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Linkages Between GHG Emissions Scenarios, Temperature Rises and Physical Climate Risk Events in South East Asia

A briefing note for the Singapore Green Finance Centre

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0. Summary

Using data at the sub-national level for eight Southeast Asian economies, this report finds that the temperature anomaly has increased from 1981-2020. The size of the temperature anomaly ranges between -1 to +2.5 degrees Celsius, and the range of the temperature anomaly varies by latitude and is higher at higher latitudes. Additionally, the correlation between the disaster intensities and anomalous temperature occurrences is 24.5 percent, suggesting that temperature anomaly has some power in predicting disaster intensities when a disaster strikes. Assuming this correlation will strengthen as the average global temperature continues to rise, using the emissions scenario data from the World Bank Climate Change Knowledge Centre, the report estimates the temperature anomaly under the RCP8.5 emissions scenario to rank the subnational regions of India and Indonesia. The canonical approach used in this study can be used to rank regions at any level (countries and sub-national regions (states and territories)). This ranking is (loan) market-level information that can complement banks' borrower-level information used in lending decisions.

1. Introduction

According to the Intergovernmental Panel on Climate Change (IPCC) (2001), climate change increases the likelihood of extreme temperatures, exacerbating future climate disasters. If the climate continues to change at its current pace, then intense climate-related disasters could become a permanent characteristic of the future. The location and physical features vary by geography. This feature induces variation in the occurrences of extreme temperatures and the severity of disasters across regions. This report aims to use this variation to show various linkages between historical and projected abnormal temperatures, greenhouse gas (GHG) emissions scenarios, and intensities of natural disasters.

While many sectors are exposed to the adverse effects of climate change, banking is of particular concern for policymakers from a financial stability perspective. The abovementioned linkages are of interest for activities in which predicting future events matters, such as lending to borrowers located in regions that are heterogeneous in the likelihood of extreme temperatures because natural disasters increase debt repayment uncertainty and increase borrowers' default probabilities in the affected regions. Suppose a bank is concerned about the diminishing debt serviceability and collateral value due to climate change. In that case, it may choose to ration credit to avoid potential future problems, such as repayment uncertainty, debt restructuring, and bankruptcy, in extreme cases. Because borrowers are geographically constrained due to reasons such as employment and immovable collateral (land or property) they own, such credit reduction may affect borrowers' post-disaster recovery capabilities in affected regions.

This report uses data from multiple sources to understand the linkages mentioned above. The sub-national annual historical and projected temperature data are from the World Bank Group's Climate Change Knowledge Portal (CCKP). The projected temperature data are from the Coupled Model Intercomparison Project - Phase 5 (CMIP5) ensemble under four representative concentration pathways (RCPs): RCP2.6, RCP4.5, RCP6.0, and RCP8.5. Among these emissions pathways, the RCP2.6 is the most optimistic scenario as it assumes that global GHG emission starts to decline in 2020 and reach zero by 2100; under the RCP4.5 scenario, the global GHG emissions peak in 2040 and start to decline after that. The RCP6.0 scenario is a `late action' scenario where GHG emissions continue to rise till 2080 and decline thereafter. Lastly, the RCP8.5 scenario is a `no action' scenario in which GHG emissions continue to rise throughout the 21st century. This report presents parts of the analysis under the RCP8.5 emissions scenario for brevity's sake.

The disaster damages data are from the EM-DAT Global Disasters Database managed by the Centre for Research on the Epidemiology of Disasters (CRED) of the Université Catholique de Louvain. The EM-DAT provides information on the location and timing of a disaster event. The EM-DAT dataset comprehensively covers six types (and their sub-types) of natural disasters. These disaster types are geophysical (volcanic activity, mass movement, earthquake), meteorological (extreme temperature, fog, storm), hydrological (wave action, landslide, flood), climatological (wildfire, glacial lake outburst, drought), biological (epidemic, insect infestation, animal accident), and extra-terrestrial (airburst, energetic particles, geomagnetic storm, shockwave, and collision) in nature. This report primarily works with disasters whose intensities are affected by the local climatic conditions; thus, it excludes geophysical, biological, and extra-terrestrial type natural disasters. It also excludes wave action (seiche) type disaster damages because earthquakes primarily cause them.

This report is divided into two parts. The first part focuses on eight Asian economies (China, India, Indonesia, Philippines, Thailand, Singapore, Malaysia, and Vietnam) to understand the historical anomalous temperature realizations and to establish a baseline correlation between anomalous temperature occurrences and disaster intensities measured as monetary amount of damages caused by natural disasters. Over the sample period spanning 40 years, starting in 1981, the two series, disaster damages, and anomalous temperature, exhibit a correlation of 24.5 percent, suggesting that anomalous temperature occurrences are informative about future disasters' intensities. As the climate continues to change at its current pace, this correlation is expected to become more significant in the future.

In the second part, using projected temperature data under the RCP8.5 emissions scenario, this report focuses on two Asian economies that are relatively more prone to adverse effects of climate change in the long-term: India and Indonesia. Given the above-mentioned historical positive correlation between disaster intensities and anomalous temperature, the report ranks sub-national regions within each country using temperature anomaly as a proxy for proneness to intense impending natural disasters. Such a ranking is helpful for financial intermediaries that may need to geographically rebalance their loan portfolios when faced with natural disasters more intense than their predecessors.

The rest of the report is organized as follows. Section 2 analyses historical temperature data for eight key Asian economies. Section 3 presents an analysis under the RCP8.5 emissions scenario for India and Indonesia. Section 4 concludes.

2. Historical Temperature Anomaly and Disaster Intensities

The temperature anomaly is defined as the deviation from an average temperature observed over a fixed reference period. In this report, the chosen fixed reference period spans 30 years, in line with that of the Goddard Institute of Space Studies Surface Temperature Analysis (GISTEMP), starting in 1951.[1] Next, for sub-national region *i* of country *c* in year *t,* the temperature anomaly is defined as follows:

$$Temperature\ Anomaly_{ict} = \left[T_{ict} - \bar{T}_{ic,1951-1980}\right]; \quad 1981 \leq t \leq 2020$$

[1] Choosing a fixed reference period makes temperature deviations from a fixed reference point comparable across periods.

Note that the mean temperature over the reference period, represented by, is specific to a sub-national region within a country. Since the temperature data are annual, the temperature anomaly is less prone to issues related to location and seasonalities.

Figure (1) presents the distributional plots of the temperature anomaly over the two twenty-year periods: 1981 – 2000 and 2001 – 2020. During 1981 – 2000, the temperature anomaly averaged approximately 0.3 degrees Celsius. The magnitude of the average temperature anomaly doubles (0.7 degrees Celsius) over the next twenty years, starting in 2001. This pattern suggests a clear rightward shift in temperature distribution. In addition, the more abnormal hot (cold) temperatures have become more (less) frequent in the recent past.

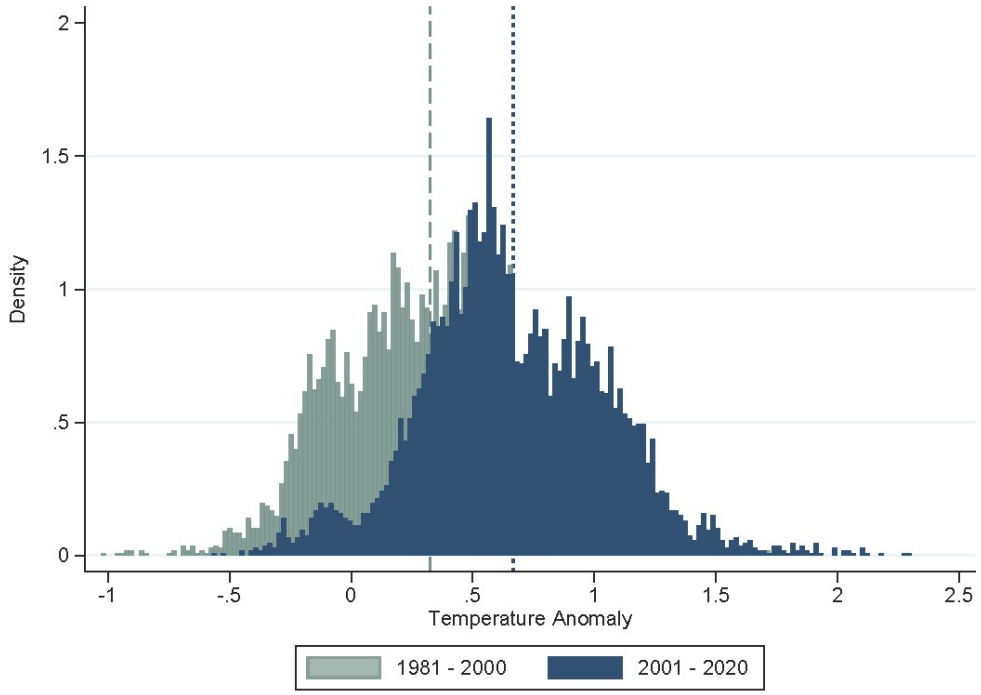

Figure 1: This figure presents the distribution of temperature anomaly for eight Asian countries over two twenty-year periods: 1981-2000 and 2011-2020.

To further investigate patterns in the temperature anomaly, Figure (2) presents the cross-sectional distribution of temperature anomaly for eight countries for the forty years (1981 – 2020). Overall, the average size of the temperature anomaly is increasing over time, consistent with the evidence presented in Figure (1). In addition, the temperature anomaly exhibits relatively more dispersion in the later years. Overall, the pictorial evidence in Figures (1) and (2) corroborate the scientific evidence that the average temperature has risen recently.

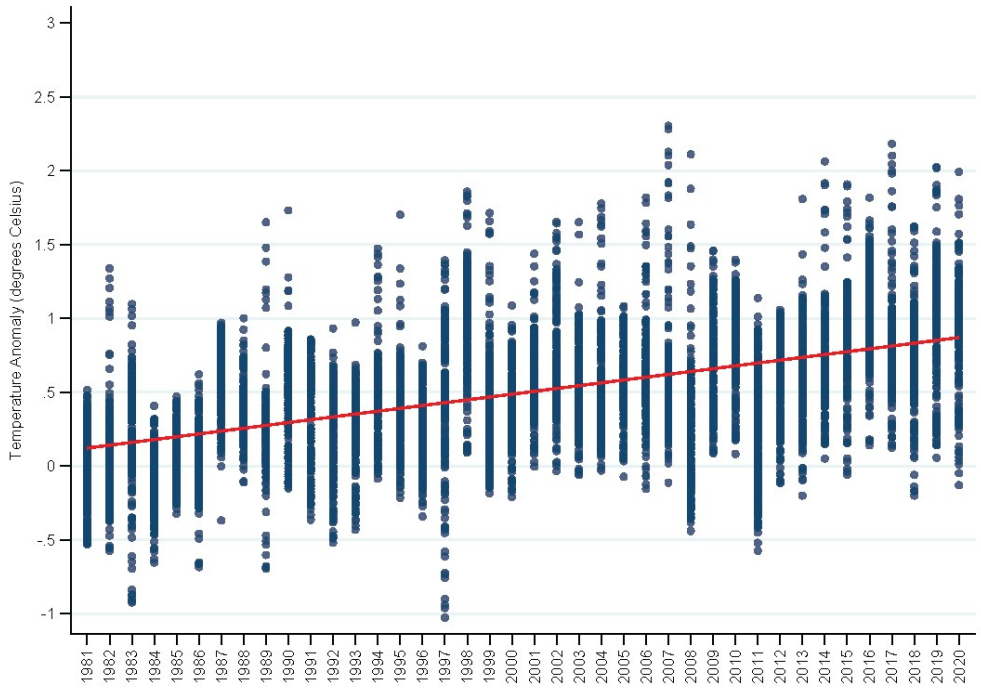

Figure 2: This figure presents the distribution of temperature anomaly for eight Asian countries over forty-year period, starting in 1981 and ending in 2020.

Desmet and Rossi-Hansberg (2015) present a theoretical model in which climate change affects the spatial distribution of economic activity, trade, migration, growth, and welfare across a hemisphere. These authors motivate their model by observing that the temperature varies by latitude lines, also known as parallels, from 0 degrees Celsius at the North Pole to 28 degrees Celsius at the equator during the growing season. Therefore, the cross-sectional heterogeneity induced by the geographic location relative to the equator (or to the north pole) is worth exploring. The reason is straightforward. Rising global temperature reduces this range and induces more moderate temperatures at higher latitudes, increasing (decreasing) productivity in higher (lower) latitude regions.

To further explore the cross-sectional heterogeneity in the temperature anomaly, Figure (3) presents the time-series of average temperature anomaly for each of the eight countries under consideration. Among the eight countries, Indonesia is the nearest to and China is the farthest from the Equator.[2] Among eight countries, Singapore, as a city/country, exhibits *urban heat island effect* as the average temperature anomaly reaches approximately 1.5 degrees Celsius in 2020, starting from 0.5 degrees Celsius in 1981. It may increase Singapore's future energy costs (due to air conditioning), air pollution levels (as tree cover shrinks to make more space for buildings), and heat-related illness and mortality. Overall, the average temperature anomaly trends upwards for all countries, although the rate of increase for countries closer to the Equator lags that of farther away from the equator. This pattern is consistent with the scientific observation that climate is changing at a relatively high pace at the higher latitude regions.

[2] Based on representative latitudes of countries, the countries closest to the Equator (in order of increasing distance from the Equator) are Indonesia, Singapore, Malaysia, Philippines, Vietnam, Thailand, India, and China.

Figure 3: This figure presents a time-series of average temperature anomaly for each country in the sample from 1981 to 2020.

According to IPCC (2001, 2012), abnormal temperatures exacerbate future climate-related disasters. To test the correlation between temperature anomaly and disaster intensities, this report uses the disaster damages data from the EM-DAT. Specifically, the measure of disaster intensity is the monetary amount of damages sustained by a country-year. In Figure (4), we show that disaster intensities increase in the size of temperature anomaly. Moreover, the correlation between two annual series, disaster intensities and temperature anomaly, over the 40-year period is approximately 24.5 percent. This plot of the data has the virtue of simplicity, but it does not account for heterogeneity, such as institutional and geophysical features, which exists among countries.

Islam and Singh (2022) focus on US counties and show that disaster intensities correlate meaningfully with the empirical probability of abnormal temperatures. In their model specifications, the authors control for events common to all US counties, and for different average levels of damages due to economic, geographic, or institutional differences between counties.

Building on the insights of Islam and Singh (2022), we run a fixed effects regression model with disaster damages as the dependent variable and lagged value of average temperature anomaly as the independent variable. We include year fixed effects to control for any year-specific events and country fixed effects to account for time-invariant differences between countries. Despite having a limited sample, the coefficient is positive and statistically significant at the 10 percent level.[3] It follows that the intuition conveyed by a simple plot in Figure (4) carries over to a setting in which one can arguably claim a causal relation running one way: abnormal temperature occurrences exacerbate impending natural disasters.

[3] The coefficient estimate is 1.05 and has a t-statistic of 1.64.

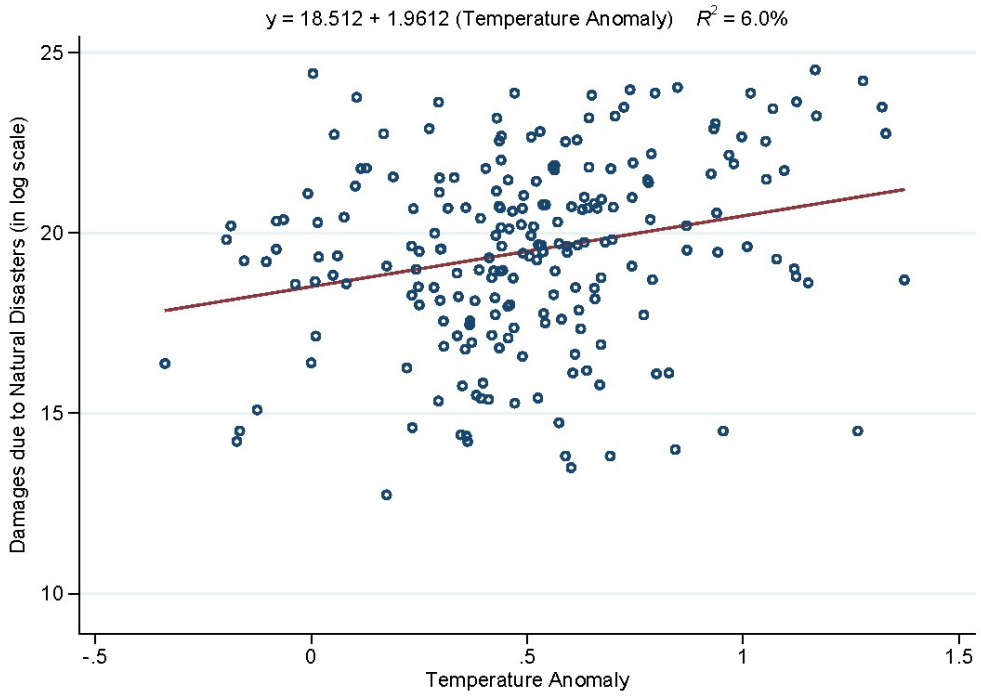

Figure 4: This figure presents a plot of disaster intensities, measured by natural logarithm of disaster damages, and the temperature anomaly. The sample period is from 1981 to 2020.

3. Projected Temperature Anomaly Under RCP8.5 Emissions Scenario

Hitherto, the report shows that temperature anomaly, a canonical measure of shift in local temperature distribution, has been increasing over the recent past. Additionally, the report shows that temperature anomaly associates positively with impending natural disasters' intensities. It follows that this measure has *decision-relevant* content as natural disasters, which are local adverse shocks, may depress borrowers' debt capacity via adverse effects on borrowers' pledgeable collateral value and income streams.

Under the business-as-usual scenario, the carbon emissions may continue to increase unabated, which implies that the rightward shift in local temperature distributions would be even more significant. Such shifts may intensify the correlation between the temperature anomaly and intensities of future natural disasters. Therefore, this section relies on the projected temperature data under the *no action* climate scenario, which corresponds to representative concentration pathway 8.5 to rank sub-national regions within a country. This ranking for a sub-national region *i* of country *c* in year *t* is based on projected temperature anomaly, defined as follows:

$$Temperature\ Anomaly_{ict}^{RCP8.5} = \left[T_{ict}^{RCP8.5} - \bar{T}_{ic,1951-1980}\right]; \quad 2021 \leq t \leq 2100$$

The analysis in this section is based on two key economies in the Asia: India and Indonesia.

3.1 INDIA

India's total land mass is 2,973,190 square kilometres and is divided into three main geological regions: the Indo-Gangetic Plain, the Himalayas, and the Peninsula region. The Indo-Gangetic Plain and those portions of the Himalayas within India are collectively known as North India. South India consists of the peninsular region, often termed simply the Peninsula. India has 7,000 kilometres of coast.

The Himalayas isolate South Asia from the rest of Asia. South of these mountains, the climate, like the terrain, is highly diverse. The short-term climate is prone to abrupt and intense changes such as the onset of monsoon rains, sudden flooding, rapid erosion, temperature extremes, tropical storms, and unpredictable fluctuations in rainfall. Thus, such weather uncertainty poses a constant challenge for the Indian agriculture sector, contributing approximately 18 percent to the national GDP in 2019 and employing approximately half of India's labour force in the same year.[4]

Figure (5) presents the average projected temperature anomaly over two periods (2021 – 2050 and 2051 – 2100) for 34 Indian states and territories. In both these periods, three states Sikkim, Himachal Pradesh, and Uttarakhand, are likely to experience temperatures farther away from their respective normal temperature over the rest of the 21st century. Interestingly, all three states are in the Himalayas: Sikkim in the eastern Himalayas and Himachal Pradesh in Uttarakhand in the western Himalayas.

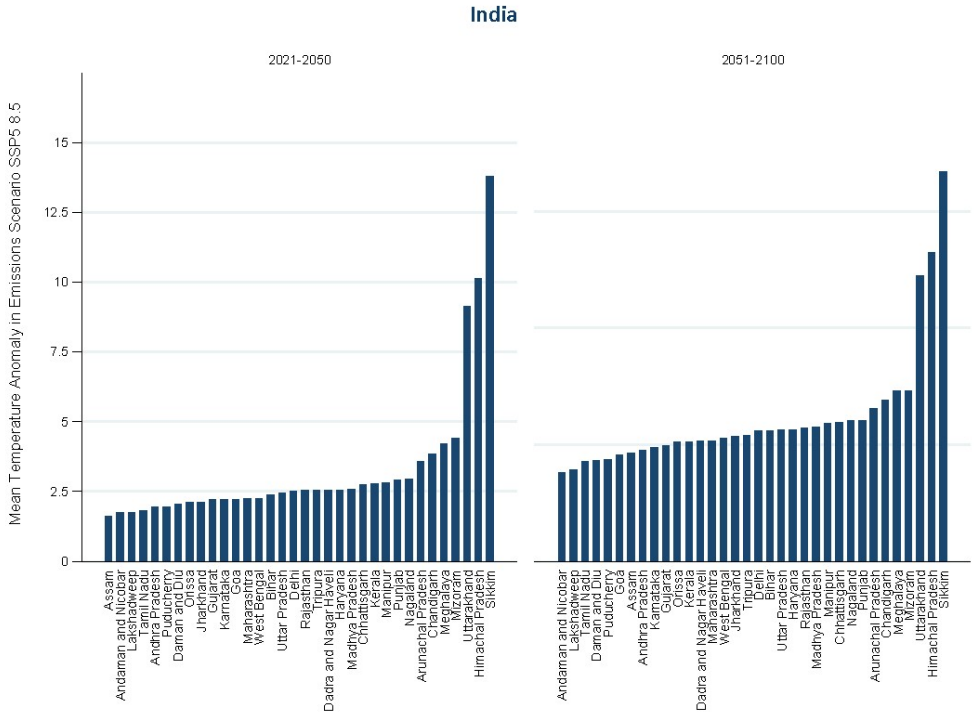

Figure 5: This figure presents the average projected temperature anomaly for 34 Indian states and territories over two periods: 2021 – 2050 and 2051 – 2100.

While the ranking in Figure (5) is useful when assessing a sector such as agriculture that is practiced in nearly all states, it is worthwhile looking at states containing vital urban areas that are the centre of major economic activity other than agriculture. The states that contain the key business centres are Delhi, Haryana, Maharashtra, Karnataka, Andhra Pradesh, and Tamilnadu. These states are also home

[4] The monsoon rainfall is important for the agriculture sector. Nearly 80 percent of the country receives most of its rainfall from the southwest monsoon from June to September.

to key metropolitan cities of India. Based on figures underlying Figure (1), Delhi and Haryana are more prone to experiencing larger deviations from the reference period temperature under the no action emissions scenario. Maharashtra, Karnataka, Andhra Pradesh, and Tamilnadu (in that order) are also likely to experience temperatures above their respective normal temperatures. In the event of natural disasters striking these states, the damage is likely to be more severe in Haryana and Delhi, relative to Tamilnadu, for instance.

3.2 Indonesia

Indonesia is a huge archipelagic country extending 5,120 kilometres from east to west and 1,760 kilometres from north to south. It encompasses more than 13 thousand islands. There are five main islands: Sumatra, Java, Kalimantan, Sulawesi, and Irian Jaya. There are two major archipelagos: Nusa Tenggara and the Maluku Islands. Indonesia's total land area is 1,919,317 square kilometres.

The primary variable of Indonesia's climate is rainfall. Indonesia's climate is entirely tropical. Historically, many tropical storm systems form in this region, but very few traverse the Indonesian archipelago. However, this number has increased in the 21st century. Between 2000 and 2021, Indonesia is affected by at least 30 storms. For instance, Cyclone Seroja affected Indonesia's West and East Nusa Tenggara regions. According to the Indonesian National Board for Disaster Management, this storm caused approximately USD 238 million in damages in East Nusa Tenggara region alone. The

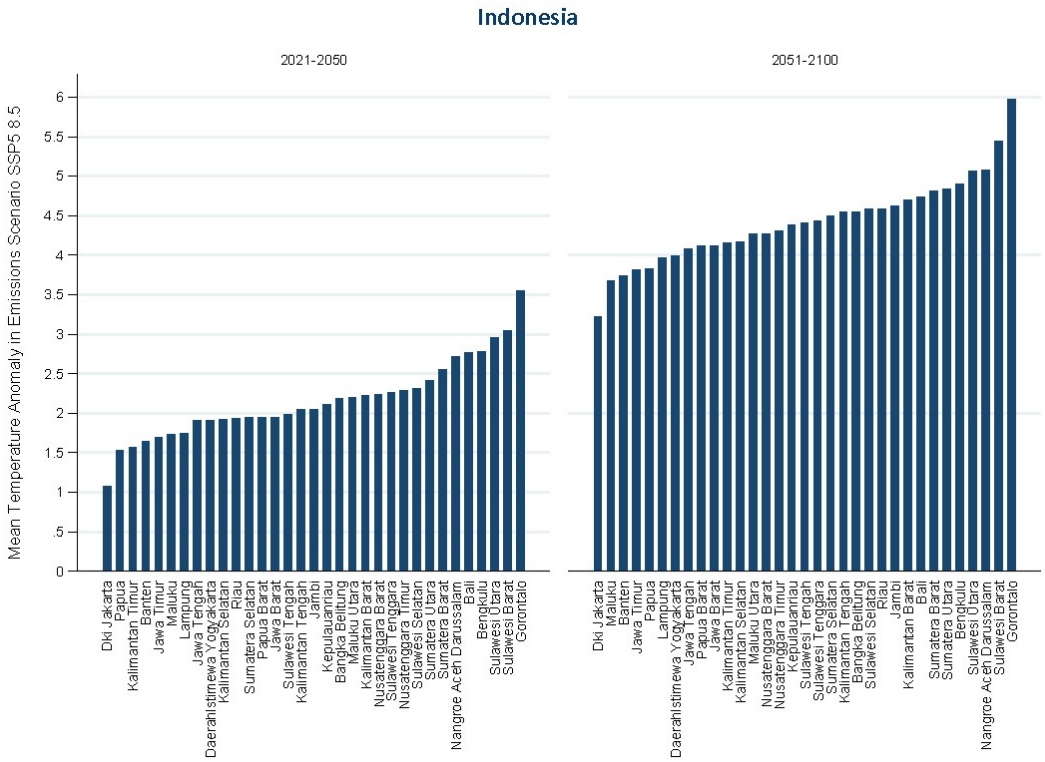

Figure 6: This figure presents the average projected temperature anomaly for Indonesian states and territories over two periods: 2021 – 2050 and 2051 – 2100.

extreme rainfall events are generally linked with the monsoons and the rainy season (December to March) resulting from mainland Asia and Pacific Ocean air masses.

Figure 6 presents the average projected temperature anomaly under the RCP8.5 emissions scenario. The temperature varies slightly across seasons or regions, given Indonesia's equatorial location. Due to this, the variation in the projected temperature is less pronounced across various Indonesian regions. Still, with increasing average global temperature and its interactions with precipitation events, some Indonesian regions are more likely to experience more extreme precipitation events. The top three regions, namely Gorontalo, Sulawesi Barat, and Sulawesi Uttara, are likely to experience temperatures that are 2.5 degrees Celsius above average. These three regions are in Sulawesi Island, which is currently one of the dampest regions of Indonesia. In the presence of other environmental problems such as deforestation and soil erosion, more abnormal temperatures can result in a more complicated environmental issue. For instance, as average temperatures at the Earth's surface rise, more evaporation occurs, which, in turn, increases overall precipitation. Such event, in the presence of deforestation that destabilises the soil, further exacerbate the landslide hazard.

4 Concluding Remarks

As a risk-neutral agent, a bank's response could be an increase in the interest it may charge to borrowers to reflect differences in proximity to sustaining intense disasters in the future. Given the multi-dimensional nature of climate-related risks, it is not easy to incorporate them in standard loan pricing models used by banks for transaction loans, such as personal loans, mortgages, credit cards et cetera. In the absence of such a model, a bank may choose to ration credit by reducing the flow of credit to regions that experience more abnormal temperatures with an increased frequency (Islam and Singh, 2022).

Such a decline in access to credit can undermine all credit-dependent functions in regions that are relatively more advanced on the scale of climate change. These functions are related to the entrepreneurial activity (Schumpeter and Opie, 1961; Banerjee et al., 2017), insurance (Udry (1994)), consumption smoothing (Gross and Souleles, 2002), income (Karlan and Zinman, 2009), and inequality (Solis, 2017) in a region. Moreover, in the face of intense natural disasters in the future, lower access to credit implies slower economic recovery. Thus, diverting credit from at-regions regions may reduce future repayment issues in banks' loan portfolios and may have unintended consequences, leading to loss of welfare for households and small businesses that primarily rely on banks for their credit needs.

Generally, banks incorporate borrower-level information into account at the loan origination stage. Perhaps, it is worthwhile to pay some attention to loan market level information, such as the physical environment in which borrowers conduct their businesses, into account as well.

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