Annex 1: Macroeconomic, Poverty and Financial Appendix

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A1.1 The Mitigation Adaptation New Technologies Applied General Equilibrium (MANAGE) Model

1 Model Details

The Mitigation, Adaptation and New Technologies Applied General Equilibrium (MANAGE) model is a single-country recursive dynamic computable general equilibrium (CGE) model designed to focus on energy, emissions, and climate change economic impacts. It considers a large number of economic sectors, commodities, production factors, and household types. In addition, the MANAGE model includes a detailed energy specification that allows for capital/labor/energy substitution in production, intra-fuel energy substitution across all demand agents, and a multi-output, multi-input production structure.

The drivers of growth in this model follow the neo-classical growth framework. The level of GDP depends on three factors: the supply of workers, investment, and productivity. The level of investment in the economy is determined through a savings-driven closure with exogenous propensity to save for households and firms. Foreign savings in foreign currency adjust to the expected domestic returns to capital and the public debt to GDP ratio. The nominal exchange rate is fixed. The real exchange rate adjusts to maintain the current account balance. Investment is distinguished between public and private sector investments.

Households
The model contains five representative household types (defined by income quintiles). Households derive their income from factor payments, transfers, and returns on government bonds. Each household supplies four types of labor (distinguished by formal/informal and skilled/unskilled) and receives income from capital, land, and natural resources. The aggregate payment of each factor of production is distributed across households based on their shares in the respective factor income. An additive Constant Elasticity of Transformation (CET) function determines the allocation of disposable income between consumption and savings depending on the return of savings (investment).

**Household demand is modeled using a two-level utility function.** At the first level, a Constant Difference in Elasticities (CDE) utility function determines the demand for aggregated consumption commodities. The use of CDE allows better representation of both income and own-price elasticities by allowing consumption shares to change as income and prices change. At the second level a transition matrix approach is used where each consumed good is composed of one or more supplied goods and combined using a CES aggregator. Energy demand is bundled into a single commodity and disaggregated by energy type which allows for inter-fuel substitution.

**Firms**

Production activities in the MANAGE model are profit maximizers under constant returns to scale technologies producing commodities for domestic and international markets. Production is modeled using a series of nested constant-elasticity-of-substitution (CES) functions designed to capture the substitution and complementary relations across the various inputs to production - notably capital, labor, and intermediate input.

One of the novelties of the MANAGE model is the ability of production activities to determine the energy intensity of production endogenously based on the energy prices. This distinction is important when analyzing carbon pricing policies. Energy is assumed to be a near-complement with capital in the short-run, but a substitute in the long-run. Thus, rising energy prices tend to lead to rising production costs in the short-run when substitution is low, but a long-run response would lead to energy-saving technologies that dampen the cost-push factor. This feature of the model is embodied in a vintage capital structure where new capital is substitutable with energy while old capital is near complement. The vintage structure also impacts the allocation of capital across sectors with new capital assumed perfectly mobile across sectors while old capital is sluggish and released using an upward-sloping supply curve. In sectors where demand is declining, the return to capital will be less than the economy-wide average.

The model allows for both multi-input and multi-output production. The former allows for the aggregation of multiple activities into a single marketed good, for example, electricity supply to be produced by multiple activities-including coal-powered, hydro, and renewable forms of electricity production. The latter allows a single activity to produce more than one product-for example, oil seed crushing produces both vegetable oils and oil cakes (for feed). The Dominican Republic model contains 49 production activities producing 72 commodities.

The government
The government collects taxes, receives transfers from rest of the world and domestic agents and then spends them on saving, transfers, government consumption and investment. Government can borrow from domestic institutions or from rest of the world but must service the debt in following periods. In the default setting all tax rates are fixed at base year levels while the volumes of government current and investment spending are exogenously determined. This implies that government savings (primary balance) is endogenous and adjust to clear the government balance. The gap between government investment demand and public saving is satisfied through foreign and domestic borrowing. Alternative government closures can be considered for the simulation. For example, the government may target a budget balance or debt ratio by adjusting taxes or spending to achieve the target.

The external sector

Rest of the world (ROW) exports from and imports to the Dominican Republic according to a CET and an Armington specification respectively. Both specifications assume that domestic commodities are not perfect substitutes with traded commodities. Thus, imports and exports are determined based on the difference between domestic prices and world prices which are assumed to be exogenous consistent with an open economy assumption. ROW also makes transfers to domestic agents and receives transfers from them. These transfers are assumed to be a constant share of GDP. Lastly, ROW savings is allocated as lending to the government and used for investment purposes (FDI, short term capital movements etc.). The current account is assumed to adjust endogenously in response to the expected rate of return to capital and to changes in the public debt to GDP ratio.

Capital market closure and interest rates

The model follows a savings-driven closure where aggregate investment is flexible and equals to the available volume of saving. Foreign saving, government saving, and household savings are all endogenous. In effect, rate of return on capital adjusts to equalize investment to the saving. Similarly, the interest rates on public debt adjust to equalize government lending to domestic and foreign funds allocated to public lending. Allocation of savings to investments and to public lending is assumed imperfect substitutes. Hence, the model has a crowding out effect where government investment displaces private investment.

Effects of climate change

The model is extended to incorporate estimated country-specific economic damages of climate change. Climate projections are run through biophysical and economic models to assess the Dominican Republic’s vulnerability to climate change under a no-action scenario, and how adaptation investments can enhance resilience. This is done by first selecting a representative set of climate scenarios, used to assess the macroeconomic effects of climate change (See annex 2 for the selection of scenarios). Macroeconomic shocks arising from relevant “channels of impact” under climate change are then explored, with these shocks serving as input for the MANAGE model. Finally, the potential benefits of different adaptation options to reduce the impacts of climate change are assessed.
The model of Dominican Republic considers ten channels of climate change impact. Of these, three channels affecting human capital (labor heat stress, human health, and water, sanitation, and hygiene), three channels affecting agriculture and natural resources (water supply, crop production and erosion) and four channels affecting infrastructure and service (inland flooding, sea-level rise and storm surge, tropical cyclones and tourism). Each individual impact channel relies on stylized biophysical models that are capable of accepting climate information and projections, and simulating changes in biophysical (e.g., streamflow or infrastructure conditions) and/or socioeconomic (e.g., labor supply hours) variables under these altered climatic conditions.

In addition to the estimated direct effects of climate change, the MANAGE model simultaneously determines the indirect (general equilibrium) effects of climate change damage shocks on the rest of the economy. For instance, the effects on output for all sectors, labor demand for each skill level in each sector, wages, and final consumption prices for all commodities. These effects, in turn, affect the real income of each household type, as wages and final consumption prices change in a way that depends on the specific labor endowments and consumption basket of each household. These changes in real household income are then used to derive the impacts on inequality.

Data and model calibration

The computable general equilibrium model is calibrated to the 2016 Social Accounting Matrix (SAM) from the Central Bank of the Dominican Republic. The SAM was combined with household survey data, allowing for workers' segmentation into four labor types. Production factors was split into capital, land and natural resources using data from GTAP. Electricity production was split by energy source using data from the GTAP power database. Data from the National Statistics Office of the Dominican Republic and the World Bank was used to split capital for formation into public and private sector and to add public borrowing and debt service to the SAM. GHG emissions was calibrated to data from GlobalFactor.

A dynamic baseline scenario to year 2050 was constructed based on projections for population growth, real GDP, consumption, and investments. The public sector accounts in the baseline were tied down by projections for public expenditures and debt. Structural changes in production were based on projections for sector shares of value added. Finally, the reference baseline contains a projected energy mix in power production, projected GHG emissions, and energy prices.

2 Climate Change impacts in the model

The Dominican Republic economy is expected to be affected by climate change, both directly and indirectly. Direct impacts arise from decreased productivity and supply of labor, land, and capital. The reduction in output caused by factor supply shocks and productivity losses can lead to an increase in prices. Additionally, the destruction of capital and land can push rental rates upward.

Indirect effects occur through seven channels.

1. Production linkages: Activities within the Rwandan economy are interconnected through forward and backward production linkages, meaning that changes in one sector can impact others.
2. **Factor substitution effect**: When the supply and productivity of factors such as labor, capital, and land are impacted by climate change, firms adjust by substituting them for others based on their relative prices and the production cost structure of the activity.

3. **Price effect**: Climate change-induced reductions in output can lead to an increase in prices, which affects purchasing power. Consumers tend to switch to substitute products with lower prices, depending on their price and income elasticity of demand.

4. **Crowding-out effect**: Climate change can lead to a decline in government revenue from direct and indirect taxes, resulting in an increase in the deficit when expenditure is held constant. This, in turn, can lead to an increase in government debt from both domestic and foreign resources.

5. **Investment effect**: The financing of investment in the Rwandan economy is impacted by climate change. Domestic private savings are declining on average, while the government deficit is increasing. Since foreign savings are fixed as a share of GDP, total savings decline, resulting in lower investment. This can exacerbate the reduction in the capital stock due to flood destruction.

6. **Income effect**: Climate change can reduce labor and capital income, which form a significant portion of household and firm income. This reduction, combined with increasing prices, can lead to a decrease in consumption and savings.

7. **Trade channel**: Climate change can lead to lower exports and a decline in imports due to lower demand for intermediate, final, and investment goods.

**Figure A1.1 Linkages between climate, biophysical, and macro models**

Source: World Bank staff elaboration.
A1.2 The Poverty Impacts of Climate Change

To evaluate the distributional impacts of climate change in the Dominican Republic (DR) between 2022 and 2050, we implement a top-down microsimulation approach. This approach uses as inputs macroeconomic projections (i.e., employment, wages, and consumption) from a Computable General Equilibrium (CGE) that takes into account the endogenous response of economic activity to climate change under different climate scenarios. These inputs are projected over the Continuous National Labor Force Survey (ENCFT, by its acronym in Spanish) in order to estimate its distributional implications. To project the inputs from the CGE on the ENCFT, we follow a full reweighting approach developed by the Equity Policy Lab (World Bank, 2023). This exercise is implemented for three climate scenarios:

1. The baseline scenario assumes no impact of climate change on the economy;
2. The second scenario is a combined dry/hot scenario that simulates high damage on the economy (pessimistic);
3. The third scenario is a combined wet/warm scenario that simulates low damage (optimistic).

Each scenario models how the economy is likely to respond to climate change effects that take place through a wide variety of channels, such as crop damage, inland flooding, labor heat stress, human health, storm surges, tourism, and tropical storms.

In the baseline scenario, the percentage of people living in poverty (measured by the national poverty line) is expected to plunge from 27.7 to 4 percent between 2022 and 2050 (see Figure A1.2.1). Economic growth, spurred by increased productivity and technological change, is expected to increase labor income and reduce poverty. As an upper middle-income country, profound changes to the economic structure of the DR have already occurred, but further structural change whereby workers move from low- to high-productivity sectors will contribute to reducing poverty. The projected decline of 23.7 percentage points in the poverty headcount ratio is explained in particular by increases in wages (14.1 percentage points) and non-labor income (10.3 percentage points), with a negligible increase of poverty (0.7 percentage points) explained by a higher dependency ratio.

However, climate change is projected to undermine these positive developments if adaptation or mitigation measures are not undertaken. By 2050, poverty will be 0.5 and 0.8 percentage points higher than the baseline scenario, as per estimates from the wet/warm and dry/hot scenarios, respectively (see Figure A1.2.2). These changes would represent nearly 70 to 110 thousand people falling into or remaining in poverty due to climate change.

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1 This note was prepared by Alejandro de la Fuente, Lukas Delgado and Daniel Valderrama within the Poverty and Equity GP at the World Bank as an input to the Climate Change Development Report for the Dominican Republic. The work was conducted in close coordination with the Macro, Trade and Investment and the CCDR teams at the World Bank, and particularly with inputs from Martin Aaroe Christensen (EMFMD), Paola Brens Ortega (ELMCU) and Gabriel Zaourak (ELMCU).

2 Industrial Economics, Inc (IEc) constructs a wide set of climate scenarios. From all of these, IEc chooses defines a combined dry/hot scenario and a combined wet/warm scenario as an average of three different climatological models that represent each of these scenarios. In addition, the combined scenarios are divided into individual channels where the IEc chooses the prediction that gives the highest (pessimistic) and the lowest damage (optimistic). Lastly for each combined scenario, IEc calculates damage under two levels of adaptation measures (high and medium).
Figure A1.2.1 Poverty headcount projections across different scenarios

- Baseline
- Combined dry/hot
- Combined wet/warm

Figure A1.2.2 Impact of climate change scenarios on poverty headcount projections

Source: World Bank calculations based on household survey microdata (ECNFT 2022). All scenarios use macroeconomic projections from the MANAGE-CGE model. Climate scenarios simulate crop damage, inland flooding, labor heat stress, human health, storm surges, tourism, and tropical storms. Note: Figure A1.2.1 plots the baseline scenario and two climate change scenarios: combined dry/hot and combined wet/warm. Figure A1.2.2 shows the deviations relative to baseline by scenario.

Figure A1.2.3 Impact of climate change by channel on the poverty headcount in 2050 projections

Source: World Bank calculations based on household survey microdata (ECNFT 2022). All channels use macroeconomic projections from the MANAGE-CGE model. Climate scenarios simulate crop damage, inland flooding, labor heat stress, human health, storm surges, tourism, and tropical storms. Note: The figure plots the deviations in the poverty headcount relative to the baseline scenario.
Labor heat stress is the channel that contributes the most to the increase in poverty, followed by damage from tropical storms and declines in rainfed crop yields. Figure A1.2.3 shows the impact of climate change on poverty through various channels, each modeled as if it affects the economy single-handedly. This exercise shows that labor heat stress impacts poverty the most. By 2050, poverty would increase between 0.5 to 0.7 percentage points relative to the baseline if the only effect of climate change on the economy was heat stress reducing labor productivity (see Figure A1.2.3). All the other channels – except for tropical storms and declines in rainfed agricultural yields – show effects on poverty smaller than 0.2 percentage points, even in the pessimistic scenario. This is important as all these channels are related to extreme weather events more likely to occur in the next decades.

**Climate change has asymmetric impacts across the income distribution.** By 2050, tropical storms will affect wealthier individuals more profoundly, likely due to losses in the accumulation of capital. Their per capita labor income will be decreased by between 6.9 percent (in the optimistic scenario) to 10.4 percent (in the pessimistic one) compared to the baseline (see Figures A1.2.4 and A1.2.5). On the other hand, the largest contributor to the increase in poverty, labor heat stress, will affect households across the income distribution to a similar degree. The combined effect of the rest of the channels will affect the labor income of poorer individuals much more than the wealthy, partly due to negative impacts on the agricultural sector, from which the poor derive most of their income.

**Figure A1.2.4 Impact of climate change channels on labor income growth, optimistic (wet/warm) scenario**

**Figure A1.2.5 Impact of climate change channels on labor income growth, pessimistic (dry/hot) scenario**

Source: World Bank calculations based on household survey microdata (ECNFT 2022). All channels use macroeconomic projections from the MANAGE-CGE model. Climate scenarios simulate crop damage, inland flooding, labor heat stress, human health, storm surges, tourism, and tropical storms. Note: The figure plots the deviations in the poverty headcount relative to the baseline scenario.
The impact of climate change is heterogeneous across job types. By 2050, climate change will increase the poverty headcount of households where the main earner works informally, by 0.6 to 1.2 percentage points relative to the baseline scenario (see Figure A1.2.6). This is partially due to the higher concentration of informal jobs in hospitality, agriculture, retail commerce, and domestic services, all of which are more prone to be affected by heat stress. Additionally, informal workers already face greater challenges in coping with the consequences of climate change, as they tend to be poorer and thus possess limited and undiversified assets. By contrast, in households where the main earner is formally employed, poverty would be expected to increase between 0.3 to 0.4 percentage points relative to the baseline scenario. Lastly, poverty will increase 1.2 percentage points in rural areas compared to a 0.8 percentage point increase in urban areas (see Figure A1.2.7). This higher poverty incidence may be explained by the direct effects of climate change on agricultural productivity. Nevertheless, poverty will remain predominantly an urban phenomenon: more than 80 percent of the population already resides in urban areas, and urbanization is expected to continue in the DR continues across the coming decades.

Figure A1.2.6 Impact of climate change scenarios on poverty headcount projections by type of job

![Figure A1.2.6](image)

Source: World Bank calculations based on household survey microdata (ECNFT 2022). All scenarios use macroeconomic projections from the MANAGE-CGE model. Climate scenarios simulate crop damage, inland flooding, labor heat stress, human health, storm surges, tourism, and tropical storms. Note: The figure plots the deviations in the poverty headcount relative to the baseline scenario.

Households in the agricultural sector are more likely to be affected by climate change in the pessimistic scenario, while in the optimistic one there are fewer differences across sectors. By 2050, in the combined dry/hot scenario, climate change will increase the poverty headcount by 1.5 percentage points in households where the main earner works in agriculture, while for both services and manufacturing, it will increase by 0.7 percentage points (see Figure A1.2.8). In this scenario, weather events that disrupt crop and livestock production patterns are more likely. On the other hand, in the combined wet/warm scenario, poverty will increase between 0.4 to 0.6 percentage points across all three employment sectors.
**Figure A1.2.8** Impact of climate change scenarios on poverty headcount projections by sector

<table>
<thead>
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<th>2050 Combined dry/hot</th>
<th>2050 Combined wet/warm</th>
<th>2050 Combined dry/hot</th>
<th>2050 Combined wet/warm</th>
<th>2050 Combined dry/hot</th>
<th>2050 Combined wet/warm</th>
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<td>0.6</td>
<td>0.7</td>
<td>0.4</td>
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<tr>
<td>Services</td>
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</tbody>
</table>

Source: World Bank calculations based on household survey microdata (ECNFT 2022). All scenarios use macroeconomic projections from the MANAGE-CGE model. Climate scenarios simulate crop damage, inland flooding, labor heat stress, human health, storm surges, tourism, and tropical storms. Note: The figure plots the deviations in the poverty headcount relative to the baseline scenario.

**Figure A1.2.9** Impact of climate change under adaptation and mitigation scenarios by 2050

Source: World Bank calculations based on household survey microdata (ECNFT 2022). All scenarios use macroeconomic projections from the MANAGE-CGE model. Climate scenarios simulate crop damage, inland flooding, labor heat stress, human health, storm surges, tourism, and tropical storms. Note: The figure plots the deviations in the poverty headcount relative to the combined dry/hot scenario in the first two columns, to the combined wet/warm scenario in the next two columns, and to the baseline scenario without climate change in the last two columns.

**Investments in adaptation are expected to alleviate the increase in poverty due to climate change.**

Under two levels of adaptation measures, high and medium, the increase in the poverty headcount due to climate change would be almost entirely neutral. The projected poverty rate increase by 2050 in the combined dry/hot scenario (0.8 percentage points) would fall by between 0.7 to 0.5 percentage points. In the combined wet/warm scenario, a projected poverty increase of 0.5 percentage points, mitigation would reduce this by between 0.4 and 0.2 percentage points. A further mitigation scenario, additional electrification of transport plus a corresponding adjustment to the electricity...
production/power mix, would have a negligible impact on poverty. On the other hand, in a mitigation scenario that targets a net zero pathway, poverty would be slightly higher, by 0.2 percentage points relative to the scenario without climate change (see Figure A1.2.9 where the first four bars show the difference between adaptation scenarios relative to the optimistic/pessimistic scenarios of climate change, and the last two bars refer to the difference between mitigation scenarios relative to the scenario without climate change).

To conclude, it is worth noting several caveats to this simulation exercise. First, climate change and output scenarios carry a certain degree of uncertainty. This uncertainty is intrinsic to long-term projections and the given geographical scale. Second, the climate scenarios assume that climate change will gradually occur over the next 25 years. As such, we do not model the impact of climatic hazards (i.e. hurricanes, floods) that can increase poverty persistently for the families directly affected. Finally, the projections on economic growth and population growth do not account for possible effects of climate change. Given the stated caveats, the findings presented should be read as indicative of the direction and possible magnitude of the effects of climate change on poverty in the DR rather than concrete forecasts.

A1.3 Greening the Financial Sector in the Dominican Republic

Climate change could present physical and transition risks for the Dominican Republic’s (DR) financial system. On the one hand, physical risks could arise from the changes in weather and climate, which impact economies and the financial sector. Physical risks are classified into chronic risks resulting from gradual changes caused by shifting rainfall patterns and temperatures, and acute risks, which pertain to the fluctuations in the frequency and severity of natural catastrophes. On the other hand, transition risks could arise from the economic and financial costs associated with adapting to a carbon-neutral economy. The materialization of transition risks can be triggered either by a policy decision to reduce GHG emissions, technological advances that reduce the cost of alternative energy sources, or changes in consumer preferences. Other triggers could arise from international regulations and rules, such as the European Union (EU) Carbon Border Adjustment Mechanism (CBAM) or the more recent EU regulation setting requirements for industries both inside and outside the Union to reduce the consumption of products from supply chains associated with deforestation or forest degradation.

Located in the hurricane alley, the DR is highly exposed to weather and climate-related disasters that are expected to increase due to climate change. The DR is one of the most vulnerable countries in the world. Historical losses from natural disasters between 1961 and 2014 are estimated at 0.69

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3 Prepared by Faruk Miguel, Beulah Chelva, and Esteban Ferro.
4 FSB, 2020
5 (Field, Barros, Stocker, & Dahe, 2012)
7 In 2022, the European Council agreed to the Carbon Border Adjustment Mechanism (CBAM), which puts a carbon price on selected carbon-intensive imports to the European Union (including, cement, steel, aluminum, fertilizers and electricity). CBAM is an approach to avoid ‘carbon leakage’ – i.e., companies based in the EU moving carbon-intensive production abroad to take advantage of softer standards, or EU products being replaced by more carbon-intensive imports. To achieve this, CBAM will equalize the price of carbon between domestic products and imports.
8 Covers timber, cocoa, coffee, soy, palm oil, and beef.
9 Hurricane Alley is a stretch of warm water in the Atlantic Ocean spanning from the west coast of northern Africa to the east coast of Central America and Gulf Coast of the Southern United States.
percent of GDP, equivalent to around US$ 420 million annually\textsuperscript{10}. On average, the DR experiences over one hydrometeorological event, such as tropical storms, hurricanes, and droughts, per year\textsuperscript{11}. These events can cause significant damage, such as Hurricane George in 1998, which caused losses and damage equal to 14 percent of the 1997 GDP. Tropical storms Olga and Noel in 2007 caused losses and damages equivalent to 1.2 percent and 5.3 percent of the national budget that year.\textsuperscript{12}

Simultaneously, the financial sector of the Dominican Republic is vital in facilitating a transition towards low-carbon and climate-resilient practices, which could pose challenges in the short run. The DR’s contribution to global emissions has been rising over time,\textsuperscript{13} with the energy sector contributing the majority of GHG emissions in the country (63 percent), followed by emissions from waste (16 percent) and agriculture (13 percent). The country recently updated its commitments under its Nationally Determined Contributions (NDCs) to reduce GHG emissions in 2030 by 27 percent, with 20 percent conditional and 7 percent unconditional commitments, compared to business as usual (BAU) levels.\textsuperscript{14} Mitigation measures include actions in key sectors: energy; industrial processes and product use; agriculture, forestry and land use; and waste disposal. According to government estimates, these sectors are expected to require investments of around US$8.9 billion\textsuperscript{15}. The country pledged the intention to achieve carbon neutrality by 2050. While the transition to a low-carbon economy could offer substantial opportunities for the Dominican Republic, reaching its NDC targets poses substantial investment and financing needs for the country, potentially leaving carbon-intensive assets stranded in the context of a disorderly transition scenario.\textsuperscript{16}

Globally, there is increasing momentum towards greening the financial sector, as more central banks and regulators warn about the potential impact of climate risks on financial system stability. Alongside concerns about financial risks, there is a growing recognition of the role that the financial sector can play in mobilizing capital for climate-related goals. Efforts are being ramped up worldwide to green financial systems, in order to manage critical climate risks and promote green finance. The Network for Greening the Financial System (NGFS), comprising 116 central banks and supervisors (including the Central Bank of the Dominican Republic - BCRD), has been established to promote international cooperation on climate-related financial risk management and green finance. Moreover, all major standard-setting bodies have published guidance and analyses on this topic. Building upon the existing body of work, Central banks and supervisors are increasingly implementing strategies to promote sustainability in their financial systems.\textsuperscript{17}

\textsuperscript{11} According to EM-DAT database, there have been 53 natural disasters in the DR between 2001-2022.
\textsuperscript{13} Emissions per capita in the country in 2019 were estimated to be 3.70 t CO2-eq/habitant, significantly lower than both the world average of 6.48 CO2-eq/habitant and the Latin America and the Caribbean average of 6.28 t CO2-eq/habitant. However, all GHG inventories have shown an increase in emissions, particularly in the periods 1990-1994 and 2010-2015. For additional information, see Global Factor (2022). Decarbonization pathways for the Dominican Republic: assessment and implementation of the NDC. First Report.
\textsuperscript{14} Conditional commitments refer to emissions reductions that the Dominican Republic would be able to undertake with additional international support or if other conditions are met, while unconditional commitments refer to reductions the country is able to undertake based on its own resources and capabilities.
\textsuperscript{15} Government of Dominican Republic 2020. Updated Nationally Determined Contribution 2020
\textsuperscript{16} Stranded assets refer to assets that can experience a decline in economic and financial value as a result of more stringent regulations aimed at achieving climate objectives, swift advancements in carbon-neutral technology, and shifts in consumer and market behavior.
\textsuperscript{17} For instance, Colombia’s Superintendencia Financiera has introduced a strategy that includes a climate risk stress test, supervisory guidelines for banks and pension funds, and the establishment of a taxonomy. Similarly, the Central Bank of Brazil has incorporated a sustainability dimension as a key component in its public agenda (Agenda BC#). This dimension involves enhancing the regulation of climate-related and other
1. Climate-related Risks to the Financial Sector

Physical risks

Evidence shows that after hurricanes Irma and Maria struck the Dominican Republic in September of 2017, the credit outstanding increased in affected province-sectors pairs by an average of 11.7 percent. The increase in loan originations offsets the marginal and no statistically significant increase in the stock of non-performing loans (NPL) in the six months after the hurricanes. Therefore, the NPL ratio (a basic measure of a banks’ credit risk and credit portfolio quality) remained relatively flat. We also examined the effects on banks’ estimations of uncollected loan payments, finding a significant increase in provisioning that was also offset by a higher loan demand. A breakdown of these effects by the borrowers’ size shows that large debtors drive the aggregate outcomes.

However, the post-hurricane marginal effects show that the credit outstanding increased across all borrowers’ sizes, and the marginal effects are larger for the smaller debtors. In detail, the total credit outstanding to micro borrowers increased by 43.8 percent, small borrowers by 11.5 percent, and large borrowers by 19.2 percent. Post-hurricane, marginal effects also show that the non-performing loans ratio increased by 1.2 percent in the six months following the hurricanes for micro entrepreneurs’ loans only. Besides, a breakdown of the effects of hurricanes on banks’ credit portfolios by gender shows that women’s constraints to accessing credit are exacerbated.

Banking sector exposures to physical risks are a function of disaster risk in a region combined with the spatial and sectoral composition of assets. To evaluate the extent of their current exposure to physical risks, micro data on the composition of bank loan portfolios is integrated with the associated risk factors related to individual provinces and economic sectors impacted by extreme weather events such as hurricanes, floods, landslides, and droughts. Finally, the outcome of this analysis is a set of value-at-risk estimates that reflect the potential losses to be incurred by these financial institutions. Further information on this methodology is provided in section 2 and 3.

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18 Estimates from difference-in-difference regressions at the bank-province-sector-month level, controlling for bank fixed effects. Affected provinces are Dajabón, Duarte, El Seibo, Espaillat, La Altagracia, Montecristi, Puerto Plata, Maria Trinidad Sanchez, San Pedro de Macorís, and Santiago. Affected sectors are Agriculture, Fishing, Construction, Hospitality Services, Transport and Storage, and Real Estate Services.

19 These findings are similar to what Bickle and Morgan (2022) show for the case of the United States.

20 As a caveat, Dominican credit cooperatives could be more exposed to these natural hazards given their penetration into the agriculture sector. However, data constraints do not allow us to perform an assessment of this market segment. Anecdotal insights from financial sector stakeholders indicate that the size of the top 5 financial cooperatives is similar to a mid to small-sized bank.

21 The largest debtors concentrate a participation of 68.6 percent in the balance of the private commercial portfolio. While the participation of the number of credits is dominated by small debtors and microentrepreneurs, 96%. During the period analyzed, the median commercial loan for large debtors was DOP 6.4 million (approximately USD 114 thousand), DOP 157 thousand (USD 2,800) for small commercial debtors, and DOP 16 thousand (USD 280) for micro-entrepreneurs.
At present, lending to corporates is concentrated in banks with high exposures to vulnerable sectors and heavily based in the capital city, which is at high risk of Tropical Cyclones (TCs). Over one-fifth of the total lending to non-financial corporates (or over 40 percent of the credit to non-financial corporates) are in economic sectors usually exposed to this type of natural disaster. Affected sectors such as accommodation and food services, real estate-related activities and construction account for over three-quarters of lending to vulnerable sectors. Lending is highly concentrated in the Distrito National with a third of total corporate credit. The exposures to affected sectors in this province reflect the national trends. Some provinces are more locally exposed to affected sectors, such as La Altagracia (a tourism industry hotspot), where over half of the credit exposures are in hotel and food service activities. Across the largest banks by lending, exposure to affected sectors is over a third of the loan book (Figure A1.3.2 Panel B). Smaller banks have, on average, over half of their loan books concentrated in affected sectors. Given the high concentration of total credit in the top three banks (measured by size of total loan book) in the DR combined with the significant debt at risk to affected sectors, these institutions may warrant closer monitoring (Figure A1.3.2 Panel B). These exposures are considerable given the systemic importance of these banks based on market share. Overall, the credit exposures to TCs represent a potentially significant contingent liability to the government should these risks materialize in the banking sector, requiring government support.

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22 Vulnerable or exposed sectors are the same used for the Irma and Maria impact analysis (paragraph 5). See Annex for a methodological background.

23 July 2022 data shows that Monte Cristi and Valverde provinces have recently developed significant concentrations in the agricultural sector, heightening their exposure to the adverse effects of droughts.
Figure A1.3.2 – Distribution of credit to affected and non-affected sectors by province and within bank size as of July 2022

Panel A – Distribution of vulnerable corporate credit across Provinces

Panel B – Vulnerable and non-affected sectors by Bank Size

Source: BCRD data

Note: Panel A shows corporate credit allocation across provinces as a percentage of total credit in the country. Panel B shows the participation of affected and non-affected sectors as a share of bank's total credit portfolio. Large banks comprise of largest three banks by percentage of total corporate lending (over 15 percent of total loan book), medium banks are the next three banks (comprising of 2-4 percent of the total loan book) and all other banks are classified as small (with a share of the total credit under 1.5 percent).

Current banking sector exposure to non-financial corporates results show a significant credit-at-risk\(^{24}\) to tropical cyclones (23.2 percent) and minor exposure to droughts (1.7 percent). Combining the exposure analysis for non-financial corporates with a disaster risk materiality score,\(^{25}\) the credit exposure-at-risk for tropical cyclones in DR is extremely concentrated in high-risk provinces, with 22.1 out of 23.2 pp corresponding to provinces with high levels of expected physical damage. Figure A1.3.3 overlays the results on credit exposure to affected sectors (bubble size) on top of the physical damage rankings across provinces (color codes on the map). Most of the credit exposure to TC and droughts is concentrated in Distrito Nacional, accounting for 12.3 percent of exposure to TCs and 0.55 percent for droughts in this province alone. Other provinces with high-materiality to cyclones and relatively significant credit exposures are La Altagracia (2.6 percent), Santo Domingo (1.8 percent), and Santiago (1.5 percent). In contrast, the low credit exposure-at-risk for droughts is concentrated in provinces with low levels of expected physical damage (1.02 pp). In comparison to regional peers, the results for tropical cyclones are in line with Mexico (18.1 percent) and significantly higher than the ones reported for Colombia (0.3 percent).\(^{26}\)

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\(^{24}\) Credit-at-risk refers the amount of lending to firms engaged in sectors deemed vulnerable to a specific peril according to the classification used in Calice and Miguel (2020), expressed as a proportion of the total credit portfolio. Details of the methodology are provided in the annex.

\(^{25}\) See Annex for an explanation of our methodology.

\(^{26}\) Calice & Miguel (2021)
Banks’ lending to households is also exposed to physical risks, as their mortgage book is highly exposed to tropical cyclones.\textsuperscript{27} Mortgages show a significant geographic concentration, with 43.6 percent allocated to Distrito Nacional alone. The physical effects of climate change directly impacts housing; damages from extreme weather events reduce the value of the collateral, compromising asset quality and increasing non-performing loans as borrowers may struggle to meet their financial commitments. Mortgage credit represents 18.1 percent of overall credit in the DR, of which 17.2 pp corresponds to provinces with high expected physical damage. Distrito Nacional has the highest credit exposure of 7.9 percent with respect to overall credit in the DR, followed by Santo Domingo (4.5 percent) and Santiago (2.2 percent). Concerningly, provinces with high levels of credit exposure to mortgages and high expected physical damage by tropical cyclones are situated in the most densely built-up areas. While part of this is attributed to the construction of the disaster risk metrics, the extremely outsized impact highlights the significant concentrations of financial sector activity in provinces facing high risks to TCs.

In the future scenario, the banking sector exposure to tropical cyclones is expected to increase as damages from strong winds would more than triple for 2021-2040 under SSP370,\textsuperscript{28} increasing the disaster risk across the country. The analysis considers how disaster risk metrics may increase for

\textsuperscript{27} 100 percent of mortgage credit is classified in the affected sector “Purchase and Remodeling of Homes.” This is consistent with recent empirical studies (e.g., Pagliari 2021; and Bank of England 2018).

\textsuperscript{28} In line with the DR CCDR, we used the shared socio-economic pathway (SSP) 3: Regional Rivalry – A Rocky Road (High challenges to mitigation and adaptation). This scenario is considered “pessimistic”
TCs using forecasted wind tracks and computed national damage estimates\textsuperscript{29}. 20.9 percent of lending is exposed to strong winds alone out of the 23.2 percent credit-at-risk to TCs, highlighting strong winds are a key component of tropical cyclones\textsuperscript{30}. Based on wind tracks data, the modeled expected annual damage increases from around 1 percent of capital under the baseline period to 3.65 percent for the 2021-2040 period and to 3.2 percent for the 2041-2060 period, respectively. Our analysis assumes that exposure, vulnerability, and financial sector credit are fixed.\textsuperscript{31} Taking into consideration the likely growth in financial sector development and urban development in areas vulnerable to disasters (based on historical trends), these risks are likely to increase as lending to vulnerable sectors may grow. Based on this static measure of credit-at-risk to TCs, La Altagracia has the highest forecasted Expected Annual Impact (0.41 percent) and a 2.85 percent credit exposure. Finally, 18.3 percent of credit exposures to strong winds (or 20.2 percent to TCs) are concentrated in 4 provinces which are generally situated in the South-East.

\textbf{Figure A1.3.3 - Credit exposure against projected EAI}

\textbf{Source:} Data sent by authorities and World Bank estimations.  
\textbf{Note:} SSP3-70 scenario. National forecasts of Expected Annual Damage (EAD) are used to estimate future impacts of strong winds, which is a key component of tropical cyclone modeling (previous figure)

\textbf{Transition risks}

The methodology for assessing transition risks applies a multi-step approach that first estimates how higher costs of GHG emissions (modeled via a carbon price) affect the financial health and debt service capacity of individual non-financial firms and then links this to credit risk in the banking sector. The methodology follows closely the methodology applied by the IMF in recent assessments for Colombia (IMF, 2021) and Norway (IMF, 2020); however, we enhance the analysis using firm-level

\textsuperscript{29} The forecasted impacts of other perils are considered using data from the WB Climate Change Knowledge Portal. However, on further examination, the high level of uncertainty in future forecasts coupled with lack of granularity precluded use in the forecasted scenario. Instead, we focus on the most reliable forecasted estimates, national wind tracks data.

\textsuperscript{30} Other components include landslides, riverine and coastal floods. Lending to sectors affected by strong winds alone would account for 20.9 percent of the credit exposure of the total loan book. This value is only a few percent higher (at 22.3 percent) for credit exposure to TCs which accounts for the aforementioned perils in tandem.

\textsuperscript{31} Due to data limitations, the results are unable to disaggregate to province-level impacts and hence show the same distribution across provinces from the current exposure analysis. Consequently, the final outcomes summarized in Figure A1.3.30 show the scaled values for forecasted EAI percent in 2021-2040. The analysis thus focuses on unpacking wind exposure is distributed at present and the scale of the expected values of impacts under this increase.
estimations of CO2 emissions (scope 2). We assume that the higher carbon prices directly reduce firms’ earnings proportional to their level of emissions. As firm-level emission data are not available for the Dominican Republic, we use firms’ expenditure on fuel and energy sectors reported to DGII through form 606 to estimate firms’ emissions. Once firm-level emission estimates are obtained, they are multiplied by the carbon price per unit of emissions under the different scenarios\(^\text{32}\) to calculate the additional financial cost for the firm resulting from the policy change. The lower earnings following the carbon price hike reduce firms’ interest coverage ratio (ICR) and thus increase the risk of debt distress (see Annex for more details).

The total share of firms at risk of debt distress (i.e., firms with an ICR below one) increases by 2 ppts under a hypothetical scenario of a 110 US$/tCO\(_2\) carbon tax. The increase will be by 1.3 ppts under the 52 US$/tCO\(_2\) carbon tax scenario, by 1.2 ppts under the 45 US$/tCO\(_2\) carbon tax scenario, and by 0.5 ppts under the 12 US$/tCO\(_2\) carbon tax scenario. The aggregate numbers, however, hide important differences across economic sectors. The increase in the share of firms at risk of debt distress is highest in the transport sector (between 6.3 and 11.3 ppts), followed by the agriculture and fishing sectors (between 1 and 6.1 ppts), the hospitality sector (between 0.6 and 4.7 ppts), and the manufacturing sector (between 0.8 and 4.6 ppts). The relative impact on the sectors is in line with the emission intensity of these sectors but also reflects the pre-shock health of the firms and, thus their shock-absorbing capacity.

The total share of debt that is classified as debt-at-risk increases by 4.4 ppts under the scenario of a 110 US$/tCO\(_2\) carbon tax. This metric will increase by 2.7 ppts under the 52 US$/tCO\(_2\) carbon tax scenario, 2.6 ppts under the 45 US$/tCO\(_2\) carbon tax scenario, and by 1.3 ppts under the 12 US$/tCO\(_2\) scenario. The increase is larger than that of the share of firms suggesting that the carbon taxes are affecting firms with higher debt more than smaller firms with low debt. The sectoral dynamics show that the debt at risk increases largely in the agriculture sector (between 6.8 and 18.2 ppts), transportation sector (between 6.5 and 12.2 ppts), and manufacturing sector (between 3.2 and 11.2 ppts).

System-wide, 18.8 percent of total commercial loans are estimated to be at increased credit risk following the implementation of a 110 US$/tCO\(_2\) carbon tax. A 12 US$/tCO\(_2\) carbon tax would put 5.6 percent of system-wide corporate loans at increased credit risk. Recognizing that the simplifying assumptions of the model will probably lead to conservative estimates, the impact on the banking sector of a transition to a greener economy through an increase in carbon prices is thus substantial but seems manageable. Interlinkages between physical and transition risks could worsen shocks to the financial system. While transition and physical risks are often modelled separately, it is likely that the impacts of physical and transition risks will be experienced at the same time. This could amplify the economic and financial impacts of climate change due to feedback effects of both types of risks within the financial system, or between the financial system and the real economy.

\(^{32}\) We use the NFS scenarios: Delayed transition, National Determined Contributions, Below 2°C, and Net Zero 2050.
Figure A1.3.5 Impact of carbon tax implementation on Dominican Republic’s banks’ firms and banks’ portfolio

Panel A – Increase in share of firms with ICR<1 (ppts)  
Panel B – Loans subject to increased credit risk (debt-at-risk approach)

Source: Own calculations using data provided by DGII and the Dominican Republic’s Central Bank

2. Physical risks methodology

Physical risks from climate change on the financial sector are analyzed in three stages: (i) assess the historical impact of past disasters; (ii) ascertain the current exposure of the banking sector to financial risks; and (iii) project the potential impacts to the financial sector arising from future climate events.

Figure A1.3.6 - Methodology for estimating effects of physical risks on credit quality in the past, present, and future

1. Historical impacts of natural disasters
   An event analysis of major disasters in the DR using diff-in-diff regression methods
   OUTPUT: Estimated elasticities of credit quality to past tropical cyclones

2. Current banking sector assets at risk
   Measures concentration of exposures to hazards as value at risk to the banking sector
   OUTPUT: Exposure maps of credit at risk to the banking sector

3. Future climate scenario: credit exposure outlook
   Projected wind tracks data using climate models released under the IPCC Sixth AR framework
   OUTPUT: projected EAI estimates based on national wind projections

Source: Own elaboration.

First, the empirical methodology for estimating the causal effect of large-scale natural disasters on banks’ asset quality consists of a difference-in-difference (DiD) econometric specification. Specifically, we analyze the difference between affected and non-affected economic sectors-province pairs in several financial measures of bank activity and portfolio quality before and after the climate event. The disaster impact in the affected economic sectors-province pair is equal to the average
difference of the change in the financial measure. Following and Schüwer, Lambert, and Noth (2019), we estimate the following baseline specification:

\[ Financial_{i,s,p,t} = \alpha_i + \beta_1 Post_t + \beta_2 Affected_{sp} + \beta_3 (Post_t \times Affected_{sp}) + \varepsilon_{ispt} \]

where \( Financial_{i,s,p,t} \) is the bank \((i)\), sector \((s)\), province \((p)\) specific financial measure at month \(t\); \( Affected_{sp} \) equals 1 for province-economic sector pairs, and 0 otherwise; \( Event_i \) equals 1 for periods greater or equal to the date the natural disaster occurred, and 0 otherwise. Hence, the interaction term \( Affected_{sp} \times Post_t \) equals one if both variables are equal to 1, and 0 otherwise. The coefficient \( \beta_3 \) is our primary interest and shows how banks' credit portfolio vary after the shock compared to their counterfactuals. Additionally, the term \( \alpha_i \) captures bank fixed effects, controlling for any unchanging macro-financial and institutional conditions that have a bearing on NPLs within each bank. An unobserved robust error term clustered at the province-sector level is captured by \( \varepsilon_{ispt} \).

Second, in order to measure the current banking sector’s exposure to climate-related physical risks, we estimate the impact of the relevant perils on the current financial sector balance sheet. The approach involves combining disaster risk metrics and sectoral information to ascertain which sectors are affected by perils and relating this to province-level lending by sector. The modeling approach combines hazard, exposure, and vulnerability to estimate the baseline disaster risk metrics. The baseline is then combined with financial sector data to ascertain the scale of exposure of banks’ lending portfolios to droughts and tropical cyclones.

**Figure A1.3.7 - Components of exposure analysis**

**Panel A - Components**

- Bank credit portfolio
  - Lending by sector and province
- Bank's exposure:
  - credit at risk
  - % of lending at risk by peril & province
- Impacted sectors
- Sectors most affected by peril

**Panel B - Disaster risk flow**

1. **HAZARD**
   - Frequency
   - Intensity
2. **EXPOSURE**
   - Category
   - Size and Value
3. **VULNERABILITY**
   - Impact Function/Classification
4. **CLIMATE & DISASTER RISK BASELINE**
   - Expected Annual Exposure (EAE)
   - Expected Annual Impact (EAI)
5. **MATERIALITY**
   - Synthetic risk index
   - Composite Score for TC

**Source:** authors' own elaboration

We employ a model-based approach to determine province-specific disaster risk metrics, expressed in the baseline as a materiality rating. Formally, disaster risk is the probability of a
negative impact caused by a natural hazard. Such risk is a function of three components: (i) the probability and intensity with which a hazard occurs, (ii) the exposure of people and assets to a specific hazard, and (iii) the vulnerability of these exposed people or assets. Figure A1.3.9 - Panel B summarizes the workflow of the modeling approach where hazard, exposure, and vulnerability layers interact with each other to produce the expected annual impact (EAI) or Expected Annual Exposure (EAE) measures, which are used to compute the final materiality scores. Finally, a synthetic qualitative risk index is produced for 1) tropical cyclone hazard, as a combination of river floods, storm surges, landslides, and strong winds; and 2) drought hazard. This was done by normalizing all exposure categories using the maximum and minimum nonzero values and calculating the geometric mean between different components of the same risk score. The normalized geometric averages for each peril present the materiality score. For tropical cyclones, the highest value of the perils that can trigger TCs (floods, storm surges, landslides, and strong winds) is used.

We then combine the materiality scores with financial sector data to gain the final exposure measures (Figure A1.3.8). The mapping of affected economic sectors by natural disasters closely follows the one proposed by previous literature (incl. Calice and Miguel (2020)) shown in Figure A1.3.9 Panel A, which tails a similar identification as what historic events in Central America suggest and relies on scenario analysis from a wide variety of sources, including previous World Bank FSAP assessments, McKinsey Global Institute (2020). Note that the affected sectors are not province-specific.

Figure A1.3.8 Methodology for estimating peril-specific debt-at-risk at risk in each municipality

Estimation steps

1 - Estimate materiality scores for each peril by province
2 - Banks’ credit exposure in each province
3 - Identification of economic sectors most affected by peril
4 - Bank’s credit portfolio at risk

An example for assessing bank’s debt-at-risk | Natural disaster: Drought | Province: Bahoruco

1 - Bahoruco province has a high disaster risk materiality rating for droughts
2 - Banks lend X% of their total credit portfolio to Bahoruco
3 - From the literature, droughts affect mostly the agriculture sector which represent X_{Agri}\% of banks credit portfolio in province Bahoruco.
4 - X_{Agri}\% of banks agriculture credit portfolio in province Bahoruco is at high risk of potentially damaging droughts

Source: Own elaboration

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33 Figure A1.3.9 Panel B shows the distribution of economic losses from 13 large-scale natural disasters that affected Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, and Belize during the 1974 – 2020 period.
3. Transition risks methodology

To proxy the impact of higher carbon prices on non-financial firms, the assessment uses a balance sheet measure that indicates if a firm can cover its annual interest expenditures with its earnings. This measure is called interest rate coverage ratio (ICR) and is calculated as earnings divided by interest expenditure. If the ICR is below one, a firm does not generate sufficient earnings to cover its interest expenditures and is thus classified at risk of debt distress.

We assume that the higher carbon prices directly reduce firms’ earnings proportional to their level of emissions. As firm-level emission data are not available for the Dominican Republic, we use firms’ expenditures on fuel and energy sectors reported to the Tax Administration Office (DGII) through forms IR-2 and 606 to estimate firms’ emissions. Once firm-level emission estimates are obtained, they are multiplied by the carbon price per unit of emissions under the different scenarios outlined below to calculate the additional financial cost for the firm resulting from the policy change. The lower earnings following the carbon price hike reduce firms’ ICR and thus increase the risk of debt distress.

We estimate emissions from electricity consumption and from fuel consumption separately due to data constraints. To estimate a firm’s CO2 emission from electricity consumption, we use expenditure reported in DGII form 606 in ISIC sectors 401301-Electrical power distribution and 401302-Sale of electricity to the user. Using DGII information on a firm’s location, we assign an average price per KWh to each firm, based on the average price reported by the Electricity Distribution Companies of the Dominican Republic: EDESUR, EDENORTE, and EDEESTE (EDEs) that serve a specific location in a specific year. Dividing the firms’ electricity expenditure data by the
assigned average price, based on the firm’s location, we obtain the firm’s energy consumption in KWh. To estimate CO2 emissions from energy consumption, it is necessary to estimate a conversion factor from KWh consumed to kg of CO2 emissions based on the fuels used for energy generation in the Dominican Republic and reported by the National Energy Information System (SIEN). To estimate a firm’s CO2 emission from fuel consumption, we use the emissions data reported by SIEN. We match the relevant firm expenditure data from DGII’s form 606 to the economic activity sectors reported in SIEN’s CO2 emissions. We then assign the emissions share corresponding to each firm based on their share of total non-electric energy expenditure from Form 606 for that activity.

Figure A1.3.10– Transition risk methodology

1. Introduction of a carbon tax
   • Different scenarios for carbon tax level

2. Impact of the tax proportional to firm’s carbon emissions
   • Firm-level scope 2 emissions measured based on administrative tax reporting information

3. Carbon tax affects firm’s earnings and debt service capacity
   • Carbon tax assumed to reduce EBIT (under the assumption of no-pass through) and the interest rate coverage ratio (ICR = EBIT / Interest expenses). A lower ICR indicates a higher risk of debt distress.

4. Banks’ credit risk increases through exposure to firms with ICR<1
   • The banking stress is estimated as the increase in debt-at-risk in its loans loan portfolio.

Source: Own elaboration
Additional Results

Figure A1.3.11 - Non-financial corporates’ exposure to perils expressed as percent of total loan book

Notes: Color denotes materiality rating score by peril. Values express the percentage of credit to non-financial corporates vulnerable to Tropical cyclones (TC) and droughts (DR).
Source: own calculations based on BCRD data