ECONOMIC BENEFITS OF BUILDING RESILIENCE TO NATURAL HAZARDS AND CLIMATE CHANGE[1]

Peru is the most vulnerable country to climate change among the LA5 group and is highly exposed to periodic El Niño events, which impair production in the country's fishing, agriculture, and construction sectors, as well as inflict sizeable damages to physical assets. Given Peru's low adaptive capacity, climate change will likely increase damages from natural disasters and undermine potential growth in the future. Investments in climate structural resilience and adaptation can unlock substantial potential output gains and fiscal savings for Peru. Complementing these investments with reforms and capacity building to increase public investment efficiency can deliver even greater fiscal benefits.

A. Physical Risks and Policy Gaps

1. Peru is exposed to multiple climate hazards, including floods, droughts, and storms (Figure 1). Peru experienced 61,708 emergencies linked to natural phenomena between 2003-2019 (World Bank, 2022a). The climate-related physical risk profile of the country is dominated by floods, landslides, droughts, and storms. These natural hazards weigh heavily on socio-economic outcomes and constitute recurring fiscal costs as authorities rebuild damaged infrastructure and support affected populations. For example, economic losses and damages from disasters in 1982-83, 1997-98, and 2017 amounted to 11.6, 6.2, and 1.6 percent of GDP, respectively (World Bank, 2016). Approximately 40 percent of total damages in 2017 were inflicted on the road network (Macroconsult, 2017).

2. Vulnerability to *El Niño Costero* results in an uneven distribution of physical risks across time, geography, and economic sectors. Peru is particularly exposed to *El Niño Costero*, a recurring warming of the sea surface temperature along its coast (Niño 1+2 region) occurring every 4-5 years.[2] Owing to its complex geography and hydrology, Peru can experience a wide range of impacts from strong El Niño events.[3] In the northern coast, which typically lacks precipitation, heavy rainfall translates into substantial infrastructure damages from floods, lower agricultural yields, and a slowdown in the construction sector. In the southern regions, *El Niño Costero* manifests as a reduction in precipitation that reduces rainfed agriculture's output. Moreover, the rise in the sea

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[2] El *Niño* is a warm phase of the El Niño Southern Oscillation (ENSO), a periodic warming and cooling of waters in the central-to-Eastern Pacific Ocean. In Peru, El Niño events come in two types: Costero and Global. The distinction between the two is based on the region of the Pacific Ocean where the temperature anomaly occurs. El Niño Global increases the likelihood of storms hitting the Peruvian coastline and is associated with significant global spillovers. The cool phase of ENSO is called La Niña.

[3] The strength of *El Niño Costero* is typically classified into weak, moderate, strong, and very strong (extreme) based on the value of the ICEN index (Tahakashi and others, 2014). This annex defines the strong El Niño as strong or very strong Costero event based on the ICEN classification.

surface temperature during *El Niño Costero* adversely affects fish production along Peru's coastline (lower anchovy catches) and associated manufacturing activities (processing of fishmeal and fish oil), while higher air temperatures across the country disrupt flowering and pollination (e.g., blueberries, avocados, mangoes, olives).

3. **Strong to extreme El Niño Costero events typically cause temporary hikes in food and overall price levels, contraction in agricultural output and fish production, as well as a deterioration in the fiscal balance.** While temporary, the effect can be severe and persistent. The sharp drop in fish production (70 percent) and agricultural output (11 percent), as well as the rise in non-core CPI (2.2 p.p.) and non-core food prices (8.1 p.p.), generally takes over a year to recover to pre-El Niño levels. The increase in the core CPI (1 p.p.) and core food prices (2.3 p.p.) in the second year following a strong event, provides evidence of inflation passthrough from non-core price increases. Strong El Nino events can also be fiscally costly, as a sufficiently strong event is likely to decrease public revenues through reductions to tax collections and trigger increased spending on disaster recovery and reconstruction (See section B for details).

4. **In addition, climate change will likely reduce productivity of key economic sectors, such as agriculture and fisheries.** [4] Peru is the most vulnerable country to climate change among the LA5 group and third most vulnerable country in Latin America (IMF-adapted ND-GAIN, 2021).[5] Climate change is expected to undermine the country's natural capital and exacerbate water shortage, likely reducing the stock of fish in the Humboldt current (Salvatteci and others, 2022) and lowering crop yields across the board (World Bank, 2021a). Peru's economy is dependent on these resources as agriculture and fish production jointly constitute 7.6 percent of GDP and employ 28 percent of the workforce (OECD, 2023). Moreover, these sectors represent a notable part of the country's trade with the rest of the world, accounting for over 18 percent of total exports. Overall, climate change could result in large potential output losses in the long run, in the range of -26.2 to -102.3 percent of GDP depending on the global warming scenario (see Section C for details).

5. **Peru's vulnerability to physical risks is exacerbated by the lack of adaptive capacity and low resilience of public infrastructure.** Peru's vulnerability to climate change predominantly reflects one of the lowest adaptive capacities in the region. The wide gap in adaptive capacity relative to LA5 peers, can be attributed to insufficient water management capacity (e.g., dams, water treatment plants), as well as a relatively low quality of infrastructure (e.g., ports, railroads, roads,

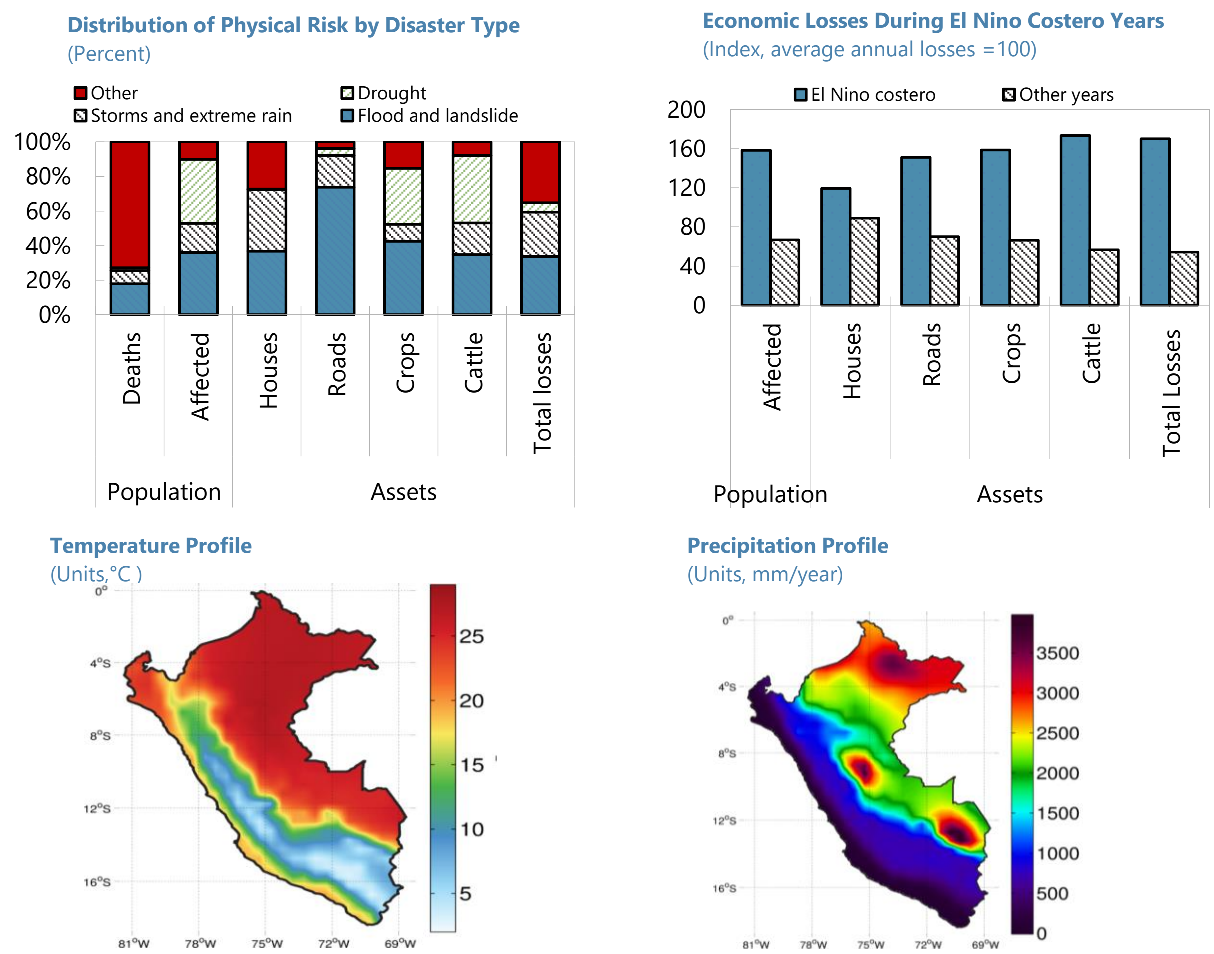
[4] Peru also faces several mitigation challenges from emissions produced by Land Use, Land-Use Change and Forestry (LULUCF), energy, transport, industry, and agriculture. Unlike most of the world, a large share of these emissions result from deforestation and land use (69% in 2020). Peru also relies heavily on fossil fuels such as natural gas, diesel, and gasoline. Despite the expanding capacity of hydro power, fossil fuels still constitute a large share of electricity generation (36 percent in 2020). The 2020 NDC includes an absolute unconditional target of 208.8 million tons of CO_2 equivalent by 2030, approximately equal to a 30 percent reduction from the business-as-usual baseline. This ambition heavily relies on slowing down the rate of deforestation as well as rolling out a carbon tax. The 2023 Article IV Staff Report (Annex XI) provides several examples of how these policy measures can be combined with revenue recycling to produce a net benefit for the Peruvian economy.

[5] IMF-adapted ND-GAIN defines vulnerability to climate change as a combination of exposure, sensitivity, and adaptive capacity. Although Peru's ecosystem is less exposed to the impacts of climate change compared to the LA5 average, the country's economy is more sensitive to its adverse effects. Finally, the adaptive capacity of the country is much lower than the LA5 average.

information technology).[6] Moreover, potential for improving adaptive capacity is undermined by weak public investment management, lack of coordination between various levels of government, and capacity gaps in the civil service.[7] In combination with a chronic under-execution of capital budgets, these reasons also represent a major obstacle to effective investments in structural resilience (Figure 2).

Figure 1. Peru: Natural Disaster Profile and El Niño

Peru's physical risk profile is dominated by floods, landslides, storms, and droughts with an uneven distribution of risk across time, due to the presence of the El Niño phenomenon, and across geography, due to the country's asymmetric temperature and precipitation profiles.



Sources: IMF staff calculations, UNDRR DesInventar database, NOAA (2024), Massetti and Tagklis (2023) and Harris et al. (2020).
Notes: DesInventar database includes disasters that occurred in Peru from 1970 to 2013. Precipitation and temperature profiles based on an average annual climatology for 1990-2021.

[6] Peru has one of the most unevenly distributed infrastructure networks in Latin America (World Bank, 2022b).

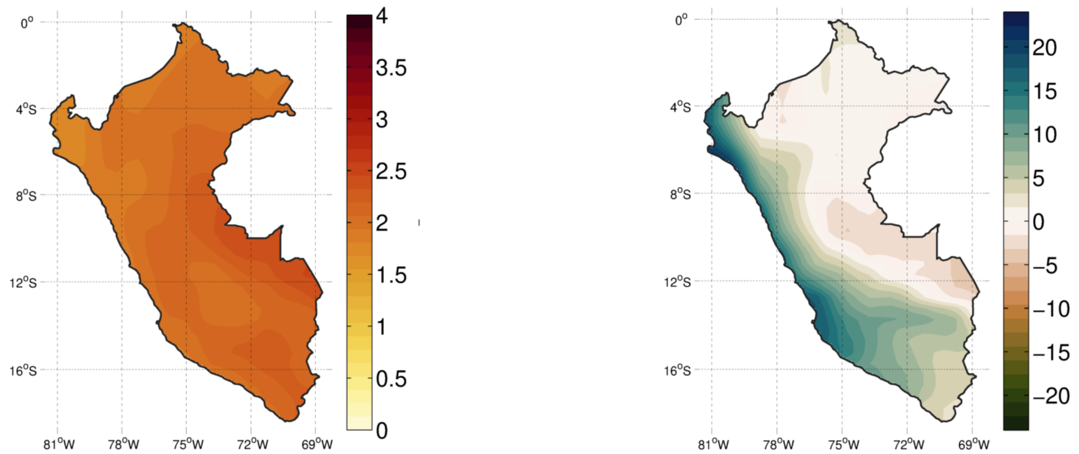
[7] OECD (2023) identifies weak public investment management, lack of coordination between various levels of government, and capacity gaps in the civil service as main causes for low public investment efficiency in Peru.

Figure 2. Peru: Climate Change Risks

Global warming will likely increase average temperature nationwide and cause higher precipitation in areas already vulnerable to floods.

Temperature Change in 2070 (SSP2-4.5)
(Percent, relative to 1986-2014 average)

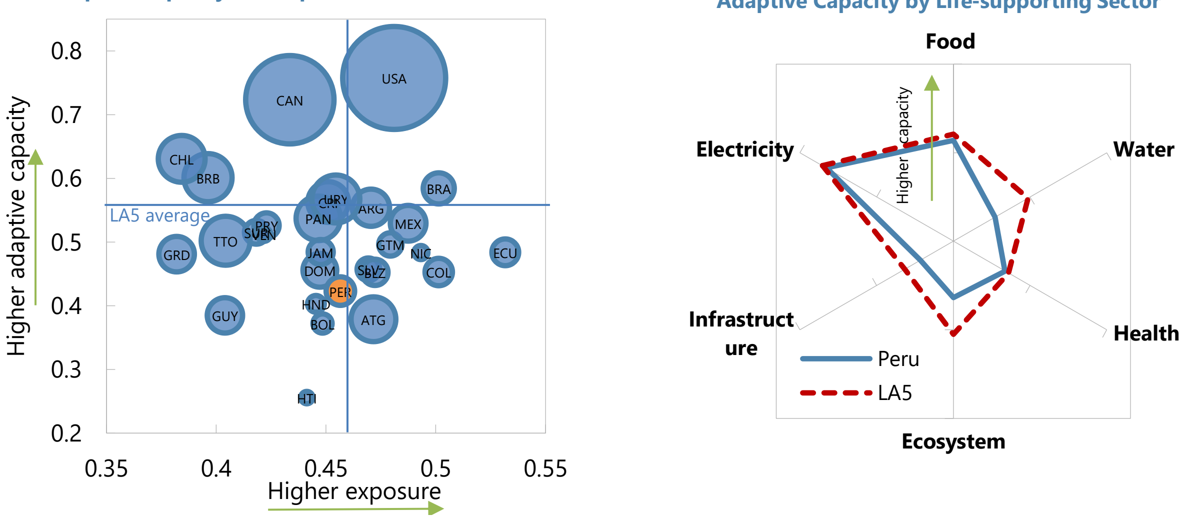
Precipitation Change in 2070 (SSP2-4.5)
(Percent, relative to 1986-2014 average)



Although Peru's ecosystem is less exposed to climate change than some LA5 countries, the adaptive capacity of the country is one of the lowest in the region due to insufficient water storage capacity and low quality of trade and transport infrastructure, making it the most vulnerable in LA5.

Adaptive Capacity and Exposure

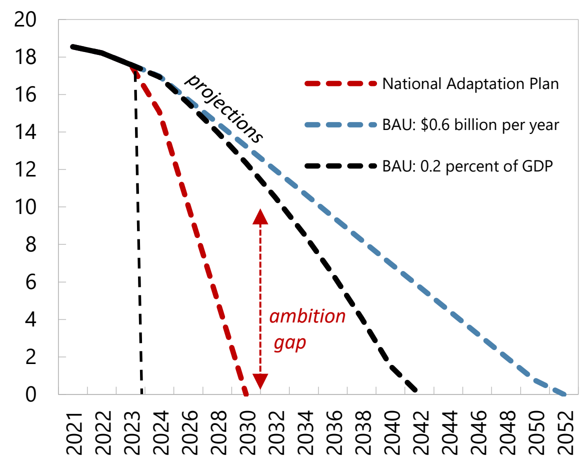
Adaptive Capacity by Life-supporting Sector



Sources: IMF staff calculations, IMF-adapted ND-GAIN, Massetti and Tagklis (2023) and Harris et al. (2020).
Notes: Average annual temperature anomaly between a 30-year time period centered around 2070, relative to 1986-2014. Adaptive capacity index is the difference between one and the capacity indicator so that higher values indicate greater capacity. Bubble size indicates per-capita GDP in USD (2019).

6. Authorities have created a framework for climate adaptation, but current implementation remains well below ambition. Peru has established a legal framework and committed to a comprehensive roadmap to enable climate adaptation. The 2018 *Framework Law on Climate Change* sets a legal basis for integrating public adaptation principles into strategic national planning and territorial planning, as well as for integrating climate change risks in the public investment management process. Furthermore, it requires the Ministry of Environment (MINAM), in coordination with various line ministries, to provide annual progress reports to Congress. The 2021 *National Adaptation Plan* (NAP) outlines the country's sectoral adaptation priorities across 5 key thematic areas (Health, Water, Agriculture, Aquaculture, and Forests).[8] It details 84 associated adaptation measures scheduled for completion by 2030.[9] As of July 2023, implementation has commenced for 33 out of 84 measures included in the NAP, 18 of which are concentrated in the water thematic area.[10] However, despite the progress, annual expenditure on adaptation remains significantly below identified needs and does not align well with the targets set in the NAP. If the current annual adaptation expenditure level of $0.6 billion (as of 2023) is maintained, it would take approximately 20 years more (until 2052) to implement costed adaptation plans originally set for 2030 (Figure 3).

Figure 3. Peru: Remaining Adaptation Needs
(USD, billions)



Sources: IMF staff calculation, MINAM (2021b), MEF (2024).
Notes: Business as Usual (BAU) projections assume annual adaptation expenditure at the 2023 level: $0.6 billion in nominal terms and 0.2 percent as a share of GDP.

7. Despite important steps to strengthen structural protection, the progress remains slow. Peru established the *National Framework for Disaster Risk Management* (SINAGERD) in 2011. Within this framework, 2021 marked the release of the *National Disaster Risk Management Policy by 2050* and an updated *National Plan for Disaster Risk Management* (PLANAGERD 2022-2030). The national Disaster Risk Management (DRM) plan includes 21 strategic actions aimed at enhancing capacity and access to knowledge, incorporating DRM into operational and territorial planning, incorporating DRM principles into the public investment management process, and climate-

[8] MINAM currently works on expanding the thematic coverage of the national adaptation plans by including two additional thematic areas, Transport and Tourism, as well as the associated adaptation measures.

[9] The Ministry of Environment (MINAM) devised an ambitious set of adaptation measures aimed at safeguarding critical sectors like agriculture and fisheries. These measures involve enhancing water management capacity, implementing early warning systems, strengthening risk transfer systems, and investing in essential infrastructure. Additionally, these measures encompass diversification of vulnerable primary economic activities and adoption of preventive measures in agriculture and fisheries.

[10] Assessing the progress in adaptation efforts over the last three years presents a challenge due to the recent revisions of the methodology for classifying progress with the adaptation measures by MINAM. These revisions were aimed at homogenizing the definitions of progress across the five thematic areas, as declared by the responsible ministries.

proofing public infrastructure.[11] Under the umbrella of this strategy, the Ministry of Transport and Communications (MTC) constructs new bridges with adequate provisions in areas exposed to riverine floods, provides maintenance to prepare the road infrastructure for upcoming *El Niño* events and reconstructs them ex-post.[12] Established in 2023, the National Infrastructure Agency (ANIN) will take over a fraction of infrastructure projects from subnational governments, aiming to strengthen structural resilience of public assets (e.g., schools, reinforced riverbeds) by adopting international engineering standards and focusing on disaster risk management in construction planning. Nonetheless, natural disasters still inflict sizeable damages to public infrastructure as resources are often diverted towards other development objectives.[13]

8. Peru's government has implemented a disaster risk retention system, which now requires a thorough assessment of its financial buffers. In 2016, the World Bank and the Ministry of Economy and Finance (MEF) developed the 2016 *Comprehensive Strategy for Financial Protection against Natural Disasters*. This strategy envisages a multi-layered approach to centralized financing of expenses relating to major emergencies (levels 4 and 5), comprising of a risk retention (fiscal stabilization fund, contingency credit lines, and reserves) and risk transfer components (indemnity insurance and cat-bonds).[14] By 2024, all elements of the strategy's risk retention component were operational and had been utilized in managing recent natural disasters. However, the adequacy of these financial safeguards had not been assessed against a wider set of potential natural hazard risks, as currently only earthquake risk is included.

9. Significant financial protection gaps remain in the country's risk transfer system which stands to gain from further improvement. While insuring public assets is mandatory, it is subject to the availability of funds. The absence of a centralized inventory of public assets complicates the monitoring of public sector insurance coverage.[15] Furthermore, the progress with adopting nontraditional insurance instruments has stalled since the 2018 Pacific Alliance issuance of cat-bonds linked to earthquake risk. Catastrophe insurance penetration in the private sector remains low, with only 8 percent of properties insured against natural disasters as of 2017.[16] Authorities need

[11] Its predecessor (PLANAGERD 2014-2021) oversaw capacity and resilience building enhancements. For example, approximately half of regional governments implemented Early Warning Systems for natural disasters between 2014 and 2021 (MINAM 2021a). However, some strategic actions, notably the integration of disaster risk management into territorial planning and zoning regulations, showed a lack of progress.

[12] MTC also provides material support (e.g., fuel) to subnational governments to assist in the preparation to upcoming *El Niño* events as well as in post-disaster response.

[13] For example, the goal of enhancing structural resilience of the national road infrastructure conflicts with the goal of eliminating unpaved national roads. The share of unpaved national roads fell from 46.4 percent in 2011 to approximately 20 percent in 2023. Facing limited resources, the government often compromises between various development objectives.

[14] Local and regional budgets are expected to rely on their institutional budgets in responding to emergency levels 1, 2, and 3. Peru's Fiscal Stabilization Fund is not climate specific.

[15] The existing system requires that each public entity individually insures its managed assets. Creating a centralized inventory of public assets could enable the government to collectively negotiate insurance coverage, thereby achieving savings by consolidating the various indemnity insurances into a single policy.

[16] Among insured properties, insurance policies often exclude flood risk.

to be conscious that a significant share of uninsured public and private assets represents an implicit contingent liability for the government, which could overwhelm the risk retention system if a tail risk materializes.

B. Estimating the Impact of El Niño on Economic Activity

10. Peru's vulnerability to *El Niño* transcends damages to physical assets, also reflecting temporary deterioration in natural capital and productivity. *El Niño* events are often associated with significant damages to private and public capital, which are documented through data on economic losses in major disaster databases (e.g., EM-DAT and DesInventar). However, these events also tend to influence the stock of natural capital and productivity of some economic activities (e.g., agriculture and construction), channels that are not accounted for in such databases. This section aims to quantify the broader range of channels through which *El Niño* affects Peru's economy by estimating the magnitude of impact on sectoral output, prices, and fiscal outcomes.

11. The local projection method proposed by Jordà (2005) is used to estimate impulse response functions for strong *El Niño* events. The impact of an average strong *El Niño Costero* shock is estimated for a 1–2-year horizon using the equation below:

$$\Delta y_{t+h|t-1} = \beta_0^h + \beta_1^h s_t^{EN} + \sum_{i=1}^{4} \beta_2^i \, \Delta y_{t-i} + x_{t-1} + v_t^h$$

where β_0 is the constant term, s_t^{EN} is a binary variable equal to one during the onset of an *El Niño Costero*, $\sum_{i=1}^{4} \beta_2^i \, \Delta y_{t-i}$ includes the lags of the dependent variable, and x_{t-1} includes a set of control variables, such as oil price indices for Peru's main oil import partners (U.S. and Nigeria), a global fertilizer index, and a local production index for the regressions on monthly prices. The model is estimated on quarterly data for sectoral output and monthly data for the price indices.[17]

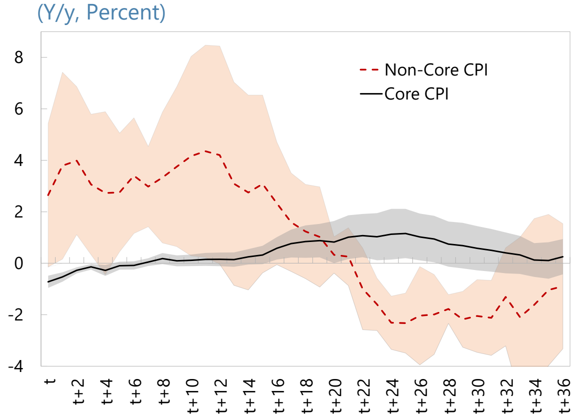
12. The empirical analysis in this section indicates that strong *El Niño* events have historically been associated with inflationary pressures. Both core and headline inflation rates rose following strong *El Niño Costero* events. Non-core inflation increased immediately after the shock, reaching a 4.4 percentage point increase in the year over year inflation rate by the end of the first year, then gradually declining and entering a period of deflation as prices normalize to pre-*El Niño* levels. Core inflation, on the other hand, only started rising about 12 months after the shock, suggesting a possible passthrough from headline to core (Figure 4).

[17] For quarterly dependent variables the production index is omitted.

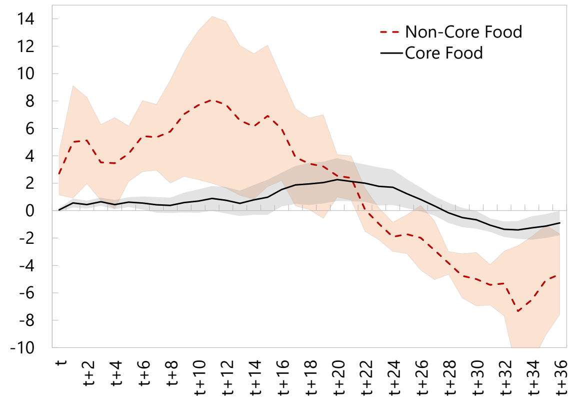
Figure 4. Peru: Change in Inflation Indicators Following El Niño Shock

Strong/very strong El Niño Costero events were followed by an increase in y/y inflation during the first year and core inflation during the second year, with associated increases in food (non-core and core) inflation.

Monthly Inflation Increase After El Nino Costero
(Y/y, Percent)



Monthly Food Inflation After El Nino Costero
(Y/y, Percent)



Sources: IMF staff calculations.
Notes: Shaded areas show the 68 percent confidence interval. "t+x" corresponds to x quarters after the onset of *El Niño Costero*.

13. One of the primary channels of *El Niño*'s impact on inflation works through food prices. The increase in the non-core food inflation, which tracks price fluctuations of perishable foods like fresh fruit and vegetables, closely mirrored the path of the headline rate but with a significantly larger magnitude. Non-core food inflation registered an 8.1 percentage point (p.p.) increase by the end of the first year. Core food prices, being less sensitive to weather extremes, only picked up in the second year, registering a 2.3 p.p. increase in the inflation rate 20 months after the onset of *El Niño Costero*. In line with these results, the ongoing 2023 *El Niño Costero* triggered temporary spikes in year over year CPI inflation for the Fish and Seafood component, 11 p.p. increase between February and June, and the Fruits component, 22.6 p.p. increase between February and September.

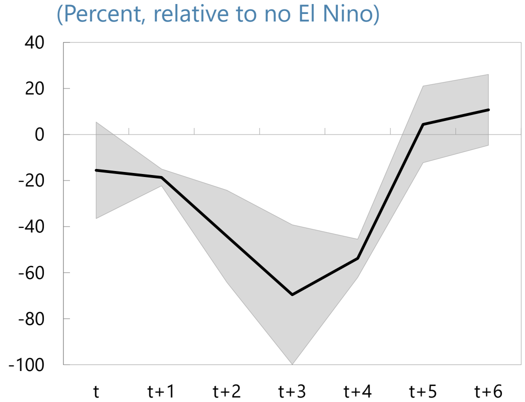
14. Within a year of the onset of a strong *El Niño Costero* event, both fish production and agricultural output experience a sharp decline. In the past, the output of fisheries dropped by 70 percent within the first year since the onset of *El Niño*, on average, quickly followed by a recovery to pre-*El Niño* levels as the normalization of sea surface temperature restored availability of fish in the Humboldt current. Agricultural output dropped by about 11 percent within the same time span, followed by a more gradual recovery. Historically, the impact on agriculture was more persistent with production still about 3.4 percent below pre-*El Niño* levels 1.5 years after the shock. The ongoing *El Niño Costero* episode, which reached the "strong" classification in April 2023, has disrupted two fishing seasons, lowered agricultural yields, and reduced construction and manufacturing activity. In March-November 2023, fishing and agriculture output was 27.3 and 4.9 percent below trend. Construction and manufacturing output were 9.2 and 6.6 percent lower, respectively.

15. Strong *El Niño* events typically last slightly longer than a year, influencing other weather-related anomalies and contributing to reductions in the primary balance. Accounting for the spillovers into the manufacturing sector, as well as the impact on construction and mining, *El Niño Costero* events typically reduced real GDP by 5 percentage points within the first year, relative to a baseline real GDP trajectory. An offsetting factor during *El Niño* events was usually an increase in public expenditure to rebuild infrastructure and support affected populations. The central government's primary balance would typically fall by about 2 percent of GDP for the same period, reflecting increased expenditures and lower collections. Consistent with the staff estimates, the annual central government primary balance fell by around 1.2 percent of GDP from 2022 to 2023, reflecting about half a percentage point increase in nominal primary expenditures and 6 percent lower nominal revenues during a strong *El Niño Costero* year.

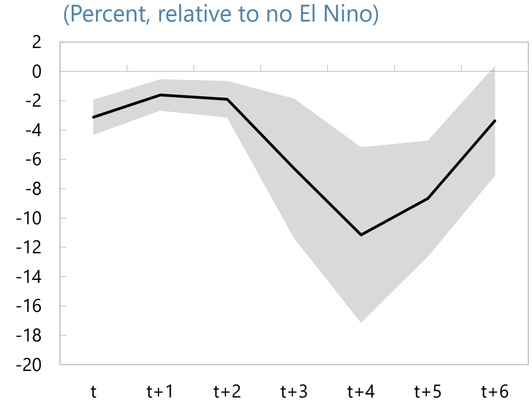
Figure 5. Peru: Change in Sectoral Output and Primary Balance Following an El Niño Shock

Strong/very strong El Niño Costero events caused sizeable contractions in sectors such as fisheries and agriculture…

Fish Production
(Percent, relative to no El Nino)

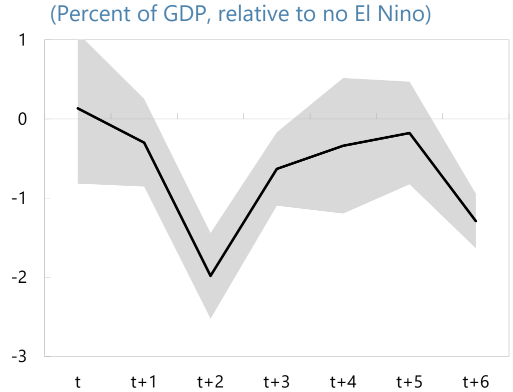


Agricultural Production
(Percent, relative to no El Nino)

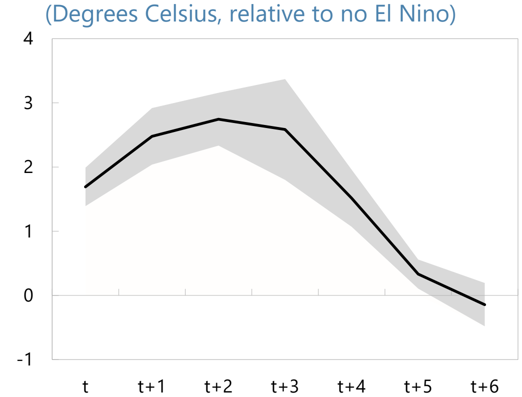


… as well as reductions in the primary balance. Elevated sea surface temperatures persisted for slightly over a year.

Primary Balance
(Percent of GDP, relative to no El Nino)



ONI 12 Index
(Degrees Celsius, relative to no El Nino)



Sources: IMF staff calculations
Notes: Shaded areas show the 68 percent confidence interval. "t+x" corresponds to x quarters after the onset of *El Niño Costero.*

C. Measuring Economic Benefits of Building Resilience and Adapting to Climate Change

16. The IMF's climate FGG DSGE model is used to quantify the long-term impact of natural disasters and climate change on the economy of Peru and illustrate the benefits of investing in adaptation and resilience ex-ante. The FGG model (Fernandez-Corugedo, Gonzalez, and Guerson, 2023) is a Markov-switching dynamic small open economy model designed to evaluate the macroeconomic returns of investment in resilience to natural disasters and climate change. The model assumes that the economy oscillates between two states: one in which a natural disaster shock materializes and the other in which the economy is not affected by such shocks. The key assumption in the model is that there are two types of public capital: standard capital and resilient capital. Standard capital is vulnerable to natural disasters, and part of it is destroyed each time the economy enters a "disaster" regime. Resilient capital is immune to disasters and is not affected by regime shifts. Both types are used as an input to production by firms, jointly with private capital and labor.

17. The FGG model is extended to account for the impact of *El Niño* on natural capital and the role of public investment efficiency in determining macro-fiscal outcomes. Following Gallic and Vermandel (2020), the baseline model is extended to include the natural capital in the production function:

$$Y_t^H = [\theta(s)K_{t-1}^N]^{\omega}[z_t^Y(K_{t-1}^G)^{\alpha_G}(N_t)^{\alpha_k}\,(K_{t-1}^Y)^{1-\alpha_k}]^{1-\omega}$$

where $\theta(s)$ is the parameter capturing the impact of natural disasters on natural capital, K_{t-1}^N is the stock of natural capital, z_t^Y is productivity, K_{t-1}^G is the stock of public capital, N_t is the labor input, and K_{t-1}^Y is the stock of private physical capital. The elasticity of output to various production inputs are captured by the respective parameters (ω, α_G. α_K). Finally, only a fraction of public investment is assumed to transform into productive public capital, capturing possible inefficiencies in public investment management (Buffie et al. 2012):

$$K_t^G = (1-\delta(s))K_{t-1}^G + (1-\epsilon)I_t^G$$

where I_t^G is government investment, $\delta(s)$ is the depreciation rate, and ϵ is the inefficiency parameter. (s) denotes parameters changing value between states. In this setup, the Markov-switching model has two states: the one in which natural disasters inflict modest damages and the other in which damages and losses from natural disasters are amplified by the presence of *El Nino Costero*.[18] Natural disasters inflict damages to physical assets, as in the conventional FGG setup, but also to the

[18] A key distinction between the traditional use of the FGG model for small island states prone to tropical cyclones and its current application to a large emerging economy like Peru is the frequency and scale of natural disasters. While Peru faces natural disasters on an annual basis, the average impact of each event is smaller, yet more frequent, compared to those typically modeled for small island states. Therefore, even during what would be considered the "normal" regime, some level of damage from natural disasters is anticipated in Peru.

country's stock of natural capital.[19] Furthermore, the total stock of public capital now includes adaptation capital which reduces the impact of weather on natural capital by changing $\theta(s)$.

18. Recurring natural hazards already take a heavy toll on Peru's economy, while the losses are expected to amplify with climate change. Peru is affected by repeated natural disasters without being able to fully return to the initial level of capital and productivity. In other words, the effects of sequences of shocks accumulate over time, weighing permanently on macroeconomic outcomes.[20] In the case of Peru, staff's illustrative analysis captures a wide array of climate hazards, including floods, droughts, storms, landslides, and the weak upwelling that reduces fishing yields. The model simulations illustrate that existing climate hazards already undermine the country's economy, reducing potential output by 4.1 percent in 2023, relative to the no climate counterfactual. Moreover, the anticipated effects of climate change will likely amplify these losses. Cai and others (2021) argue that ENSO-related rainfall in the equatorial Pacific will intensify and move eastward.

19. Temperature anomalies undermine future potential growth, but market agents are allowed to adapt over the long run.[21] To account for the possible impacts of climate change, we compute projections of potential output until 2100 under three global warming scenarios: Delayed Net Zero (SSP1-2.6), Intermediate GHG emissions (SSP2-4.5), and Hothouse world (SSP3-7.0). Potential output paths are given by:

$$Y_t^{potential,i} = Y^{SS,i} \times T_t^i$$

where T_t^i is a measure of long run trend which produces the balanced growth path of output when multiplied by the steady-state output level $Y^{SS,i}$. The growth rate of potential output is decreasing in the size of the temperature anomaly $T_t^i - T^{*,i}$ under the three global warming scenarios obtained from Massetti and Tagklis (2023), with the magnitude of the impact governed by elasticities β_1 and β_2 taken from Chirinos (2021):

[19] The impact of strong/very strong El Niño shocks on physical capital is set to 2.6 percent of the capital stock per quarter; calibrated by averaging damages for select severe events available from World Bank (2016, 2021a). The impact on natural capital is set to match empirical estimates from the previous section. Weak and moderate El Niño shocks are assumed to inflict ¼ of damages and losses resulting from a strong/very strong event. The impact of other natural disasters (unrelated to El Niño) is calibrated by dividing the average El Niño impact by 3.13 (implied by the difference in real asset losses between El Niño Costero years and the rest of the sample declared in DesInventar database). The transition probabilities are calibrated using the history of El Niño occurrences since 1980.

[20] See Cantelmo, Melina, and Papageorgiou (2019), Melina and Santoro (2021), or Fernandez-Corugedo, Gonzalez-Gomez, and Guerson (2023) for detailed discussions of the long-run output losses from recurring climate shocks.

[21] Several limitations of this approach warrant attention. Firstly, the construction of temperature anomalies leverages median temperature projections from the climate models, disregarding the model uncertainty associated with such projections. Secondly, the elasticities derived from Chirinos (2021) are backward looking by construction, and their application to future projections implicitly assumes no changes in the pace of technological progress, natural adaptive capacities, or shifts in market behavior due to policy interventions. Thirdly, the method employs conservative estimates from Chirinos (2021) to assess the impact of global warming on potential growth, using parameters β_1 and β_2 based on absolute temperature deviations and regional GDP weighted by population. The approach does not account for the uncertainty surrounding these estimated elasticities, as they are not detailed by the authors in their publication.

$$\frac{T_t^i}{T_{t-1}^i} = 1 + g^{SS} - (\beta_1 + \beta_2) \times (T_t^i - T^{*,i})$$

where g^{ss} is the long run growth under no climate impacts, while i denotes the climate change scenario. $T^{*,i}$ is the baseline climate profile calculated using a 30-year rolling average of temperature. This modelling choice is crucial as it produces smaller temperature anomalies that tend to gravitate to zero if global warming slows down over time. The underlying rationale for this choice is the belief that economic agents will autonomously adapt to increments of global warming that took place in the distant past. Additionally, the hothouse world scenario (SSP3-7.0) assumes a 59 percent rise in the number of strong *El Niño* events by the second half of the century.[22]

20. Potential output losses from climate change increase over time but depend on the assumed progress with the global mitigation effort. Combining the additional impact of climate change with the existing losses from climate, potential output could be up to 16.1-22.8 percent lower by 2050 and 28.2-102.3 percent lower by 2100, relative to the no climate change counterfactual (Figure 6). This is equivalent to a 0.1-0.3 percentage point reduction in the average annual potential growth rate due to climate and climate change. In all scenarios except for the hothouse world, losses in potential growth are front-loaded. This is because the rate of global warming is anticipated to decelerate in the future under the SSP1-2.6 and SSP2-4.5 (Figure 6).

21. Investments in adaptation and structural resilience combined with increased public investment efficiency deliver sizable output gains in the long-term. Investing in resilience and adaptation offsets the impact of natural hazards and climate change on productive factors and growth. Structural resilience involves making public infrastructure, like roads, bridges, and schools, climate-proof, effectively representing a shift from standard to resilient capital. Adaptation investments cover expenditures on knowledge systems, irrigation and water management, and diversification of crops and livestock, among other items.[23] Within the model, these investments reduce the impact of natural disasters on natural capital and partially offset the reduction in the long run growth rate due to positive temperature anomalies.[24] According to the model simulations, a policy package that includes: (a) 0.8 percent of GDP in public adaptation investments per year until 2030; (b) climate proofing 80 percent of Peru's transport infrastructure; and (c) increasing public investment efficiency by 5 percentage points can produce potential output gains as high as 9.3-12.3

[22] Important limitation of our approach is that Cai and others (2014) simulate the increase in El Nino intensity under RCP8.5, whereas we assume this increase under a less severe global warming scenario, SSP3-7.0. Therefore, our approach likely overestimates the cost of climate change for SSP3-7.0 global warming scenario.

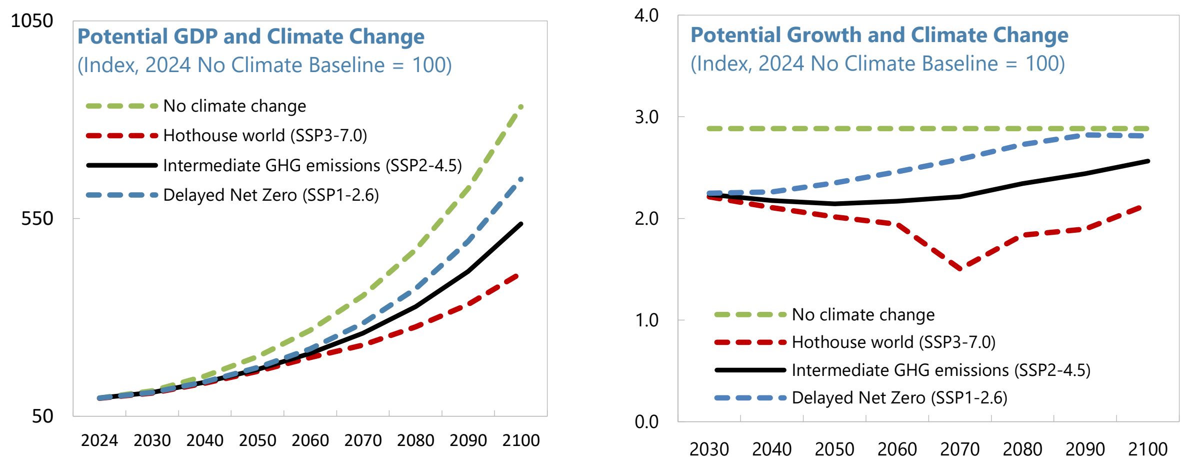
[23] Adaptation investments include expenses on pest management, resistant genetic resources, agricultural risk transfer systems, crop and livestock diversification, cultivated pasture conservation, soil erosion management and control technologies, soil fertilization, water supply and sanitation, multipurpose water storage, supporting technified irrigation, drainage systems, adapting landing sites for artisanal fishing, strengthening early warning systems, aquaculture management, among others.

[24] Results are based on a conservative view on the benefits from adaptation, which are typically associated with large uncertainties. The baseline scenarios consider that investments in adaptation will offset 1/3 of the climate's impact on natural capital and productivity.

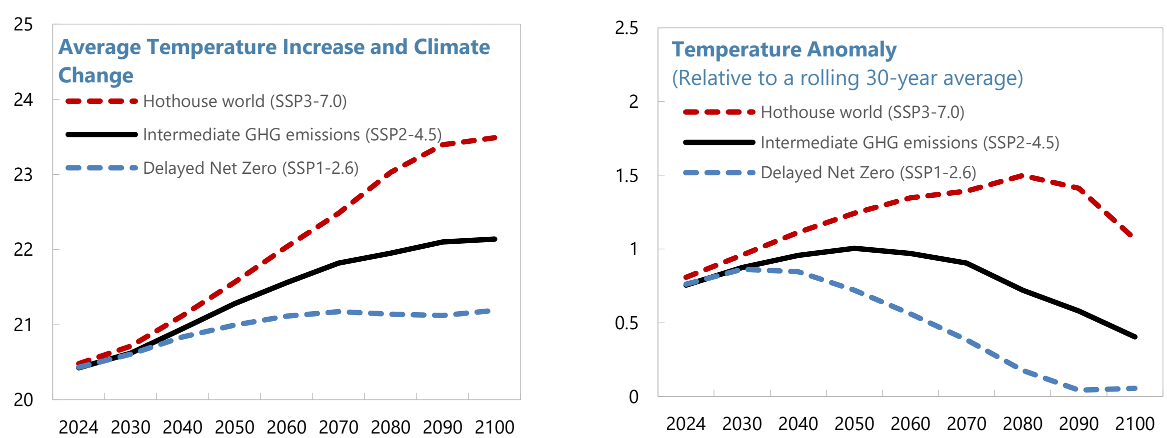
percent by 2050 and 12.4-31 percent by 2100 (Figure 7).[25] The policy package does not totally eliminate the projected decline in potential output due to climate impacts. Residual output losses still amount to 6.8-10.5 percent by 2050 and 15.8-71.3 percent by 2100. However, the proposed policy package is cost-effective under all three global warming scenarios since it simultaneously lifts the potential output trajectory and produces fiscal savings.

Figure 6. Peru: Potential Output Losses and Climate Change

Potential output losses will rise over time under all climate change scenarios as rising temperature undermines growth. However, the long-term growth outlook is expected to improve in scenarios where global emissions are reduced and the rate of temperature increase in Peru slows down.



The gradual recovery in the potential growth rate under SSP1-2.6 and SSP2-4.5 results from the reduction in the pace of warming and the associated reduction in temperature anomalies.

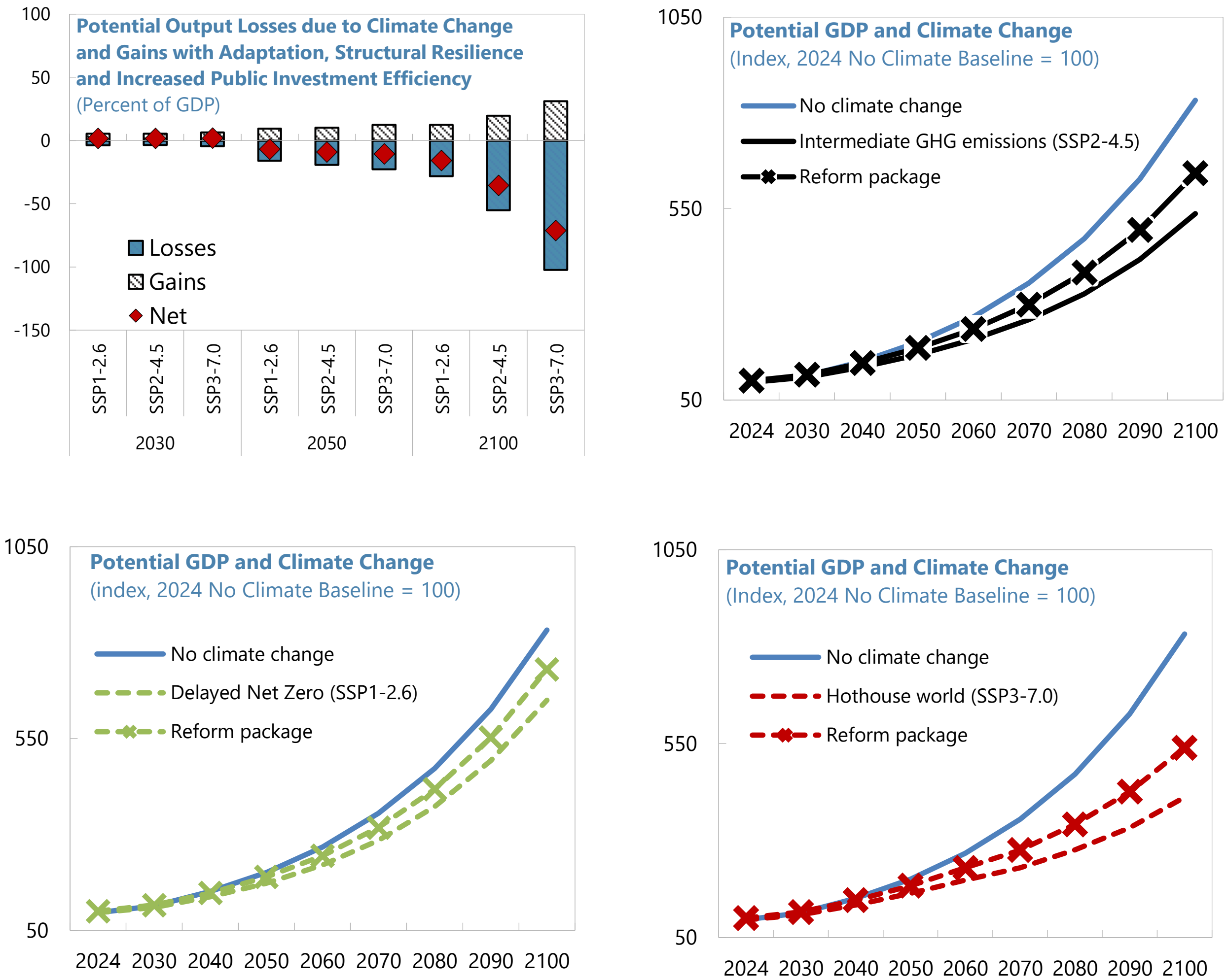


Sources: IMF staff calculations using the FGG model, Massetti and Tagklis (2023), Harris et al. (2020), and Chirinos (2021); Riahi et. Al.,The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview, Global Environmental Change, Volume 42 (2017).

[25] It is worth noting that these results are not driven by the increase in the public investment efficiency, as it only accounts for a 0.8 percent positive shift in the potential GDP trajectory.

Figure 7. Peru: Potential Output Gains from Building Resilience and Adapting to Climate Change

Investing in adaptation and resilience, along with implementing reforms to enhance the efficiency of public investment, can yield significant output gains across all global warming scenarios, compensating for a good amount of the output losses from climate change.



Sources: IMF staff calculation using the FGG model, Massetti and Tagklis (2023), Harris et al. (2020), and Chirinos (2021); Riahi et. Al.,The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview, Global Environmental Change, Volume 42 (2017).

22. **Public investments in adaptation and resilience are also associated with large fiscal returns.** Making public infrastructure resilient to *El Niño* and other natural disasters leads to fiscal savings by preventing the need to repeatedly reconstruct damaged roads and bridges, as well as by mitigating the transitory reduction in government revenues associated with these events. Investments in adaptation partially offset the impact of global warming on the potential growth rate, thereby producing a higher trajectory for the tax base and tax receipts. Between 2024 and 2100, the combined benefits produce, on average, an annual 2.3-4.6 percent of GDP in fiscal savings. However, the fiscal benefits materialize over time, whereas fiscal costs are immediate. To account for this discrepancy, discounted fiscal savings must be calculated. Table 1 clearly demonstrates that investments in adaptation and structural resilience are cost-effective under all three global warming

scenarios even when accounting for the time value of money and under a range of discount rates (Figure 8).

23. **Authorities should also consider improving coordination within the government, enhancing financial resilience, and enforcing stricter DRM-linked zoning regulations.** The effectiveness of public efforts in adaptation and disaster risk management could be enhanced through improved coordination among various levels and branches of the government. For instance, the MEF could estimate the costs of measures outlined in the national adaptation and DRM plans—a first step towards effective budgeting of climate policies—or adopt green budget tagging. In terms of financial protection, authorities should generate a comprehensive framework for quantification of fiscal risks that includes all major natural hazards. Furthermore, authorities should focus on ensuring comprehensive insurance coverage for public assets and fostering development of a disaster insurance market. Enhancing insurance uptake by the private sector can diminish macroeconomic volatility and mitigate contingent risks for the public sector. Finally, Peru requires a robust and holistic strategy for territorial planning that includes DRM considerations. It is imperative for subnational governments to diligently enforce zoning regulations. Without such enforcement, physical assets of the most-at-risk communities (e.g., rural, low-income) will remain exposed to future natural hazards.

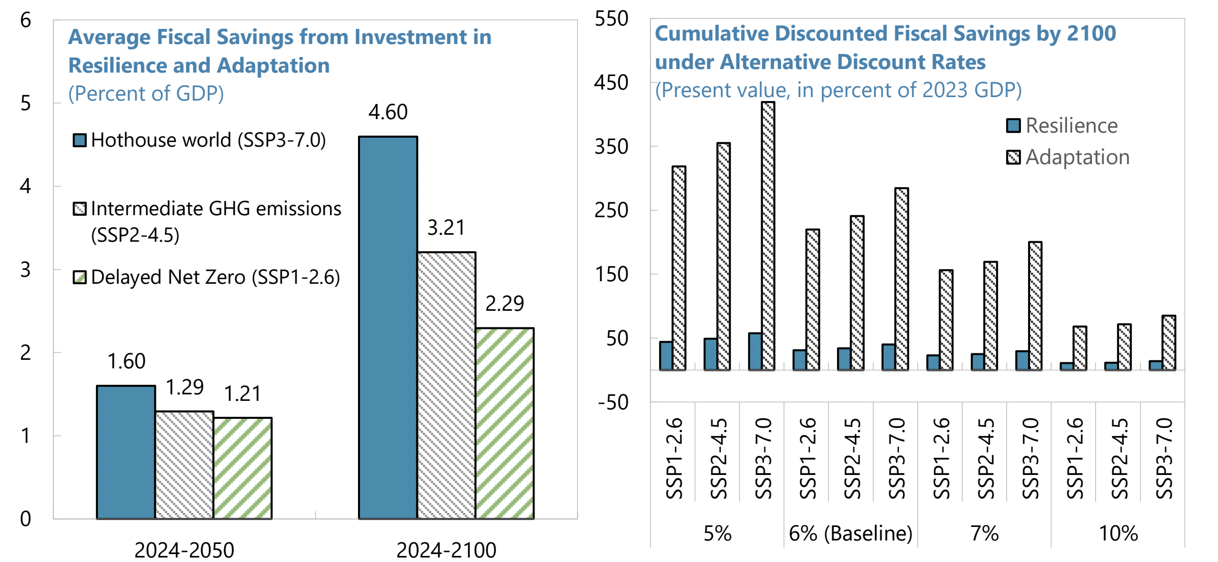
Table 1. Peru: Cumulative Discounted Fiscal Savings from Investment in Resilience and Adaptation

(Present value, in percent of 2023 GDP) 1/ 2/

		SSP1-2.6		SSP2-4.5		SSP3-7.0	
		2050	2100	2050	2100	2050	2100
Total Return (a)		**120.25**	**262.36**	**122.34**	**286.80**	**143.05**	**336.35**
Stock saving	Decrease in reconstruction cost after NDs	4.53	6.84	4.71	6.89	4.78	6.96
Flow saving	Moderation of tax base decline after NDs	16.28	31.00	16.58	33.92	19.52	39.97
Potential growth	Increase in the tax base trajectory	99.43	224.52	101.04	245.99	118.75	289.42
Total Cost (b) 3/		**10.53**	**11.65**				
Adaptation	Investments in Water, Agriculture, Forestry, and Fisheries	4.84	4.92				
Resilience	Investment to climate proof and maintain transport infrastructure	5.69	6.73				
Net annual saving (a) - (b)		**109.72**	**250.71**	**111.81**	**275.15**	**132.52**	**324.70**

Sources: Fund staff calculations using FGG model, Massetti and Tagklis (2023), Harris et al. (2020), and Chirinos (2021).
1/ Assumes government implements measures specified in the NAP and increases investment in resilient infrastructure to reduce damages by climate-related natural disasters to 20 percent, while maintaining historical investment rates. Present values are calculated using projections up to 2100.
2/ The discount rate is set to 6 percent.
3/ The cost of adaptation and resilience is constant and does not depend on the global warming scenario.

Figure 8. Fiscal Savings from Building Resilience and Adapting to Climate Change



Sources: IMF staff calculation using the FGG model, Massetti and Tagklis (2023), Harris et al. (2020), and Chirinos (2021).

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