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Addressing Income Inequality and Climate Change Vulnerability in Pune, India: A Scenario Linkage Approach

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Growing income inequality amplifies social vulnerability to climate change. By linking global with local scenario building for the case of Pune, our approach identifies future trends in inequality and assesses to which degree policy measures considered in Pune account for the climate vulnerability of low-income groups.

Abstract: Rapidly increasing income inequality and the impacts of climate change present substantial challenges for urban areas in low- and middle-income countries, difficult to address by local policymakers. For the case of the Indian city Pune, this study examines the potential effects of future income inequality on social vulnerability to climate change and identifies policy measures that can address these challenges. To this end, we adopt an integrated approach, linking the global scenarios of the Shared Socioeconomic Pathways (SSPs) with local insights and a normative scenario from two workshops held in Pune in 2019. Our findings indicate that income inequality will likely increase, exacerbating the potential social vulnerability of low-income groups through various channels, e.g. via unequal access to resources and the risk of urban flooding. The policy measures, proposed by local experts, provide suggestions to enhance the resilience of low-income groups in Pune. These policies, however, do not address all previously identified channels to the same degree and partially lack the consideration of systemic aspects to confront growing inequality and climate change impacts.

Keywords: Income inequality, climate change vulnerability, scenario design, stakeholder workshops.

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1. Background

Over recent decades, the rapid economic growth of emerging economies has translated into significant improvements in human well-being, lifting millions of people out of extreme poverty. However, the distribution of wealth resulting from this economic boom has been highly uneven, depriving lower-income groups of equal benefits (Ravallion 2014). Moreover, the process of rapid urbanization, accompanied by the expansion of informal settlements, exacerbates these inequalities (Williams et al. 2019). As recently shown by Savelli et al. (2023), socioeconomic inequalities hinder disadvantaged groups to access basic resources, such as water. In light of increasing climate change impacts and related resource scarcity, these dynamics present major challenges to policymakers around the world.

Growing income inequality[1] is expected to significantly amplify the social vulnerability to climate change, in addition to its association with absolute poverty (Islam and Winkel 2017; Rao et al. 2019; Rasch 2017). Local policymakers face difficulties in altering global dynamics, such as climate change and macroeconomic developments, leaving unanswered the question of how to address these issues at the local level. In light of these challenges, this paper introduces a scenario linkage approach, applied to the city of Pune in Western India: Future changes in income inequality driven by global dynamics are downscaled (top-down scenarios) and their potential impact on the social vulnerability to climate change is assessed with local insights from workshops (bottom-up challenges). These are used to construct a normative scenario and to provide suggestions for local policies (bottom-up scenario and policy suggestions). Pune encapsulates all the aforementioned issues, including rapid urban growth, equity issues, and high susceptibility to climate change.

Traditionally, different types of scenarios have been treated separately, without considering the potential for their integration (Star et al. 2016). However, this study takes a different approach by combining a top-down approach, involving the downscaling of global scenarios, with a bottom-up approach, contributing local insights from stakeholders and experts. By integrating these two techniques, we leverage the strengths of each approach and bridge the gap in scale and context, which is crucial for effective climate change adaptation planning. This integration

[1] This paper uses a definition of income inequality as "the extent to which income is evenly distributed within a population" (OECD 2023). Income is defined as the household disposable income, consisting of "earnings, self-employment, capital income and cash transfers" (ibid.).

enables the explicit consideration of global-local interactions, encompassing external driving forces and internal response options through policy measures.

Pune, the second-largest city in the West Indian state of Maharashtra, has a population of approximately 9.1 million people in its metropolitan region as of 2020 (Schiavina et al. 2022). A combination of various socioeconomic and biophysical factors renders Pune particularly susceptible to the adverse effects of climate change: Even though extreme poverty has significantly decreased in the recent decades (Census 2011), income inequality in urban areas of Maharashtra has been rapidly rising (World Bank 2017).

This income inequality is particularly evident in the housing situation of Pune's residents. During the last decades, informal settlements have considerably grown (Butsch et al. 2017; Mundhe 2019). Presently, estimates suggest that between 22% (Census 2011) and 40% (Mundhe 2019) of Pune's population resides in slums. Many of these settlements are situated close to riverbanks and canals (Mundhe 2018; Mundhe 2019), making them particularly vulnerable to climate change impacts. The altered monsoon patterns in Western India contribute to their vulnerability, with more frequent and severe flood events resulting from extreme precipitation (Menon et al. 2013).

2. Materials and methods

To apply the proposed scenario linkage approach to Pune, we introduce a conceptual framework that links inequality to vulnerability based on previous research. Then, we analyze the existing strand of literature on scenario types and subsequently present our approach to link top-down scenarios with bottom-up insights from Pune. We also present the top-down scenarios used (SSPs) and the bottom-up perspective and scenario we use from workshops held in Pune in 2019.

2.1. Conceptual framework

To elucidate the impact of income inequality on social vulnerability to climate change, we provide a concise explanation of how we employ the concept of vulnerability in our study. In the Intergovernmental Panel on Climate Change's (IPCC) Fourth Assessment Report (AR4), vulnerability was defined as a function of a system's exposure, sensitivity, and adaptive capacity (IPCC 2007). Even though in the subsequent IPCC report (AR5) a risk-centric approach was introduced, where exposure is regarded as a distinct component contributing to risk (Estoque et al. 2023), we have chosen to incorporate exposure into our concept of vulnerability, since

inequality also affects the exposure of low-income groups (Füssel and Klein 2006; Rasch 2017). The focus of our study is low-income groups in Pune, who are negatively affected by income inequality (Islam and Winkel 2017). Thus, we posit the following causal relationships: income inequality increases the exposure and sensitivity of low-income groups to climatic hazards while diminishing their adaptive capacity to respond to these hazards (Fig. 1).

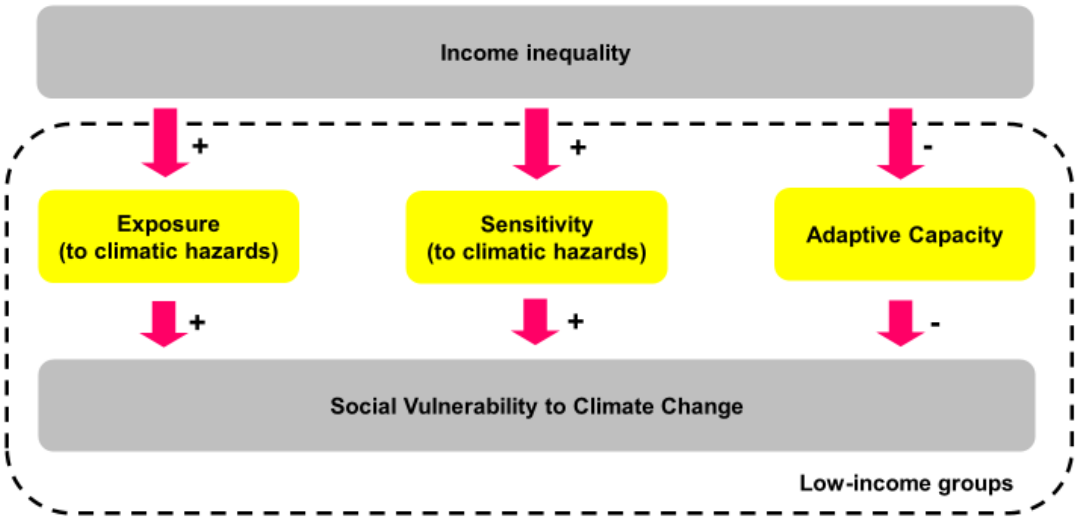

Figure 1: Conceptual framework of the impact of income inequality on the social vulnerability to climate change

These assumptions are supported by previous work: income inequality contributes to the increased exposure of low-income households, as they are often compelled to settle in informal locations that are more susceptible to environmental hazards such as landslides and floods (Rasch 2017). Furthermore, inequality exacerbates the sensitivity of low-income groups to climatic hazards, such as the spread of diseases following flooding, due to limited access to healthcare services and other protective measures (Hallegatte et al. 2016). Lastly, income inequality diminishes the adaptive capacity of low-income groups, as they typically lack the necessary resources to effectively cope with the adverse impacts of climate change (Barbier et al. 2009; McDowell and Hess 2012).

2.2. Scenario Design: Prior efforts

In climate change adaptation research, scenarios are increasingly used for policy-making, enabling discussions on alternative response options in the face of uncertainties (Flynn et al. 2018). Scenarios, which represent postulated pathways of future developments, can be developed through either a researcher-driven "top-down" approach or a participatory "bottom-

up" approach, where stakeholders or decision-makers contribute their perspectives (Flynn et al. 2018; Star et al. 2016). Additionally, scenarios can be explorative, considering a range of possible futures, or normative, focusing on preferred futures and visions (Star et al. 2016). Normative scenarios follow a transformative "back-casting" logic, where a vision is first created as a normative goal, which is then used to identify what must happen to reach this goal (Kok et al. 2011).

2.3. Linking top-down and bottom-up scenarios for Pune

While top-down and bottom-up scenario approaches have often been applied separately in past research, integrating different types of scenarios can enhance their relevance for policy-making in climate change adaptation planning. Therefore, we subsequently present an approach that connects global top-down scenarios with local, bottom-up insights (Fig. 2). As top-down scenarios, we downscale the global Shared Socioeconomic Pathways (SSPs) to Pune. For the bottom-up scenario, we use a normative scenario that emerged from two workshops conducted in Pune in 2019 as part of the FUSE[2] research project.

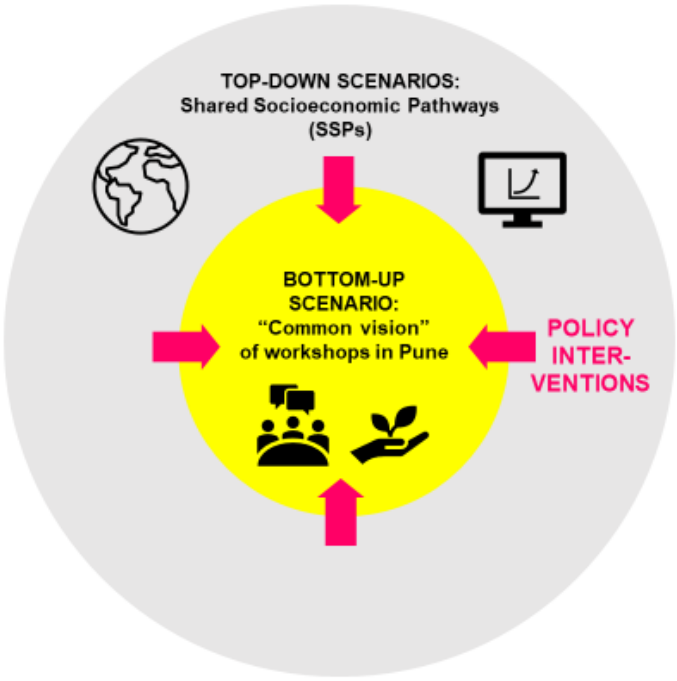

Figure 2. Linking top-down and bottom-up scenarios for the case of Pune, adapted from Wada et al. (2019).

[2] For further information, see https://fuse.stanford.edu/

The outer circle in Fig. 2 represents global trends beyond local policy influence. The inner circle represents the sphere of influence, where local developments can supersede global trends (similar to Wada et al. 2019). We use the participatory "common vision" of the workshops as a normative scenario. By comparing this with the global top-down scenarios of the SSPs, it is possible to derive the local actions needed to steer Pune with policy interventions towards the "common vision". Ideas for such policy interventions were raised by local experts during the second workshop.

2.4. Top-down scenarios of the Shared Socioeconomic Pathways (SSPs)

The five exploratory scenarios of the global SSPs, as depicted in Fig. 3, were designed to capture various potential trajectories for the 21st century. Further details about the storylines can be found in the Appendix A2. The SSPs have been quantified for important socioeconomic variables at the national scale (Riahi et al. 2017). Using statistical and arithmetic downscaling steps, we regionalized the SSP projections to the level of Pune (see Appendix A1).

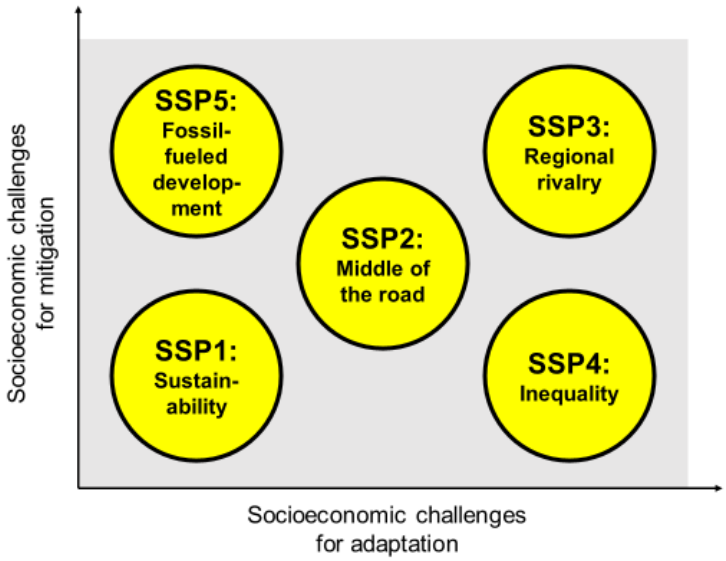

Figure 3. The dimensions of the Shared Socioeconomic Pathways, adapted from O'Neill et al. (2017).

2.5. The Sustainability Nexus Workshops (SNW) in Pune

We analyze input from two workshops, which represent so-called Sustainability Nexus Workshops (SNW) (Karutz et al. 2022; Klauer et al. 2022). These workshops focused on the food-water-energy (FWE) nexus in Pune and involved various groups of interest. The FWE nexus refers to the interdependencies among agriculture, water, and energy sectors in providing essential resources to humans (Bazilian et al. 2011; Mukhopadhyay et al. 2023). The nexus

approach has been used for more than a decade to study the interlinked effects of climate change, aiming to overcome “silo thinking” (Bazilian et al. 2011). In our analysis, we use the link to the FWE nexus, which is inherently connected to inequality (Romero-Lankao and Gnatz 2019), as it enables the formulation of targeted policies to address climate change impacts.

The first workshop was held in Pune on February 18, 2019, and engaged 30 local stakeholders from NGOs (11), farmers' associations (10), research institutions (5), and small companies (4). The stakeholders were provided with potential future developments of the FWE nexus in Pune and then discussed current and future challenges related to the nexus. The second workshop, on February 20, 2019, involved 35 policymakers and experts, including representatives from public institutions (20), academia (11), and the private sector (4). Building upon the stakeholder challenges from the first workshop, the experts developed a "common vision" for Pune, representing a desirable future (Fig. 4). Using a back-casting approach (Kok et al. 2011), the experts identified policy interventions needed to align Pune with this common vision.

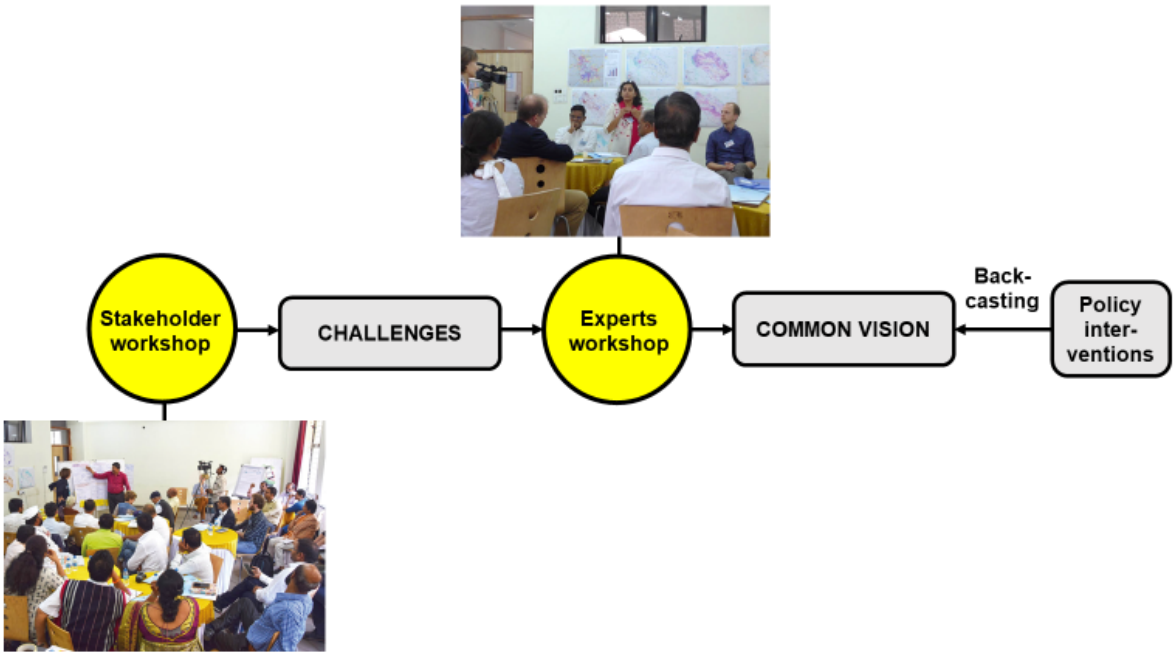

Figure 4. The process of the first-stage Sustainability Nexus Workshops (SNW). Photos: FUSE Project, https://fuse.stanford.edu/about/working-together/pune-workshops

3. Results and discussion

In this section, we first present the regionalized projections of income inequality in Pune based on the SSPs which represent socioeconomic boundary conditions. Drawing on the bottom-up challenges identified by stakeholders in the first SNW, we then examine how inequality contributes to social vulnerability in Pune through various channels. Further, we analyze the bottom-up scenario and the derived local policy measures proposed by experts in the second SNW to assess their potential to reduce social vulnerability to climate change.

3.1. SSP projections for Pune

We present the historical developments of extreme poverty and income inequality in Pune (2011-2019) and downscaled projections from 2019-2050, based on the SSPs (Rao et al. 2019). The applied downscaling techniques are described in the Appendix A1.

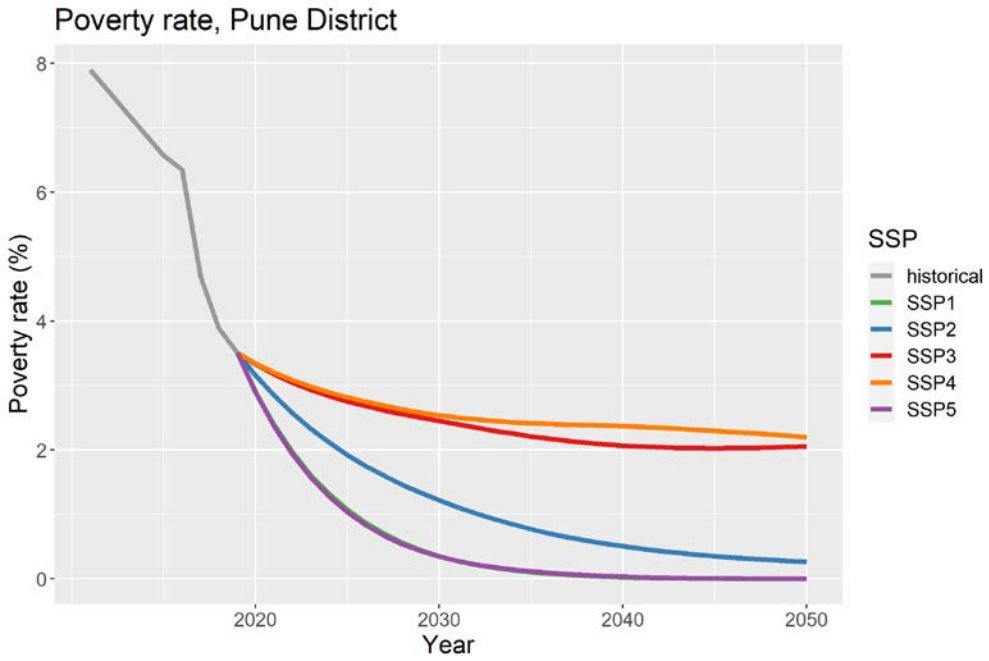

Figure 5: SSP projections of the poverty rate for Pune District. Note: The graphs of SSP1 and SSP5 overlap in the figure.

The projected share of people living in extreme poverty in Pune, defined by the threshold of 1.90 USD per day (World Bank 2015), is expected to decline in all SSPs until 2050, as shown in Fig. 5. In SSP1, SSP5, and SSP2, the poverty rate approaches nearly 0%. However, in contrast to the decreasing trend in extreme poverty, the projections for income inequality in Pune show an opposite trend, as illustrated in Fig. 6.

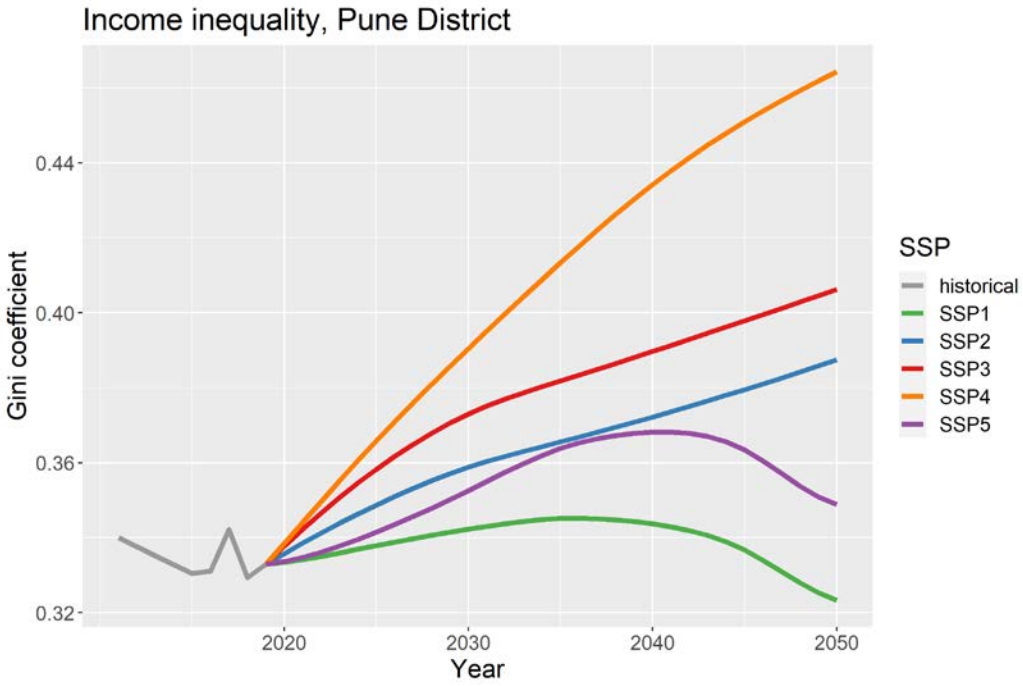

Figure 6: SSP projections of the Gini coefficient for Pune District.

Based on Rao et al. (2019), we utilize the Gini coefficient to measure income inequality, with values ranging from 0 (no inequality) to 1 (Sen 1992). The resulting projections indicate that in Pune, the Gini coefficient is expected to increase notably in SSP4, but also in SSP3 and SSP2. This projected increase in inequality is substantial compared to other emerging economies, primarily due to India's relatively low public investment in education and health (Rao et al. 2019). Only SSP1 and SSP5 show a slight decrease in the Gini coefficient towards 2050, but both scenarios require significant progress in human well-being, which is not currently evident (Thampi 2019).

Simultaneously, the total population in Pune is projected to increase: According to the urban growth projection presented by Karutz et al. (2023), the population of Pune will grow by between 3.4 million (SSP3), 5 million (SSP2), and 5.7 million people (SSP1) by 2050[3]. As a consequence, we see growing inequality in most scenarios (SSP2, SSP3, SSP4) and a greater number of people affected by inequality in all scenarios.

[3] As Jiang and O'Neill (2017) present, the SSP urbanization projections for India for SSP4 and SSP5 match with SSP1.

3.2. The Sustainability Nexus Workshops (SNW) in Pune

While the Gini coefficient alone does not provide insights into the actual circumstances of low-income households, the challenges identified by stakeholders during the first SNW are used to examine the role of income inequality in the vulnerability of these specific groups. These challenges, derived from the stakeholder workshop analysis by Karutz et al. (2022), are presented in Tab. 1. By examining these challenges, we can identify the specific channels of how income inequality affects climate change vulnerability.

Table 1: Challenges of the stakeholder workshop and their relation to inequality and vulnerability

No.	Challenges (see Karutz et al. 2022)	Explicit role of income inequality	Expected primary effect on social vulnerability to climate change of low-income groups
1	Constrained and unequal access to water	The workshop participants highlighted the issue of intermittent piped water supply in Pune, particularly in informal areas and the city fringe. They emphasized that this lack of access to reliable piped water disproportionately affects low-income groups, who are often living in informal settlements.	**High sensitivity and low adaptive capacity** (e.g. due to health impacts)
2	Increasing risk of flood events	The participants stated that slum dwellers have been hit especially hard by recent floods, due to inadequate infrastructure and climate change. Empirical evidence from Link et al. (2021) and Mundhe (2018) confirmed that slum dwellers and rural migrants are specifically prone to flooding in Pune.	**High exposure** (e.g. due to the location of informal settlements in flood-prone areas)
3	Constrained and unequal access to electricity	The participants expressed concerns about interrupted electricity supply throughout the city, with slum areas experiencing particularly high rates of interruptions. Additionally, they noted that energy prices have increased in recent years, so low-income households spend a higher share of their income on electricity.	**Low adaptive capacity** (e.g. due to missing cooling opportunities during heatwaves)

4	Constrained and unequal access to nutritious food	Participants highlighted the uneven access to nutritious food in Pune. They observed that the middle and upper classes have greater access to imported food, while low-income households rely on local food sources with lower and more stable prices.	**High sensitivity and low adaptive capacity** (e.g due to health impacts)
5	Impacts on rural livelihoods of transformations in the ag sector	The participants raised concerns about the income of smallholder farmers in Pune's surrounding areas and noted that rural dwellers often migrate to the city and settle in flood-prone informal areas, as supported by findings in the study by Karutz and Kabisch (2023).	**High exposure** (e.g. due to direct impacts of climate change on agriculture), **low adaptive capacity** (e.g. due to lack of resources)

The role of income inequality related to the stakeholder challenges presented in Tab. 1 is determined through statements made by the workshop participants and supported by relevant references. The assessment of the expected primary impact of income inequality on vulnerability is based on the conceptual framework introduced earlier.

3.3. The normative scenario (“common vision”) of the SNWs

In contrast to the challenges discussed by stakeholders in the first workshop, the normative scenario, referred to as the "common vision”, was formulated by experts and policymakers during the second workshop. Through a visioning exercise, participants in smaller groups depicted their envisioned future for Pune using visual representations such as pictures or mind maps (Fig. 7).

Figure 7: Impressions from the process to formulate a "common vision" scenario. Photos: Karutz et al. (2022), S1.

The common vision for Pune encompasses several key elements, which all relate to the five challenges identified in the stakeholder workshop: The wish for **"equal access to resources"** aligns with challenges 1, 3, and 4, which pertain to unequal access to water, electricity, and nutritious food. The envisioned **"equal access to infrastructure"** addresses challenge 2, related to the increased risk of informal settlements to flood events, while the imagined **"equality between urban and rural areas"** addresses challenge 5, which pertains to the impacts on rural livelihoods resulting from transformations in the agricultural sector.

3.4. Policy interventions: From the SSPs to the common vision of the SNWs

The downscaled SSP scenarios represent large-scale boundary conditions. The stakeholder challenges of the SNWs, on the other hand, provide valuable insights into the local dynamics, highlighting the specific impact of income inequality on the city's population. The common vision, created in the second SNW, offers a normative scenario for Pune which tackles these challenges. Building upon this, we present policy interventions, proposed by the experts in the second SNW, that address the common vision in a back-casting approach, as depicted in Fig. 4.

Table 2: Proposed policy interventions from the expert workshop

No.	**Challenges (see Karutz et al. 2022)**	**Policy interventions proposed by experts *(selection)***	**Expected primary effect on social vulnerability to climate change of low-income groups**	**Expected overall impact**
1	Constrained and unequal access to water	More stringent implementation of laws regarding the distribution of water between sectors, regions, and different users	Reduced sensitivity, higher adaptive capacity	Moderate
		Enhancing water availability to all times and places (e.g. Pune 24/7 initiative)	Reduced sensitivity, higher adaptive capacity	High *(if access to slums is included)*
2	Increasing risk of flood events	Flash flood forecasting/early warning systems	Higher adaptive capacity	Moderate
		Implementation of a disaster response center	Higher adaptive capacity	Moderate
		Incentivize green roofs	Reduced exposure and sensitivity	Low
3	Constrained and unequal access to electricity	Incentivize the use of solar energy	Higher adaptive capacity	Moderate
		Establish a demand-responsive (smart) grid	Higher adaptive capacity	Low

4	Constrained and unequal access to nutritious food	Eliminate support of cash crops *(mainly used for exports)*	Higher adaptive capacity *(if more staple crops are grown)*	Low
5	Impacts on rural livelihoods of transformations in the ag sector	Incentivize crop insurances	Higher adaptive capacity	Low
		Improving weather forecasts and early-warning systems for droughts	Higher adaptive capacity	Moderate
		Capacity building for climate-resilient agriculture	Higher adaptive capacity	Low

Tab. 2 displays a selection of policy interventions proposed by experts and their potential impact on social vulnerability to climate change. Notably, a majority of the policy interventions primarily focus on enhancing adaptive capacity, encompassing more feasible measures with low to moderate expected impacts. This especially holds for challenge 2 **"Increased risk of flood events"**, where no structural measures, such as dams, are suggested. Given the projected population intensification of low-income groups in flood-prone areas (Karutz et al. 2023), the suggested policies are expected to have only a moderate impact. For challenge 1 **"Constrained and unequal access to water"**, the proposition of enhanced water availability has a higher potential impact, however, this only holds if informal settlements gain access to piped water supply. For the other challenges, the overall expected impact on low-income groups is rather low and indirect, since they target single sectors (electricity, agriculture) and lack emphasis on low-income groups. Overall, we conclude that the proposed policies address the identified channels through which inequality raises social vulnerability in Pune to a varying degree, and that they partially lack the consideration of systemic effects.

4. Conclusions

In summary, this study effectively combined top-down and bottom-up scenarios to examine the interactions between global and local factors in Pune. The SSP projections indicate that income inequality is projected to increase in Pune in the medium term, leading to potentially heightened social vulnerability to climate change for low-income groups, as evidenced by the challenges identified in the SNWs. Unequal access to basic resources, such as water, electricity, and food, as well as urban flood risk, are identified as channels through which inequality exacerbates the social vulnerability to climate change in Pune. The policy interventions proposed in the second

part of the SNWs offer targeted approaches to address the specific challenges within the FWE nexus and potentially reduce social vulnerability to climate change. Yet, it is important to note that, in the face of growing climate change impacts and inequality, the proposed policies do not address all identified channels to the same extent and they fail to incorporate systemic components to target the heightened challenges of low-income groups comprehensively.

We would like to acknowledge the limitations of this study, including the lack of empirical testing of the relationship between income inequality and vulnerability to climate change and the effect of the suggested policies. Future research should focus on evaluating the effectiveness of the proposed policy measures, while also exploring alternative interventions for comprehensive analysis. Here, the development of coupled human-natural system models can aid in comparing the impact of different policy interventions, providing valuable insights for local policymakers.

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Appendix A1. Arithmetic and statistical methods of downscaling the SSP projections

The presented SSP projections are based on the SSP projections of the poverty headcounts[4] and the Gini coefficient on the national level by Rao et al. (2019). We further regionalized these projections by using temporal and spatial downscaling processes, which are facilitated using two important tools: Interpolation over time and standardization over space. Interpolation is used to estimate new data points between existing ones (James et al. 2013). In the case of the SSP values, this is important because only five-yearly time series for the years from 2010 to 2100 are available (2010, 2015, etc.). The simplest, yet most suitable interpolation in the case of the SSPs is the cubic spline function, where piecewise polynomials of degree 3 are used to connect the existing values with a fitting curve (James et al. 2013).

The latest estimates for the poverty rate and Gini coefficient on the Pune District level are based on the 68th NSS Household Consumer Expenditure survey, available for 2011/12 (Bhandari and Chakraborty 2015; Tripathi 2016). Since no more recent estimates on the level of Pune are available, we use data on the level of India to prolong the time series until 2019 (World Bank 2023a; 2023b). Therefore, we calculate the percentual change of the poverty rate and Gini coefficient for India between 2011 and 2019 and apply this to the value of 2011 in Pune. Likewise, for the SSP projections, we use spatial standardization to project the poverty rate and Gini coefficient starting from 2019 by only using the fractional growth between any two sequential annual SSP projections for India from Rao et al. (2019). The results for Pune are given in the Tables S4 and S5 below.

[4] We divided the poverty headcounts by the SSP population projections for India from K.C. and Lutz (2017) to obtain the poverty rate (the share of the population below the poverty line).

Appendix A2. A short description of the five SSP scenarios regarding India after O'Neill et al. (2017).

SSP1	This scenario is the most optimistic scenario, in which a significant transition will take place towards the adaptation of green technologies and inclusive development. Emerging economies like India will not follow the resource-intensive path of high-income countries.
SSP2	The "business as usual" scenario is mainly based on the extrapolation of historical global trends. India will grow fast in the beginning, but then growth will decelerate due to technological and demographic boundaries.
SSP3	The scenario of regional rivalry emerges from resurgent nationalism and rising regional conflicts. India will face slow economic and income growth; inequalities will persist and worsen at the national and international scale.
SSP4	This scenario is defined by increasing inequalities on all scales. This results in the segregation of society into a highly educated elite and a poorly educated remaining society living from labour-intensive work. High- and middle-income countries experience moderate growth, whereas low-income countries like India stay behind.
SSP5	SSP5 tells the story of a disruptive future. Technological progress and human capital formation are accelerated on a global scale. Due to high economic participation, a new broad global middle class is formed. In India, birth rates fall rapidly and the global population peaks in the middle of the century.