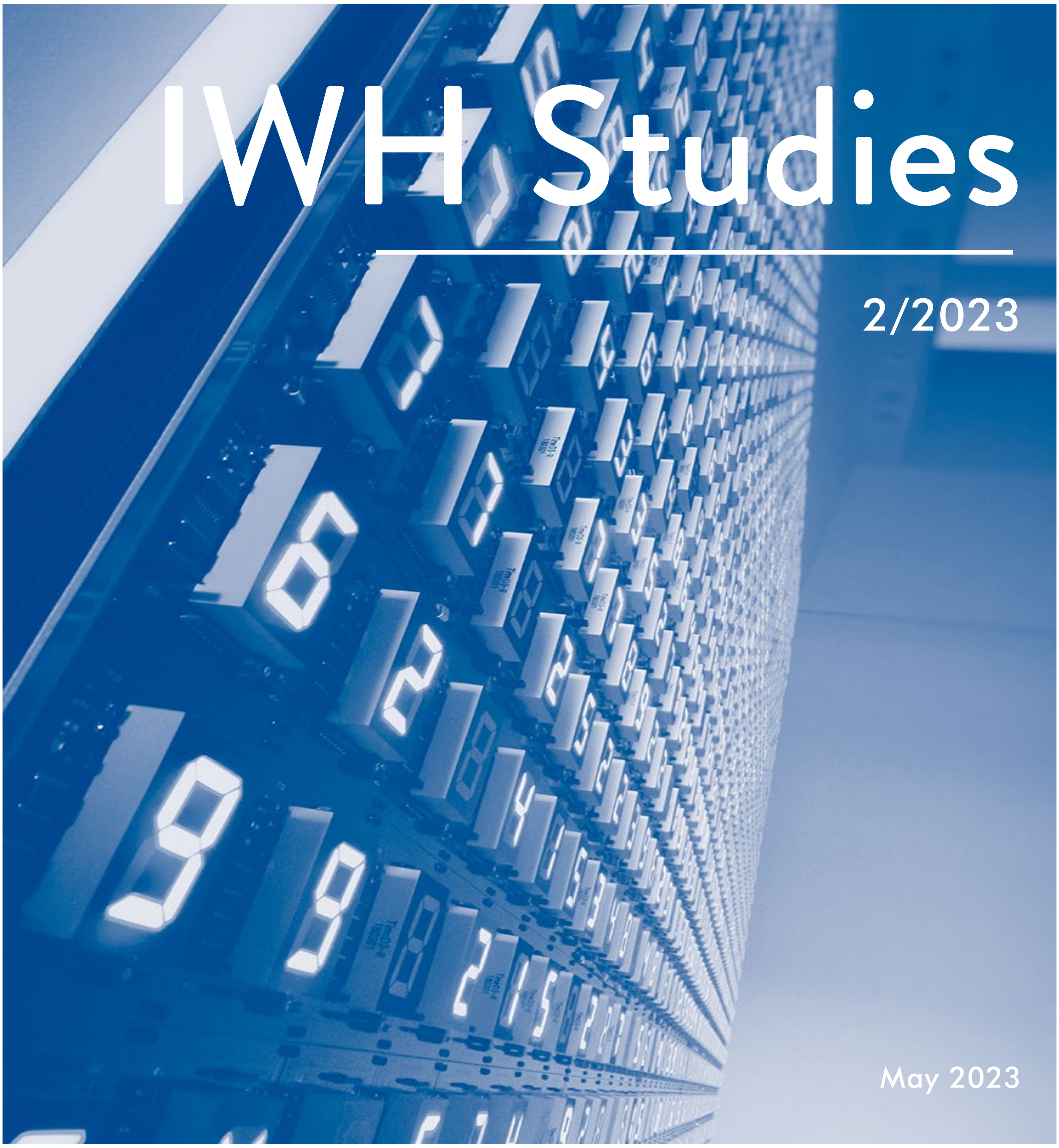
IWH
Halle Institute for Economic Research
Member of the Leibniz Association



Evidence-based Support for Adaptation Policies in Emerging Economies

Maximilian Banning, Anett Großmann, Katja Heinisch, Frank Hohmann, Christian Lutz, Christoph Schult

Imprint

Contact
Dr Katja Heinisch (corresponding author)
Tel +49 345 77 53 836
Fax +49 345 77 53 799
E-mail: katja.heinisch@iwh-halle.de

Authors
Maximilian Banning (GWS Osnabrueck)
Anett Großmann (GWS Osnabrueck)
Katja Heinisch (Halle Institute for Economic Research – IWH)
Frank Hohmann (GWS Osnabrueck)
Christian Lutz (GWS Osnabrueck)
Christoph Schult (Halle Institute for Economic Research – IWH)

This work was supported by the GIZ IKI Global Programme on Policy Advice for Climate Resilient Economic Development (CRED) on behalf of the German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV). We thank the national experts supporting the CRED project in Kazakhstan, Georgia and Vietnam with data and extensive feedback to our model approach and results.

Issuer
Halle Institute for Economic Research (IWH) –
Member of the Leibniz Association

Address
Kleine Maerkerstrasse 8
D-06108 Halle (Saale), Germany

Postal Address
P.O. Box 11 03 61
D-06017 Halle (Saale), Germany

Tel +49 345 7753 60
Fax +49 345 7753 820

www.iwh-halle.de

Citation
Banning, Maximilian; Großmann, Anett; Heinisch, Katja; Hohmann, Frank; Lutz, Christian; Schult, Christoph: Evidence-based Support for Adaptation Policies in Emerging Economies. IWH Studies 2/2023. Halle (Saale) 2023.

ISSN 2702-4733

Evidence-based Support for Adaptation Policies in Emerging Economies

Supported by the GIZ IKI Global Programme on Policy Advice for Climate Resilient Economic Development (CRED)

Halle (Saale), 2023-05-11

Content

1 Summary

In recent years, the impacts of climate change become increasingly evident, both in magnitude and frequency. The design and implementation of adequate climate adaptation policies play an important role in the macroeconomic policy discourse to assess the impact of climate change on regional and sectoral economic growth. We propose different modelling approaches to quantify the socio-economic impacts of climate change and design specific adaptations in three emerging market economies (Kazakhstan, Georgia and Vietnam) which belong to the areas that are heavily exposed to climate change. A Dynamic General Equilibrium (DGE) model has been used for Vietnam and economy-energy-emission (E3) models for the other two countries. Our modelling results show how different climate hazards impact the economy up to the year 2050. Adaptation measures in particular in the agricultural sector have positive implications for the gross domestic product (GDP). However, some adaptation measures can even increase greenhouse gas emissions. In addition, the focus on GDP as the main indicator to evaluate policy measures can produce welfare-reducing policy decisions.

2 Introduction

In recent years, the impacts of climate change become increasingly evident across the globe, both in magnitude and frequency. Climate change is a major and urgent challenge for environmental and socioeconomic development and poses serious risks in the mid to long term. Its consequences reinforce the need for approaches to assess the impact of climate risks and potential adaptation scenarios on a country's economy. The latest IPCC (2022a) report confirms the urgency to act quickly and comprehensively. Climate change is already underway and will continue to accelerate in the upcoming decades due to the inertia of natural systems. As an option for action, „climate-resilient development integrates adaptation measures and their enabling conditions with mitigation to advance sustainable development for all“ (IPCC 2022b). Evidence-based projections are necessary for policymakers to implement appropriate economic policies. These may include shifting investments to low or zero-emission technologies (mitigation) as well as measures that reduce negative effects in sectors particularly affected by climate change (adaptation).

At the United Nations Climate Change Conference COP27, the importance of adaptation to climate change was emphasized yet again and a general agreement has been reached to provide loss and climate-related damage funding for vulnerable countries. Policymakers need tools to evaluate the macroeconomic impacts of sector-specific economic risks and benefits (raising awareness) as well as different sectoral adaptation strategies (preparedness) to be able to initiate the transition to a climate-resilient economy and integrate findings into long-term strategies.[1] Various adaptation options and evaluations exist for key economic sectors and climate hazards. Macroeconomic impacts and intersectoral effects of climate change and adaptation which go beyond single economic sectors are often still not considered, particularly in emerging economies. To inform policymakers on the effects of climate change on the economy and on the impact of suitable climate adaptation measures to reduce economic losses requires more profound data collection. Also data sharing on a wider range of topics including climate-related risks and loss, sectoral and regional characteristics and interdisciplinary collaboration is necessary.

[1] See https://unfccc.int/process/the-paris-agreement/long-term-strategies.

We propose an approach developed under the programme “Policy Advice for Climate Resilient Economic Development (short CRED approach) that supports long-term economic planning that considers the costs of climate change and the policy benefits of mitigation and adaptation. Within a multi-country framework, we collected data from three vulnerable emerging economies that represent exemplary different climate zones and cover different climate hazards – Vietnam, Kazakstan, and Georgia. Furthermore, the selection of countries is also driven by accessibility to sectoral and regional expert knowledge, which is one of the most important sources for the model implementation. Whereas structures of underlying macroeconomic and labour market data in all three countries are similar, the climate-related data, economic structures, and adaptation and mitigation policy options are different. Kazakhstan and Georgia are both vulnerable to droughts, while Vietnam is suffering the most from climate change-induced sea-level rise.

The CRED approach covers multiple steps: First, the CRED uses data gathered from global and in many cases regionalized climate models in the respective country. Second, CRED builds on nationally and internationally available knowledge for the translation of damages and the effects of adaptation measures into monetary terms. Third, CRED brings together national climate change experts and decision-makers for socio-economic long-term planning, so that the effects of climate change and adaptation measures are best understood, and long-term planning is improved with this knowledge. Overall sectoral and regional aggregation allows for flexibility across countries. In Vietnam, a Dynamic General Equilibrium (DGE) model has been implemented that emphasizes the supply side. On the one hand, the optimization can represent economic adjustments under these conditions well, on the other hand, it can also lead to numerical problems, which can complicate its use by model builders. In Kazakhstan and Georgia, similar macro-econometric economy-energy-emission (E3) models are applied which are more demand-side oriented and less price-sensitive in the feedback mechanisms (Großmann et al, 2023). The comparison of scenario results for each country allows national policymakers to identify those adaptation measures that are highly effective and beneficial for the economy, employment, and the environment.

3 Macroeconomic modelling and climate change adaptation

3.1 Climate change and macroeconomic modelling

Climate change leads to economic shocks that can affect either the demand or the supply side of the economy. Demand-side shocks are those that affect the components of the aggregate demand, such as private (household) or public (government) consumption and investment, business investment and international trade. Supply-side shocks affect the productive capacity of the economy, acting through the components of potential supply, i.e. labour, physical capital and technology.

The impacts on the economy associated with climate change and climate change policy can be divided into two categories (Batten, 2018). In addition to direct risks of climate change, transition risks associated with the efforts to reduce greenhouse gas emissions (GHG) and the transition to decarbonised production processes affect economic activity and the structure of value creation. For both categories, it is important to analyse the different impact channels according to whether they are relevant in the short, medium or long term, which interactions between climate change, climate protection policy and economic activity need to be taken into account, and which adaptation and transformation processes of economic development can be expected. Direct (or physical) risks of climate change can be further divided into "acute" risks (e.g. extreme weather events (EWE)) and "chronic" risks (e.g. rising sea levels), which build up gradually over long periods. Studies focusing on the consequences of the physical risks of climate change in the short term (1-3 years) and medium term (4-8 years) are mainly concerned with the consequences of EWE such as floods or storms. A general overview of the economic consequences of natural disasters is provided by Cavallo and Noy (2011). In addition to the immediate supply-side disruptions to production and corresponding economic losses as a result of such disasters, there are also possible demand shocks in the form of disrupted foreign trade, increased uncertainty or negative wealth effects (Batten et al, 2016). Output losses are also likely to occur in the medium term as a result of the loss of capital stock. Concerning the long term (more than 8 years including very long-term developments beyond 2045), the focus is on the consequences of temperature and precipitation changes; for example, reduced labour productivity (Kahn et al 2021, Acevedo et al 2020, Hübler et al 2008).

To assess the consequences of climate change and adaptation policy as well as possible interactions, a variety of models are used in the literature. Generally, five types of models can be identified: i) "Integrated Assessment Models" (Nordhaus 1997, 2017a, Nordhaus and Sztorc 2013) play a central role in this literature, as they represent the economy and climate transparently in a unified model framework and enable scenario analyses. For instance, Hsiang et al (2017) use a micro-founded sectoral bottom-up approach with damage functions to identify the economic damages of climate change in the US. ii) Computable General Equilibrium (CGE) models are also used in the literature to incorporate a higher level of detail at the regional or sectoral level, which can be particularly relevant for transition risk modelling (McKibbin and Wilcoxen 1999, 2013, Chateau et al 2018, Jaumotte et al 2021). iii) Macroeconometric models, like CGE models, can be quite detailed in terms of economic sectors and regional coverages and are also used to evaluate alternative climate policies. A major difference is that macroeconometric models do not assume that consumers and producers behave optimally or that markets reach equilibrium in the short term. Instead, they rely on econometrically estimated parameters based on historical data and relations to simulate the dynamic behaviour of the economy (Nikas et al 2019, Lehr, Lutz 2020). iv) Furthermore, dynamic macroeconomic models extended by climate components can also be found in the literature. These include, for example, dynamic stochastic general equilibrium models (DSGE models, Heutel 2012, Hassler and Krusell 2018). These can be used, for example, to investigate how climate protection policy should optimally react to cyclical fluctuations. v) In addition to theoretically motivated and/or micro-founded models, methods from the field of time-series econometrics are also used, such as structural panel vector autoregression (Cicarelli and Marotta 2021).

All the models mentioned have strengths and limitations, which have to be taken into account when assessing the consequences of climate change and development.[2] In most of the existing models, the integration of climate risks into macroeconomic projection models has been insufficiently represented and, hence, the evaluation of specific adaptation policies is rather limited. International models mainly evaluate climate change mitigation and make use of the international GTAP database (Aguiar et al, 2019).[3] In contrast, there are only a few models at the country or even subnational level that have been

[2] For a recent overview on strengths and limitations, *Worldbank* (2022).

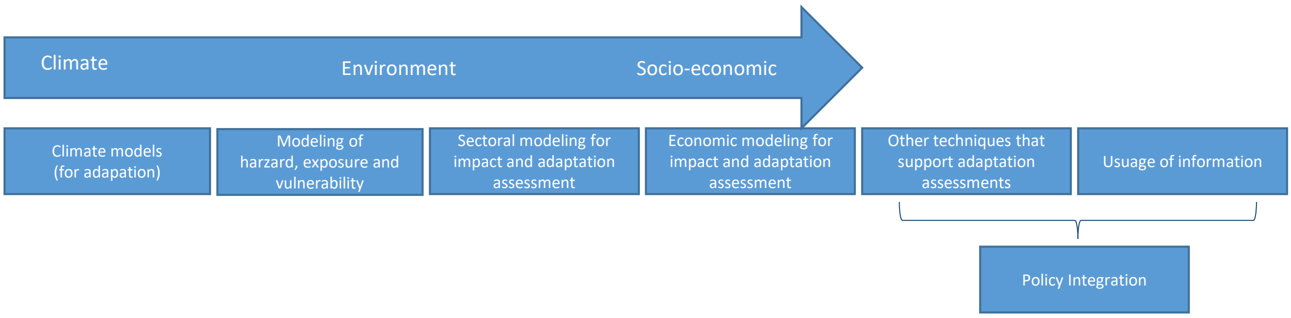
[3] See e.g., *United Nations Climate Change* (2022) for a list of mainly global models, and *Schwarze, R. et al.* (2022).

used to quantify the economic impacts of climate change and adaptation measures (Steininger et al 2016, Hsiang et al 2017, Lehr et al 2020, Vrontisi et al 2022). The CRED approach is considering especially the specific natural and political conditions in emerging economies. Adequate mapping of climate damages requires, among other things, that climate data and results from sectoral models are incorporated into macroeconomic models in order to depict the effects of climate change on various (socio-)economic variables. Based on the data availability and existing modelling experience in a country, we apply different approaches for each country.

3.2 Modelling approach

The CRED approach goes beyond these approaches in several ways, especially taking into account the specific conditions and data shortcomings in emerging economies. It builds on multiple inputs covering climate modelling and cost-benefit (micro) analyses (CBA) of different sector-specific adaptation measures (see EU Commission 2021) (see Figure 1).

Figure 1
Adaptation modelling typology



Source: Own illustration based on EU Commission 2021, 6.

As a baseline scenario, a business-as-usual scenario based on national long-term planning, is implemented for each country, i.e. a path where no adaptation measures are applied and the hazards are kept constant over time. The following steps are chosen: First, the modelling of climate effects is used in a simplified manner. For this purpose, results of global, and in many cases regionalized, models are available in the literature and can be processed for use in the respective country with limited effort. Second, CRED makes use of historical, national and international data and expert advice. It builds on nationally available knowledge for the translation of damages and the effects of adaptation measures into monetary terms or enables national decision-makers and experts to transfer internationally available knowledge to their country contexts. National damage data of recent EWE can directly be used. Third, CRED brings together national climate change experts and decision-makers for socio-economic long-term planning, so that the effects of climate change and adaptation measures are best understood and long-term planning is improved in this knowledge. Macroeconomic models are the core of this process, as different national stakeholders can bring in their specific knowledge, and evaluate and discuss different adaptation options among each other along with the modelling results.

The implementation of the CRED approach in the three countries has taken place under different conditions. Table 1 shows a variety of differences, but also similarities in key characteristics in the countries.

In general, we implemented two different types of models and both model types have proven to be useful. In Georgia and Kazakhstan, we established macro-econometric (dynamic) economy-energy-emission (E3) models and in Vietnam a Dynamic General Equilibrium (DGE) model.

The E3 models are implemented in Microsoft Excel using the model-building framework DIOM-X (Dynamic Input-Output Models in Excel; Großmann and Hohmann 2019). Behavioural parameters are estimated econometrically based on time-series data. They are less price-sensitive in the feedback mechanisms compared to equilibrium models. They are demand-side driven but also consider supply-side effects. Climate impacts and adaptation measures are implemented by adjusting appropriate model variables such as productivity, investments, or sector prices.

Dynamic General Equilibrium models are a standard macroeconomic tool that uses representative optimizing agents to assess the impact of different policy measures, as they allow for a detailed breakdown of the economy. Accounting for different productivities across sectors allows us to understand how each of them evolves in the presence of varying climate circumstances. To consider the impact of climate change, the model uses sector and region-specific damage functions that affect labor and capital productivity. A central requirement for modelling the structural effects of climate change and adaptation measures is that in all models the economy is divided into different economic sectors such as agriculture and energy. Further, the models for Kazakhstan and Vietnam even allow for regionalization.

For all countries, the baseline scenario builds on long-term planning regarding GDP development and assumes no new policies for the environmental issues addressed and thus provides a benchmark against which policy scenarios can be assessed. Climate change and adaptation scenarios were designed comprising information and data on the most relevant climate hazards, their sector-specific impacts as well as suitable adaptation options. We embed our analysis in the RCP (representative concentration pathways) and SSP (shared socioeconomic pathways) framework to simulate different climate change scenarios.

The economy-wide effects of investments in different adaptation options are assessed. This allows us to compare a set of adaptation measures and thereby identify those measures (or a combination thereof) contributing the most to economic development. The selection of adaption measures is based on the national experts' opinions and the availability of data. Results from national sector models and analyses are used as inputs into macroeconomic models. Model results are complemented by other information available in the countries. Furthermore, for socio-economic development, the climate damages need to be translated into monetary terms. Monetary data on previous damage events in countries proved to be an important source in this regard.

Table 1
Key features of the three country models

	Georgia	Kazakhstan	Vietnam
Available data	Macroeconomic and sectoral data Labour market data (employment, wages) (limited availability for) climate scenarios, damage data and CBA of adaptation options		
	Energy balances	Energy balances and prices	
Regionalization	no	16 regions	6 economic regions
Model type	e3.ge model (economy-energy-emission)	e3.kz model (economy-energy-emission)	DGE-CRED model
Modelling specifics	Excel-based model framework (DIOM-X[4]) Macro-econometric (dynamic) Input-Output model Extended by environmental aspects such as energy balance, energy prices and emissions		MATLAB-based model framework
	Simulation model with a mid to long-term perspective (until 2050)		
Quantified climate change impacts	• Heat waves • Extreme precipitation / flood • Extreme winds • Sea-level rise	• Heat waves • Extreme precipitation / flood • Extreme winds • Droughts	• Temperature increase • Forest fires • Storms • Sea-level rise • Landslide
Evaluated adaptation measures	*agriculture sector* • Investing in rehabilitating and expanding irrigation systems • Investing in windbreaks *tourism and infrastructure sector* • Investing in (re-) construction of coastline protection • Investing in climate-resilient roads and bridges	*agriculture sector* • Investing in rehabilitating and expanding irrigation systems • Investing in precision agriculture: the case of parallel driving *energy sector* • Expansion of underground powerlines • Deployment of wind power and energy efficiency improvements in the housing sector *infrastructure* • (Re-)construction of storm-proofed houses • "Green Belt" mass afforestation (Re-) construction of climate-resilient roads	*agriculture sector* • endogenous adaptation to climate change through disinvestment from highly vulnerable to less vulnerable sectors. • private action, which is implicitly modelled by optimising agents. *housing* • build houses with reinforced walls and bricks • raise a house on stilts *forestry* • mixed plantation *transport* • roadbed elevation • poly mere asphalt

Source: GIZ (2022a, b, forthcoming).

[4] DIOM-X: Dynamic Input-Output Modelling Framework in Excel. *Großmann and Hohmann*, 2022, 2019.

We provide simulations until 2050 and divide the economy into different sectors, which is a requirement for modelling the structural effects of climate change and adaptation measures. The climate change and adaptation policy options considered differ due to the natural spatial conditions of the countries, but also due to differences in population density and other socio-economic factors. The agricultural sector is important in all three countries, as agriculture is highly exposed to climate change and accounts for a large share of employment. Measures in transport, buildings and reforestation were considered in at least two countries. The selection is partly influenced by the measures for which data on costs and benefits have already been collected in the country. A detailed description of the approaches in the three countries can be found in the respective country reports (GIZ 2022 a, b, c). A comparison of the key features of the approaches is provided by a global report (GIZ 2022d) and summarized in Table 1.

4 Results

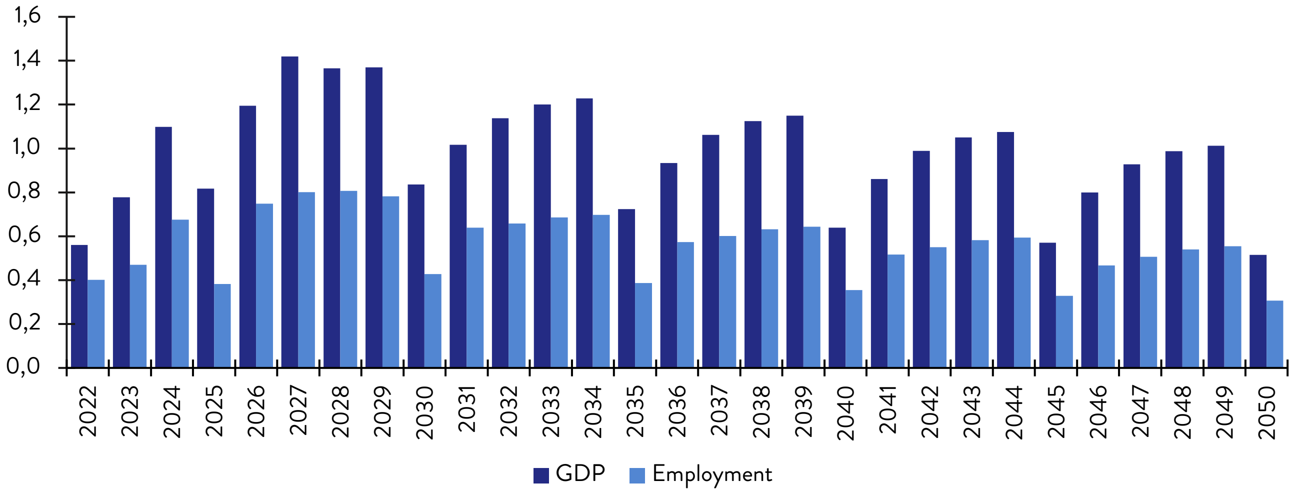
Comparing the macroeconomic impacts of adaptation options provides an opportunity to prioritize adaptation options for the respective sector. Furthermore, modelling results reveal possible synergies or trade-offs with other political priorities such as carbon neutrality. In the following, we present the macroeconomic impacts of selected adaptation measures for each country.[5] Given the different types of models used for each country, this report presents rather a framework of possibilities of adaptation measures and their corresponding impacts than a comparison across countries.

4.1 Georgia

Several climate trends in Georgia have already changed during recent decades, e.g., the frequency and severity of extreme weather events (EWE). For instance, heat waves, droughts and precipitation with more severe landslides occur more frequently. The results of vulnerability modelling and the results of cost-benefit analyses provide the basis for scenario building. For example, CBA on windbreaks available from 2019 allows a precise breakdown of the necessary investments and the potential yields in agriculture that can be achieved. In a second step, the inclusion of the results of the CBA for windbreaks in the macroeconomic model provides information on the indirect and induced effects of higher investments in windbreaks but also raises the question of financing and the possible negative macroeconomic effects if farmers cannot spend the money elsewhere or if state support is then lacking elsewhere. The example shows that it is not enough to quantify economically sensible adaptation measures, but that broader interrelationships and ultimately the sequence of different options should also be compared to best inform policy decisions about the effectiveness of different measures.

5 National specific modelling details are described in the national reports and the global report, respectively. Available at https://www.giz.de/en/worldwide/79266.html

Figure 2
Economy-wide effects of windbreak investments – differences compared to a scenario without adaptation
in %



Source: Own figure based on GIZ (2022a).

Georgia's agriculture sector is expected to be increasingly affected by EWE, such as heavy winds and resulting wind erosion, especially in dryland areas. In the baseline scenario, such an EWE is assumed occurring every five years. GDP will be about 0.3% lower in years with assumed EWEs and 0.1% lower in other years. To evaluate the usefulness of different adaptation options, Georgia's macroeconomic model e3.ge was used to assess the potential effects of investments in windbreaks amongst other adaptation measures.

Figure 2 shows how investments in windbreaks could affect Georgia's GDP and employment level. Compared to a scenario without adaptation, investments in windbreaks result in a yearly increase of up to 1.4% of GDP and up to 0.7% higher employment rates creating to up to 12,000 additional jobs. Such investments have positive sectoral linkages leading to increased wage levels and higher consumption expenditure of up to 1.1% per year compared to a scenario where no adaptation action is taken. From a sectoral perspective, the agricultural sector experiences an increase in production due to increased yields as a result of the windbreaks, but also because the plants required for the windbreaks (seedlings) are grown domestically.

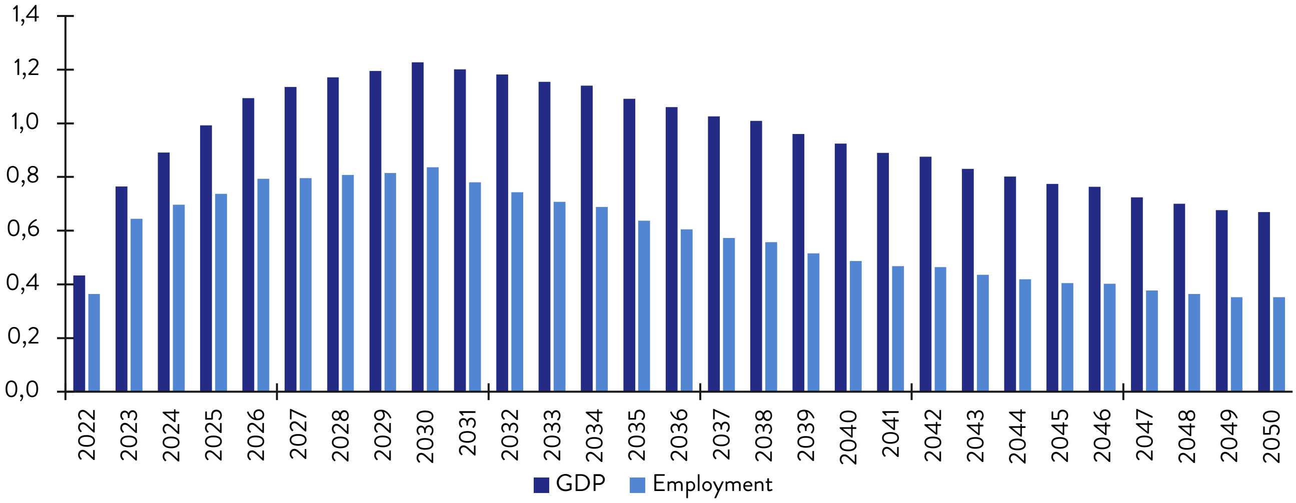
4.2 Kazakhstan

The e3.kz model applied for Kazakhstan shows the potential impacts of climate change and identifies which adaptation options have positive effects on the economy, employment, and emissions (win-win options). In the context of adapting to the increasing occurrence and severity of droughts due to climate change, Kazakhstan's macroeconomic model e3.kz was applied to show the economy-wide effects of investments on the rehabilitation and expansion of irrigation systems in Kazakhstan. Figure 3 shows the impacts of such investments on GDP and employment.

Figure 3

Economy-wide effects of irrigation investments – differences compared to a scenario without adaptation

in %



Source: Own figure based on GIZ (2022b).

Compared to a scenario without adaptation, investments in the agricultural water infrastructure result in an annual increase of up to 1.2% in GDP and up to 0.8% higher employment corresponding to up to 78,000 additional jobs. These investments increase agricultural output, also in years when droughts are not occurring. Other sectors along the value chain are indirectly positively affected, for instance, food production or the construction sector, which profits from the rehabilitation and expansion of water canals and reservoirs. A higher growth path leads to an annual rise of energy-related CO2 emissions of up to 0.4%. This identification of potential trade-offs with mitigation efforts is crucial to lay the foundation for additional mitigation actions.

4.3 Vietnam

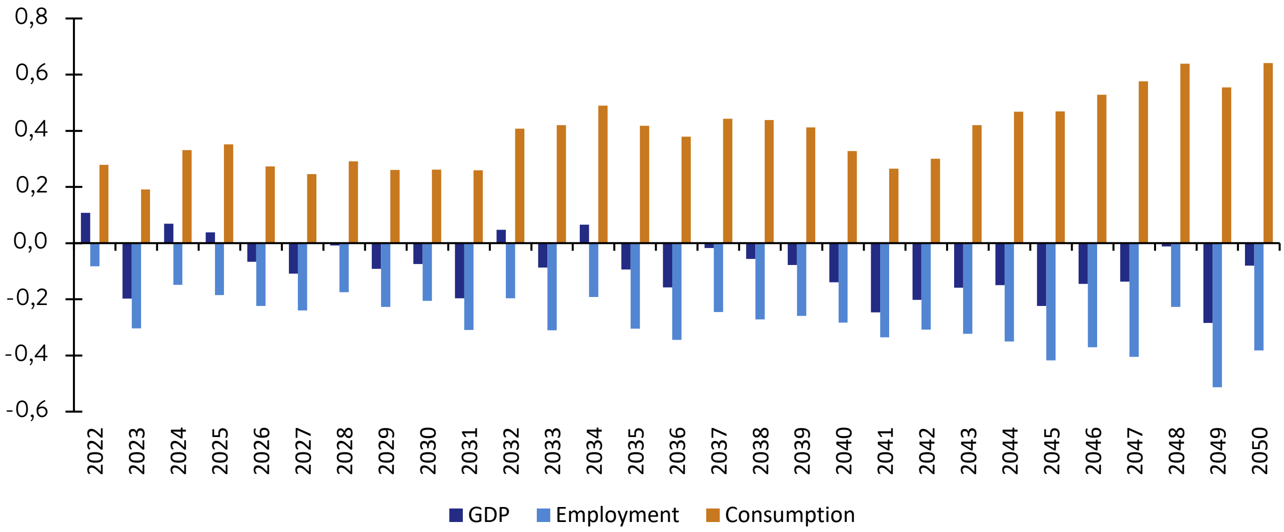
Vietnam is projected to be one of the countries most severely affected by climate change and EWE, particularly vulnerable to rising sea levels. Furthermore, the foreseeable higher intensity of cyclones and typhoons will put increasing pressure on Vietnamese infrastructure and inhabitants. Therefore, shifting investment to more climate-resilient sectors and addressing the vulnerability of sectors particularly affected by climate change is of utmost importance. To consider the impact of climate change, the model uses sector and region-specific damage functions that affect labour and capital productivity. Different Shared Socioeconomic Pathways (SSP), including IPCC's SSP119, 245 and 585 (scenarios with low, medium and high levels of mitigation challenges), provide a series of projections to examine how society, demographics, and economics might evolve over the next century on a global scale.

Our results indicate that climate change will negatively impact Vietnam's GDP, which is consistent with previous findings in the literature. The model results imply that lower productivity due to climate change leads to more investment into capital stock and lower consumption levels.

Figure 4

Economy-wide effects of an investment in dykes – differences compared to a scenario without adaptation

in %



Source: GIZ, forthcoming (own illustration).

Among the evaluated adaptation measures the upgrading of the dyke system is the most important one. Figure 4 shows the impacts on consumption and GDP when dykes are being built as an adaptation measure under the SSP 585 scenario in comparison to no adaptation investments. Importantly, the adaptation measure has a positive impact on social welfare as illustrated by the consistently higher consumption in comparison to no adaptation. It should be noted that the construction of dykes is associated with lower GDP (and investments) and employment in the short, medium and long run, as the dykes prevent damages to the capital stock by e.g. floods, which in turn leads to fewer investments in reconstruction. This shows that looking beyond the pure effects on GDP is important for a comprehensive understanding of the economic impacts of climate change and relevant adaptation investments, i.e. positive impact on private consumption.

5 Discussion

For Georgia, two adaptation options, investments in irrigation systems and windbreaks, were examined. The analyses show that adaptation measures provide co-benefits: On the one hand damages in years with climate change effects be reduced and on the other hand crop yields can be increased every year. Similar results are reported for adaptation for the agriculture, energy and infrastructure sector in Kazakhstan. In Vietnam, each adaptation measure itself yields high returns in relation to its estimated costs.

The usage of different modelling approaches always raises the question of which approach is most appropriate. Models are based on different theories of macroeconomic interrelationships, which, depending on the country, the economic structure, the economic situation and the question at hand, are differently suited to depicting the economic effects of climate change and adaptation measures (Nikas, 2019). They also converge in part because all models have inherent weaknesses in what they can given that they are a simplification of reality. Especially about climate change, many research questions are also still open.[6]

The climate change impacts considered differ due to the natural spatial conditions of the countries, but also due to differences in population density and other socio-economic factors. For example, it must be taken into account that certain EWEs like heat waves or storms have different effects and thus comparable climate impacts have different effects and cause different damages in different countries.

Accordingly, the policy options evaluated partly differ from country to country, though the agricultural sector plays an important role in all three countries, being highly exposed to climate change. Adaptation measures in the countries differ depending on the focus of cultivation. Measures in transport, buildings and reforestation were considered in at least two countries. The selection is partly influenced by the availability of data on their costs and benefits in each country.

6 Conclusions

In the face of climate change, policy advice for climate-resilient economic development is becoming increasingly important. The main challenges for policymakers in emerging and developing economies are the assessment of climate change impacts on economic growth and the identification as well as the implementation of policies to make countries more resilient to climate change. The CRED approach helped to quantify the socio-economic impacts of climate change and design specific adaptation measures as part of long-term strategies. The proposed framework supports understanding and mitigating the economic and social risks due to climate change. In all three countries, raising awareness of the need to adapt to climate change, information sharing and communication on current and projected climate risks, as well as capacity development on climate change adaptation and the impacts on economic development have triggered and enabled climate resilient planning. Based on expert knowledge as a key input for our modelling tools, our results contribute to accomplishing national adaptation goals in national climate strategies, national adaptation plans and NDCs. However, the data availability and quality determine the quality of the results. To limit the trade-offs, mitigation and adaptation action should be considered in a holistic approach to combat climate change. Mitigation should be climate resilient, and adaptation should not lead to an increase in GHG emissions. Furthermore, adaptation measures that primarily support the domestic economy are even more beneficial.

[6] See *EU Commission* (2021) and *Rising* (2022) for further information.

References

Acevedo, S.; Mrkaic, M.; Novta, N.; Pugacheva, E.; Topalova, P.: The Effects of Weather Shocks on Economic Activity: What Are the Channels of Impact?, in: Journal of Macroeconomics Vol.65, September 2020, https://doi.org/10.1016/j.jmacro.2020.103207.

Aguiar, A.; Chepeliev, M.; Corong, E. L.; McDougall, R.; van der Mensbrugghe, D.: The GTAP Data Base – Version 10, in: Journal of Global Economic Analysis, Vol. 4 (1), 1–27, 2019, https://doi.org/10.21642/JGEA.040101AF.

Batten, S.: Climate Change and the Macro-economy: A Critical Review. Bank of England Working Paper Series, Nr. 706, 2018.

Batten, S.; Sowerbutts, R.; Tanaka, M.: Let's Talk about the Weather: The impact of Climate Change on Central Banks. Bank of England Working Paper Series, Nr. 603, 2016.

Cavallo, E.; Noy, I.: Natural Disasters and the Economy – A Survey, in: International Review of Environmental and Resource Economics, Vol. 5 (1), 63-102, 2011, http://dx.doi.org/10.1561/101.00000039.

Chateau, M.; Bibas, R.; Lanzi, E.: Impacts of Green Growth Policies on Labour Markets and Wage Income Distribution: A General Equilibrium Application to Climate and Energy Policies. OECD Working Paper Series, Nr. 137, 2018.

Ciccarelli, M.; Marotta, F.: Demand or Supply? An Empirical Exploration of the Effects of Climate Change on the Macroeconomy. ECB Working Paper Series, Nr. 2608, 2021.

European Commission: Directorate-General for Climate Action [Ebrey, R.; Ruiter, M.; Botzen, W. et al]. Study on Adaptation Modelling: Comprehensive Desk Review: Climate Adaptation Models and Tools. Publications Office, 2021, https://data.europa.eu/doi/10.2834/280156.

GIZ: Supporting Climate Resilient Economic Development in Georgia. Application of the e3.ge Model to Analyze the Economy-wide Impacts of Climate Change Adaptation [Flaute, M.; Reuschel, S.; Lutz, C.; Banning, M.; Hohmann, F.]. Bonn and Eschborn, 2022a, https://downloads.gws-os.com/giz2022-en-supporting-climate-resilient-economic-development-in-georgia.pdf.

GIZ: Supporting Climate Resilient Economic Development in Kazakhstan. Application of the e3.kz Model to Analyze the Economy-wide Impacts of Climate Change Adaptation [Großmann, A.; Hohmann, F.; Lutz, C.; Reuschel, S.]. Bonn and Eschborn, 2022b, https://www.giz.de/de/downloads/giz2022-en-supporting-climate-resilient-economic-development-in-kazakhstan.pdf.

GIZ: Supporting Climate Resilient Economic Development in Vietnam. Economic Impacts of Climate Change and Adaptation: An Application of the "Dynamic General Equilibrium Model for Climate Resilient Economic Development" (DGE-CRED) [Drygalla, A.; Heinisch, K.; Schult, C.]. IWH Technical Report, Halle (Saale), forthcoming.

Großmann, A.; Flaute, M.; Lutz, C.; Hohmann, F.; Banning, M.: Modeling Climate Resilient Economic Development, in: Walter Leal Filho, Marina Kovaleva, Fatima Alves, Ismaila Rimi Abubakar (eds), Climate Change Strategies: Handling the Challenges of Adapting to a Changing Climate. Springer Nature, 2023, forthcoming.

Großmann, A.; Hohmann, F.: Macroeconomic Modelling for Climate Policy Planning. Impact Analysis with an Excel-based E3 (Economy-EnergyEmission) Model Building Framework. Bonn, 2022, https://downloads.gws-os.com/giz-2022-EN-CRED-macroeconomic-modelling-for-climate-policy-planning.pdf.

Großmann, A.; Hohmann, F.: Static and Dynamic Input-Output Modelling with Microsoft Excel. SHAIO Conference Paper, 2019, https://downloads.gws-os.com/GrossmannHohmann2019_DIOM-X.pdf.

Hassler, J.; Krusell, P.: Environmental Macroeconomics: The Case of Climate Change, in: Handbook of Environmental Economics. Ed. by Partha Dasgupta, Subhrendu K. Pattanayak, and V. Kerry Smith. Vol. 4, 2018, Amsterdam: Elsevier. Chap. 8, 333-394, https://www.sciencedirect.com/science/article/abs/pii/S1574009918300081.

Heutel, G.: How Should Environmental Policy Respond to Business Cycles? Optimal Policy under Persistent Productivity Shocks, in: Review of Economic Dynamics, Vol. 15 (2), 2012, 244-264, https://doi.org/10.1016/j.red.2011.05.002.

Hübler, M.; Klepper, G.; Peterson, S.: Costs of Climate Change – The Effects of Rising Temperatures on Health and Productivity, in: Ecological Economics, Vol. 68 (1-2), 2008, 381-393, https://doi.org/10.1016/j.ecolecon.2008.04.010.

Hsiang, S. et al.: Estimating Economic Damage from Climate Change in the United States, in: Science (6345), 2017, 1362-1369, https://www.science.org/doi/10.1126/science.aal4369.

IPCC: Climate Change. Impacts Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, 2022.

Jaumotte, F.; Liu, W.; McKibbin, W. J.: Mitigating Climate Change: Growth-friendly Policies to Achieve Net Zero Emissions by 2050. IMF Working Papers 2021/195, 2021.

Kahn, M. E.; Mohaddes, K.; Ng, R. N. C.; Pesaran, M. H.; Raissi, M.; Yang, J.-C.: Long-term Macroeconomic Effects of Climate Change: A Cross-country Analysis, in: Energy Economics, Vol. 104, 2021, https://doi.org/10.1016/j.eneco.2021.105624.

Kondrup, C. et al.: Climate Adaptation Modelling, in: Springer Climate, 2022, https://doi.org/10.1007/978-3-030-86211-4.

Lehr, U.; Flaute, M.; Nieters, A.; Ahmann, L.; Hirschfeld, J.; Welling, M.; Wolff, C.; Gall, A.; Kersting, J.; Mahlbacher, M.; von Möllendorff, C.: Vertiefte ökonomische Analyse einzelner Politikinstrumente und Maßnahmen zur Anpassung an den Klimawandel, in: UBA Climate Change 43/2020, Dessau-Roßlau, 2020.

Lehr, U.; Lutz, C.: Macro-econometric and Structural Models, in: Soytaş, U.; Sarı, R. (eds), Routledge Handbook of Energy Economics. London: Routledge, 2020, 473–481.

McKibbin, W.; Wilcoxen, P.: The Theoretical and Empirical Structure of the G-Cubed Model, in: Economic Modelling, Vol. 16 (1), 1999, 123-148, https://doi.org/10.1016/S0264-9993(98)00035-2.

McKibbin, W.; Wilcoxen, P.: A Global Approach to Energy and the Environment: The G-Cubed Model. Handbook of CGE Modelling North-Holland, 2013, 995-1068. https://doi.org/10.1016/B978-0-444-59568-3.00015-8.

Nikas, A.; Doukas, H.; Papandreou, A.: A Detailed Overview and Consistent Classification of Climate-Economy Models, in: Doukas, H.; Flamos, A.; Lieu, J. (eds), Understanding Risks and Uncertainties in Energy and Climate Policy. Springer, Cham, 2019, https://doi.org/10.1007/978-3-030-03152-7.

Nordhaus, W. D.: Economic Growth and Climate: The Carbon Dioxide Problem, in: American Economic Review, Vol. 67 (1), 1977, 341-346.

Nordhaus, W. D.: Revisiting the Social Cost of Carbon, in: Proceedings of the National Academy of Sciences, Vol. 114 (7), 2017, 1518-1523, https://doi.org/10.1073/pnas.1609244114.

Nordhaus, W. D.; Sztorc, P.: DICE 2013R: Introduction and User's Manual. Version Second, 2013, https://www.econ.yale.edu/~nordhaus/homepage/homepage/documents/DICE_Manual_100413r1.pdf.

Rising, J. A.; Taylor, C.; Ives, M. C.; Ward, R. E. T.: Challenges and Innovations in the Economic Evaluation of the Risks of Climate Change, in: Ecological Economics, Vol. 197, 107437, July 2022, https://doi.org/10.1016/j.ecolecon.2022.107437.

Steininger, K. W.; Bednar-Friedl, B.; Formayer, H.; König, M.: Consistent Economic Cross-sectoral Climate Change Impact Scenario Analysis – Method and Application to Austria, in: Climate Services, Vol. 1, March 2016, 39–52. https://doi.org/10.1016/j.cliser.2016.02.003.

Vrontisi, Z.; Charalampidis, I.; Lehr, U.; Meyer, M.; Paroussos, L.; Lutz, C.; Lam-González, Y. E.; Arabadzhyan, A.; González Hernández, M. M.; León, C. J.: Macroeconomic Impacts of Climate Change on the Blue Economy Sectors of Southern European Islands, in: Climatic Change, Vol. 170, (27), 2022, https://doi.org/10.1007/s10584-022-03310-5.

World Bank:: World Bank Group Macroeconomic Models for Climate Policy Analysis. Equitable Growth, Finance and Institutions Notes. World Bank, Washington, DC, 2022, https://openknowledge.worldbank.org/handle/10986/36833.

Halle Institute for Economic Research (IWH) –
Member of the Leibniz Association

Kleine Maerkerstrasse 8
D-06108 Halle (Saale)
Germany

P.O. Box 11 03 61
D-06017 Halle (Saale)
Germany

Tel +49 345 7753 60
Fax +49 345 7753 820

www.iwh-halle.de

ISSN 2702-4725