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Weathering Tomorrow: Climate Analogues and Adaptation Gaps in Europe

Armand Fouejieu, Shakill Hassan, Ruben Atoyan and Yiran Zha

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ABSTRACT: The European continent is warming at more than twice the global average. The human and economic costs of higher temperature and more frequent and extreme natural disasters—already substantial in Europe—are expected to increase further unless suitable adaptation strategies are implemented. This paper shows that while Europe's overall vulnerability to climate risks is lower than other regions', the countries in Central and Eastern Europe face greater human and economic costs from climate disasters compared to their advanced European peers, which are likely to further increase in the future. We use an ensemble of climate models to project future climates for each country in Europe, and identify the country whose present climate best approximates this projection. We rely on this information on countries' representative future exposure to climate risks to calibrate country-level macro analyses of natural disasters, and how investment in adaptative infrastructure can help mitigate these shocks. We find that adaptation infrastructure can significantly reduce output losses from natural disasters, mitigate medium-term economic scarring, and support sustainable long-term growth. However, we show that effective implementation of adaption strategies in EMEs/LICs is likely to be constrained by limited domestic financial resources, weaker institutional quality, and may create policy trade-offs, if not accompanied by external support.

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Author's E-Mail Address:	AFouejieu@imf.org; SHassan@imf.org; RAtoyan@imf.org ; YZha@imf.org

WORKING PAPERS

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Prepared by Armand Fouejieu, Shakill Hassan, Ruben Atoyan and Yiran Zha*

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Executive Summary

Economic losses from climate-related extremes in Europe reached around half a trillion euros over the past four decades.[1] About 70,000 deaths were attributed to abnormal temperature (extreme heatwaves) in Europe in 2022. The discernible shift in weather patterns, characterized by an increased frequency and intensity of extreme events—such as floods, storms, heatwaves, and unprecedented cold winters—has created a complex web of challenges.

While Europe has established ambitious targets for reducing CO2 emissions, the attainment of these targets remains uncertain, and the challenges posed by climate risks, which depend on global emissions, are expected to intensify. Climate change is anticipated to lead to more frequent and severe extreme weather events, whose impacts (social and economic) depend partly on implementation of adaptation strategies.

Europe's overall vulnerability to climate risks is lower than other regions', but there are notable disparities between advanced and emerging countries, and between north and south. Despite facing similar exposure to climate risks, some countries in Central and Eastern Europe (CESEE) are comparatively more vulnerable, experiencing greater human and economic costs from climate disasters. This vulnerability is due to weaker adaptation capacity in emerging European nations compared to their advanced counterparts, especially where economic activity is more dependent on sectors sensitive to climate change, such as agriculture, and have invested less in climate-resilient infrastructure.

This paper uses climate analogue mapping to help inform future adaptation strategies. We use an ensemble of climate models to project the future climate for each European country and identify the countries whose present climate best approximate this projection. This approach provides tangible and relatable information about the climatic characteristics countries should anticipate in the coming decades, which helps inform the extent and nature of adaptation required. We then use this information to calibrate macro analyses of climate-related shocks, using models which depend on country-level parameters; and assess how investment in adaptative infrastructure can help mitigate these risks. By identifying climate analogues under different emission scenarios, the method also gives some sense of the degree of uncertainty about the future climate of countries in Europe.

We show how adaptation infrastructure can significantly reduce output losses from natural disasters and mitigate medium-term economic scarring, and how such investments support sustainable long-term growth. The growth benefits of infrastructure investments would be greater when complemented with reforms to improve public investment efficiency (PIE). However, due to limited domestic financial resources, external support—ideally in the form of grants or concessional loans—and concerted efforts for domestic revenue mobilization and expenditure rationalization will be critical to help meet many adaptation needs in CESEEs without endangering debt sustainability. Improving PIE, which implies strengthening governance and quality of institutions, would also further boost real GDP growth by leveraging new (private) investment opportunities.

[1] Losses of assets due to weather- and climate-related extremes, estimated at 2022 prices (see EEA, 2021).

Introduction

Climate change has exerted a substantial impact in Europe, affecting populations and economies to varying degrees. Economic losses from climate-related extremes in Europe reached around half a trillion euros over the past four decades. Over roughly the same period, temperatures in Europe have increased at more than twice the global average—by about 0.5 degrees Celsius on average per decade, which is faster than any other continent, according to the World Meteorological Organization. About 70,000 deaths were attributed to abnormal temperature (extreme heatwaves) in Europe in 2022 (Ballester et al., 2024). The discernible shift in weather patterns, characterized by an increased frequency and intensity of extreme events—such as floods, storms, heatwaves, and unprecedented cold winters—has created a complex web of challenges. Beyond the immediate social impact and threats to human lives, these climatic transformations have permeated various economic sectors. Agriculture, a vital component of some European economies (particularly in some emerging market economies) is grappling with challenges arising from shifting growing seasons and unpredictable weather, resulting in diminished crop yields and possibly compromising food security. Coastal regions, facing heightened risks from rising sea levels and altered precipitation patterns, confront threats to critical infrastructure and the sustainability of local livelihoods. The economic toll extends beyond immediate damages, encompassing long-term adaptation and recovery costs.

While Europe has established ambitious targets for reducing greenhouse gas (GHC) emissions, the challenges posed by climate change are likely to persist. The attainment of mitigation targets remains uncertain, both within the region and the rest of the world, and the costs due to climate change depend on the lagged effect of global emissions. Even in more optimistic GHG emission scenarios, ongoing changes in global climate conditions will continue to pose substantial risks, necessitating immediate adaptation actions.

Although Europe's overall vulnerability to climate risks is lower than other regions', there are notable disparities between advanced and emerging or developing countries. Despite facing similar exposure to climate risks, the countries in Central and Eastern Europe (CESEE) are comparatively more vulnerable, experiencing greater human and economic costs from climate disasters. This vulnerability is attributed to weaker adaptation capacities in emerging and developing European nations compared to their advanced counterparts. These economies are more dependent on sectors sensitive to climate change, such as agriculture, and have invested less in climate-resilient infrastructure. As global initiatives to curb global warming remain constrained and comprehensive transition strategies are yet to be widely developed, the immediate priority is to enhance resilience to natural disasters, particularly for the most vulnerable countries.

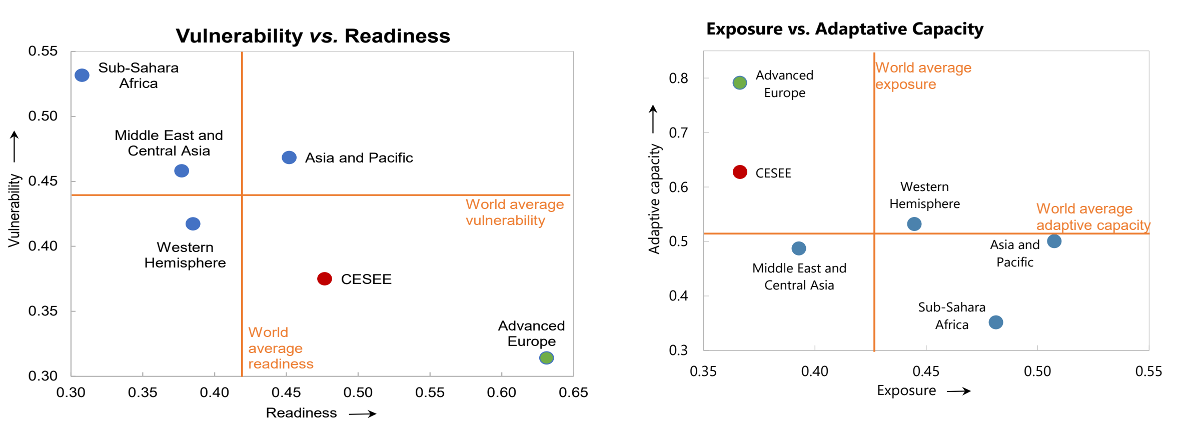
In this paper we propose the use of climate analogues to calibrate macro analyses of climate-related shocks, and of how investment in adaptative infrastructure can help mitigate these shocks. Robust resilience strategies should be customized to address country-specific needs with the goal of bridging adaptation gaps in relation to relevant climate risks. This requires a thorough understanding of a country's exposure to various sources of climate risks and natural disasters, how these risks are expected to evolve, and the most effective policy responses to mitigate them. Climate analogues can help inform this process. Understanding which areas currently have climatic conditions reasonably comparable to another area's future climate informs the extent and nature of adaptation required. The paper uses an ensemble of climate models to project the future climate for each European country and identifies the country or region whose present climate best approximates this projection. For a given country, the analogue provides tangible information about the climate characteristics anticipated in the coming decades. This information is then used to calibrate the impact of natural disasters in the IMF's Debt-Investment-Growth and Natural Disaster (DIGNAD) Model and to simulate the role of investments in adaptive infrastructure as well as their sustainable financing strategies.

We show that adaptation infrastructure can significantly reduce output losses from natural disasters and mitigate medium-term economic scarring**.** We also show that such investments can support sustainable long-term growth, and ultimately help reduce inequality (as climate shocks tend to have a disproportionate impact on the most vulnerable populations). The growth benefits of infrastructure investments would be greater when complemented with reforms to improve public investment efficiency (PIE). However, due to limited domestic financial resources, external support—ideally in the form of grants or concessional loans— and concerted efforts for domestic revenue mobilization and expenditure rationalization will be critical to help meet many EMs' adaptation needs without endangering debt sustainability. Increasing PIE, which implies strengthening governance and quality of institutions, would also further boost real GDP growth by leveraging new (private) investment opportunities.

Vulnerability to Climate Change and Readiness for Adaptation Actions[2]

Europe's vulnerability to climate risks is below the global average, though significant divides are evident between advanced economies (AEs) and emerging market economies (EMEs) (Figure 1)**.** AEs enjoy the lowest aggregate vulnerability to climate change compared to other regions, while CESEE countries are more vulnerable to natural disasters. Exposure to climate risks (mostly reflecting countries' geographical locations) is similar for AEs and CESEE countries. However, large adaptative capacity gaps in the CESEE make these countries significantly more vulnerable to climate shocks, while readiness for effective implementation of adaptation actions is equally weaker.

Figure 1. Vulnerability to Climate Risks and Readiness for Effective Adaptation Actions



Sources: ND-GAIN, IMF, and IMF Staff Calculation

[2] Based on ND-GAIN data (see Box 1).

Box 1. Notre Dame Global Adaptation Index (ND-GAIN)[1]

The ND-GAIN is composed of two aggregate indices: a *vulnerability* index, measuring the propensity or predisposition of human societies to be negatively impacted by climate hazards; and a *readiness* index, capturing preparedness to make effective use of investments for adaptation actions thanks to a safe and efficient business environment.

The vulnerability index is broken down into 3 sub-indices:

Exposure[2]: The extent to which human society and its supporting sectors are stressed by future changing climate conditions. Exposure in ND-GAIN captures physical factors external to the system that contribute to vulnerability.

Sensitivity: The degree to which people and the sectors they depend upon are affected by climate related perturbations. The factors increasing sensitivity include the degree of dependency on sectors that are climate-sensitive and proportion of populations sensitive to climate hazard due to factors such as topography and demography.

Adaptative capacity: The ability of society and its supporting sectors to adjust to reduce potential damage and to respond to the negative consequences of climate events. In ND-GAIN, adaptive capacity indicators seek to capture a collection of tools (e.g., disaster preparedness strategies) readily deployable to deal with sector-specific climate change impacts.

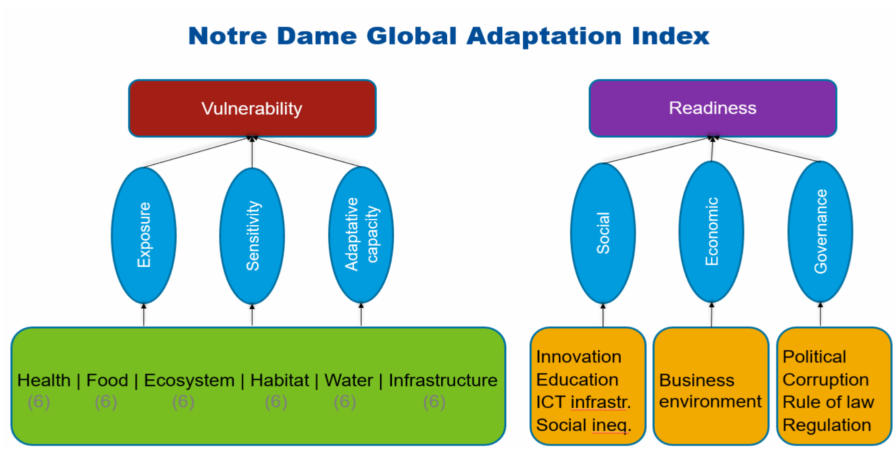
Each of the three sub-indices are constructed based on data covering six sectors: health, food, ecosystem, habitat, water, and infrastructure.

The readiness index also encompasses three dimensions:

Economic: Capacity of the economy to attract adaptation investment.

Governance: Capacity to promote and maintain a sound governance/institutional framework, which can contribute to attract external financing and support deployment of adaptation actions and adaptation-related policies.

Social: Social characteristics, including wealth, education, and access to technology, that can help support resilience to extreme climate events and foster implementation of adaptation strategies, as well as innovation capacity that can support identification of adaptation solutions.



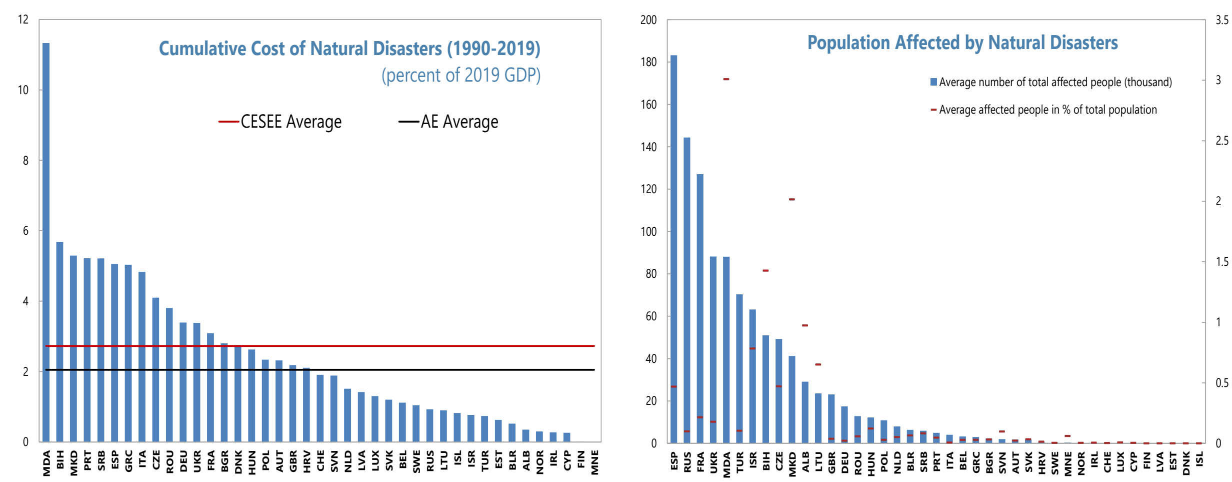
1/ See Notre Dame Global Adaptation Initiative and related technical notes for additional details.

2/ Based on mid-term projections (2040–2069) of a set of indicators covering the six sectors described above.

Exposure and Sensitivity

The cumulative cost of climate-related disasters (in percent of 2019 GDP) is about 1 percentage point higher in the CESEE compared to AEs (Figure 2). Countries with the largest costs include Moldova (close to 12 percent), Bosnia and Herzegovina (about 7 percent) and North Macedonia (about 5.5 percent). Some AEs, mostly from the southern part of Europe, have also incurred large damages from climate shocks (e.g., about 5 percent of 2019 GDP cumulatively in Spain, Portugal, and Greece). The human and social impact of adverse climate events is also comparatively larger in the CESEE, and the top 5 countries with the most affected population are from this region. These include Moldova (average 3 percent of the population affected by climate disasters in the past 30 years), North Macedonia (2 percent), and Bosnia and Herzegovina (1.5 percent). ND-GAIN projects CESEE countries' exposure to climate change to remain broadly similar to AEs (Figure 4, top-left). However, risks for the agriculture sector (captured by the projected change of cereal yields) and flood hazards are expected to be more prominent in the CESEE. AEs are likely to be more exposed to impacts of sea level rise and change in annual runoff.

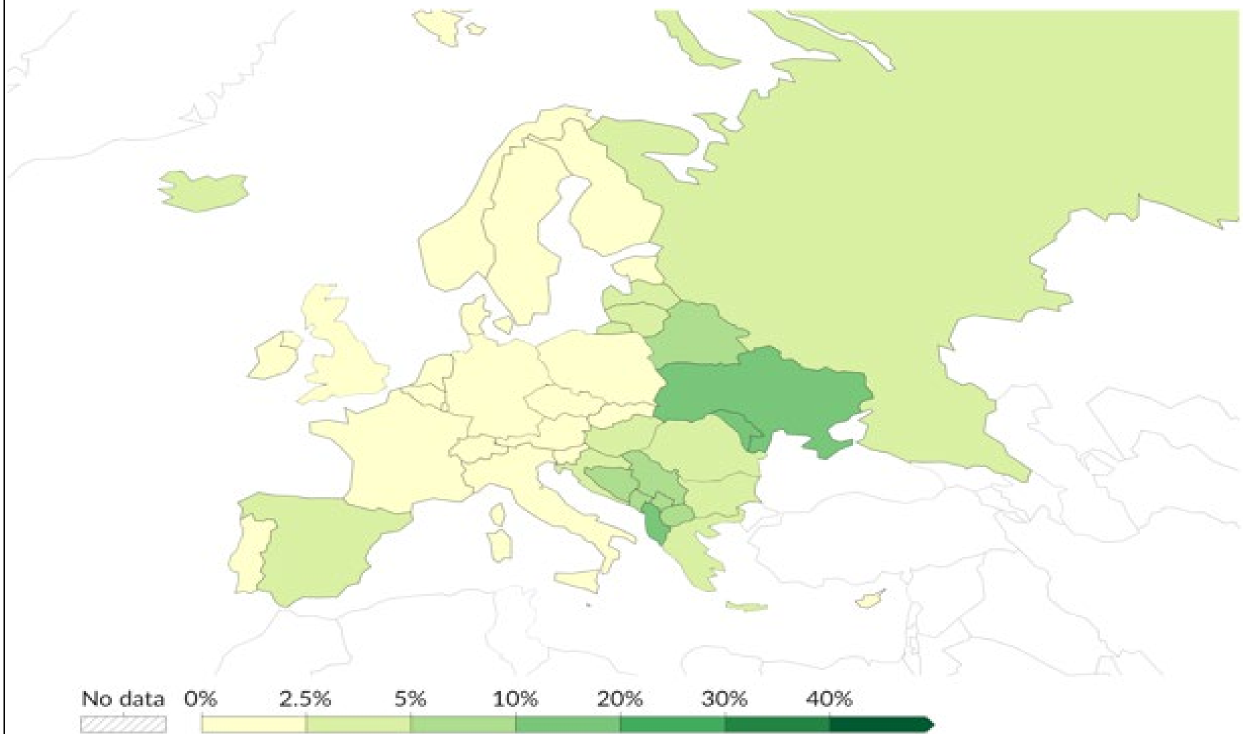
Figure 2. Costs of Past Natural Disasters



Sources: EM-DAT, IMF, and IMF staff calculations

Sensitivity to climate shocks is also broadly similar in the CESEE and AEs, although important differences on sources of sensitivity can be highlighted (Figure 4, top-right). The larger share of rural population in the CESEE, likely with higher dependence on agricultural activities (including subsistence farming, Figure 3) and weaker infrastructure quality, implies relatively higher sensitivity to changes in climate conditions and climate disasters compared to AEs. AEs on the contrary are characterized by significant concentration of larger share of the population in smaller urban areas, making them more sensitive to adverse climate conditions (e.g., extreme temperature (See Lankoa, 2008).

Figure 3. Share of GDP from Agriculture, 2021

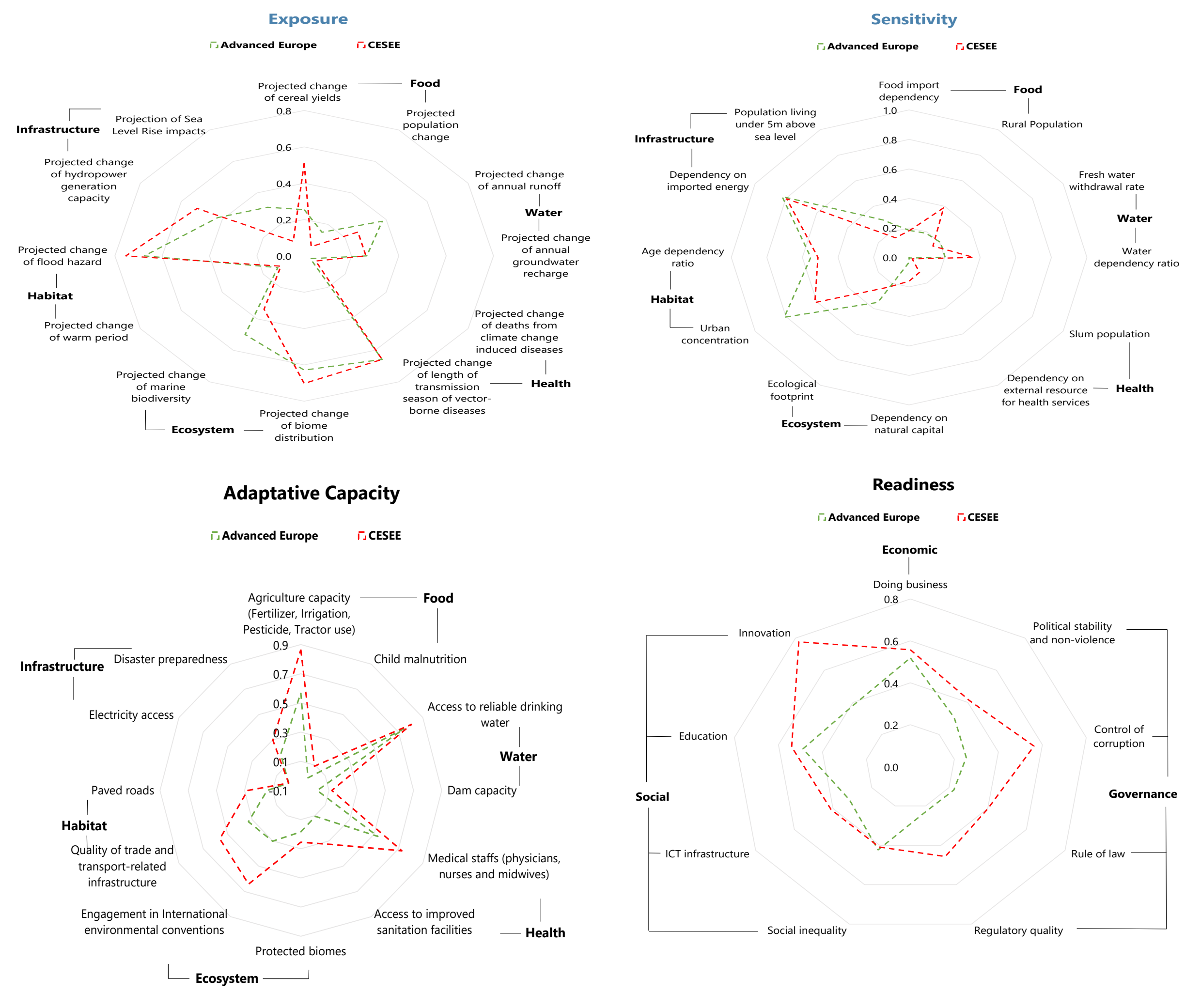


Source: World Bank, OECD, Our World in Data

Adaptative Capacity and Readiness

Challenges in adapting to a changing climate magnify the impact of climate shocks in the CESEE region compared to AEs (Figure 4, bottom-left). Adaptation in the agriculture sector in the CESEE—captured by irrigation capacity and availability of fertilizers and automotive infrastructure—is below AEs average, weakening the sector's capacity to withstand natural disasters. The quality of infrastructure, including transport and trade-related infrastructure, is also weaker in the CESEE on average. ND-GAIN data further suggest that the health sector, which plays a crucial role in mitigating the human and social costs of disasters, is less well prepared in the CESEE compared to their AE peers. The comparatively weaker disaster preparedness strategy hinders CESEE's ability to effectively cope with climate shocks. These adaptation deficiencies expose emerging countries in Europe to more substantial and far-reaching consequences when faced with changing climate conditions, resulting in relatively larger impact on the population and the economy when compared to AE.

Figure 4. Sources of Vulnerability to Climate Shocks and Readiness for Effective Adaptation Actions



Sources: University of Notre Dame's Global Adaption Index and IMF staff calculations

While their adaptation gaps are large, emerging European countries appear to be less well prepared for effective implementation of adaptation actions (Figure 4, bottom-right). Governance challenges, for example, characterized by relatively limited institutional capacity and lack of coordination among key stakeholders, can hinder the translation of adaptation strategies into actionable measures. Although governance quality has improved in recent years in many cases, some key governance indicators (political stability, control of corruption, respect of the rule of law, and regulatory quality) in the CESEE remain well below AE, stressing significant scope for further improvement. Emerging Europe also lags behind advanced country peers regarding its social readiness—measured through innovation, education, ICT infrastructure, and social inequality—for strong adaptation measures. Finally, a less-favorable business environment may curtail private sector involvement in the development of climate-resilient infrastructure, limiting the potential to catalyze private investment for adaptation action.

Climate Analogues Mapping

Adapting to climate change is likely to partly entail adopting behavior, technologies, and policies used in places with a similar climate today to a country's future climate (Massetti and Mendelsohn, 2018, Bellon and Massetti, 2022). Consumption and production choices, from what people eat to a country's energy mix, largely reflect long-term, incremental, and reactive adaptation to the climate. Knowing which areas currently experience climatic conditions which can be regarded as reasonably comparable to another area's future climate, helps inform the extent and nature of adaptation likely to be required. Climate analogue mapping, which consists of matching the projected future climate at a location to the current climate of another (familiar) location, under a suitable quantitative measure (Hallegate, Hourcade, Ambrosi, 2007, Williams, Jackson, Kutzbach, 2007), provides a natural analytical approach to identify such areas. These analogues are identified so as to minimize *seasonal* differences in temperature and precipitation, between one country's future climate, and another country's present climate (Box 2).[3] The analogues give us a concrete and relatable sense of some of the main features of the adaptation required by climate change.

The 2023 Intergovernmental Panel on Climate Change's Assessment Report (IPCC AR6) uses five illustrative scenarios (Table 1) to describe possible paths for GHG emissions, and the associated climate change. The scenarios are based on assumed Shared Socio-Economic Pathways (SSPs), and Representative (Atmospheric) Concentration Pathways (RCPs). The SSPs are narratives outlining broad characteristics of the global future, expected to lead to different emissions trajectories. The RCPs reflect different emission flows and GHG concentrations, each leading to specific estimated radiative forcing levels—and average global warming—by 2100.[3]

We project Europe's future climates through an ensemble of approximately thirty climate models of temperature and precipitation, under different possible GHG emission concentration paths, and identify their present analogues.[4] Projection (modeled) data is from the Coupled Model Inter-comparison Projects (CMIP6) overseen by the World Climate Research Program, for different emissions scenarios, each of these summarized through an SSP-RCP pathway.[5]

In this paper, our baseline is the "rocky road" global warming scenario (SSP3–7.0, which is also the IPCC's baseline). This scenario is characterized by GHG emissions associated with an end-of-21st century radiative forcing level of 7 watts per square meter, and—from the relationship between radiative forcing and warming (Foster et al, 2007)—a *very likely* range of increase in average global surface temperature of 2.8 to 4.6 degrees Celsius.[6] We then use the model ensemble median to project a set of climate variables for each of the

[3] An important caveat is that for some countries in Europe, the main known climate adaptation risks stem from other variables, such as rising sea levels.

[3] Radiative forcing is a measure of the difference between the amount of energy that enters the Earth's atmosphere (from the sun), and the amount of energy that leaves it, measured in watts per square meter of surface. This balance controls the Earth's surface temperature (see Foster et al, 2007). The link to the emission scenarios is that GHGs in the atmosphere impede the outward radiation of energy from Earth into space, raising Earth's energy imbalance (positive forcing) and leading to warming.

[4] The exact number of models used depends on the SSP-RCP scenario.

[5] The projections are from a multi-model ensemble, for different CO2e concentration paths, all accessed through the World Bank Group's Climate Knowledge Portal.

[6] The increase in average global temperature is measured relative to the average of the period 1850–1900, and the increase in radiative forcing is relative to 1750, which is the IPCC's baseline year.

countries of interest in this paper.[7] The use of an ensemble of models (instead of a single one) minimizes model bias. Results are shown under two additional scenarios: SSP2–4.5, with lower emissions or more mitigation than the baseline, and SSP5–8.5, with higher emissions or less mitigation than the baseline.

Table 1: Illustrative Scenarios of Global Warming

			Near term, 2021-2040		Mid-term, 2041-2060		Long term, 2081-2100	
SSP label	SSP-RCP scenarios	Assumed GHG emissions	Best estimate (°c)	Very likely range (°c)	Best estimate (°c)	Very likely range (°c)	Best estimate	Very likely range (°c)
"Taking the green road"	SSP1-1.9	Very low	1.5	1.2 to 1.7	1.6	1.2 to 2.0	1.4	1.0 to 1.8
"Taking the green road"	SSP1-2.6	Low	1.5	1.2 to 1.8	1.7	1.3 to 2.2	1.8	1.3 to 2.4
"Middle of the road"	SSP2-4.5	Intermediate	1.5	1.2 to 1.8	2.0	1.6 to 2.5	2.7	2.1 to 3.5
"A rocky road"	SSP3-7.0	High	1.5	1.2 to 1.8	2.1	1.7 to 2.6	3.6	2.8 to 4.6
"Fossil fueled development"	SSP5-8.5	Very high	1.5	1.3 to 1.9	2.4	1.9 to 3.0	4.4	3.3 to 5.7

Source: IPCC, Climate Change 2021: The Physical Science Basis.

Notes:

Changes in global surface temperature, assessed based on multiple lines of evidence, for selected 20-year time periods and the five illustrative emissions scenarios considered. Temperature differences relative to the average global surface temperature of the period 1850–1900 are reported in °C.

The SSPs narratives can be briefly described as follows:

SSP1: Sustainability - Taking the Green Road (Low challenges to mitigation and adaptation)

SSP2: Middle of the Road (Medium challenges to mitigation and adaptation)

SSP3: A Rocky Road - Regional Rivalry (High challenges to mitigation and adaptation)

SSP5: Fossil fueled Development (High challenges to mitigation, low challenges to adaptation)

[7] The same models inform the IPCC Assessment Reports.

Box 2. Analytical Method for Identification of Climate Analogues

Let $i = 1, \dots m$ denote the set of candidate analogues, $j = 1, \dots n$ the set of 'target' countries in Europe (or the world), and Ω the set of climate variables, for which we use seasonal temperature and seasonal precipitation, so #Ω=8 (average temperature in each of four seasons, and average precipitation in each of four seasons). The procedure can be summarized in three steps. First, for each country of interest j, we project each climate variable through 2100 (under the assumed GHG emission concentration pathway). Second, we find the current climate analogue: for each country of interest j, we quantify dissimilarities between early and late 21st century climates by calculating the standardized Euclidean distance (following the approach in the seminal contribution of Williams, Jackson, and Kutzbach, 2007) given by:[1]

$$SED_{i,j} = \left(\sum_{\omega \in \Omega} \frac{\left(b_{\omega j} - a_{\omega i}\right)^2}{\sigma_{\omega i}^2} \right)^{1/2},$$

where $a_{\omega i}$ and $b_{\omega j}$ are the 2002–2021 and 2080–2099 means for climate variable ω for countries *i* and *j,* and $\sigma_{\omega i}$ is the standard deviation of the interannual variability for 2002–2021,

$$b_{\omega j} = \frac{1}{\#T} \sum_{\tau \in T} \omega_j(\tau), \; T = \{(2080), \dots, (2099)\}$$

and

$$a_{\omega i} = \frac{1}{\#S} \sum_{s \in S} \omega_i(s), \; S = \{(2002), \dots, (2021)\}.$$

This yields an m-vector of climate dissimilarities for country *j*. The procedure is repeated for each other target country in *j=1,…n,* which gives, for a given concentration pathway scenario, the matrix:

$$\mathbf{D} = \left[SED_{ij} \right]_{m \times n},$$

where each column is a vector of the dissimilarities between the projected end-of-21st century climate of one of the $j = 1, \dots n$ countries, and the current (early 21st century) climate in each of *m* candidate analogues, under one scenario for the evolution of GHG concentrations. m=52 when limiting the set candidate analogues to Europe; and m=243 when expanding the set of candidate analogues to every state in the world. The analogue is identified, for each country, by the pairing with minimum standardized Euclidean distance (i.e., the minimum value in each column of matrix *D*). The procedure is repeated for alternative concentration pathways.

Data consist of historical annual average temperature and precipitation for every country in the world, historical seasonal average temperature and seasonal precipitation for every country in Europe, and projected values of the same climate variables for every country in Europe, into 2100.

[1] Note that the procedure is quite different from comparing an index of country A's future climate, with an index of country B's present climate: such a comparison of averages would erroneously pick cases with vastly different climatic patterns but similar averages as analogues.

The "rocky road" scenario is a one with lower global emissions than the scenario which most closely matches implemented policies of the recent past (that would be SSP5–8.0), but with higher emissions than more optimistic scenarios. According to the United Nation's latest (November 20, 2023) Emissions Gap Report, "If mitigation efforts implied by current policies are continued, global warming will be limited to 3°C above pre-industrial levels throughout this century." This is within the very likely range for the increase in the global average temperature under the "rocky road" scenario. This baseline scenario is, however, not necessarily the most likely.

The results of the analogues mapping are shown in Figure 5 and Annex I and II. Here, we focus on the case with candidate analogues from Europe, which keeps differences in level of economic development relatively contained.[8] The 'climate relocation maps' give a synthetic view of climate change impacts, and the alluvial charts map each country in Europe (left column) to the country whose current climate is the closest to the former's projected future climate (right column). The results show a general shift to the south, reflecting projected change in temperatures resulting from global warming.

These analogues give a sense of where countries in Europe are headed in terms of broad exposure to climate risks from changing temperatures and precipitation, and the extent of adaptation needed to contain their impact. As noted in the IPCC AR6, adaptation options that are feasible and effective today will become constrained and less effective with increasing global warming, stressing the critically of a good understanding of what tomorrow's climate will look like. While adaption gaps are larger among the less developed economies and will continue to widen at the current pace of implementation, we show in the next section that closing these gaps will require significant financing and may create difficult trade-offs with other macro-policy objectives.

[8] Annex II shows the results based on a "global search", whereby the analogue for a country in Europe can be located in any part of the globe. In this case however, the mapping excludes seasonal variations in temperature and precipitations due to limited data availability.

Figure 5. Indicative Climate Analogues for Europe Under Different SSP-RCP Scenarios

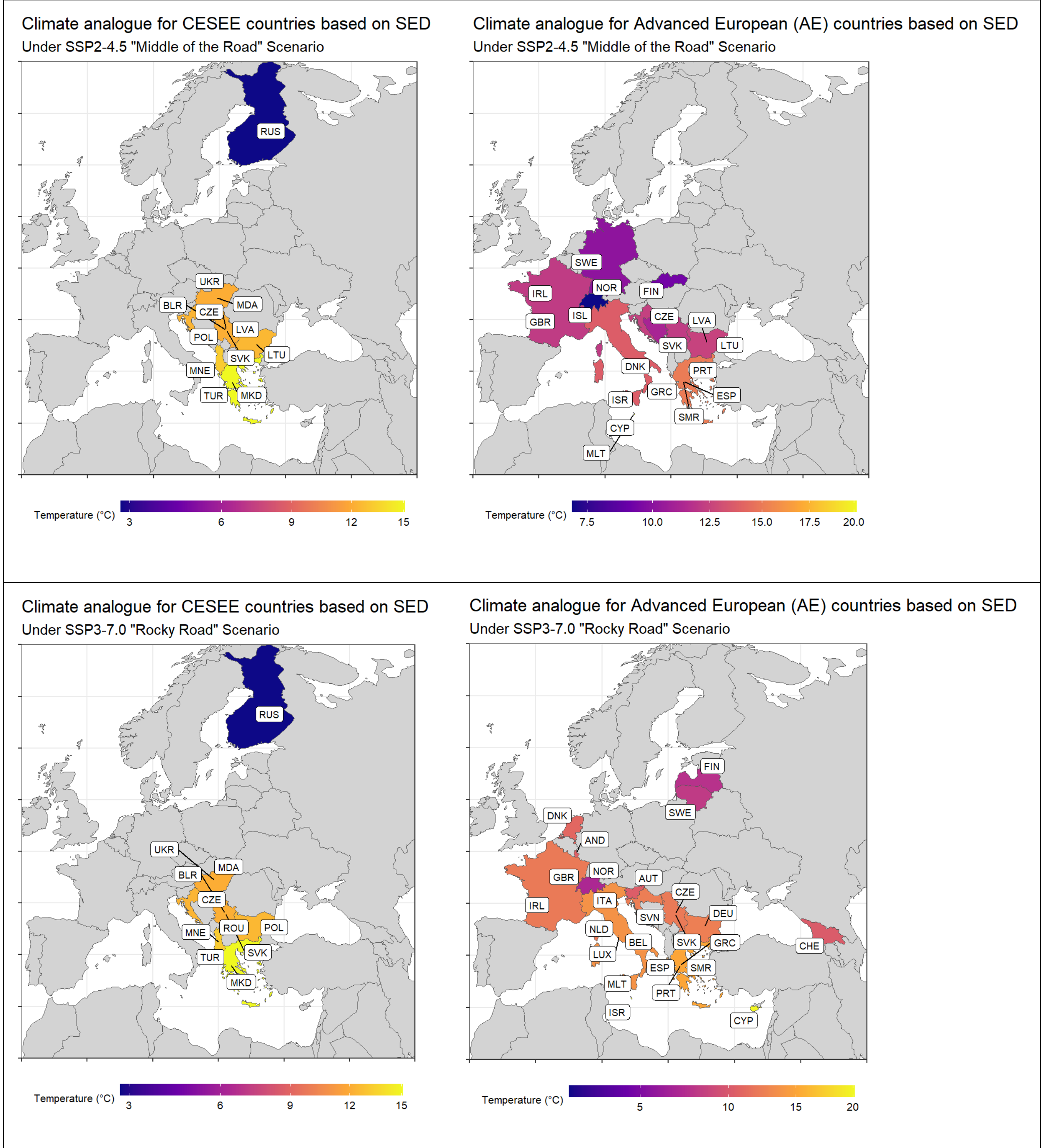
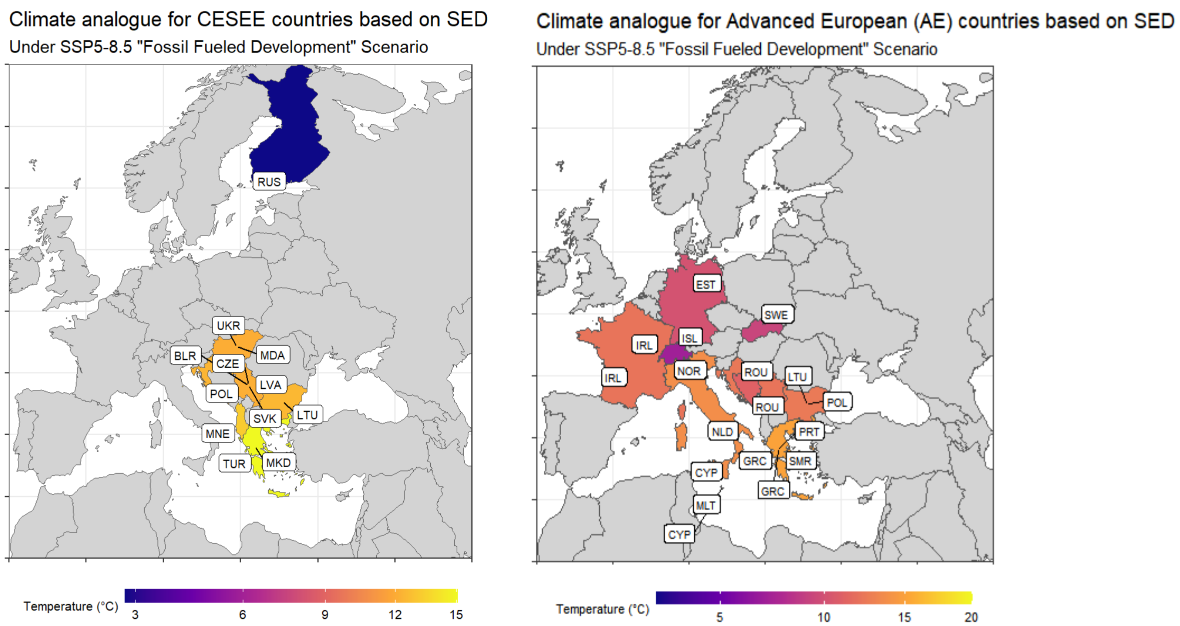


Figure 5. Indicative Climate Analogues for Europe Under Different SSP-RCP Scenarios



Sources: World Bank Climate Change Knowledge Portal, IMF, and IMF staff calculations

Notes: Maps show CESEE (left panels) and non-CESEE AE (right panels) countries at location of their analogues—i.e., countries with present climates close to the former countries' future climate; under different GHG concentration scenarios.

Closing the Adaptation Gaps and Building Resilience to Future Shocks: A Case Study

While investments in adaptation infrastructure can help build resilience to climate shocks and support medium-to-long-term growth, some countries could face policy challenges, especially with respect to financing, due to limited fiscal space for the most-needed investments to address climate change risks. From an international donors' perspective, there exists the intertemporal trade-off between financing adaptation investment *ex ante* or financing reconstruction *ex post*. To model these complex interactions, we perform simulations based on the DIGNAD model (Box 3), using Moldova as the case study country. While its exposure to adverse climate events is broadly similar to the rest of Europe, Moldova's adaptation capacity is significantly weaker, even when controlling for levels of income. This is due to several factors, including limited investments in climate-resilient infrastructure as well as weaknesses in climate risk and disaster management and PFM frameworks. While Moldova is the country with the largest economic costs due to climate disasters (See Annex III)[9], lessons from simulations presented below can be generalized for all countries in the CESEE region.

[9] Sectors at particular risk include: (i) agriculture and forestry, key pillars of the economy, especially for employment, as well as water and infrastructure; and (ii) the energy sector, where the distribution and transmission infrastructure may be impacted by extreme weather and potential to reduce energy imports through development of renewable sources could be compromised.

Box 3: A Framework for Evaluating the Macroeconomic Impact of Climate-Resilient Infrastructure: The DIGNAD Model

The DIGNAD model is a dynamic general equilibrium model describing a small open economy. It can help quantify and assess the impact of climate disasters and different policy scenarios for investment in adaptation infrastructure. The model encompasses three main and interdependent blocks (Buffie et al. 2011; Marto et al. 2018; Aligishiev et al., 2023):

The private demand block describes household consumption and saving decisions, with two types of households (savers who have access to financial instruments and liquidity-constrained households who do not). Both types of households face an intratemporal decision that determines their supply of labor, whereas savers also face an intertemporal decision that determines savings. Households earn labor income, receive remittances from abroad and transfers from the government, and consume domestically-produced and imported goods.

The private supply block describes firm decisions on labor and capital demand. Tradable and non-tradable goods are produced by two representative firms following a Cobb-Douglas production function with capital and labor inputs. Firm output also increases with total factor productivity (TFP), which, in turn, depends on the stock of public infrastructure (climate-resilient infrastructure and standard infrastructure).

The policy block depicts a set of financing options to cover government investment plans in standard or climate-resilient infrastructure. Fiscal instruments include consumption taxes, labor taxes, and net transfers to households. The government can also issue commercial debt (domestic and/or external), external concessional debt, or receive grants or other forms of costless external financing. Government policy choices can be assessed using two perspectives in the model. First, a strict fiscal rule framework, whereby taxes adjust automatically to close the financing gap created by new investment and prevent excessive accumulation of debt. Second, a framework where there is no automatic adjustment of taxes, and debt financing is allowed.

Natural disasters are assumed to affect GDP through three main channels: (1) destroying the stock of public infrastructure, (2) destroying the stock of private capital, and (3) reducing TFP. Each of these channels has different macro-fiscal implications. The stock of public infrastructure can only be rebuilt by the government, generating fiscal costs that can be financed as described above. The stock of private capital can only be rebuilt by private sector investment, which is subject to adjustment costs. TFP is exogenous and can gradually recover to its pre-disaster level at an exogenously assumed pace. Natural disasters can affect the economy via two additional mechanisms. First, by increasing government borrowing costs through an increased risk premium on external commercial debt, which may be triggered by perceived higher risk of default after a natural disaster. Second, the efficiency of government infrastructure investment may decline because of limited government capacity to manage large-scale reconstruction, especially after a natural disaster.

Another key characteristic of the DIGNAD model concerns the specific features of climate-resilient infrastructure. The model assumes that the total stock of public infrastructure consists of two types of infrastructure: standard and climate-resilient. Climate-resilient (or adaptation) infrastructure reduces the output cost of natural disasters, while standard infrastructure does not. A larger share of adaptation infrastructure implies potential for larger mitigation of the impact of natural disasters (a more resilient economy). However, the cost of climate-resilient infrastructure is assumed be higher compared to the cost of standard infrastructure (e.g., it requires more qualified and scarce technical skills, more expensive materials, or advanced technologies).

Box 3: A Framework for Evaluating the Macroeconomic Impact of Climate-Resilient Infrastructure: The DIGNAD Model (concluded)

Adaptation infrastructure is also assumed to have a lower depreciation rate (e.g., climate-proofed roads are more likely to withstand adverse climate events), and a higher rate of return (the low existing stock of adaptation infrastructure in many low-income countries suggests that the rate of return of initial investments may be high). While the higher cost of climate-resilient infrastructure may create short-term trade-offs (by diverting extra budgetary resources towards adaptation), the medium-to-long term benefits are large, as discussed in the sections below (larger contribution to growth during the investment phase, compared to standard infrastructure; and reduced output losses when faced with climate shocks, followed by faster economic recovery).

Investment, Growth, and Fiscal Adjustment in DIGNAD1/: The model captures the relationship between growth and investment via a neoclassical production function with labor, public and private capital, as inputs. The Cobb-Douglas production function type is described as follow:

$$Y_t = A_t (K_t^g)^{\phi} (K_t)^{\alpha} L_t^{1-\alpha}$$

Where Y_t is the output; A_t total factor productivity; K_t^g and K_t public capital and private capital, respectively; and L_t labor. ϕ is the parameter capturing the rate of return of public capital.

The fiscal reaction function describes the debt trajectory as a function of different financing options available to the government, fiscal revenues, as well as expenditure (including investment and transfers). The budget constraint takes the following form:

$$e_t \Delta X_t + e_t \Delta Z_t + \Delta D_t = e_t r_{X,t-1} X_{t-1} + e_t r_{Z,t-1} Z_{t-1} + r_{D,t-1} D_{t-1} + I_i^g + G_t - \Lambda_t - R_t - \sum_{j=1}^{n} \gamma_{jt} x_{jt}$$

Where e_t is the real exchange rate. ΔX_t, ΔZ_t, ΔD_t are external commercial, external concessional, and domestic debt, respectively; r_X, r_Z, r_D their respective interest rate. Government spending covers public investment (I_i^g) and public consumption/transfers (G_t). The government receives grants (Λ_t), other revenues (R_t) and tax revenues from income and consumption ($\sum_{j=1}^{n} \gamma_{jt} x_{jt}$, where γ_{jt} is the tax rate, and x_{jt} consumption or income from productive sources). Grants and external concessional loans are determined exogenously to the model. In absence of enough financing to cover the assumed expenditure, taxes and transfers are adjusted to close any financing gap.

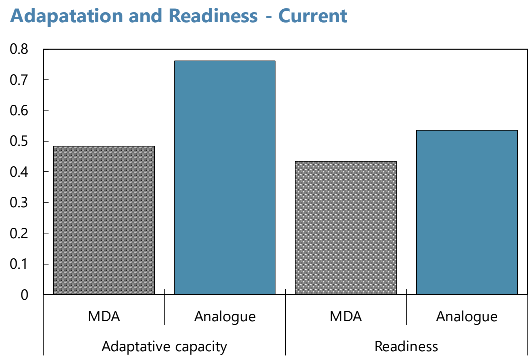
1/ See also Melina and Santoro (2021).

Calibrating the Impact of Future Natural Disasters Based on Climate Analogues

Existing analyses with the DIGNAD have relied on historical data to calibrate the impact of natural disasters embedded in the model's simulations. However, as outlined in the previous section, a shift in climate conditions can significantly alter the nature of climate risks and therefore their economic impact.

For example, higher intensity and frequency of shocks can be expected in many cases, and new sources of vulnerability may emerge. We therefore leverage the analysis of analogues to form a view on future climate risks that Moldova may face and to calibrate their economic costs.

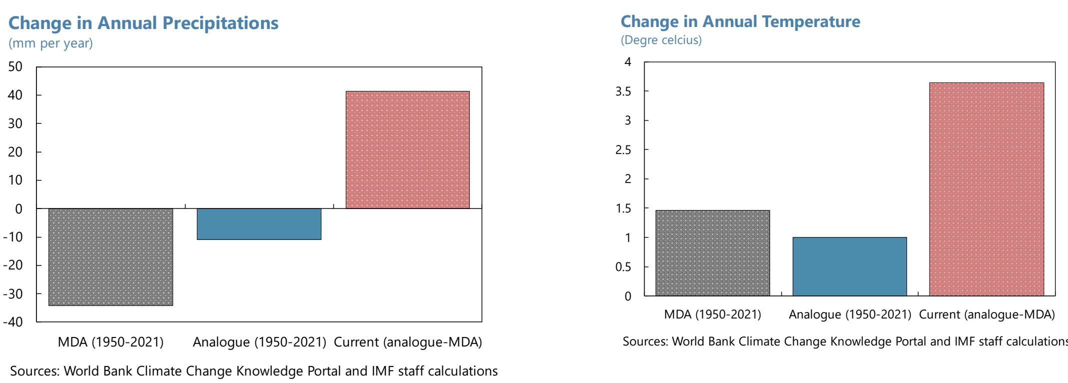
Under the “rocky road” GHG global emission scenario, Moldova’s climate analogue exhibits significantly different climate conditions over the next half a century, pointing to expected amplified climate risks (Figure 6).[10] The analogue suggests a sharp increase in annual precipitation compared to the historical declining trend. Seasonal precipitations are also expected to be more volatile. Annual temperature is likely to increase by about 3.5 degree Celsius on average (from an average increase of 1.5 degree Celsius in the past 50 years).



Sources: ND-GAIN and IMF staff calculations

The implied economic cost of future climate shocks could more than double compared to past disasters. Moldova’s analogue further shows that the expected shift in climate conditions will be associated with more frequent adverse climate events in the next three decades. Especially, flood events could be five times more frequent, while storms may occur much more often (thirteen times compared to historical), driven by higher and more volatile precipitations. Temperature increase is expected to more than double the frequency of droughts, and triple the occurrence of episodes of extreme temperatures. In addition, Moldova could be subject to wildfires, which have not been recorded in recent past. It is estimated that under Moldova’s current weaker adaptation capacity, future climate disasters would have an economic impact amounting to about 10 percent GDP on average per occurrence (compared to the historical of about 6 percent of GDP (an earlier publication uses historical/backward-looking calibration of climate disasters impact for Moldova).[11]

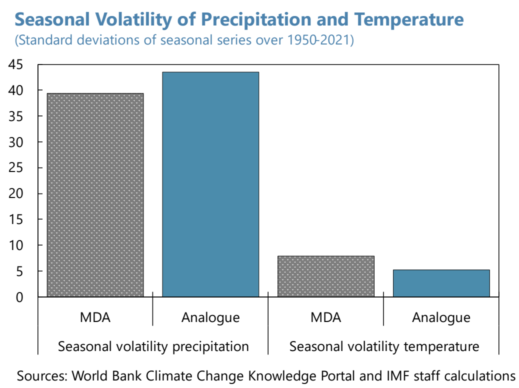
Figure 6 Present vs. Future Climate

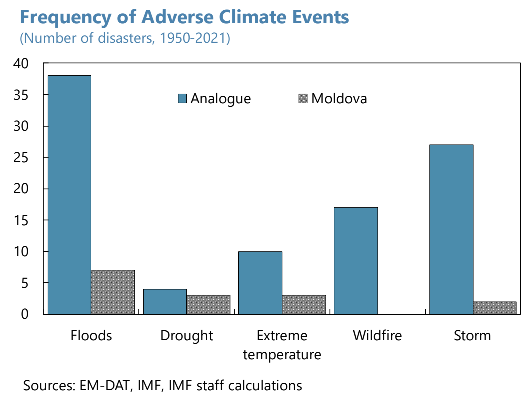


[10] Spain is Moldova’s analogue under this scenario.

[11] Conservative estimate based on higher frequency of shocks (excluding the new ones) and assuming similar costs as in past events.

Figure 6 Present vs. Future Climate (conluded)





Note: "Current" referes to latest obeservations (2021 in most cases)

Baseline Calibration of Model's Parameters

The simulations cover a 20-year horizon. Key calibration parameters are presented in Table 2. It is assumed that the government increases investment in infrastructure (standard or climate-resilient) during the first 5 years of the simulation period (see Box 4 on estimations of adaptation investment). A natural disaster hits in Year 6, and the reconstruction process starts immediately afterwards. The reconstruction period—the time needed for the government to rebuild the damaged public infrastructure—lasts 5 years. The natural disaster affects the economy through the three main channels discussed above (impacting both tradable and non-tradable sectors), as well as by reducing the efficiency of government infrastructure investment. We assume no impact on risk premium on government commercial external debt since Moldova has not incurred any new commercial debt on international markets in at least the past 5 years.

Table 2. Moldova: Main Parameters Calibration

Parameter Description	Values	Parameter Description	Values
Public infrastructure investment to GDP ratio	4.0%	Trend per capita growth rate in absence of natural disasters	6.0%
Public adaptation infrastructure investment to GDP ratio	0.0%	Value added in NT-sector	60.0%
Consumption tax rate (VAT)	20.0%	Efficiency of public infrastructure investment	65.0%
Labor income tax rate	12.0%	Ability of adaptation capital to withstand natural disaster	30.0
Public domestic debt to GDP ratio	9.6%	Cost ratio adaptation vs standard investment	25.0%
Public concessional debt to GDP ratio	26.0%	Initial return standard on infrastructure investment	25.0%
Public external commercial debt to GDP ratio	0.0%	Initial return on adaptation infrastructure investment	35.0%
Private external debt to GDP ratio	50.6%	Depreciation rate of public capital (standard infrastructure)	7.5%
Real interest rate on public domestic debt	4.0%	Depreciation rate of public capital (adaptation)	3.0%
Real interest rate on public external commercial debt	6.0%	Division of fiscal adjustment parameter - Transfers	20.0%
Grants to GDP ratio	0.5%	Division of fiscal adjustment parameter - Consumption tax	40.0%
Natural resources revenues to GDP ratio	0.0%	Division of fiscal adjustment parameter -Labor income tax	40.0%
Remittances to GDP ratio	14.1%	Public debt adj. between commercial external and domestic	50.0%
Imports to GDP ratio	58.9%		

Box 4: Quantifying Adaptation Investment Needs for Moldova

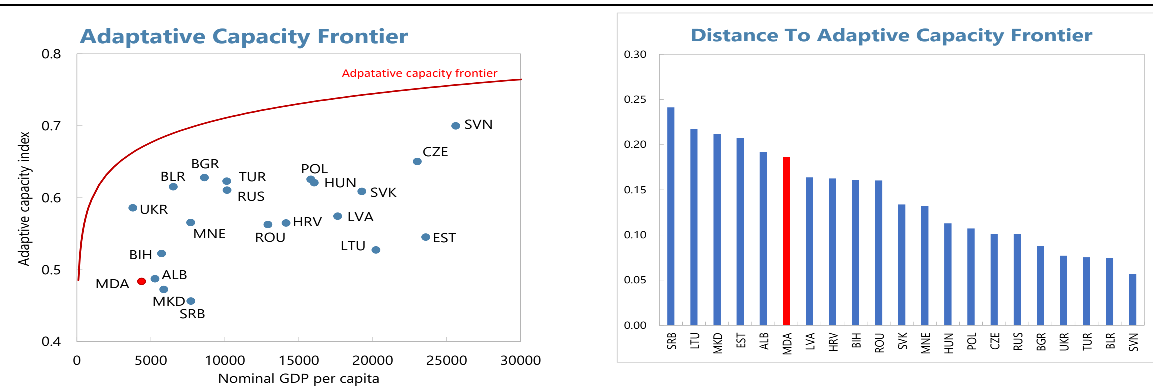
Quantifying the cost of adaptation investments is a difficult exercise as this involves a wide range of sectoral policies and processes to be put in place, all aiming to build resilience against future shocks, with impacts that are also difficult to estimate. For purpose of this paper, we rely on two approaches:

A sectoral approach, based on an analysis from the World Bank on Moldova's climate adaptation investment planning (World Bank, 2016). The analysis performs a quantitative assessment of adaptation investment opportunities and returns across target sectors. Based on estimated costs by sector, this assessment suggests that a total adaptation cost of about 2 percent of GDP per year over the next 10–15 years is needed.

Sector	Objectives	Period	Cost (in ml. USD)
Agriculture & water management	Rehabilitation/Modemization of centralized irrigation system	2017-2040	975
	Investments in farm irrigation technologies	2017-2040	130
	Rehabilitation/Modemization of drainage infrastructure in irrigated areas	2017-2040	120
	Institutional Reforms/Capacity Building	2017-2040	140
Forestry	Ecological reconstruction of forests	2020-2029	91.3
	Ecological reconstruction of forest belts	2020-2030	4.9
	New forest belts	2025-2034	56.5
	Afforestation of degradated land	2023-2044	199.7
	Afforestation of degradated pastures	2023-2044	28.3
Health		2017 -	0.4
Water supply	Improve municipal and industrial water system & reduce 15% of losses	capex in 1 year	29.4
	Improving rural water	na	na
	100 mcm reservoir in lower Nistru & 25 mcm reservoir in upper Nistru & 1 mcm reservoir in Reut	construction over 5 years	24.9
Water supply and sanitation (WSS)	Rehabilitation of existing and construction of new WSS infrastructure	na	439
Flood prevention	Structural flood prevention	2020-2040	360.8
	Non-structural flood mitigation	2020-2040	136.6
Disaster response		2020 -	11
Total			2747.8

Sources: World Bank and IMF Staff Calculations

A frontier analysis approach, whereby we estimate an adaptation frontier using the full sample of countries in Europe (the top performers being advanced economies) and compute the distance to the frontier for CESEE countries. Based on this approach, it is estimated that investment of about 2.5 percent of GDP per year in adaptation will be needed over the next 20 years to close adaptation gaps[1].



Note: The adaptative capacity frontier is estimated to fit a production function with a single input, the logarithm of per capita GDP in USD. Sources: IMF staff calculations based on 2020 data from the WEO, and University of Notre Dame's Global Adaption Index

Box 4: Quantifying Adaptation Investment Needs for Moldova (concluded)

It is worth noting that Moldova's 2020 Nationally Determined Contribution estimates adaptation investment needs to be 2.5 percent of GDP per year over the next 10–15 years. We use the lower bound of these estimates range (2 percent of GDP) for the simulations in the paper.

[1]First, we identify a country with similar income per capita as Moldova but closer to the adaptative capacity frontier (e.g. UKR). Then we simulate a public capital investment profile for Moldova in next 20 years, that is needed to reach the level of that peer country, while accounting for the differences in public investment management. Due to the lack of historical data on climate adaptation investment, we project total public capital investment and assume that additional capital expenditure (on top of the baseline) is aimed at strengthening adaptation to climate risks.

Standard vs. Climate-Resilient Investments

The first set of simulations aims at illustrating the benefits of climate adaption investment. Three scenarios are explored:

- *Unchanged policies scenario*. The key macro-variables under the baseline are kept unchanged. Especially, there is no additional public infrastructure investment beyond what is assumed in the baseline.
- *Standard investment scenario*. Assumes an additional 2 percent of GDP for public standard infrastructure investment annually.
- *Adaption investment scenario*. The additional 2 percent of GDP (annually) public investment is entirely directed towards climate-resilient infrastructure to strengthen Moldova's adaptation capacity (Box 3).

We further assume that the government faces a tight budgetary constraint and fiscal policy is guided by a strict fiscal rule that does not allow debt financing. Also, no new external grants or concessional loans are available beyond the baseline assumptions. Therefore, any new spending is financed through tax increases or savings from reduced public transfers.

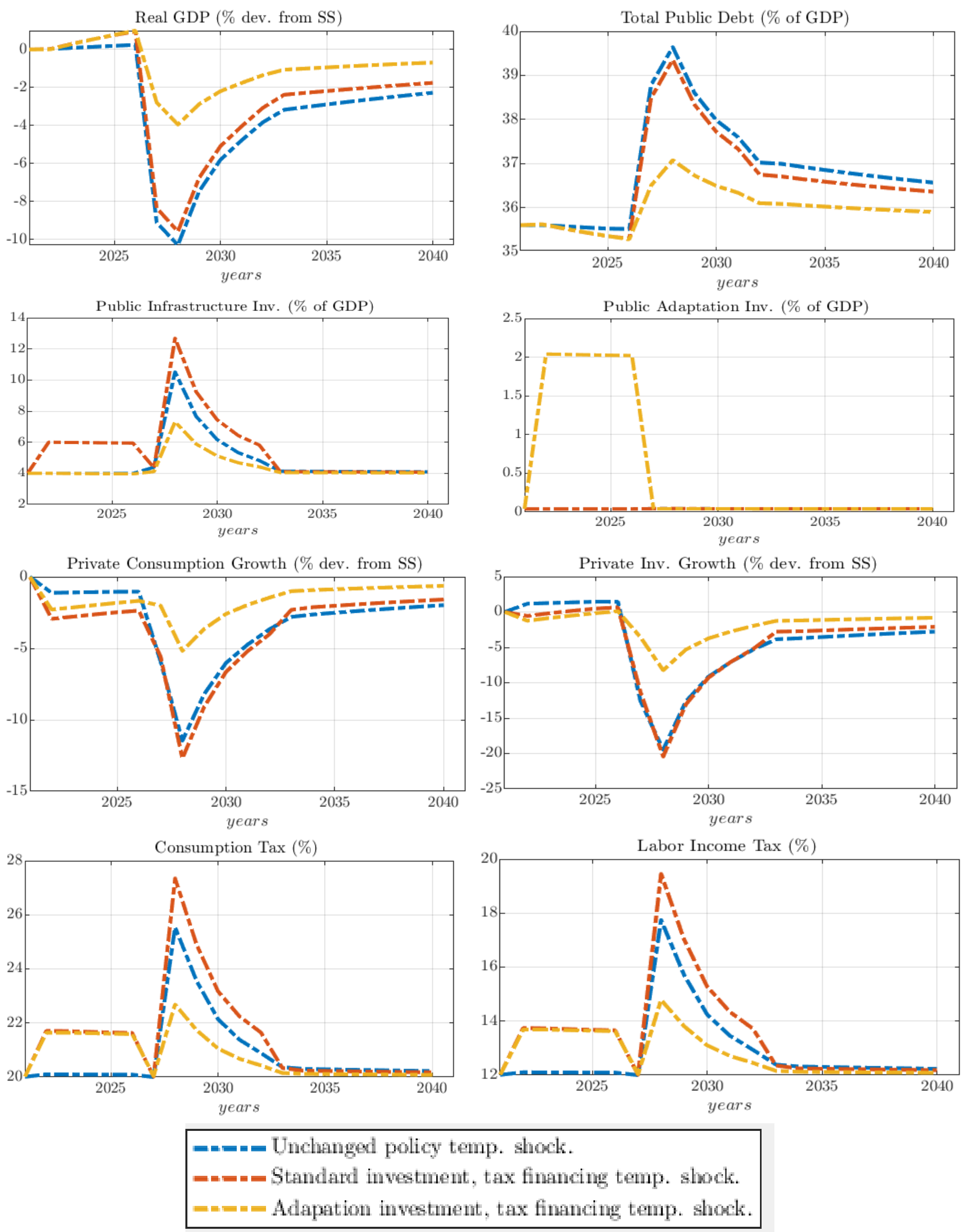
The simulation results are presented in Figure 7.

- *Pre-disaster*. New infrastructure contributes to boost GDP growth by about 1 ppt above the baseline during the investment phase. However private investment and consumption decline due to the tax increase and cut in public transfers (to finance additional public investment).

- *Shock*. In absence of investment in climate-resilient infrastructure (unchanged policy or standard investment scenarios), the climate disaster shock causes GDP to contract by about 10 percent. However, the scenario with pre-disaster accumulation of adaptation investment shows a GDP contraction of about 4 precent, suggesting that resilient infrastructure could absorb more than half of the disaster impact on economic activity. Under the unchanged policy or standard investment scenarios, public debt increases from 35 percent to about 39.5 percent of GDP. Public debt increases by a smaller magnitude under the adaptation investment scenario (to about 37 percent of GDP). Given the stricter fiscal rule assumed in these first set of simulations, the debt-to-GDP increase is exclusively driven by the denominator effect (change in GDP).

- *Post-disaster*. The discussion on the post-disaster period focusses on how the economy recovers from the shock. Under the unchanged and standard investment scenarios, the simulations suggest that medium-term scarring is significant, with GDP growth remaining about 4 to 5 ppts below the steady state 5 years after the disaster (in the longer term, GDP growth stands at about 2 ppts below the steady state more than a decade after the shock). The long-term debt-to-GDP ratio is also slightly above the steady state, by about 1.5 ppts. Thanks to more resilient infrastructure (and milder destruction of capital stock), economic activity recovers faster under the adaption investment scenario. GDP returns closer to the steady state level within a bit more than a decade after the disaster, while the deb-to-GDP ratio converges back to about 35 percent by the end of the simulation horizon.

Figure 7. Moldova: Macro Impact of Unchanged, Standard, and Adaptation Investments



Alternative Financing Options

In the following set of simulations, we explore several options of public financing of adaptation infrastructure, and their macroeconomic impacts, especially on public debt and medium-to-long-term economic growth (Table 3). We assume (i) an additional 0.5 percent of GDP in grant financing is available to the government annually (bringing baseline grant financing to 1 percent of GDP); and (ii) increased access to concessional loans by 1 percent of GDP annually.[12] This, however, leaves a financing gap of about 0.5 percent of GDP annually, to fully finance climate-resilient infrastructure. The government has two options to close the financing gap: (1) increase public commercial debt, or (2) mobilize additional tax revenues and/or generate savings from current transfers.

Public investment efficiency. We further assess to what extent improving public investment efficiency (PIE) could support investment outcomes and growth in the medium-to-long-term. For each of the financing options discussed below, we consider a scenario where PIE increases by 15 ppts to 80 percent, similar to top performers among emerging countries.[13]

Table 3. Parameters for Public Financing of Adaptation Investments

	Debt financing	Tax and exp. rationalization
Scenario 1	All commercial debt	All tax and exp. rationalization
Scenario 2	Grant: + 0.5 ppt Concessional loans: + 1 ppt Commercial debt: ~	Grant: + 0.5 ppt Concessional loans: + 1 ppt tax and exp. rationalization: ~
Scenario 3	Grant: + 0.5 ppt Concessional loans: + 1 ppt Commercial debt ~ PIE: + 15 ppts	Grant: + 0.5 ppt Concessional loans: + 1 ppt tax and exp. Rationalization: ~ PIE: + 15 ppts

Financing Option 1: Increased Public Debt Financing to Close the Financing Gap

The simulation results for this financing option are presented in Figure 8. The scenario with additional grants and concessional borrowing (scenario 2) is compared to a scenario where such extra funding and cheaper borrowing are not available, and the government instead finances adaptation infrastructure exclusively by increasing commercial debt (scenario 1). In the latter scenario, public debt would peak at about 54 percent of GDP (from about 35.5 percent) and remain broadly at that level 10 years after the shock. In line with the simulation results discussed in the previous sub-section, new investment in adaptation infrastructure boosts growth by about 1 ppt above the pre-disaster baseline, helping limit the economic impact of climate disaster by more than half, and reducing medium-term scarring.

[12] Such concessional financing could include funds from the IMF's Resilience and Sustainability Facility, which is expected to catalyze additional financing from international donors to support the country's climate adaptation efforts.

[13] Public Investment Efficient measures the share of budgeted funds effectively used for the expenditure items they were allocated to (see Dabla-Norris et al., 2011, and Aligishiev et al., 2023).

Under the scenario with additional grants and concessional loan financing, the growth impact of adaptation investment is larger by about 0.2 ppt by the end of the investment cycle and over the entire post-shock period, implying significant cumulative economic benefits in the long term. This is driven, inter alia, by a smaller crowding out impact on private investment than public domestic debt financing would have generated under a fully-debt-financing scenario. The debt-to-GDP ratio reaches a maximum of 49 percent, before declining to 47 percent by end of the forecast horizon.

The simulations also emphasize the role of PIE. Improving PIE through public financial management and public investment management reforms is found to further support the impact of adaptation investment on growth regardless of the financing modality. Growth stands at about 0.3 ppt higher by the end of the investment phase, thanks to strengthened PIE. Post-shock, the economy recovers faster, taking growth back to the steady state level by end of the forecast horizon.

Financing Option 2: Mobilizing Tax Revenue and Expenditure Savings to Close the Financing Gap

The economic impact under this financing option (Figure 9) is very similar to the *Financing Option 1*. The growth benefits of adaptation infrastructure before and after the shock, as well as resilience to climate disaster, are of comparable magnitude to the previous scenario. The growth outcomes are larger in the scenario with additional grants and concessional debt financing, compared to a scenario where adaptation investment is fully financed through taxes and expenditure rationalization. In the latter case, tax increases (on income and consumption) depress private investment and consumption, weakening the growth impact of public infrastructure investment. The positive impact of improving PIE is also in line with the results discussed in the previous scenario.

However, debt sustainability implications are markedly different compared to the debt-financing option. The debt-to-GDP ratio peaks at about 41 percent following the shock and declines gradually to 38 percent by end of the forecast horizon. This financing option therefore preserves public debt sustainability, while providing a similar growth and climate-resilience impact.

Figure 8. Moldova: Macro Impact of Debt Financing of Adaptation Investments

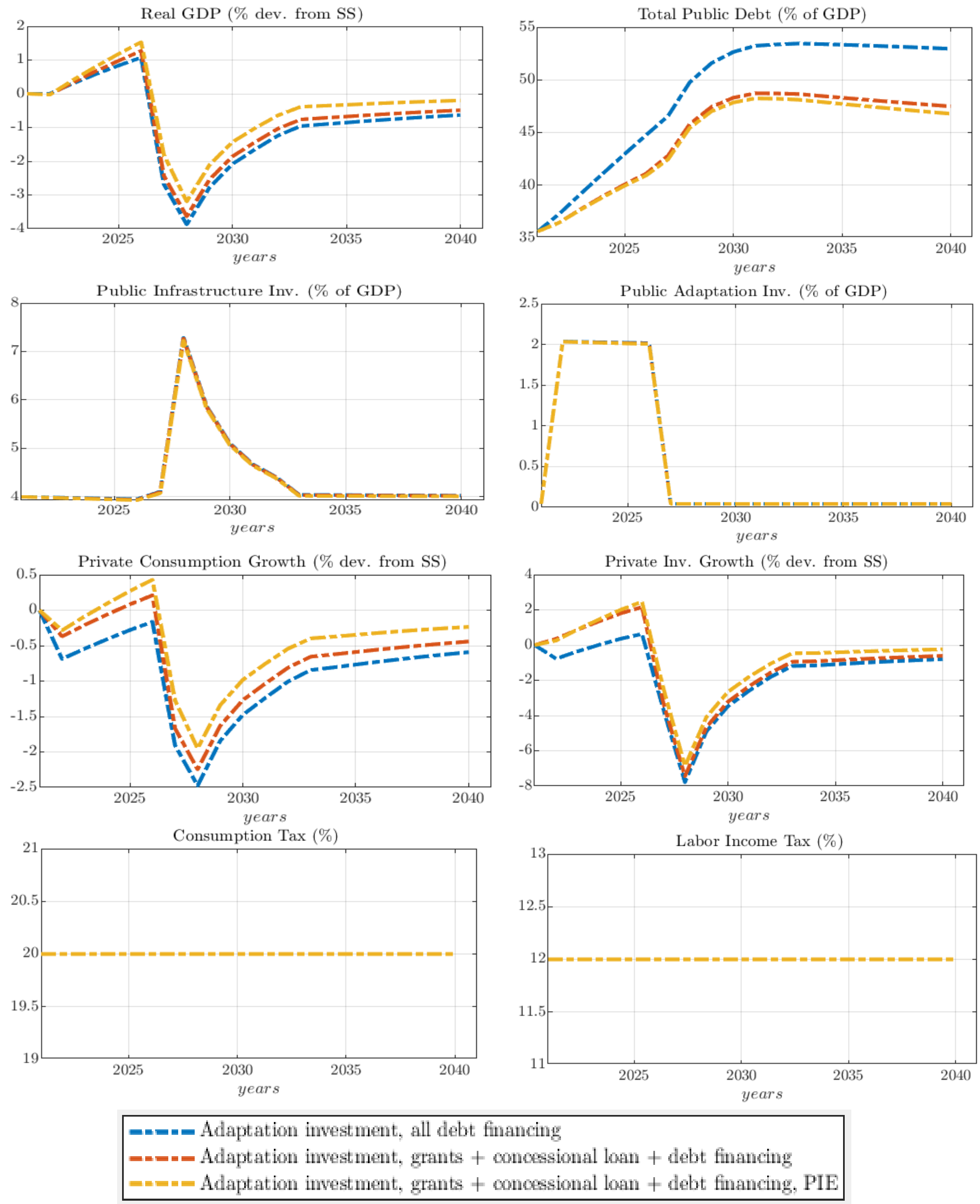
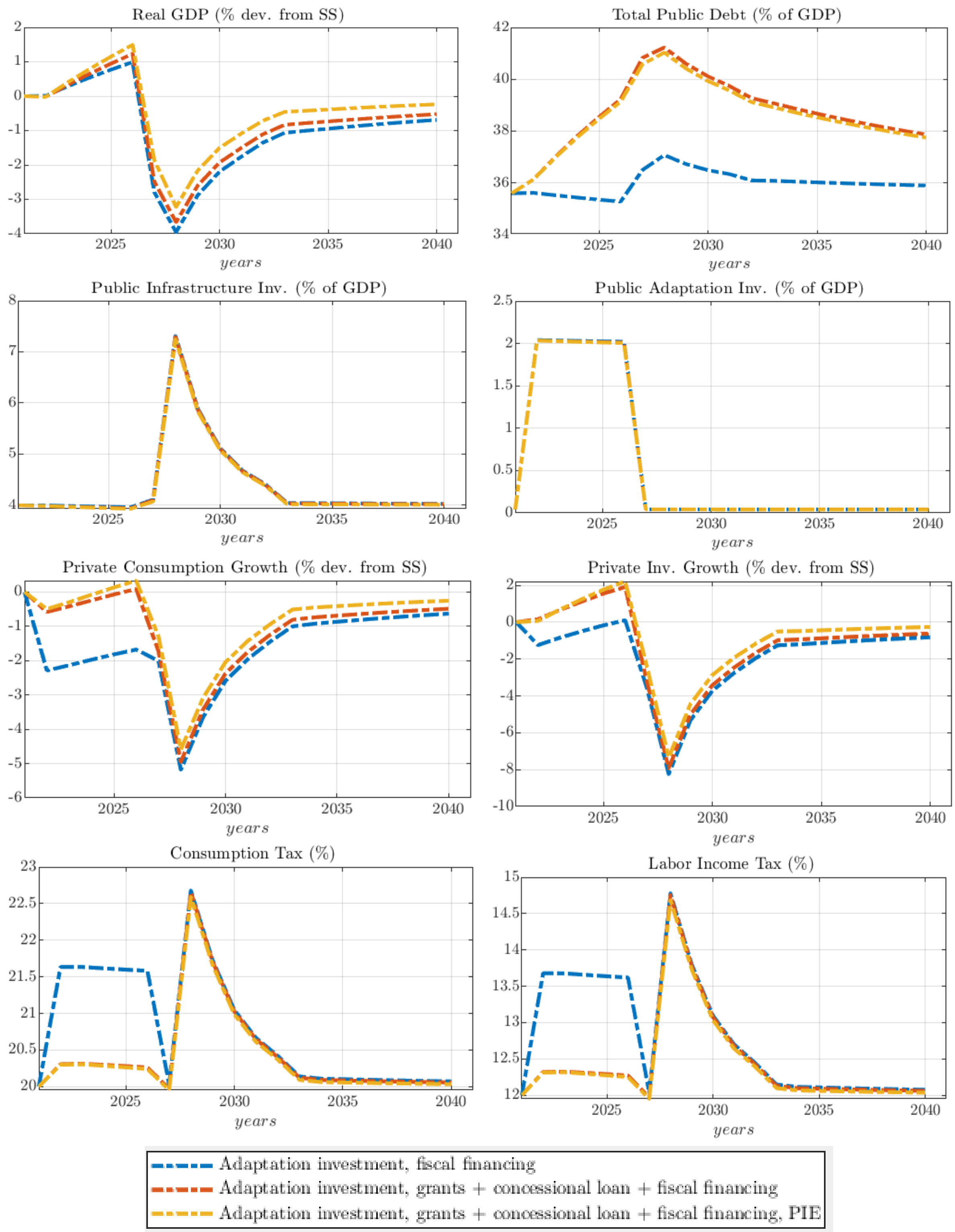


Figure 9. Moldova: Macro Impact of Fiscal Financing of Adaptation Investments



Trade-Offs and Considerations for Donors

As highlighted in the previous section, closing adaptation gaps may generate trade-offs between the need to bolster the stock of climate-resilient infrastructure, supporting economic activity, and maintaining debt sustainability. Given the costs and impact, it may be more reasonable and efficient to provide financial assistance to Moldova not only during the reconstruction phase, once a disaster hits, but importantly, before any disaster, to support resilient investments. This is particularly important given Moldova's limited financial resources, constrained access to commercial domestic and external debt, and limited fiscal space.

This section aims to answer how large the net savings (or losses) would be if donors were to fund investments in adaptation infrastructure *ex ante* (before a climate disaster), reducing the need to support reconstruction *ex post*. The analysis assumes that donors provide financial assistance for all reconstruction efforts following a disaster. We then calculate the net present value of future costs associated with such reconstruction in the event of a climate shock. The present value of future reconstruction costs is compared to the cost of investment in climate-resilient infrastructure ex-ante.

Donors' net savings from supporting adaptation investments are large. The results presented in Table 4 suggest that donors' savings would amount to about 26 percent of total *ex post* reconstruction costs if they were to support adaptation investments *ex ante*. With global climate conditions continuing to deteriorate, the impact of future natural disasters may be of even larger magnitude. Our analysis suggests that donors' savings would also be larger under such scenario. For example, donors' net savings would be equivalent to about 32 percent of reconstruction costs, should the impact of future natural disaster be 50 percent larger than historical shocks.

Table 4. Moldova: Discounted Net Savings of International Donors
(In percent of reconstruction cost)

Magnitude of Hazard	Net Savings
Average Impact	25.9
Average Impact + 30%	30.2
Average Impact +50%	32.1
Average Impact +100%	35.2

Conclusion

Although Europe's aggregate vulnerability to climate risks is below that of other regions, CESEE countries face higher risks. This is due to significant gaps in adaptation capacity among emerging and developing Europe compared to advanced countries. Under current trends of global warming, higher volatility of seasonal temperature and precipitations, more recurrent extreme weather events and the other climate-related disasters, are projected to generate even larger social and economic cost in emerging Europe. These economies are more reliant on sectors sensitive to climate change and have accumulated less climate-resilient infrastructure in recent years. While future (longer-term) climate perturbations and associated impact largely depend on progress on mitigation and transition policies, strengthening resilience to natural disasters is a short-term priority for many countries. However, effective adaptation strategies require a forward-looking approach and a good understanding of future climate risks. The paper makes use of climate analogue mapping to identify countries currently experiencing climatic conditions which can be regarded as reasonably comparable to another country's future climate. This analysis reveals significant shifts in climate conditions in most cases and helps quantify the impact of future climate shocks. These outcomes are critical to gauge future efforts to mitigate the impact of climate change through adaptation investment.

This paper assesses the impact of investment in adaptation infrastructure on the resilience to climate shocks, as well the medium-to-long term economic growth. We find that adaptation infrastructure resulting from public investments can significantly reduce output losses from natural disasters and mitigate medium-term economic scarring. We also find that such investments will support sustainable long-term growth, which ultimately can reduce inequality and support Sustainable Development Goals. Increasing PIE, which implies strengthening governance and quality of institutions, would also further boost GDP growth by leveraging new investment opportunities.

However, the analysis also reveals important challenges. First, limited financial resources could delay adaptation investments, leaving many countries in a precarious position when faced with climate change. We find that in the absence of donors' support, it may be challenging to finance the most needed climate-resilient investment without endangering public debt sustainability or weakening growth potential. Therefore, external support is critical to help the most vulnerable countries close the adaptation gaps. The analysis also suggests that donors' savings from such support ex-ante (to build resilience) are large relative to reconstruction costs ex-post. Second, emerging European countries appear to be relatively less well prepared for effective implementation of adaptation actions compared to advanced Europe. This is due primarily to weaker governance quality and large gaps in innovation technologies. Continued progress toward building strong fiscal governance institutions will help make the most of investment in climate-resilient infrastructure, while bolstering or maintaining high education investment and outcomes can contribute to boost innovation and support climate-resilient strategies. Continued efforts to stimulate a favorable business environment will help crowd in private investments for climate actions is also critical to achieve adaptation objectives.

While climate analogues under different concentration pathways employed in our paper provide tangible information about countries' (likely) future climate, significant uncertainty over the nature and the costs of future climate-related shocks remain, which complicates formulation of appropriate adaptation responses. The uncertainty arises (in addition to scientific uncertainty intrinsic to climate change) from the fact that global efforts to reduce GHG emissions face various risks that could hinder their effectiveness. One significant challenge lies in the lack of universal commitment and coordinated action among nations, as countries with diverse economic interests may prioritize short-term gains over long-term sustainability. Additionally, geopolitical tensions and competition for resources could impede collaborative efforts, leading to fragmented initiatives that fall short of achieving meaningful emission reductions. Economic concerns, particularly in developing nations heavily reliant on carbon-intensive industries, may create resistance to rapid transitions toward cleaner technologies. Technological and infrastructural barriers also pose risks, as the global community may struggle to develop and implement scalable and affordable alternatives to fossil fuels. Furthermore, unforeseen natural disasters and environmental feedback loops may exacerbate the urgency and complexity of climate change mitigation, necessitating adaptive strategies. Addressing these risks requires a comprehensive, globally coordinated approach that considers diverse socioeconomic contexts and emphasizes innovation, equity, and resilience in the pursuit of sustainable emissions reduction.

Annex I. Climate Analogues under Different SSP-RCP Scenarios

Climate Analogues for CESEE Countries under Europe Search

Country		SSP2-4.5	SSP3-7.0	SSP5-8.5
Albania	→	Italy [1/]	Italy [1/]	Italy [1/]
Belarus	→	Romania	Serbia	Serbia
Bulgaria	→	Serbia	Italy [1/]	Italy [1/]
Bosnia and Herzegovina	→	Croatia	Croatia	Italy [1/]
Czech Republic	→	Serbia	Serbia	Serbia
Croatia	→	Italy [1/]	Italy [1/]	Italy [1/]
Estonia	→	Slovak Republic	Kosovo	Kosovo
Hungary	→	Hungary	Italy [1/]	Italy [1/]
Lithuania	→	Slovak Republic	Kosovo	Bulgaria
Latvia	→	Slovak Republic	Kosovo	Bulgaria
Moldova	→	Hungary	Hungary	Hungary
North Macedonia	→	Serbia	Greece	Greece
Montenegro	→	Albania	Albania	Albania
Poland	→	Serbia	Bulgaria	Serbia
Romania	→	Serbia	Serbia	Italy [1/]
Russian Federation	→	Finland	Finland	Finland
Serbia	→	Serbia	Italy [1/]	Italy [1/]
Slovak Republic	→	Serbia	Serbia	Serbia
Slovenia	→	Croatia	Croatia	Croatia
Türkiye	→	Greece	Greece	Greece
Ukraine	→	Hungary	Hungary	Hungary

Climate Analogues for EE Countries under Europe Search

Country	SSP2-4.5	SSP3-7.0	SSP5-8.5
Albania	Italy [1/]	Italy [1/]	Italy [1/]
Belarus	Romania	Serbia	Serbia
Bulgaria	Serbia	Italy [1/]	Italy [1/]
Bosnia and Herzegovina	Croatia	Croatia	Italy [1/]
Hungary	Hungary	Italy [1/]	Italy [1/]
Kosovo	Serbia	Italy [1/]	Italy [1/]
Moldova	Hungary	Hungary	Hungary
North Macedonia	Serbia	Greece	Greece
Montenegro	Albania	Albania	Albania
Poland	Serbia	Bulgaria	Serbia
Romania	Serbia	Serbia	Italy [1/]
Serbia	Serbia	Italy [1/]	Italy [1/]
Türkiye	Greece	Greece	Greece
Ukraine	Hungary	Hungary	Hungary

Climate Analogues for AE Countries under Europe Search

Country	SSP2-4.5	SSP3-7.0	SSP5-8.5
Austria	Slovenia	Slovenia	Croatia
Belgium	France	Italy	Italy [1/]
Cyprus	Cyprus	Cyprus	Malta
Czech Republic	Serbia	Serbia	Serbia
Croatia	Italy [1/]	Italy [1/]	Italy [1/]
Denmark	Netherlands	Netherlands	Italy
Estonia	Slovak Republic	Kosovo	Kosovo
Finland	Estonia	Latvia	Slovak Republic
Germany	Kosovo	Bulgaria	Italy [1/]
France	Italy	Italy [1/]	Italy [1/]
Greece	Greece	Greece	Greece
Ireland	France	France	France
Iceland	Iceland	Iceland	Switzerland
Israel	Cyprus	Malta	Malta
Italy	Italy [1/]	Italy [1/]	Italy [1/]
Lithuania	Slovak Republic	Kosovo	Bulgaria
Luxembourg	France	Italy	Italy [1/]
Latvia	Slovak Republic	Kosovo	Bulgaria
Malta	Malta	Malta	Malta
Netherlands	France	Italy	Italy [1/]
Norway	Switzerland	Switzerland	Switzerland
Portugal	Portugal	Greece	Greece
San Marino	Greece	Greece	Greece
Spain	Greece	Greece	Greece
Slovak Republic	Serbia	Serbia	Serbia
Slovenia	Croatia	Croatia	Croatia
Switzerland	Georgia	Georgia	Bosnia and Herzegovina
Sweden	Estonia	Lithuania	Germany
Andorra	Luxembourg	Luxembourg	Kosovo
United Kingdom	France	France	France

Climate Analogues for CESEE Countries under World Search

Country		SSP2-4.5	SSP3-7.0	SSP5-8.5
Albania	→	Portugal	Portugal	Uruguay
Belarus	→	United States	Serbia	Lesotho
Bulgaria	→	Greece	Lebanon	Italy [2/]
Bosnia and Herzegovina	→	Albania	Nepal	Portugal
Czech Republic	→	Netherlands	Lesotho	Italy
Croatia	→	Nepal	Portugal	Uruguay
Estonia	→	Slovak Republic	Netherlands	France
Hungary	→	Greece	Lebanon	Italy [2/]
Lithuania	→	Chile	Netherlands	Serbia
Latvia	→	Slovak Republic	Netherlands	France
Moldova	→	Lesotho	Spain	Lebanon
North Macedonia	→	Greece	Argentina	Italy [2/]
Montenegro	→	Korea	Korea	Nepal
Poland	→	Netherlands	Lesotho	Monaco
Romania	→	Italy [1/]	Monaco	Lebanon
Russian Federation	→	Finland	Finland	French Southern Territories (the)
Serbia	→	Monaco	Lebanon	Italy [2/]
Slovak Republic	→	France	Lesotho	Monaco
Slovenia	→	Korea	Albania	Portugal
Türkiye	→	Greece	Lebanon	Italy [2/]
Ukraine	→	Bulgaria	Lesotho	Spain

Climate Analogues for EE Countries under World Search

Country		SSP2-4.5	SSP3-7.0	SSP5-8.5
Albania	→	Portugal	Portugal	Uruguay
Belarus	→	United States	Serbia	Lesotho
Bulgaria	→	Greece	Lebanon	Italy [2/]
Bosnia and Herzegovina	→	Albania	Nepal	Portugal
Hungary	→	Greece	Lebanon	Italy [2/]
Kosovo	→	Italy	Greece	Lebanon
Moldova	→	Lesotho	Spain	Lebanon
North Macedonia	→	Greece	Argentina	Italy [2/]
Montenegro	→	Korea	Korea	Nepal
Poland	→	Netherlands	Lesotho	Monaco
Romania	→	Italy [1/]	Monaco	Lebanon
Serbia	→	Monaco	Lebanon	Italy [2/]
Türkiye	→	Greece	Lebanon	Italy [2/]
Ukraine	→	Bulgaria	Lesotho	Spain

Climate Analogues for AE Countries under World Search

Country		SSP2-4.5	SSP3-7.0	SSP5-8.5
Austria	→	United Kingdom	Slovenia	Croatia
Belgium	→	Guernsey	Italy [1/]	Monaco
Cyprus	→	Australia	New Caledonia	Iraq
Czech Republic	→	Netherlands	Lesotho	Italy
Croatia	→	Nepal	Portugal	Uruguay
Denmark	→	Netherlands	France	Lesotho
Estonia	→	Slovak Republic	Netherlands	France
Finland	→	Estonia	Lithuania	Slovak Republic
Germany	→	Belgium	Lesotho	Monaco
France	→	Monaco	Monaco	Portugal
Greece	→	Gibraltar	Saint Helena	Eswatini
Ireland	→	Croatia	Croatia	Croatia
Iceland	→	French Southern Territories (the)	French Southern Territories (the)	French Southern Territories (the)
Israel	→	Iraq	Iraq	Kuwait
Italy	→	Portugal	Italy [2/]	Saint Helena
Lithuania	→	Chile	Netherlands	Serbia
Luxembourg	→	Belgium	Lesotho	Monaco
Latvia	→	Slovak Republic	Netherlands	France
Malta	→	Australia	Botswana	Australia
Netherlands	→	Guernsey	Italy [1/]	Monaco
Norway	→	French Southern Territories (the)	DKRP	Faroe Islands (the)
Portugal	→	Gibraltar	Gibraltar	Saint Helena
San Marino	→	Saint Helena	Saint Helena	Eswatini
Spain	→	Italy [2/]	Gibraltar	Cyprus
Slovak Republic	→	France	Lesotho	Monaco
Slovenia	→	Korea	Albania	Portugal
Switzerland	→	Slovenia	Slovenia	Slovenia
Sweden	→	DKRP	DKRP	Andorra
Andorra	→	DKRP	Andorra	Netherlands
United Kingdom	→	Luxembourg	Croatia	Croatia

Sources: World Bank Climate Change Knowledge Portal, IMF, and IMF staff calculations

[1/] The best analogue is San Marino.

[2/] The best analogue is Vatican.

Notes:

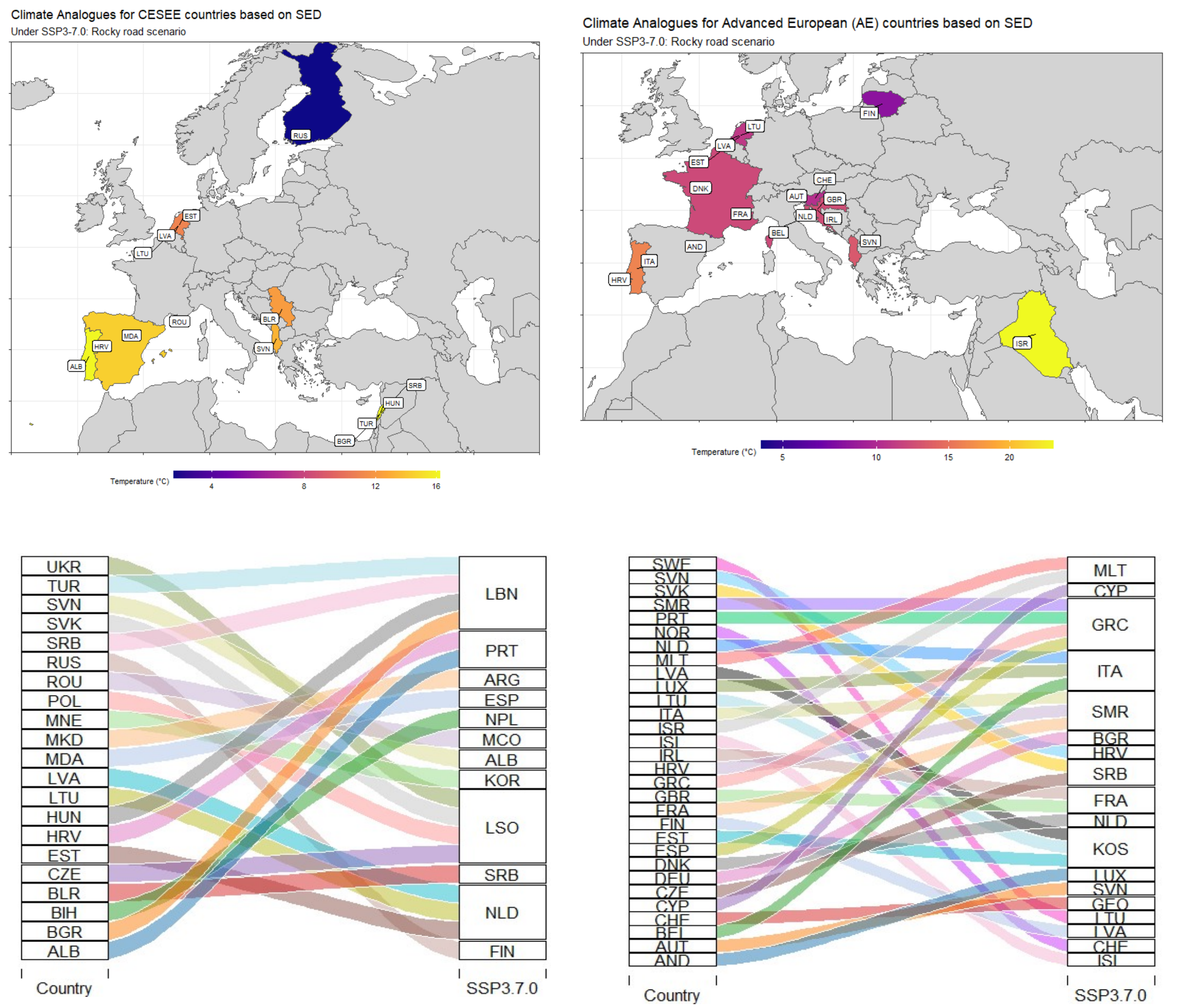
The transition from green to red signifies a rise in average temperature.

SSP2–4.5: Middle of the Road (Medium challenges to mitigation and adaptation)

SSP3–7.0: A Rocky Road - Regional Rivalry (High challenges to mitigation and adaptation)

SSP5–8.5: Fossil Fueled Development (High challenges to mitigation, low challenges to adaptation)

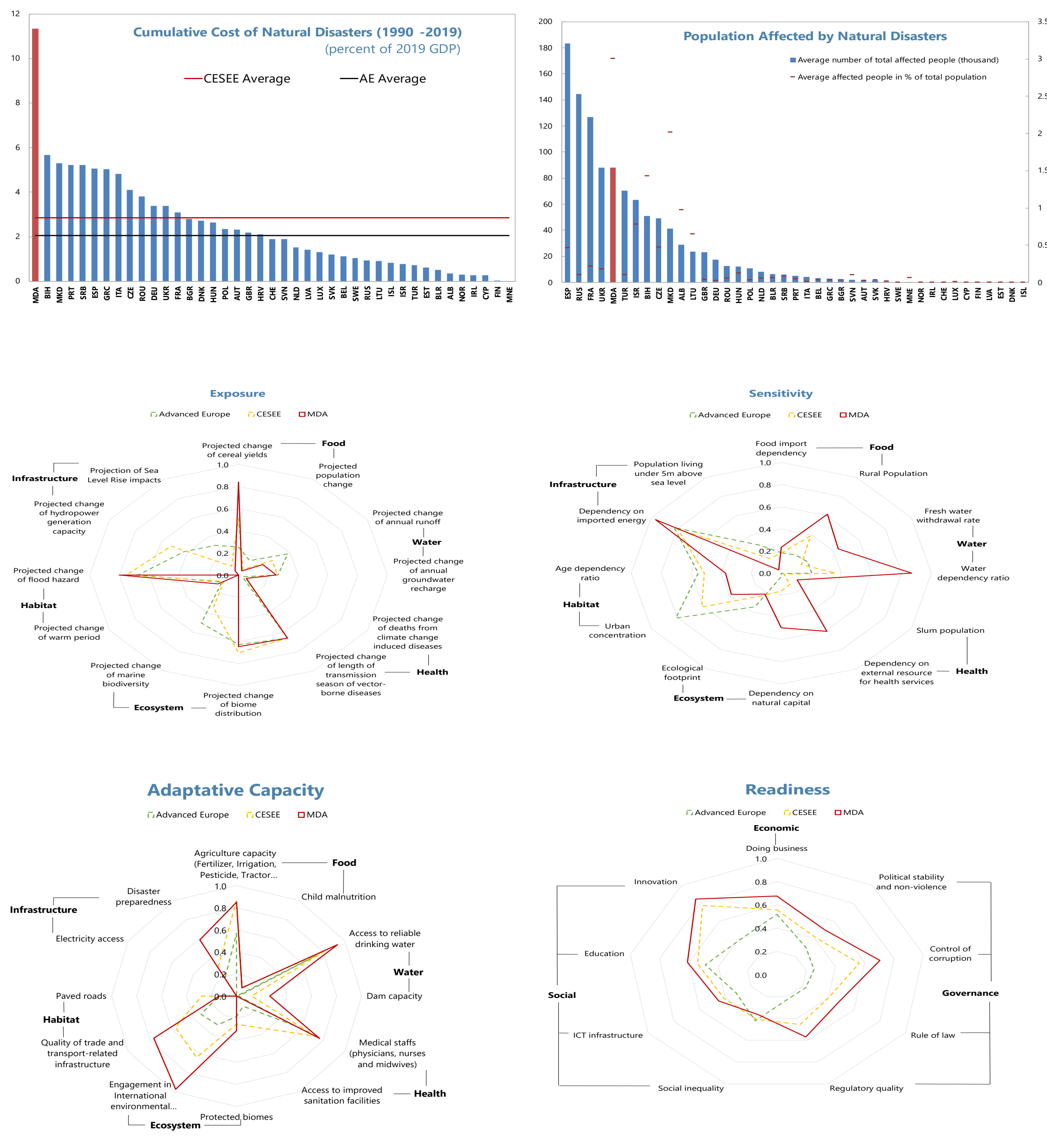
Annex II. Climate Analogues with Global Search



Sources: World Bank Climate Change Knowledge Portal, IMF, and IMF staff calculations Maps show CESEE (top-left panel) and non-CESEE AE (top-right panel) countries at location of their analogues—i.e., countries with present climates close to the former countries' future climate.

Climate analogues for CEESE (bottom-left panel) and AE (bottom-right panel)

Annex III. Moldova: Costs of Past Natural Disasters and Sources of Vulnerability and Readiness



Sources: University of Notre Dame's Global Adaption Index, EM-DAT, and IMF staff calculations

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