switzerland. <sup>14</sup>University of Vic-Central University of Catalunya, Barcelona, Spain. <sup>15</sup>Heriot-Watt University, Edinburgh, UK. <sup>16</sup>University of East Anglia, Norwich, UK. <sup>17</sup>University of Denver, Colorado, USA. <sup>18</sup>Alliance of Bioversity International and International Center for Tropical Agriculture (CIAT), Dakar, Senegal. <sup>19</sup>University of Michigan, Ann Arbor, USA. <sup>20</sup>American University in Dubai, Dubai, UAE. ✉email: [anjal\\_prakash@isb.edu](mailto:anjal_prakash@isb.edu)