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Exposure to Climatic Risks and Social Sustainability in Vietnam

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Abstract: This article constructed two spatial indices to better understand the interactions between social sustainability (an important but poorly defined concept) and exposure to climatic and environmental risks. The indices, and the Choropleth maps used to represent them, can be combined and operationalized across different country contexts to yield insights into how climate change and social vulnerabilities intersect and can be jointly addressed. The two indices were here applied to Vietnam, a country particularly exposed to climate change. While Vietnam is well-known for its vulnerability to changing temperatures and rising sea levels, there was huge variation within and between regions for these two risks. The analysis also found enormous spatial variation within the risks from precipitation, drought, deforestation, and air pollution. Social inclusion generally outperformed resilience and social cohesion, as well as empowerment in Vietnam. Our findings were robust for choices of indicators, weights, and aggregation specifications.

Keywords: climate change; social sustainability; spatial distribution; risks; exposure; Vietnam

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Citation: Cuesta, J.; Cai, L.; Madrigal, L.; Pecorari, N. Exposure to Climatic Risks and Social Sustainability in Vietnam. *Sustainability* **2023**, *15*, 3260. https://doi.org/10.3390/su15043260

Academic Editors: Andrei P. Kirilenko and Chin-Yi Fang

Received: 23 November 2022
Revised: 30 January 2023
Accepted: 2 February 2023
Published: 10 February 2023

1. Introduction

Climate change has huge, diverse spatial impacts, both globally and within countries [1]. It has disastrous economic and social consequences, increasing poverty, forced migration, food insecurity, and conflict [2–5]. Dell, Jones, and Olken [6] estimated that every 1 °C of warming reduced global income by 1.2 percent in the short run and between 0.5 percent and 3.8 percent in the long run. The burdens of air, water, and soil pollution are felt mainly in developing countries, whose dependence on natural resources is also the highest. In fact, many countries with the greatest projected future poverty risk also display the lowest level of preparedness for climatic and environmental disasters [7]. An Overseas Development Institute report concluded that the 45 countries most exposed to climatic hazards will be home to some 325 million people by 2030, highlighting the close links between poverty, hazards, and poor risk governance [8].

The benefits of concerted action are enormous. Limiting global warming to 1.5 °C rather than 2 °C above preindustrial levels could reduce the number of people exposed to climate risks and vulnerable to poverty by between 62 million and 457 million [9]. It would also lessen the risks of food and water insecurity, adverse health impacts, and economic losses experienced by poor people. The benefits would be particularly felt in regions already facing development challenges [9]. The benefit-cost ratio of investing in resilient infrastructure ranges from USD 2.5–11 for every USD 1 invested in boosting resilience to various hazards [10]. IMF [11] estimated that investing in resilience in the Caribbean would increase potential economic output by 3–11 percent, with a growth dividend of 0.1–0.4 percent a year. However, realizing such combined international efforts will not be cheap. The costs of adapting to climate change in developing economies are currently estimated at USD 56–73 billion, two to three times greater than the currently available financing [12]. The required adaptation costs are also projected to rise to USD 140–300 billion by 2030.

The existence of such interactions between economic and environmental sustainability is well-established (originally framed by the IUNC, UNEF, and WWF [13] and the Brundtland Commission report [14]. By contrast, the connection between climate change and social sustainability remains less conclusively unpacked [15]. This is in part because standard analyses of sustainability have disproportionally focused on the ecological consequences, including irreversible damage, of prevailing economic models of growth [16]. Furthermore, despite a growing body of work seeking to refine the concept, social sustainability is often poorly understood, vaguely defined, and simplistically equated to poverty reduction [17].

In the literature, the complexity of social sustainability in terms of its components, interactions, and goals led to either incomplete definitions or unworkably long lists of attributes. Commonly discussed features include equity, intra- and intergenerational well-being, quality of life, and the satisfaction of basic needs. Other analyses emphasized social interaction and interconnectedness, social integration and participation, freedom, safety and security, and access to basic infrastructure and services. Both approaches (consisting of either vague or overly long definitions) are unhelpful in delivering a definition that can be understood, agreed upon, and operationalized. Notably, only a few works have discussed policies associated with attributes of social sustainability (such as [16,18–21]).

Other efforts have meanwhile merged environmental and social sustainability into a single index. This is the case in the extensive literature on resilience to natural disasters, including [22–38]. These indices brought multiple dimensions of environmental and social sustainability together, typically including social, environmental, institutional, economic, physical/infrastructure, and community capacity aspects. They were related to a wide range of disasters and contexts (urban, rural; provincial, national; developed and developing countries). The underlying concept of resilience was framed around risk management: a combination of increasing readiness and reducing exposure and vulnerability [39]. However, such indices required a huge amount of data: [33] drew on 68 indicators, while [38] used 62. This makes it difficult to replicate them and, thus, draw comparisons across different country contexts. Additionally, the social dimension was often underdeveloped or poorly integrated with these indices of resilience. Incidence of poverty, family structures, socioeconomic dependency, access to services, presence of vulnerable groups, citizen participation, social capital, and female empowerment were variously included. There is, however, no commonly agreed set of social indicators nor a clear sustainability framework behind their selection. There remains a need for a consistent, meaningful, and comparable set of indicators that simultaneously measures exclusion, trust, voice, participation, and transparency; all of which are critical components of social sustainability (see below, Section 2).

As a result, we propose the construction of two separate indices. One captures exposure to environmental and climatic risks beyond natural disasters alone. The other captures social sustainability, systematically including aspects of social resilience and social cohesion, exclusion, and empowerment. Each index will be able to capture multiple risks and dimensions of social sustainability. Each works with a manageable and easily replicable set of indicators (8 climatic and environmental risks and 21 indicators of social sustainability). Each can be unpacked, and their key drivers identified. At the same time, they can be overlapped geographically, generating a combined social and environmental sustainability spatial profile. The new proposed indices can also be applied across and within countries (at the regional, provincial, and municipal levels).

To apply our proposed measure and spatial analysis, we focused on Vietnam: a country particularly vulnerable to climate change and with readily available data to construct alternative measures of both climatic risks and social sustainability. Vietnam's annual mean temperature has increased by between 0.5 and 0.7 °C since 1960, almost twice the rate of global warming [2]. Sea levels are projected to rise between 0.18 and 0.56 m by 2090 [40]. Annual precipitation is projected to increase by 10 to 20 percent by 2045–2065 [41]. A third of Vietnam's population is at risk of extremely severe floods [42]. The country experienced 8 to 12 natural disasters every year between 2016 and 2020, mostly cyclones and floods that killed hundreds [43]. Such disasters have cost Vietnam between 1 to 1.5 percent of its GDP per year since 1990 [44]. Chapman and Dang Tri [45] reported that the 2015–16 drought, one of the worst in the past century, caused salt water to intrude over 80 km inland, destroying at least 160,000 ha of crops in the Mekong Delta.

Beyond economic losses, there are mounting concerns surrounding the social impacts of climate change. The Mekong Delta Research Institute and Oxfam [45] noted that climate hazards in Vietnam further limited access to transportation and services, increased commute times to school, depressed wages among low-skilled workers, made food shortages more frequent, and damaged or polluted homes. These impacts increased disadvantaged groups' susceptibility to health problems and damaged their education, access to dignified work, living conditions, and financial security. Disproportionally affected were the ill, the elderly, children, people with disabilities, pregnant women, and less-educated ethnic minorities. Narloch and Bangalore [46] found that households in communes with steeper slopes, higher temperature variability, and greater flood and drought hazards had lower consumption levels. Those living in communes with higher air pollution meanwhile displayed lower consumption growth. Their analysis also noted that ethnic minorities and poor households were much more exposed to multiple environmental risks than other groups, as they tended to disproportionally live in such areas.

Furthermore, some 84 percent of the Vietnamese population believes that climate change is a "very" or "somewhat serious" threat [47]. Clement et al. [2] projected that climate change will displace some 1.5 to 3.1 million people within Vietnam's borders by 2050. Chapman and Dang Tri [45] suggested that 1 million out of a population of 18 million in the Mekong Delta had already migrated elsewhere due to climate change. They indicated that climate change might act directly, through disaster-led displacement, as well as indirectly by affecting agricultural production. Kim and Minh [48] concluded that harsh environmental conditions are the dominant push factor for at least 20 percent of migrants leaving the Mekong Delta, mostly for Ho Chi Minh City. Other projections are even gloomier. One in every ten Vietnamese people risks losing their home to rising sea levels [49], while Ha [50] predicted that vulnerable rural populations would swell due to salt intrusion.

A common shortcoming of the reviewed literature on Vietnam is its focus on a single climatic risk and social impact at a time—for example, salt intrusion and livelihoods or floods and migration. This paper addresses the resulting evidence gap for Vietnam by simultaneously analyzing the connections between multiple climatic and environmental risks and numerous social dimensions.

After this introduction, Section 2 of the paper describes the methodology and data needed to develop our original indices measuring exposure to climatic and environmental risks and indices of social sustainability in a given country. Section 3 reports the results for Vietnam. Those results describe the spatial distributions of risks, the geographical distribution of social sustainability, and their joint distribution. Section 4 discusses our findings and further unpacks key results. Section 5 concludes, reflecting on the implications for policymaking of the complex way in which environmental risks and social sustainability are distributed and connected.

2. Materials and Methods

2.1. Methods

Using open-source satellite data, we initially computed an original index for the spatial distribution of multiple environmental and climatic risks in a given country. This climatic and environmental risk exposure index, CEREI, is estimated as follows:

$$CEREI = \sum_i \left[\partial * \frac{x - x_{min}}{x_{max} - x_{min}}\right]_i \quad (1)$$

where x is the i-th risk considered, which is normalized between 0 to 1 (1 = the highest risk exposure) and aggregated through a scalar, ∂, which, for simplicity, is assumed to be

$1/i$—that is, each risk is equally weighted. The aggregated exposure index, CEREI, ranges from 0 to 1, with 0 representing the lowest overall exposure.

CEREI includes the following risks: air pollution, deforestation, drought, earthquake, flood, precipitation variation, sea level rise, and temperature variation. The normalization of exposures to all such risks between 0 and 1 allows for a straightforward comparison of the exposure to different risks. Unfortunately, CEREI does not include climatic and environmental risks such as salinity intrusion and water pollution. Nor does satellite imagery report such phenomena with precision.

Regarding spatial aggregation, satellites can provide a resolution as sharp as 30 m $\times$ 30 m cells in the case of deforestation. However, the most precise units of analysis need to be aggregated into higher-level common units, for example, districts. To do so, different weights were used: geographic weights, equal weights, and population weights. In addition, district-level indicators were then aggregated at the provincial and regional levels. We did this by taking the mean of districts (provinces) so that we could obtain provincial (regional) aggregates. This can be performed using geographical, equal, and population weights in alternative measures. For the purpose of this exercise, it was originally assumed that all districts in the same province contributed to the provincial-level value equally. All districts were treated equally regardless of their population or size. This resulted in using equal means. Then, this assumption was relaxed, and robustness checks were conducted with the two alternative geographical and population weights. We adopted an additive model that took the sum of all standardized indicators in order to construct the aggregate exposure index.

We then constructed an index of social sustainability. Social sustainability was initially defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [14]. At other times, social sustainability has been equated with social inclusion [51]. It has also been described as some combination of community and national dynamics, contemporary and intergenerational equity, social justice, voice, inclusion, participation, and citizenship [16,19–21,52,53]. The list of features employed in the literature is long and open-ended. Dempsey et al. [20] proposed a list of 27 elements, whereas Weingaertner and Moberg [54] identified 17 dimensions. However, Ballet, Bazin, and Mahieu [16] identified just three recurring aspects of social sustainability in the literature: social cohesion (coherence in the attitudes and behaviors of members of a given society), equity (lack of inequalities), and safety (protection from economic shocks). They also showed that each of these components was closely connected with environmental sustainability. Littig and Griessler [18] defined social sustainability as interactions between individuals and related institutional arrangements. Those links help satisfy an extended set of human needs and fulfill the normative claims of social justice, human dignity, and participation. World Bank [55] provided a conceptually similar definition of socially sustainable development. According to the World Bank, development is socially sustainable when it promotes inclusive, resilient, cohesive, and accountable institutions.

In spite of the absence of a consensus around the concept or measurement of social sustainability, there was sufficient common ground to discard some elements and include others in our proposed framework. We defined social sustainability parsimoniously as a composite of three pillars: social inclusion, resilience and social cohesion, and empowerment. These definitions are closely aligned with [16] but not identical. We used social inclusion rather than equity. We did not focus on income inequalities and unequal access to services but on equal access to economic, political, civic, and physical spaces. Instead of safety—which was already covered in our proposed measure under access to physical spaces—we employed resilience, which allowed us to capture readiness for all kinds of shocks. We retained social cohesion, participation, and agency and added empowerment. Our definition of social inclusion aligns closely with World Bank [51,56]. By adding empowerment—defined below—we included a feature emphasized by others such as [20,57] as necessary to maintain social sustainability. Our empowerment component also accommodates [18]'s reference to participation. Finally, our choice of components is similar to the package of inclusion, cohesion, resilience, and institutions adopted by the World Bank [55].

Our framework contends that social sustainability is a feature of inclusive societies, where vulnerable and non-vulnerable groups alike have access to services and markets. This access allows them to participate in society with dignity and reach their potential. It occurs when communities are resilient and able to withstand exogenous shocks, when individuals of all backgrounds can realize their aspirations, and when they can voice their needs to governments that are trusted, accountable, and responsive. Underpinning social sustainability is needed for cohesive societies and communities that are not fractured by conflict and political or ethnic tensions. In such societies, decisions by local, national, and international actors are made in such a way that they are viewed as legitimate and promoting the greater good.

We defined social inclusion as the process of creating opportunities for all people and addressing deep systemic inequalities. It, therefore, involves improving the ability of all people to access basic services and markets regardless of their personal or community characteristics. We measured social inclusion by assessing access rates to key markets and services. Relevant indicators included labor force participation; access to water, sanitation, and electricity; internet access; secondary educational enrolment; and access to healthcare.

Resilience and social cohesion refer to the ability of communities and groups in both fragile and nonfragile environments to cope with shocks such as climate change, pandemics, interpersonal violence, and conflict. We measured resilience with indicators that captured the ability of households to deal with shocks. Such indicators included the presence of multiple sources of income in the household and their capacity to save in previous years before being surveyed. Social cohesion was measured by determining levels of interpersonal trust; trust in institutions (captured by trust in elections and the justice system); attitudes towards minority groups (captured by tolerance of LGBTI people); and perceptions of insecurity. These definitions are consistent with those frequently used by the literature on resilience to natural disasters (see [33,36]). They emphasize both exposure to hazards and the ability to resist, absorb, accommodate, and quickly recover from them [58].

Empowerment can be understood as expanding vulnerable groups' voices and influence. This increased voice helps them shape development solutions, influence public policy, and foster accountable service delivery. We measured empowerment through several indicators that capture women's empowerment specifically, as well as the empowerment of other vulnerable individuals and groups. The indicators used include the prevalence of inegalitarian gender social norms, more specifically, the views that women should not earn more than men and that men make better political leaders. Other indicators included membership in organizations, groups, and clubs; participation in voluntary associations; the share of the population that recently worked with other citizens to solve local problems; the ability to join organizations without fear; and the share of the population that feels free to speak their minds.

We aggregated those indicators across social sustainability components through the following regional social sustainability index:

$$SSI = \sum_j \theta_j \sum_i (w\, s)_i \tag{2}$$

where θ_j is the weight of the j-th SSI component (j = 1, 2, 3), that is, social inclusion, resilience and social cohesion, and empowerment in each region;, while w is the weight for each i-th social sustainability indicator; and s is used to define the respective component, following the most parsimonious definition in our index, $\theta_j = 1/3$ and $w = 1/i$. In practice, the Social Sustainability Index was defined here at the regional level. That was the most disaggregated level at which social data sources were statistically representative.

Unlike in the CEREI, the Social Sustainability Index could not be further disaggregated into smaller units of analysis. This was the case because household surveys had a more highly aggregated representativity than indices based on satellite data. Thus, even though household surveys in Vietnam report data for provinces, the surveys are not designed to be statistically representative at the provincial level. This contrasts with, for example, Mexico or Indonesia ([59,60]. These national surveys provide municipality- and village-level representative data, respectively. The exact gain in precision from a more disaggregated spatial distribution is discussed below in the case of Vietnam (see Section 4 below).

Choropleth maps were used to report both the CEREI and SSI indices. A Fisher's natural breaks method was used to determine the color coding of the map. This method maximized the homogeneity of observations grouped in the same interval [61].

In conclusion, our methodology consisted of three steps. First, we constructed two indices, CEREI and SSI, to separately profile the exposure to climatic and environmental risks and social sustainability. Second, each index was further unpacked by risk and by social component, respectively. This unpacking captures the variation between risks and social components within regions. Thus, an analyst can compare the extent to which exposure to flooding is similarly distributed with respect to exposure to temperature variation. The analyst can also determine if the country's regional patterns of social inclusion and social cohesion are homogeneous or heterogeneous. These spatial profiles can be expressed numerically (through the value of the indices) or visually (through Choropleth maps). Third, both indices were combined to determine the intersections between climate change and social vulnerabilities. This was performed by overlaying both CEREI and SSI Choropleth maps into a single map. Overlaying the spatial distributions of social sustainability with climatic risks identifies which regions are best equipped to confront risks in a socially sustainable way. As before, the overlaid map can be further disaggregated by type of risk and social component. By bringing together the outcomes of these three steps, we can better understand the association between climatic and social sustainability in a given country.

2.2. Data

Table 1 describes the risks considered in Vietnam and the data sources, measures, and resolutions used in our exposure index. Exposure values capture how frequently climatic and environmental risks are expected to occur at the given location. Vulnerability increases with rising exposure to adverse risks and the inability of socioeconomic systems to cope with those risks (as the framework articulated by the Intergovernmental Panel on Climate Change predicts). Of all climate risks, Vietnam is most exposed to temperature variation and sea level rise, for which the index exceeds 0.6 and 0.5, respectively. Forest loss, air pollution (both exceeding 0.3), and earthquakes (under 0.2) are expected to be the least prevalent.

Table 2 reports the indicators, data sources, and values of the SSI for Vietnam. Social inclusion levels are high in Vietnam. The country exhibits very high rates of labor force participation (76 percent), easily accessible healthcare (79 percent), secondary education enrolment (80 percent), and close to universal access to the internet, sanitation, and water services (at or above 90 percent; see Table 2). Resilience indicators report a high capacity to save and diversify labor supply among Vietnamese households (33 and 94 percent, respectively). Social cohesion is weaker; however, interpersonal trust, trust in institutions, and tolerance of minorities (in terms of sexual orientation) are all below 40 percent. Some 17 percent of the population report feeling unsafe in their neighborhoods. Empowerment scores even worse: less than 30 percent of the population participates in associations or community affairs. Further, negative gender norms are widespread. About half of the population believes men make better political leaders and should earn more than women. Additionally, nearly a third of people feel afraid to speak their minds. This share rises to half of the population when it comes to feeling afraid to join an organization.

Table 1. Climatic and environmental risks in Vietnam, circa 2020, and their data sources.

Indicators	Measures	Spatial Resolution	Mean Values (0 = Min, 1 = Max)	Data Sources
Floods	Number of floods, 1985–2020	Incidents	0.402	Dartmouth Flood Observatory
Earthquakes	Average earthquake exposure, 1976–2002	5 km	0.167	NASA's Global Earthquake Hazard Frequency and Distribution
Absolute forest loss	Average loss of forest coverage, 2000–2019	30 m	0.321	Hansen Global Forest Change
Air pollution	Average levels of fine particulate matter, 2018	10 km	0.333	Socioeconomic Data and Application Center (SEDAC)
Temperature variation	Average monthly temperature variation, 2007–2017	27 km	0.612	University of Delaware-NOAA
Precipitation variation	Average monthly temperature variation, 2007–2017	10 km	0.465	University of Delaware-NOAA
Droughts	Standardized Precipitation-Evapotranspiration Index (SPEI), 2017–2020	1 degree	0.481	Global Drought Monitor
Sea level rise	2018 sea surface height compared with a 20-year mean reference period (1993–2012)	0.25°	0.539	Copernicus Marine Environment Monitoring Service (CMEMS) and the Copernicus Climate Change Service (C3S)

Source: Data from [62–69].

Table 2. Social sustainability indicators and data sources in Vietnam, %, c. 2020.

Pillars	Selected Indicators	Year	Data Sources	Mean Value, %
A. Social Inclusion				
	1. Labor force participation (% of total population ages 15+)	2018	VHLSS	76.4
	2. Share of households with access to electricity, %	2018	VHLSS	99.6
	3. Share of households with access to water, %	2018	VHLSS	95.3
	4. Share of households with access to adequate sanitation, %	2018	VHLSS	88.9
	5. Share of population that uses the internet, %	2018	Asian Barometer	87.2
	6. Secondary enrollment rate, %	2018	VHLSS	80.5
	7. Share of population that finds accessing healthcare relatively easy, %	2018	Asian Barometer	79.9
B. Resilience and Social Cohesion				
	1. Share of population that saved during the past year, %	2020	World Values Survey	33.5
	2. Share of households with multiple sources of non-agricultural income, %	2018	VHLSS	93.8
	3. Share of population that believes most people can be trusted, %	2020	World Values Survey	27.7
	4. Share of population that has confidence in elections, %	2020	World Values Survey	22.8
	5. Share of population that has confidence in the justice system/courts, %	2020	World Values Survey	27.7
	6. Share of population that is ok with having neighbors of different race, %	2020	World Values Survey	37.6
	7. Share of population that feels secure in their neighborhood, %	2020	World Values Survey	83.6

Table 2. *Cont.*

Pillars	Selected Indicators	Year	Data Sources	Mean Value, %
C. Empowerment				
	1. Share of population that doesn't agree that women shouldn't earn more than men, %	2020	World Values Survey	52.9
	2. Share of population that doesn't agree that men make better political leaders, %	2020	World Values Survey	44.8
	3. Share of population that agrees (strongly or somewhat) that there is freedom to speak, %	2018	Asian Barometer	69.0
	4. Share of population that participates in voluntary associations, %	2018	Asian Barometer	19.8
	5. Share of population that is a member of a club, group, or organization, %	2020	World Values Survey	30.7
	6. Share of population that got together in person to solve local problems at least once during last year, %	2018	Asian Barometer	25.0
	7. Share of population that (strongly or somewhat) agrees people can join any organization without fear, %	2018	Asian Barometer	51.0

Source: Data from [70–72]. Note: Vietnam Household Living Standard Survey (VHLSS).

3. Results

Climatic and environmental risks are unevenly distributed in Vietnam. Northern and coastal regions are more exposed. (Figure S1 in Supplementary Materials maps the country's regions and provinces). Our aggregate risk exposure index for circa 2020 finds that the Northern Midlands and Mountain Area is the most vulnerable to climatic and environmental hazards. The Red River Delta region and the North Central and Central Coastal region follow in aggregate risk exposure. By contrast, the Central Highlands, Southeast, and the Mekong River Delta regions are the least exposed to such risks (see Figure 1).

More complex and distinctive patterns of exposure emerge when this aggregate exposure to climatic risks is unpacked across risks and within regions. Table 3 reports distinct patterns across risks and regions. The CEREI exposure index for each risk ranges widely, between less than 0.17 for earthquakes to over 0.61 for temperature variation (with 0 being the lowest exposure possible and 1 the highest). Importantly, aggregated results hide marked differences both across risks and geographically. Choropleth maps in Supplementary Materials Figure S2 visually unpack the spatial variation in the exposure to each risk by province. Table 3 provides geographical averages of the exposure of each risk.

Table 3. Unpacking the CEREI Index across risks and regions, c. 2020.

Climatic and Environmental Risk	Northern Midlands and Mountain Area	Red River Delta	North Central and Central Coastal Region	Central Highlands	Southeast	Mekong River Delta	National Average
Flood	0.518	0.169	1.000	0.651	0.072	0.000	0.402
Earthquake	1.000	0.000	0.000	0.000	0.000	0.000	0.167
Sea level rise	0.000	0.966	0.396	0.000	0.871	1.000	0.539
Air pollution	0.567	1.000	0.219	0.000	0.108	0.102	0.333
Precipitation variation	0.729	0.000	1.000	0.531	0.193	0.339	0.465
Temperature variation	1.000	0.388	0.942	0.856	0.000	0.485	0.612
Absolute forest loss	0.184	0.000	0.148	1.000	0.355	0.238	0.321
Drought	1.000	0.959	0.000	0.122	0.807	0.000	0.481
CEREI	1.000	0.465	0.544	0.351	0.085	0.000	0.407

Source: Authors' elaboration from data sources drawn from Table 1.

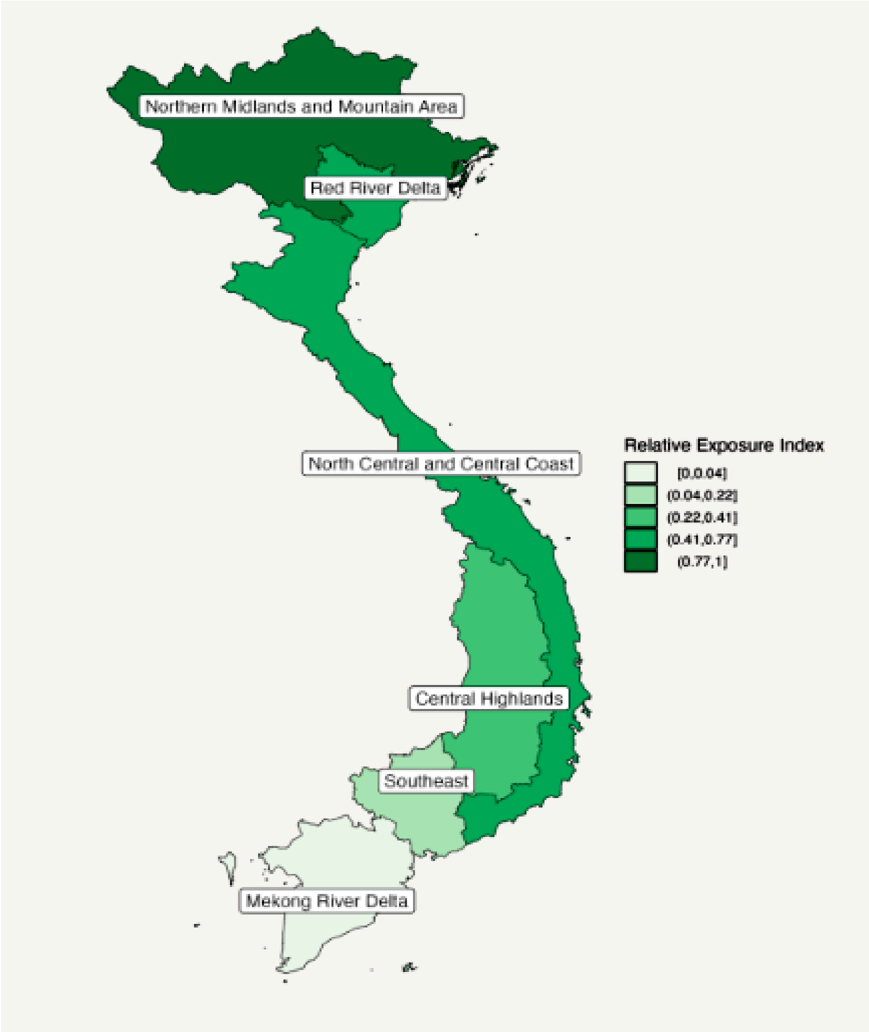


Figure 1. Aggregated exposure to climatic and environmental risks in Vietnam (0 = lowest, 1 = highest), c. 2020. Source: Authors' elaboration from data sources reported in Table 1. Note: An increasingly dark color palette indicates a higher exposure to climatic and environmental risks.

While the Mekong River Delta region is the least exposed to aggregated climatic and environmental risks, it is the most exposed to sea level rise. In fact, a handful of provinces in the region, in particular, are the most vulnerable to rising sea levels: Ca Mau, Kien Gang, Tien Gang, Tra Vinh, Sock Trang, and Can Tho City. The provinces of Vung Tau, in the Southeast region, and Ninh Binh, Thai Binh, and Hai Phong City in the Red River Delta region are also among the most exposed to sea level rises (Supplementary Materials Figure S2). By contrast, the Northern Midlands and Mountain Area is the region most exposed to multiple risks and displays wide variations within its provinces and districts. This region's provinces of Lai Chau, Lao Cai, and Thai Nguyen are significantly exposed to highly variable rainfall (alongside Ca Mau province in the Mekong River Delta region). The largest risks of temperature variation are also observed in the Northern Midlands and Mountain Area (Dien Bien, Son La, Lao Cai), Ca Mau province (in the Mekong River Delta), and some pockets of the Central Highlands region. In turn, drought risks are also concentrated in the Northern Midlands and Mountain Area (with a significant overlap with temperature variations). Significant drought risks are also observed in a handful of provinces (Quang Binh and Quang Tri) in the North Central and Central Coastal region, the Southeast region (Binh Thuan), and the Mekong River Delta region (Ca Mau). The northern regions of the country also report the most intense exposure to air pollution, especially across the Red River Delta region—where Hanoi, the capital city, is located. Air pollution is also widespread in the Northern Midlands and Mountain Area and adjacent provinces of the North Central and Central Coastal region. Severe risks of floods (coastal or otherwise) are widely distributed across the North Central and Central Coastal and Central Highlands regions. The North Central and Central Coastal region (especially Ngae An and Quang Nam provinces) and the Central Highlands and Southeast regions, in general, exhibit the largest risk of forest loss.

Vietnam exhibits moderate levels across the board with regard to social sustainability. As shown in Figure 2 below, the aggregated Social Sustainability Index (SSI) averages a narrow range of 0.56 to 0.60. However, this very uniform level of aggregate social sustainability should not be equated with a uniform pattern across all three components. Both Table 4 and Figure 3 show quite the opposite, depicting very distinct patterns of social inclusion, resilience and social cohesion, and empowerment across Vietnam.

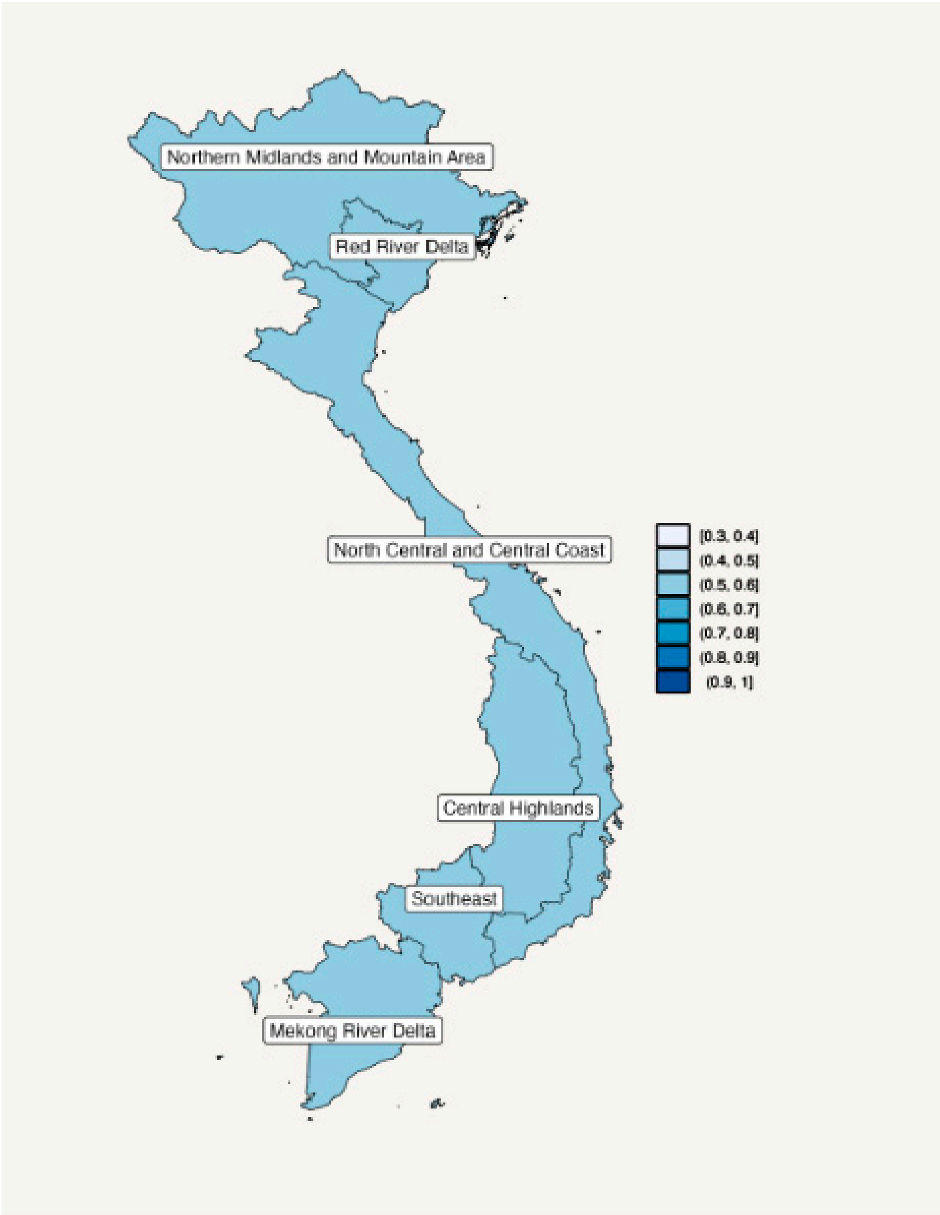
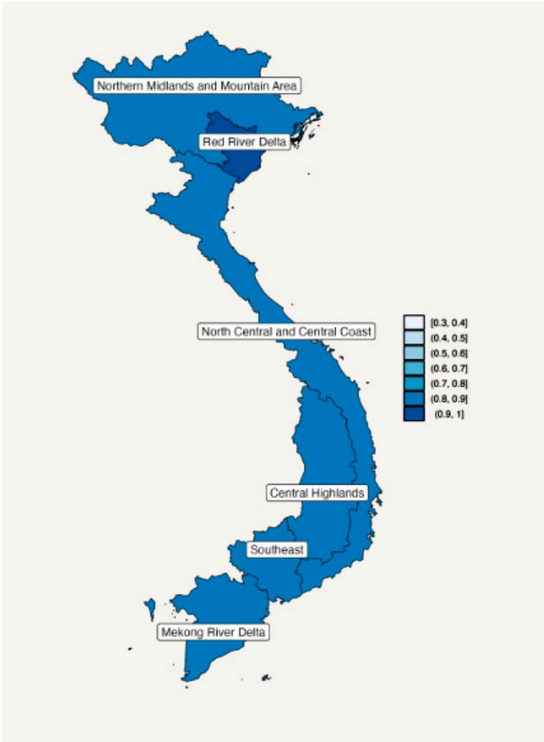
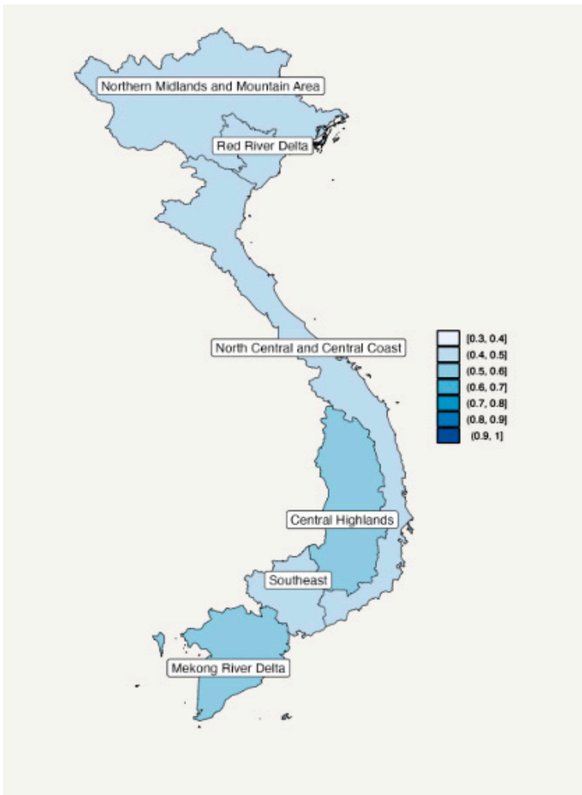


Figure 2. The spatial distribution of social sustainability in Vietnam (0 = lowest, 1 = highest), c. 2020. Source: Authors' elaboration from data sources reported in Table 2. Note: An increasingly dark color palette indicates a higher exposure to climatic and environmental risks.

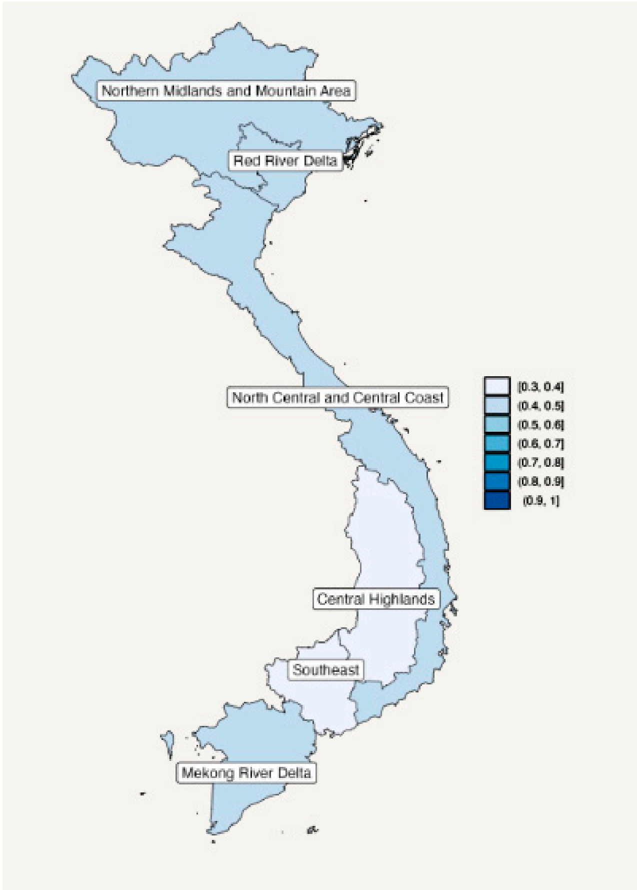


Social Inclusion



Resilience and social cohesion

Figure 3. *Cont.*



Empowerment

Figure 3. The spatial distribution of social sustainability components in Vietnam (0 = lowest, 1 = highest), c. 2020. Source: Authors' elaboration from data sources reported in Table 2. Note: An increasingly dark color palette indicates a higher exposure to climatic and environmental risks.

Table 4. National and regional averages for SSI components in Vietnam, c. 2020.

	National	Northern Midlands and Mountain Area	Red River Delta	North Central and Central Coastal Region	Central Highlands	Southeast	Mekong River Delta
Social Inclusion	0.868	0.813	0.916	0.892	0.832	0.885	0.822
Resilience and Social Cohesion	0.467	0.458	0.443	0.453	0.577	0.449	0.502
Empowerment	0.419	0.422	0.433	0.429	0.350	0.390	0.426
SSI Aggregated Index	0.585	0.565	0.597	0.592	0.586	0.575	0.583

Source: Authors' elaboration from data sources reported in Table 2.

Social inclusion is high, by far the best-performing pillar of social sustainability. Its score ranges from 0.8 to 0.9, with the Red River Delta, North Central and Central Coastal, and Southeast regions leading the rest (see Figure 3). The mean value of this component index is 0.86, as shown in Table 3. By contrast, resilience and social cohesion and empowerment trail behind significantly. Their scores are roughly half those of social inclusion (between 0.35 and 0.60, as reported in Figure 4, and mean index scores of 0.46 and 0.41, respectively). The Central Highlands is the region with simultaneously the largest score for resilience and social cohesion and the lowest levels of empowerment.

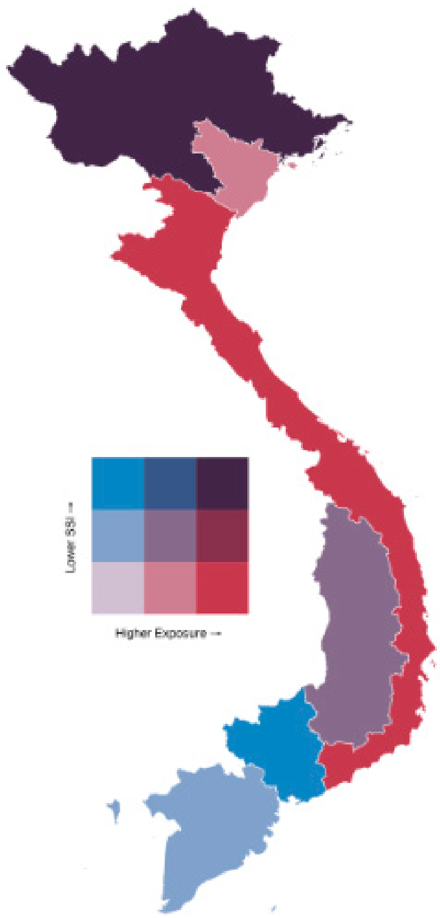


Figure 4. The joint spatial distribution of climatic/environmental risks and social sustainability in Vietnam, c. 2020. Source: Authors' elaboration from data sources reported in Tables 1 and 2. Note: An increasingly red palette indicates a higher exposure to climatic and environmental risks. An increasingly blue palette indicates weaker social inclusion. A deep purple indicates the worst scenario: weak social inclusion and higher exposure to risks.

Regional patterns differ by component but tend to average out. A given region can perform well in one component and poorly in another (See Figure 3 and Table 4). Indeed, the Red River Delta and North Central and Central Coastal regions simultaneously have the highest levels of social inclusion and empowerment nationwide, along with the lowest in resilience and social cohesion. Similarly, the Northern Midlands and Mountain Area and the Mekong River Delta region report the lowest levels of social inclusion along with the highest scores for empowerment. The Southeast region meanwhile displays high levels of social inclusion but weak resilience and social cohesion. These distinct patterns explain why the aggregate index of social sustainability is so uniform, despite substantive differences by component and region.

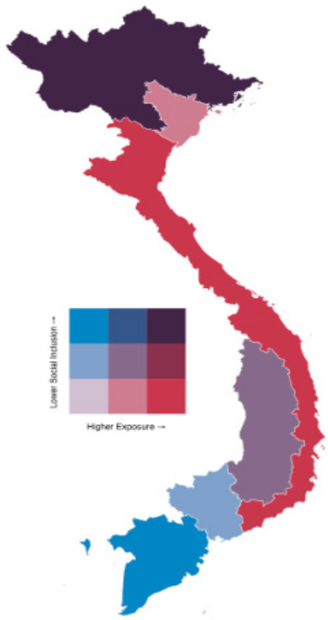
Overlaying the spatial distributions of social sustainability with climatic risks identifies which regions are least equipped to confront risks in a socially sustainable way. The Northern Midlands and Mountain Area show the highest exposure to climatic risks and weakest social sustainability in Vietnam. Conversely, the Mekong River Delta region has the least climactic risk exposure and strongest social sustainability of anywhere in the country (see Figure 4). Different patterns are observed for the other regions (see also summary Table 5). The Red River Delta and the North Central and Central Coastal regions display considerable exposure to risks but stronger social sustainability. By contrast, the Southeast and Central Highlands regions have lower exposure to climate risks and moderate social sustainability.

Table 5. Summary of the distribution of risks across regions in Vietnam, c. 2020.

Region	Key Risks	Weakest Social Sustainability Component
Northern Midlands and Mountain Area	Precipitation variation Temperature variation Drought Air pollution	Resilience and social cohesion
Red River Delta	Air pollution Sea level rise	Resilience and social cohesion
North Central and Central Coastal	Floods Drought Sea level rise	Resilience and social cohesion
Central Highlands	Precipitation variation Temperature variation Floods	Empowerment
Southeast	Drought Forest loss	Empowerment
Mekong River Delta	Sea level rise Precipitation variation Temperature variation	Empowerment

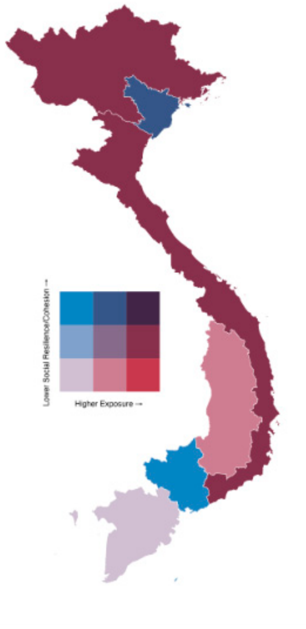
Source: Authors' elaboration from data sources reported in Tables 1 and 2.

Further unpacking the overlap of risks and social sustainability confirms that the Northern Midlands and Mountain Area has the worst combined profile of climactic risks and the weakest social inclusion, resilience, and empowerment (Table 5). The Mekong River Delta suffers from severe vulnerabilities despite being the region with the most favorable overlay of risks and social sustainability. That region's exposure to floods is limited, but its vulnerability to rising sea levels exceeds that of all the other regions in the country (see Figure 5). Hence, it is critical to understand both the aggregated exposure to all climatic and environmental risks and the unpacked exposures between risks and within regions (Table 5).

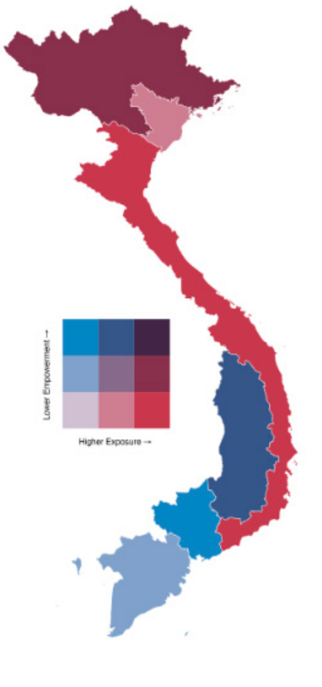


Exposure and social inclusion

Figure 5. *Cont.*



Exposure and resilience and social cohesion



Exposure and empowerment

Figure 5. The joint spatial distribution of climatic and environmental risks and social sustainability in Vietnam by component, c. 2020. Source: Authors' elaboration from data sources reported in Tables 1 and 2. Note: An increasingly red palette indicates a higher exposure to climatic and environmental risks. An increasingly blue palette indicates a weaker social inclusion. A deep purple indicates the worst scenario: weak social inclusion and higher exposure to risks.

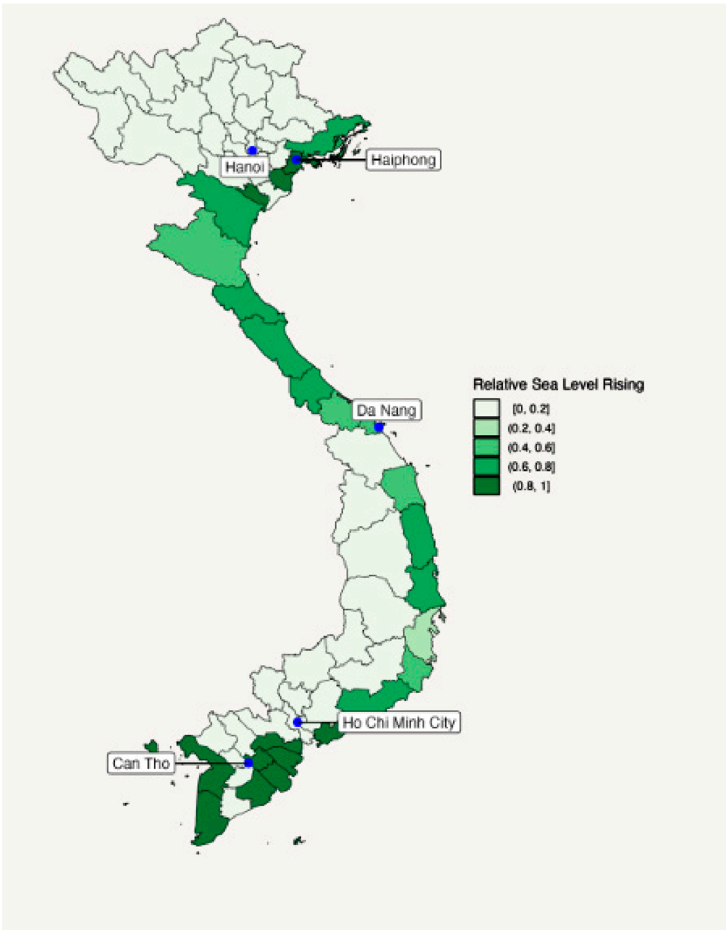
The current overlay of risks and social sustainability is complex and suggests that ethnic minorities are more vulnerable to climatic risks. This compounds the well-known gaps in well-being, economic opportunities, and access to services and the overreliance on agriculture for their livelihoods. Only the two delta regions report low levels of risks and more favorable levels of social sustainability. Both northern regions—including the Northern Midlands and Mountain Area, where ethnic minorities are concentrated—and the North Central and Central Coastal region show higher climate risks and moderate social sustainability.

4. Discussion

4.1. The Precision Loss from Aggregation

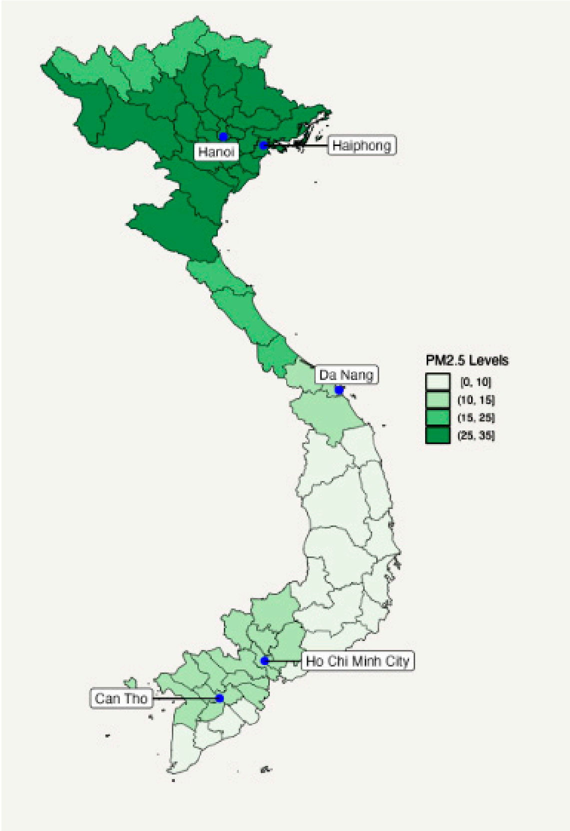
Unpacking aggregate results, be it by risk, social component, or region, emphasizes a remarkable diversity of results. Overall moderate levels of social sustainability turn into quite distinctive patterns by components. Similarly, an apparently equal distribution of exposure to risks across regions is belied by looking at exposure in individual provinces. Further unpacking the province-level analysis (see Supplementary Materials Figure S2) into district-level maps of the spatial exposure to climatic risks provides additional insights into the distinctiveness of results within regions.

Figure 6 below illustrates two opposing cases. Districts along the entire coast consistently report high levels of exposure to sea level rise. This is the case even though province maps do not report the same level of high exposure to sea level rise for all coastal provinces. By contrast, air pollution tends to be worst in the large sprawling cities of Hanoi and Hai Phong, which considerably affects neighboring districts. This increases the chance that the entire province containing those districts will become highly exposed to the risk of air pollution. Hence, both the spatial distributions reported by province and by district follow very similar patterns in the case of air pollution.

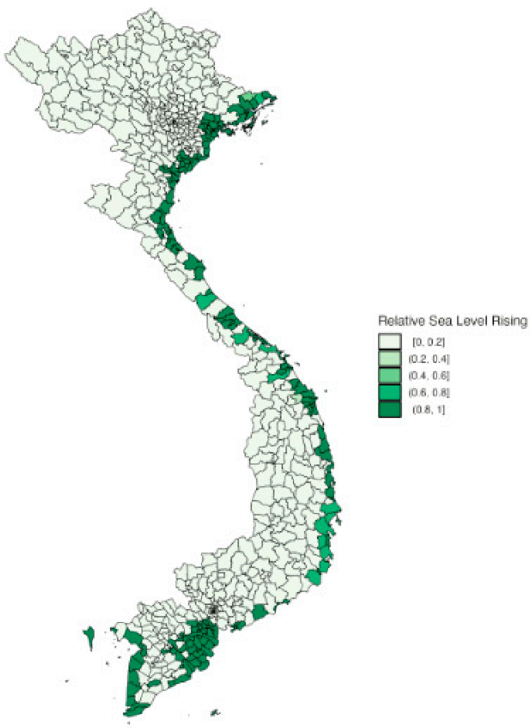


Provincial sea level rise

Figure 6. *Cont.*



Provincial air pollution



District sea level rise

Figure 6. *Cont.*

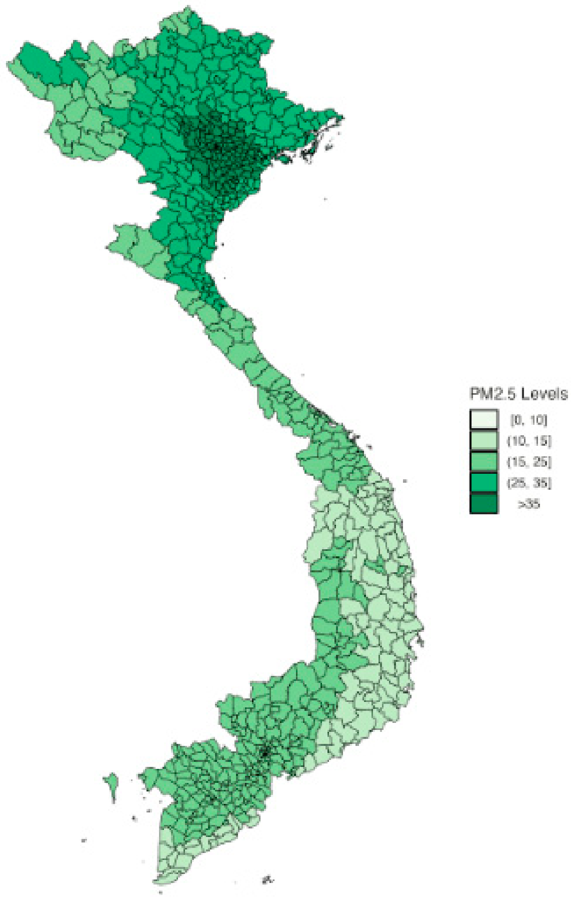


Figure 6. The distinct patterns of exposure to sea level rise and air pollution between and within provinces in Vietnam, c. 2020. Source: Authors' elaboration from data sources reported in Table 2. Note: An increasingly dark color palette indicates a higher exposure to climatic and environmental risks.

There is, therefore, a loss of precision when aggregating patterns from districts to provinces and from provinces to regions (a point made by [36]). The more socioeconomically, demographically, or geographically diverse a province (region) is, the greater the loss of precision. In other words, the lack of statistical representativeness of household surveys from which social sustainability indicators are drawn makes our estimates less precise. Does this matter in practice? The aggregated map of climatic and environmental risks in Vietnam hides a complex and diverse incidence across risks that might prove misleading when designing mitigation policies. More concretely, the focus on a single risk, a particular region, or specific populations might lead to substantive omissions. For example, ethnic minorities are concentrated in the Northern Midlands and Mountain Area and the Central Highlands. The former is the region most exposed to aggregated risks, while the latter is one of the least exposed [41]. Thus, focusing on the low exposure to climactic risks among ethnic minorities in the Central Highlands could lead to the mistaken conclusion that they face limited risks elsewhere.

4.2. The Choice of Social Sustainability Indicators

The geographical unpacking of social sustainability components further demonstrates that the performance of each varies considerably. In fact, Vietnam's strong levels of social inclusion consistently outperform regional and global benchmarks. Yet, its resilience and empowerment are lagging (See Supplementary Materials Figure S3). In particular, Vietnam's levels of interpersonal trust and perceptions of insecurity are similar to international benchmarks, while institutional trust and tolerance for ethnic minorities perform worse than average. Empowerment is even more worrisome: most of the indicators considered for Vietnam fall far behind regional and global averages (see Supplementary Materials Figure S3).

Examining the variation within each social component can yield meaningful insights. The source of regional variation between the three pillars reported in Figure 3 and Table 4 above can be traced back to a handful of variables. For example, access to healthcare in the case of social inclusion, savings in terms of resilience, and participation in local associations as part of empowerment have marked regional variations (see Table 6).

Notwithstanding those variations, the geographical patterns for social sustainability are robust for the choice of indicators. Table 7 below reports the results of two alternative social sustainability indices, both nationally and by region. One reduces the number of indicators to three per component, and the other aggregates the individual components using a geometric, rather than arithmetic, mean. The results show that social inclusion continues to outperform the other two social sustainability components. The number of indicators included hardly alters the score of the index. The geometric mean changes the scores somewhat, but the value of social sustainability remains higher, more than double those of empowerment and social inclusion.

4.3. Spatial Autocorrelation of Risks and Social Sustainability Components

To formally test the extent to which the spatial correlation of each exposure to climatic and environmental risks differs, we computed Moran I tests. The Moran I statistic was first constructed to capture the global spatial correlation of a variable: in this case, the exposure to each risk considered in our analysis [73]. The statistic lies between −1 and 1, with an asymptotic value of zero when the variable in question is randomly distributed in space. The value of −1 (1) describes a perfect negative (positive) autocorrelation of the variable, indicating that regions neighboring a region with high (low) values show low (high) values. Table 8 reports Moran I test values and respective z values for the hypothesis of spatial randomness across provinces. Moran I values confirm that the spatial distributions of risks are all positively correlated in Vietnam. In other words, high levels of exposure to one risk in a province make it more likely that the neighboring province will report a similarly high exposure. This is especially the case for air pollution and floods (with Moran I values exceeding 0.9) but much less so for sea level rise and earthquakes (at or about 0.3). These results are consistent with the above discussion on the loss of precision when exposures to risks are aggregated spatially. Table 8 confirms all results are statistically significant at a $p < 0.001$, except for earthquakes ($p < 0.002$).

Table 6. Regional variation of social sustainability indicators, per component, in Vietnam, %, c. 2020.

Selected Indicator	Mean	Northern Midlands and Mountain Area	Red River Delta	North Central and Central Coastal Region	Central Highlands	Southeast	Mekong River Delta
A. Social Inclusion							
Labor force participation (% of total population ages 15+)	76.4	85.0	72.6	79.3	79.0	72.0	73.9
Share of households with access to electricity	99.6	98.4	100.0	99.5	99.7	99.9	99.9
Share of households with access to water	95.3	86.9	99.6	94.4	94.8	99.6	94.3
Share of households with access to adequate sanitation	88.9	81.4	99.3	89.4	78.8	97.2	77.4
Share of population that uses internet	87.2	89.4	89.6	89.2	92.5	93.9	73.3
Secondary enrollment rate	80.5	71.9	90.7	85.3	71.9	79.8	74.7
Share of population that finds accessing healthcare relatively easy	79.9	56.4	89.3	87.5	65.9	77.0	81.7
B. Resilience and Social Cohesion							
Share of population that saved during past year	33.5	13.9	26.4	26.3	47.7	43.9	49.6
Share of households with multiple sources of non-agricultural income	93.8	94.5	95.2	94.9	95.4	90.8	93.6
Share of population that believes most people can be trusted	27.7	44.5	42.7	16.2	21.2	19.1	20.9
Share of population that has confidence in elections	22.8	24.0	19.9	20.5	34.8	20.6	26.4
Share of population that has confidence in the justice system/courts	27.7	24.7	18.2	24.7	48.5	28.4	37.7
Share of population that is ok with having neighbors of different race	37.6	25.3	29.0	43.6	75.8	36.8	38.9
Share of population that feels secure in their neighborhood	83.6	93.8	78.7	90.7	80.3	74.5	84.1
C. Empowerment							
Share of population that doesn't agree that women shouldn't earn more than men	52.9	69.2	53.1	55.2	33.3	38.2	58.2
Share of population that doesn't agree that men make better political leaders	44.8	42.5	46.5	47.9	53.0	43.6	39.7
Share of population that agrees (strongly or somewhat) that there is freedom to speak	69.0	67.0	75.7	66.6	38.0	63.5	76.4
Share of population that participates in voluntary associations	19.8	15.8	28.9	18.6	0.0	15.5	20.7
Share of population that is a member of a club, group or organization	30.7	26.7	26.9	37.8	53.0	30.9	23.4
Share of population that got together in-person to solve local problems at least once during last year	25.0	30.9	18.1	24.8	38.2	26.1	26.2
Share of population that (strongly or somewhat) agrees people can join any organization without fear	51.0	43.5	54.2	49.6	29.2	55.2	53.7

Source: Authors' elaboration from data sources drawn from Table 2.

Table 7. Robustness checks for SSI index, Vietnam, c. 2020.

Original Index	**National**	**Northern Midlands and Mountain Area**	**Red River Delta**	**North Central and Central Coastal Region**	**Central Highlands**	**Southeast**	**Mekong River Delta**
Social Inclusion	0.868	0.813	0.916	0.892	0.832	0.885	0.822
Resilience and Social Cohesion	0.467	0.458	0.443	0.453	0.577	0.449	0.502
Empowerment	0.419	0.422	0.433	0.429	0.350	0.390	0.426
SSI Aggregated Index	0.585	0.565	0.597	0.592	0.586	0.575	0.583
3-Indicator Components	**National**	**Northern Midlands and Mountain Area**	**Red River Delta**	**North Central and Central Coastal Region**	**Central Highlands**	**Southeast**	**Mekong River Delta**
Social Inclusion	0.841	0.813	0.876	0.863	0.819	0.838	0.810
Resilience and Social Cohesion	0.323	0.329	0.343	0.271	0.344	0.316	0.355
Empowerment	0.362	0.423	0.327	0.393	0.415	0.318	0.359
SSI aggregated Index	0.509	0.521	0.515	0.509	0.526	0.491	0.508
Geometric Mean Aggregation of Components	**National**	**Northern Midlands and Mountain Area**	**Red River Delta**	**North Central and Central Coastal Region**	**Central Highlands**	**Southeast**	**Mekong River Delta**
Social Inclusion	0.124	0.115	0.130	0.127	0.118	0.125	0.117
Resilience and Social Cohesion	0.058	0.052	0.052	0.052	0.074	0.055	0.063
Empowerment	0.055	0.054	0.056	0.057	0.000	0.051	0.055
SSI aggregated Index	0.024	0.198	0.203	0.202	0.000	0.200	0.204

Source: Authors' elaboration from data sources drawn from Table 2.

Table 8. Moran's I values and tests for spatial autocorrelation of Vietnam's exposure to climatic and environmental risks, c. 2020.

Variables	**Moran's I Value**	**z Value**	**Significance**
Air pollution	0.976	11.385	***
Earthquakes	0.308	6.640	**
Floods	0.912	10.880	***
Droughts	0.434	5.191	***
Absolute forest loss	0.340	4.318	***
Precipitation variation	0.718	8.510	***
Temperature variation	0.629	7.540	***
Sea level rise	0.330	3.989	***
CEREI	0.689	8.201	***

Source: Authors' elaboration from data sources reported in Table 2. Note: *** Statistical significance, $p < 0.01$; ** statistical significance, $p < 0.05$.

5. Conclusions

This article constructed two spatial indices to better understand the interactions between social sustainability and exposure to climatic and environmental risks. The indices and the Choropleth maps used to represent them quantified nationwide exposure to risks and social sustainability. They also allowed us to unpack exposures by risk, region, province, and district, and social sustainability by component and region. By combining this evidence (for example, by overlaying maps of risks and social sustainability), it was possible to determine which geographic areas are better equipped to address their exposure to climatic risks in a socially sustainable way. Ultimately, this study contributes to the literature on sustainability in two ways. First, it constructs two original indices that separately profile exposure to climatic and environmental risks and social sustainability. Those indices also unpack evidence by risk, component, and spatiality. Second, the combination of the two indices allows for a simultaneous diagnosis of the intersections and links between multiple risks and social dimensions. These two indices also complement the vast literature measuring resilience to natural disasters. While existing indices cover multiple aspects of economic, environmental, social, infrastructure, institutional, and community preparedness and exposure, they fail to consistently and comprehensively capture many important aspects of social sustainability (exclusion, cohesion, resilience, and empowerment) in a comprehensive and replicable way. They also focus on natural disasters and do not cover other long-term climatic risks. In addition, by generating a multi-region, multi-risk, and multi-indicator index, we fill a serious evidence gap in Vietnam. Our findings differ from existing studies in Vietnam that narrowly focus on one climatic risk and a social dimension at a time (for example, coastal flooding and migration).

Spatial exposure to climatic and environmental risks, and the ability to confront those risks inclusively and cohesively, are unevenly distributed in Vietnam. Northern and coastal regions are the most exposed. By contrast, the Central Highlands, the Southeast, and the Mekong River Delta regions are less exposed. Behind the aggregated picture, the exposure to each risk significantly varies between (and within) regions. Overall, Vietnam exhibits middling levels of social sustainability compared to international peers. The Red River Delta leads the country's regions in terms of social sustainability. The Northern Midlands and Mountain Area and the Central Highlands region—where ethnic minorities are concentrated—exhibit lower levels. Social inclusion is high and is the country's best-performing pillar of social sustainability. Social inclusion in Vietnam exceeds the regional and global average. This is also consistently the case for labor force participation and access to the internet, water, sanitation, electricity, education, and healthcare. However, regional profiles are markedly distinct. For example, social inclusion and empowerment are highest in the Red River Delta region and the North Central and Central Coastal region, which are simultaneously the least resilient regions.

It remains unclear what the economic, demographic, and social consequences of climate change will be in Vietnam. They will depend in part on the country's ability to implement mitigation and adaptation policies. However, levels of social sustainability are already of some concern. Strengthening social cohesion and resilience, expanding voice and accountability, and extending social inclusion to minority groups will not happen automatically. Improving social cohesion may well not advance voice or inclusion by itself; empowering ethnic minorities and strengthening the resilience of internal migrants will not result from a single quick fix.

Beyond Vietnam, strategies to tackle climatic risks in an inclusive and cohesive manner need to consider spatial differences in the interaction of risks and social issues. Our proposed spatial indices and their overlay provide a single diagnostic replicable across contexts other than Vietnam. Those diagnostics are easily constructed from widely available household and satellite data. We are aware of several limitations to our data and methodology, chief among them are the inability to provide a detailed spatial resolution for social sustainability issues or to predict future climatic and environmental risks precisely for small geographical areas. Despite these limitations, our analysis underlines that while social sustainability is an elusive and intricate concept, it can be operationalized in a way that captures its complexity. This can be performed in a relatively simple way through a manageable set of meaningful indicators, flexibly used in the service of evidence-based policy. Jointly analyzing these indices along with information on current climatic and environmental risks can provide policymakers with key insights to help societies respond to and address climate change inclusively and effectively.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su15043260/s1, Figure S1: Regional and provincial map of Vietnam; Figure S2: The spatial distribution of climatic and environmental risks in Vietnam (0 = lowest, 1 = highest), c. 2020; Figure S3a: Global and regional benchmarks for social inclusion, c. 2020; Figure S3b: Global and regional benchmarks for resilience and social cohesion, c. 2020; Figure S3c: Global and regional benchmarks for empowerment, c. 2020.

Author Contributions: Conceptualization, J.C.; Methodology, J.C., L.C., L.M. and N.P.; Software, L.C.; Validation, L.M. and N.P.; Formal Analysis, J.C., L.C., L.M. and N.P.; Investigation, J.C., L.C., L.M. and N.P.; Resources, J.C.; Data Curation, L.C., L.M. and N.P.; Writing—Original Draft Preparation, J.C.; Writing—Review & Editing, J.C., L.C., L.M. and N.P.; Visualization, L.C., L.M. and N.P.; Supervision, J.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Publicly available datasets were analyzed in this study. This data can be found here: Global Active Archive of Large Flood Events. Dartmouth Flood Observatory, University of Colorado, USA. 2022. Available online: http://floodobservatory.colorado.edu/ Archives/; Copernicus Marine Environment Monitoring Service (CMEMS) and the Copernicus Climate Change Service (C3S). Available online: https://cds.climate.copernicus.eu/cdsapp#!/dataset/10.24381/cds.4c328c78?tab=overview; High-Resolution Global Maps of 21st-Century Forest Cover Change. Available online: https://glad.earthengine.app/view/global-forest-change; Terrestrial Precipitation: 1900–2017 Gridded Monthly Time Series, Available online: http://climate.geog.udel.edu/~climate/html_pages/Global2017/README.GlobalTsT2017.html; Terrestrial Air Temperature: 1900-2017 Gridded Monthly Time Series, Available online: http://climate.geog.udel.edu/~climate/html_pages/Global2017/README.GlobalTsP2017.html.

Conflicts of Interest: The authors declare no conflict of interest.

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