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Editor summary:

This Perspective highlights links between gender inequality and climate change adaptation and mitigation, and proposes a roadmap for incorporating gender issues into the Shared Socioeconomic Pathways. These scenarios could help understand challenges under diverse trajectories of gender equality.

Representing gender inequality in scenarios improves understanding of climate challenges

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Achieving gender equality can increase societies' capacities to deal with climate change. Here, we highlight empirical connections between gender equality and climate change adaptation and mitigation to propose a structured and detailed inclusion of gender-related aspects in the Shared Socioeconomic Pathways framework. The introduction of hypothetical pathways of gender (in)equality in the scenario space can help analyze interactions with other socioeconomic drivers and subsequent implications for adaptation and mitigation options. The extent of challenges to climate change adaptation and mitigation may substantially change depending on the rate at which societies progress towards equal access to resources and opportunities for self-realization for all genders. We propose steps that the scenario community could take to enrich the next generation of socioeconomic pathways.

Gender equality is one of the pillars of achieving universal human rights and a central objective of sustainable development. This key societal objective should be pursued on normative grounds,

but it can also have synergies with other socioeconomic development goals, such as economic development[1], lower child mortality[2], more effective institutions[3] and even more stringent climate policies[4]. The progress, or lack thereof, towards more inclusive and equitable societies will also have consequences for one of the greatest prerogatives that humankind is facing: our collective ability to tackle climate change. Climate change is not gender neutral. Gender-differential exposure and vulnerability result in different levels of risks and impacts being experienced by different genders. Capacities for climate action can be limited by gender unequal access to resources and decision-making.

Despite a growing body of literature and empirical studies, the issues of gender (in)equality remain largely overlooked in scenario-based global climate change research. The objective of this Perspective is to highlight the links between gender (in)equality and socioeconomic development that are currently underappreciated in the dominant scenario framework of Shared Socioeconomic Pathways (SSPs)[5], and the implications of these links for challenges to climate change mitigation and adaptation. To this end, we first present an overview of the connections between gender equality and climate change. Second, we propose a roadmap for integrating variables relevant to representing gender equality into the SSP framework. We argue that the outcomes of incorporating gender equality into the SSPs would generate twofold benefits by: (i) improving the underlying socioeconomic quantifications and (ii) redefining the "challenges space"[6] related to climate mitigation and adaptation.

Gender inequality is the result of societal and cultural roles, values, and expectations for different genders that lead to unequal access to power, opportunities, and resources. Despite decades of progress towards equality, no country has truly achieved it. Women still earn less than men and make up between 54 and 63% of the impoverished population globally[7], depending on the poverty index. They are a minority in the global labor force, with participation rates as low as 25% in some regions like South Asia, compared to 75% for men[8]. Women are more likely to work part-time or not at all and they take on three times as much unpaid household and care work as men[9,10.] Globally, one in four parliamentary seats are held by women, and only 10% of heads of state are women[11]. Wide disparities in educational attainment also exist. While globally 60% of the population without any education are women, in high income countries more women than men have higher education[12]. Women's food insecurity is higher than men's[13] and they are disproportionately affected by the lack of access to basic sanitation and water scarcity[14]. Almost one in three women worldwide have experienced some type of gender-based violence[15] and one in five women globally are married before the age of 18, which often also curtails their education, economic and health prospects[16]. According to three indices of gender inequality introduced by the United Nations (UN) (Women's Empowerment Index, Global Gender Parity Index and Gender Inequality Index), countries that score high on all three cover less than 1% of all girls and women

globally. In general, gender disparities vary substantially and are widest in the Middle East and North Africa and South Asia[7].

When we refer to the importance of considering gender, incorporating gender issues, or being gender aware, we mean that scientific assessments of the risks of climate change should include both the effects *on* and the effects *of* gender (in)equality. From a policymakers' perspective, modelling exercises using scenarios that incorporate gender (in)equality can help understand the differences in policy outcomes between a world that progresses on achieving gender equality versus one that does not. These insights can be used for identifying priorities for policy and interventions that are responsive to gender disparities and minimize risks of climate change.

This Perspective is informed by literature that in most cases analyzes differences between men and women, but it is crucial to acknowledge that the complexities of gender extend beyond this binary distinction. Gender also intersects with race, ethnicity, sexual orientation, socioeconomic status, and other sources of identity which can create unique experiences of discrimination and inequality. While our primary focus is on women as the globally single largest group that face socioeconomic disadvantages, we recognize that other groups may encounter even greater challenges in different contexts. We encourage readers to adopt cognitive flexibility in understanding and addressing these intersecting dynamics, and to use our proposal as a blueprint for incorporation of more nuanced characterizations of gender and gender equality in future research.

Key dimensions of the climate change-gender nexus

The relationship between gender and climate change has garnered increasing attention in recent decades. While the international policy discourse in the 2000s "hardly featured" or "sidetracked" gender issues[17–19], a 2021 study highlights numerous examples of high-level climate policy and scientific processes that require the inclusion of gender considerations[19]. The number of scientific articles on this topic has steadily risen from around 10 in the late 1990s to more than 1000 per year in 2023 (as per the search in Scopus in September 2024). The overview of literature presented here is organized around two main aspects of climate change research and action: 1) impacts, adaptation and vulnerability and 2) mitigation and 3) cross-cutting themes relevant for 1) and 2).

Impacts, adaptation and vulnerability

The climate change-gender discourse often focuses on differential exposure and vulnerability to climate impacts, which are linked to underlying socioeconomic factors. Two thirds of studies from

a systematic review find that women are disproportionately affected by climate impacts and are more likely to die in extreme events[20,21].

Direct and indirect impacts

Women are uniquely impacted by extreme temperatures, which can lead to endangered maternal health and increased risk of miscarriage, preterm birth or stillbirth[22]. They are also more likely to suffer climate-induced undernutrition[23] and lack of access to sanitation[24]. There is also evidence that increased salinity of water pushed upstream by sea level rise can affect maternal health[25.] Additionally, women are more exposed to adverse outdoor conditions when they are primarily responsible for securing fuel[26] or water[27]. In environmentally stressed areas where men migrate in search for better economic opportunities, women tend to take on new economic roles and with it risks when still operating in gender-biased social norms[28]. Women in rural areas are also at higher risks of vector-borne diseases because of close contact with wells and rivers while collecting water[29]. Gender-related norms can also deprive women of survival skills, such as the ability to swim[30], or impose other norm-related practices and duties that can become a burden in the face of an emergency, such as traditional clothing or mobility restrictions[31]. Domestic violence against women tends to escalate post-disaster[32]. Climate induced migration processes also put women at risk of sexual abuse and exploitation as well as trafficking[32]. However, men can also be disproportionally affected by exposure and vulnerability to floods and storms[33], suicide and depression risks during droughts[34], or heat stress in the male-dominated building industry[35,36].

Adaptive capacity and vulnerability

Gender is also highly relevant to adapt to climate change impacts. Gender (in)equality plays a crucial role in determining individuals' capacities for adaptation. Limited access to resources, including finance or credit, social networks, and information can hinder adaptation efforts. For example, women and young girls may face challenges in accessing resources for investing in irrigation, shifting the crop planting calendar, protecting against heat during pregnancy. Additionally, climate-induced hardships can lead to early marriage[37] and interrupted education, with over 12 million girls estimated to be unable to complete schooling due to climate-related stressors[38]. This has lifelong consequences for individuals and society as a whole. In some instances, adaptation actions can be maladaptive and increase gender inequality. For instance, if coping with water scarcity requires women, who are often the main water collectors in households, to travel further distances to find water, it can take time away from other activities such as schooling[39]. However, adaptation efforts also present opportunities to improve livelihoods. For example, replacing engagement in traditional climate-sensitive value chains with more profitable agricultural produce can enhance financial security.

Given socioeconomic and geographical variations in climate impacts and the capacity to adapt, it is important to gather systematic data and conduct gender-differentiated impact research to understand these differences. This information can be a first step to identify specific implications related to different contexts and hazards, which is fundamental for taking targeted actions to reduce risk and adapt to climate change.

Mitigation

There are fewer studies that focus on connections between gender equality and mitigation actions, but there has been a more than 10-fold increase in such literature over the past 20 years (as per a Scopus search in September 2024). One area of particular focus is the provision of clean cooking, as women, who are predominantly responsible for household work, are disproportionally exposed to poor air quality through cooking with toxic fuels[40]. Therefore, women would benefit greatly from transitioning to cleaner cooking fuels, an action that often also reduces climate altering emissions[41].

At the industry level, the transition away from fossil fuels poses both risks and opportunities for gender equality. Historical examples of transitions away from coal indicate that women often faced an increased burden of (usually unpaid) care work and paid work[42]. Typically, men make up the majority of employees in the fossil fuel sector, while women are more likely to be indirectly dependent on the industry through unpaid and informal work[43]. However, the transition to renewables could create opportunities for women in the green economy and also lead to measures to promote a more equal distribution of care work and supportive working conditions.

In terms of behaviors that can help mitigate climate change, several studies have found that women tend to be more considerate than men in their climate change related attitudes[44], consumer choices and voting behavior[45], even after controlling for income[46]. Gender-based differences in behavioral patterns have also been observed in areas such as transportation[47], dietary choices[48] and thermal comfort[49]. However, some argue that characterizing women as more “climate-friendly” may reinforce gender norms, as it could be linked to women’s disproportionate responsibility for environmental stewardship and other care duties[50].

It is not always clear whether income or attitudes dominate in determining consumer choices[19]. If it is income, the rising purchasing power of more educated and employed women could lead to higher emissions, as their consumption patterns and footprints converge with men’s. Similar arguments have been made for the emissions implications of increasing general education levels in a society. Nevertheless, a recent study shows that the net effect of improved education globally on emissions is modest, and that is even before accounting for changes in attitudes or

innovation in low-carbon technologies[51]. Additionally, at a macro-level, there is evidence that increased gender equality weakens the association between Gross Domestic Product (GDP) per capita and CO_2 emissions[52].

More research is needed to understand the differences in behaviors and attitudes between genders, considering social norms that shape gender roles and responsibilities. Even if additional evidence suggests that gender equality ultimately leads to higher emissions, efforts to achieve gender equality should not be abandoned. Instead, it is important to investigate how emissions are affected by different assumptions about what "equality" means (e.g., do women converge to men's patterns of behavior or vice versa), which can inform projections of future energy demand and could indicate the need for additional mitigation efforts.

Cross-cutting links

All types of climate action require strong institutions and good governance. Evidence suggests that countries with a higher share of women in parliament enact more stringent climate policy and that female bureaucrats tend to promote green procurement[4,53]. Additionally, gender equality in education enhances a country's human capital, enabling a country to tap into its entire talent pool (rather than only the male pool) for tackling local and global challenges[54]. Indeed, there is evidence pointing to the fact that a larger share of women in research is associated with higher innovative capacity of a country, including in environmental technologies[55].

Scenarios as heuristics to imagine gender (un)equal futures

A world with equal opportunities, irrespective of gender, would be a markedly different place. As a gender equal world remains hypothetical, envisioning such a society and understanding its interactions with key socioeconomic drivers of development is essential. As evident from the literature discussed in the previous section, enhancing access to education, decision-making, financial resources, clean energy, and health services for disadvantaged segments of society, is crucial for minimizing the risks of climate change.

On the flip side, if gender inequality is systemic and widespread and affects half or more of the population in a society, this weakens societies' overall capacity to act and can in turn cause vicious cycles of vulnerability and growing climate risks[56]. This is why it is equally important to imagine a future with stalled or deteriorating gender equality, especially considering recent indications of a halt in progress. In recent years, many countries have observed policy reversals on women's rights, e.g. the systemic prohibitions on women's education and participation in public life in Afghanistan[57], the restriction of women's rights to sexual and reproductive

199 healthcare in Iran implemented in 2021[58], the ban or restricted access to abortion in 21 US states
200 reintroduced in 2022[59], Covid-19 repercussions and economic hardships that have resulted in job
201 losses, food shortages, weakening of health and education infrastructure, all of which have
202 disproportionately affected women[60,61].

203 Scenarios of what the future might look like can act as "tools of scientific imagination"[62]. Both
204 optimistic and pessimistic types of scenarios can be used by policymakers to engage in what-if
205 types of questions to comprehend interactions between gender equality and other development
206 aspects. Scenario-based analyses can also help understand how societies' capacities for
207 adaptation and mitigation are enabled or constrained if, broadly speaking, half of the population
208 gains access to or remains deprived of resources and decision-making power.

209 The use of scenarios is integral to climate change research, as they help in assessing risks, impacts
210 and policy options to mitigate them. The SSP scenario framework is widely used by researchers
211 from various disciplines and has informed global climate policymaking through the Assessment
212 Reports of the Intergovernmental Panel on Climate Change (IPCC). The SSPs consist of five
213 quantifiable narratives of socioeconomic development trajectories, which define the challenges
214 of climate adaptation and mitigation in the 21st century[5]. They aim to capture a broad range of
215 plausible futures, from a rapid transition to sustainable lifestyles to increasing inequalities and
216 continued reliance on fossil fuels.

217 SSP scenarios are used primarily by Integrated Assessment Models (IAMs) and climate impact
218 models. The core quantified socioeconomic elements of the SSPs are population[63], GDP[64–66], and
219 urbanization[67], and they are available on regional, national, and partly also sub-national levels.
220 While these drivers have been recently updated to reflect novel data and methodologies[68],
221 gender equality has not been featured prominently in the SSPs and their applications. Of the
222 roughly 2,500 papers included in the SSP literature databases published between 2014 and 2021,
223 a mere 1% explicitly investigate gender-related aspects of climate change impacts, mitigation and
224 adaptation[69–71].

225 The original narratives underlying the SSP scenarios include qualitative assumptions on the level
226 of gender equality, describing it as high, medium or low, but without further elaboration.
227 Quantitatively, these assumptions to some extent translate to changes in women's educational
228 attainment, which implicitly affects population size (through reducing fertility) and explicitly
229 affects GDP (through increased human capital influencing total factor productivity)[63,64]. In Fig. 1,
230 we illustrate the relationships that have already been "formalized" in the underlying models and
231 propose new ones to be included in the next round of scenario development.

232

Figure 1: Links between gender equality and key drivers of the SSPs: population, GDP, and urbanization. Solid arrows indicate relationships that are formalized, and the dashed arrows indicate relationships that are not.

The figure illustrates that population growth is influenced by female education via its effect on fertility, but formalized statistical connections between these two variables are currently lacking. It is possible to incorporate additional assumptions, such as the spread of egalitarian values on fertility, into the existing framework. Moreover, achieving (un)met needs for sexual and reproductive health services, as outlined in the SDGs targets, could be introduced, to understand the implications of reduced global fertility rates by up to a fifth[72]. Factors like changing age at marriage, evolving attitudes and access to modern energy also play a role in shaping population trends[73]. Gender equality also matters for the life expectancy of men and women, because in addition to biological differences, gender-specific lifestyles, behaviors and broader cultural conditions affect disparities in mortality and health[74,75].

In current GDP projections, women's education is explicitly factored into the human capital dimension. However, the potential impact of increasing female labor force participation rates on GDP trajectories is currently not fully considered. Previous research indicates that women's empowerment, reflected in a better-educated labor force and better employment opportunities, boosts GDP, reduces global poverty, and extends healthy life expectancy across all scenarios[76, 77]. Explicit scenarios that consider factors that promote gender equality, such as by eliminating barriers to women's participation in engineering, science and innovation where they have historically been underrepresented, could further support GDP growth.

Finally, the relationship between urbanization and gender equality could also be operationalized in the next generation of scenarios. Urbanization fosters value changes and provides education and employment opportunities, all of which are positively associated with gender equality[78]. It may also influence population growth, as fertility rates are lower in urban than rural areas, even after controlling for education[79].

It is important to stress that the relationships shown in Fig. 1 are likely to vary by geographical contexts and socioeconomic strata and may be influenced by established structures that support different dimensions of gender (in)equality. For example, the translation of women's increased education into economically productive activity is closely tied to welfare state structures and childcare support availability. Introduction of these links in existing models thus needs to be underpinned by robust multilevel modeling that would allow for capturing heterogeneities between countries. Advances in machine learning-powered evidence syntheses can help collect and summarize country-specific parameters.

The first step towards incorporating gender (in)equality into scenarios could be to generate exogenous pathways of gender equality over the 21st century. A proposal has already been made to extend the SSPs with an indicator of gender inequality as an internally consistent extrapolation[80]. While index-based measures are effective communication tools, they typically focus on a limited set of indicators and reflect a limited interpretation of gender equality[81]. Moreover, current scenarios provide only basic descriptions of gender equality. Thus, we recommend designing trajectories of gender (in)equality with more detailed narratives. The design of the scenarios should involve an interdisciplinary group of experts, expanding beyond the traditionally represented disciplines to include gender scholars, gender economists, sociologists, political scientists, for example. Next in the process are quantifications of key variables that can be used to (re-)model other influencing factors. As shown above, projections of relevant variables such as women's labor force participation, provision of childcare, cohort-based changes in attitudes and values, rates of innovation, and so forth, could be used to enhance the existing SSPs. A more ambitious agenda for future scenarios would be to endogenize or introduce recursive feedback between gender (in)equality and the processes of socioeconomic development, which could further reinforce or hinder one another. However, not all aspects of gender (in)equality can be quantified, and any scenario development process needs to be accompanied with a transparent reporting on the set of assumptions included in the design.

Gender equality changes the "challenges space"

The SSP framework consists of five development narratives[5]: SSP2 is a scenario where technological and socioeconomic development follow the current trends. SSP1 is a world transitioning rapidly to sustainability, which poses low challenges for adaptation and mitigation. In contrast, SSP3, is a world of continued unequal, fossil-fueled development, which presents challenges for both. SSP4 and SSP5 combine high and low challenges: SSP4 sees wealthy countries transitioning to low-carbon sources, while lower-income populations struggle, and SSP5, is a wealthy world mostly reliant on fossil fuels, which faces high mitigation challenges but has the financial means to adapt. The SSPs' "challenges space" spans five combinations of scenarios: three with the same level challenges to mitigation and adaptation (both low, both medium, both high) and two with opposite challenges (high challenges for adaptation, low for mitigation and vice versa).

The implications of integrating key gender equality considerations within SSP narratives are depicted in Fig. 2, which illustrates potential changes in the "challenges space"[6] that the five SSPs are positioned in. Adaptation or mitigation challenges can intensify or diminish based on scenario-embedded national and global gender equality trends. The proposal herein is not to create a parallel set of scenarios, but to elucidate the implications of incorporating indicators of

gender (in)equality in SSP scenarios, with suggestions for how it may be done for a future round of updates to the framework.

Figure 2: Expansion of the SSP challenges space. In the top right corner, the original SSP scenario space with stars indicating the gender equality assumptions (inner square) expands into a bigger challenge space after incorporating explicit narratives and indicators of gender equality and its relationship with other dimensions of socioeconomic development. This can increase (or reduce) the original challenges to adaptation and mitigation. The expanded scenarios are labelled "SSP-G" to signify the expansion of the challenges' space (not suggesting that the SSPs should be renamed) after incorporating effects of gender equality on other socioeconomic variables . Illustrative examples of how various mitigation challenges (top left corner) and adaptation challenges (bottom right corner) may change when accounting for gender (in)equality. Figure adapted from[82]

Expanding the "challenges space" suggests socioeconomic challenges may change based on interacting national and global gender equality trends and other facets of development. These examples illustrate how diverse trajectories of gender equality could influence the storyline within each of the five SSPs, particularly in the key areas frequently explored in climate research. In an SSP1 world, gender equality facilitates the transition to low-carbon societies through the strengthening of human capital in various domains such as the workforce, politics, science, and innovation. In this scenario, both men and women converge in adopting low-emission behaviors, contributing to reductions in emissions through lower demand. SSP1 also sees reduced challenges to adaptation by ensuring higher adaptive capacity among women, enabled through equal access to different resources. In SSP2, the current sluggish gender equality progress continues. In SSP3, worsening gender inequality exacerbates challenges to both mitigation and adaptation, with women facing limited access to resources, widespread energy poverty, and remaining in unpaid labor. In SSP4, a world with rapid progress in gender equality in high-income countries but marked by significant levels of within-country inequality, sees higher challenges to adaptation due to both within and between-country gender inequality. SSP5 envisions a wealthy world with institutional gender equality. However, it diverges from SSP1 by portraying a scenario where carbon-intensive lifestyles persist for all, with no discernible shift toward egalitarian or climate-friendly values unlike in SSP1.

The strengthening of gender considerations in scenarios and quantitative modeling has several implications for scenario-based analyses and their policy implications. First, it has already been highlighted that a more nuanced and systematic incorporation of gender is crucial for a better representation of inequalities in IAMs when considering climate impacts, policies, their distributional implications and costs[82]. Mitigation pathways explored by IAMs should consider the influence of gender (in)equality on women's roles in sectors undergoing transformations. For example, an increased pool of skilled labor force could potentially speed up the transition to a low-carbon economy. When assessing behavioral changes and contributions to energy

transitions from the demand side, scenarios can be employed to investigate whether increased gender equality influences the alignment of attitudes between women and men concerning energy and resource consumption, technology adoption, mobility patterns or dietary changes. Modeling exercises that deploy such scenario-based information could offer insights into societal domains where investments in gender equality yield benefits not only for gender equality but also serve as a powerful policy lever for reducing emissions.

Second, climate impact models are continuously advancing their representation of adaptation and could greatly benefit from understanding how gender (in)equality affects the vulnerability of individuals or entire societies. By including indicators such as access to education, political participation, migration, changes in agricultural systems and health as dimensions of socioeconomic adaptive capacity, these models could provide a more comprehensive understanding of climate impacts. Even though empirical examples on successful integration of gender (in)equality-relevant aspects in climate change policies are scarce, in the context of reducing vulnerability to climate impacts, gender-sensitive investments and adaptation options that reduce burdens on women and girls are essential for interventions to work[83]. Impact models that use improved scenarios that we are proposing here can be helpful in identifying hotspots where gender inequality intersects with other vulnerabilities, thereby helping set policy priorities and identifying the need for targeted investments, ultimately leading to more effective climate policies and other developmental outcomes.

Third, just transition strategies can employ enriched scenarios that consider the role of women in transitions to green economies or account for failures to do so. For example, regions reliant on traditionally male-dominated coal mining face challenges to ensuring livelihoods when transitioning away from fossil fuels. Failing to include women in transition planning could create new societal problems, if additional opportunities for education and skill development are not provided to diversify economic activities away from coal[42].

Finally, global sustainable development strategies, such as the UN 2030 Agenda, have set ambitious goals to progress towards gender equality. Analyzing empirical connections and aligning them with future narratives can help identify strategies that would expedite achieving gender equality sooner than the 300-year timeline assessed by the UN, in the context of slow progress towards achieving the Sustainable Development Goal 5[56].

Pathways towards more gender-aware research

Based on a growing body of empirical findings and new modeling exercises, the next generation of scenarios needs to prioritize the incorporation of challenges to both mitigation and adaptation that stem from different levels of gender (in)equality. Recognizing gender equality is crucial for

374 comprehending “a set of worlds with very different development implications”[84]. Research tools,
375 such as the SSP scenarios, should not overlook gender considerations, not only on normative
376 grounds, but also because of the numerous linkages between gender and climate change that
377 are discussed here. Failing to incorporate gender considerations restricts the conceptualization
378 of the complexity of the climate problem and may lead to misguided implementation efforts. This
379 omission has already been acknowledged in some of the literature from the scenario
380 community[85–87].

381 As we currently do not live in a gender equal world, scenarios are ideal tools to explore the “what-
382 if” types of questions about the policy implications of achieving gender parity vis-a-vis climate
383 change vulnerability, and mitigation and adaptation challenges. A reversal of progress towards
384 gender equality could slow down socioeconomic development and create additional barriers for
385 adaptation and mitigation. Concretely, gender-underpinned scenarios would allow for
386 identification of hotspots of future vulnerability, for example, where policies could be built to
387 enhance resilience. Scenarios could also help assess questions of gender and mitigation, how
388 individual or household choices are affected by gender roles and norms. Finally, international
389 target-setting policy agendas, such as the Sustainable Development Goals, could be informed by
390 the potential timelines of development and understand where additional efforts are needed to
391 reach a set goal and the implications of staying in a gender unequal future. Such pathways could
392 inform assessment of investment needs and prioritization thereof, accounting for synergies and
393 trade-offs across policy domains[88].

394 Comprehensive reflection of how gender (in)equality relates to GDP, population and urbanization
395 – the key drivers of socioeconomic development in the SSP scenario framework – requires explicit
396 narratives and new quantitative indicators employed in existing models to understand
397 implications for mitigation and adaptation. Additionally, when developing quantitative scenarios
398 of governance and institutions[89] it is important to consider the influence of gender equality, as
399 women's political empowerment can contribute to effective governance[90]. To successfully
400 achieve this, the scenario community needs to ensure interdisciplinary expertise and involve
401 social scientists with gender expertise in co-designing the next generation of scenarios.

402 After developing and outlining plausible future narratives that include quantitative indicators of
403 gender equality, the modeling community could combine insights from empirical studies to
404 improve understanding of how gender equality may contribute to low-carbon economies (e.g.,
405 via the need for new and/or more skilled labor) and behavioral changes (e.g. via dietary change
406 or mobility patterns). In climate impact models, the effect of different levels of gender equality
407 on adaptive capacity could be incorporated to devise effective adaptation strategies and gain a
408 better understanding of the extent to which impacts can be mitigated through adaptation efforts.
409 Different sectors will require diverse resources and approaches for adaptation, and the

understanding of where gender inequality serves as a barrier is key to ensuring that the full potential of adaptation efforts is realized.

Important concerns have been raised about the extent to which current modelling tools, including the SSPs and the IAMs, are fit-for-purpose to provide insights on radically different socioeconomic and sociocultural paradigms[91], such as degrowth[92], or substantial changes to provisioning systems[93]. This concern could also apply to their ability to capture notions of full gender equality. For example, since GDP and its use in most IAMs do not account for care work or unpaid labor as part of aggregate economic activity, they exclude a large part of women's realities around the world. However, improving representation of gender-relevant aspects in the current scenarios, as proposed here, and understanding of the effects of this on other socioeconomic drivers is an important step forward. These efforts can improve the understanding of the option space for mitigation and adaptation, which can aid in identifying policies that effectively address climate change and simultaneously reduce gender inequalities (and those that hamper one or the other). Future efforts can be informed by inclusion of evidence from critical gender studies and existing modeling advances, such as the representation of unpaid labor and the informal economy in the International Futures model[94]. Similar advances have been proposed in the realm of justice[95], degrowth[96], and decent living standards[97].

Additionally, to fully understand the diverse ways in which women are affected by climate change and whether they have agency to act, it is important to be cognizant of the intersectional dimensions. Beyond gender, multiple other social identities (such as race, class, disability) intersect to create unique experiences of discrimination and inequality[98]. Integrating intersectional dimensions into quantitative research can be achieved through methods like multilevel modeling or the inclusion of statistical interaction terms in analyses, in order to capture the heterogeneity in effects based on various combinations of variables. One major challenge is the availability of detailed data, especially for the historical period. However, advances in data collection methods and the emergence of new indices that incorporate intersectionality can provide ways to address this in the future.

The mainstream discourse often fails to adequately question the underlying structures and norms that contribute to gender-differential outcomes. For instance, poor indoor air quality disproportionately affects women's health due to their primary responsibility for cooking. This prompts a reflection on how to change the underlying norms that define cooking as women's role in the first place. Similar reflections on the structural issues could be extended to the climate change research community itself, which needs to address its own severe gender imbalances. This affects which research questions are formulated, which tools and data are used to answer them, and which challenges are recognized in the context of societal transformations necessary to tackle climate change[99–101]. Improving gender balance and diversity within the scientific

community is perhaps a first step to enhance representation of gender in scientific output. We encourage both researchers and policymakers to always be cognizant of these structures because sustainable societal pathways should address both deeply rooted norms and their immediate manifestations[102]. Still, failing to tackle an acute problem because it does not offer a more systemic solution is arguably a zero-sum option that we cannot afford.

Competing interests

The authors declare no competing interests.

Author contributions

M.A. and C.Z. conceptualized the paper, with significant contributions from S.P. M.A. led the writing of the paper, with contributions from C.Z., J.M., R.M and S.P. M.A. conceptualized and produced the figures with contributions from C.Z. The author contributions were written by M.A. with significant contributions from C.Z.

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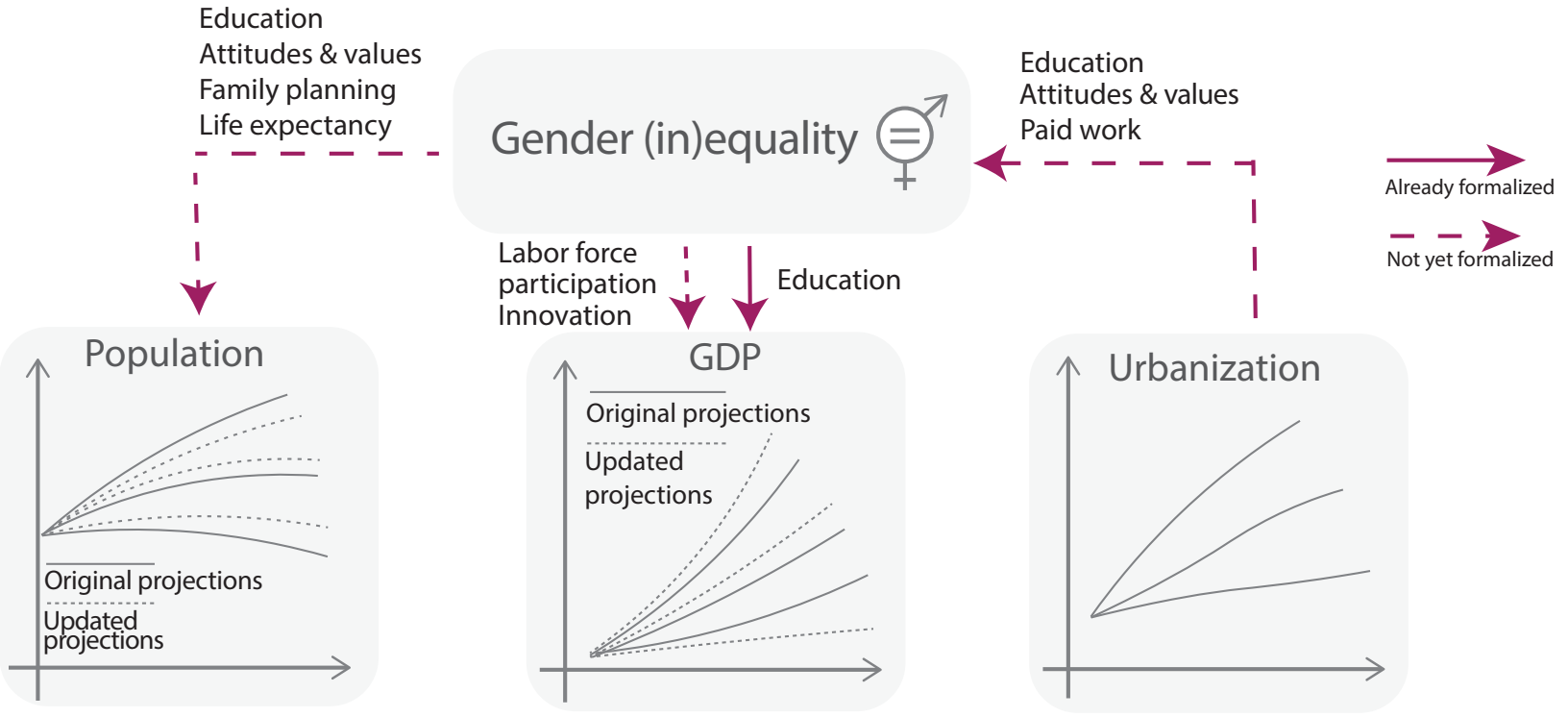
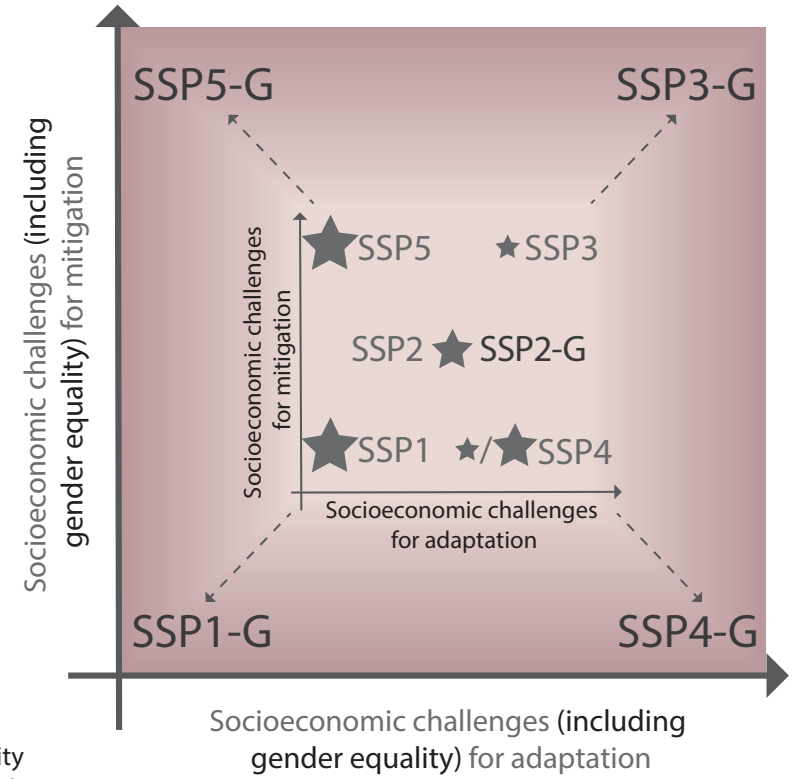

Education
Attitudes & values
Family planning
Life expectancy
Gender (in)equality
Education
Attitudes & values
Paid work
Already formalized
Not yet formalized
Labor force
participation
Innovation
Education
Population
Original projections
Updated
projections
GDP
Original projections
Updated
projections
Urbanization

Examples of links with mitigation challenges

Demand side changes	In SSP1, men AND women switch to low carbon behaviors; in SSP5, women converge with men in high carbon intensive lifestyles
Human capital	In SSP3, in high income countries, women have equal opportunities for education and employment in all fields, while in low income countries they face high barriers
Energy access	In SSP1, all women and men have access to clean and reliable energy; in SSP3, millions of women are disproportionately affected by energy poverty
Just transition	In SSP2, women form a larger share of the labor force in energy industry; in SSP3, women remain underrepresented in the energy industry globally



Implicit gender equality (O'Neill et al., 2017):

high

medium

low

Examples of links with adaptation challenges

Vulnerability	In SSP3, gender inequality exacerbates vulnerability to extreme events; in SSP4, vulnerability due to gender inequality varies substantially within and between countries
Adaptive capacity	In SSP1 and SSP5, equal access to resources enhances adaptive capacity of everyone; in SSP3, adaptive capacities are low because of persistent inequalities
Human capital	In SSP5, women are represented in decision making bodies across different sectors; in SSP2, decision-making power remains uneven and leads to less effective policymaking
Decent living services	In SSP1, everyone gains access to services essential for decent living; in SSP4, inequality within and across countries deprives women of decent living services.