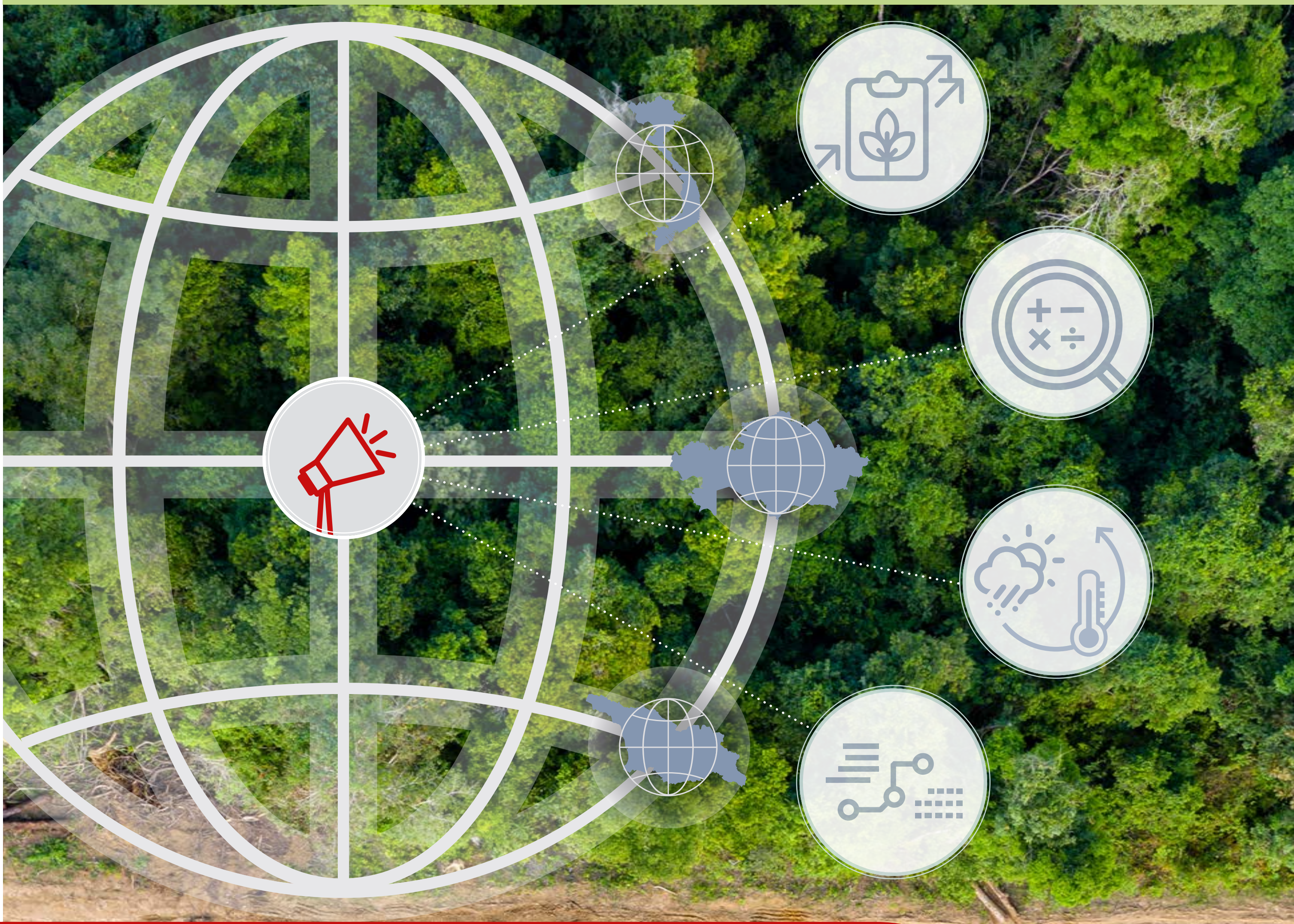

Lessons Learnt from Piloting Macroeconomic Modelling for Climate Resilience

in Georgia, Kazakhstan and Vietnam

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On behalf of German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV)

Germany, 2022

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LIST OF ABBREVIATIONS

AFD	Agence Française de Développement
BAU	Business as usual
CBA	Cost-benefit analysis
CGE	Computable General Equilibrium
CIEM	Central Institute for Economic Management (VIE)
COACCH	CO-designing the Assessment of Climate Change costs
CRED	Climate Resilient Economic Development
DGE	Dynamic General Equilibrium
DIOM-X	Dynamic Input-Output Models in Excel
ERI	Economic Research Institution (KAZ)
EWE	Extreme Weather Event
GDP	Gross domestic product
GEO	Georgia
GFDRR	Global Facility for Disaster Reduction and Recovery
GHG	Greenhouse gas emissions
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
GWS	Institute of Economic Structures Research (Gesellschaft für wirtschaftliche Strukturforschung)
IISD	International Institute for Sustainable Development
IO	Input-Output
IPCC	Intergovernmental Panel on Climate Change
IWH	Halle Institute for Economic Research
KAZ	Kazakhstan
LEDS	Long-term low-emission development strategy
LTS	Long-term strategy
MoESD	Ministry of Economy and Sustainable Development of Georgia
MEPA	Ministry of Environmental Protection and Agriculture of Georgia
NAP	National Adaptation Plan
NDC	Nationally Determined Contribution
PESETA	Projection of Economic impacts of climate change in Sectors of the European Union based on bottom-up Analysis
PIK	Potsdam Institute for Climate Impact Research
R&D	Research and Development
SSP	Shared Socioeconomic Pathways
RCP	Representative Concentration Pathways
UIB	University of the Balearic Islands
UNFCCC	United Nations Framework Convention on Climate Change
VGGS	Vietnam Green Growth Strategy
VIE	Vietnam

GLOSSARY OF KEY TERMS

Adaptation	In human systems, the process of adjustment to actual or expected climate and its effects, in order to mitigate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate and its effects.
Climate change	Climate change refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use. Note that the United Nations Framework Convention on Climate Change (UNFCCC), in its article 1, defines climate change as: 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.' The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition and climate variability attributable to natural causes.
Cost-benefit analysis (CBA)	Monetary assessment of negative and positive impacts associated with a given action. Costbenefit analysis (CBA) enables the comparison of different interventions, investments or strategies and reveals how a given investment or policy effort pays off for a particular person, company or country. CBA representing society's point of view are important for climate change decisionmaking, but there are difficulties in aggregating costs and benefits across different actors and across timescales. CBA are often conducted on a sectoral level and are an important basis for macroeconomic assessments.
DGE model	Dynamic general equilibrium models consider the interaction between demand and supply. Model equations are derived from first principles to make explicit assumptions about the behaviour of the main economic agents in the economy, i.e., households, firms, and the government.
E3 model	An **E3** model is a model covering the demand-and-supply-relationships of an **economy** and its main connections to the environment, i. e. the use of **energy** resources and the input of CO_2 **emissions** into the environment. This integrated modelling approach of the 3Es in one model framework assures a consistent view of possible transition pathways. It enables to calculate macroeconomic and sector-specific impacts as well as conclusions to be drawn on social balance and ecological benefits.
Hazard	The potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources.
Resilience	Resilience is defined as the ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a potentially hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions.
Risk	The potential for adverse consequences where something of value is at stake and where the occurrence and degree of an outcome is uncertain. In the context of the assessment of climate impacts, the term risk is often used to refer to the potential for adverse consequences of a climate-related hazard, or of adaptation or mitigation responses to such a hazard, on lives, livelihoods, health and wellbeing, ecosystems and species, economic, social and cultural assets, services (including ecosystem services), and infrastructure. Risk results from the interaction of vulnerability (of the affected system), its exposure over time (to the hazard), as well as the (climate-related) hazard and the likelihood of its occurrence.
Scenario	A plausible description of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces (e.g., rate of technological change, prices) and relationships. Note that scenarios are neither predictions nor forecasts but are used to provide a view of the implications of developments and actions.
Vulnerability	Vulnerability is defined as the propensity or predisposition to be adversely affected. In the field of disaster risk, this includes the characteristics of a person or group and their situation that influences their capacity to anticipate, cope with, resist, and recover from the adverse effects of physical events.

Source: Based on IPCC (2018) for climate-related terms.

EXECUTIVE SUMMARY

Climate change poses a major challenge to long-term economic development. **The global programme "Policy Advice for Climate Resilient Economic Development" (CRED) supports long-term economic planning that considers the costs of climate change and the benefits of mitigation and adaptation**. The project has been implemented in **Georgia, Kazakhstan and Vietnam** that are highly affected by climate change. In close collaboration with national political partners, CRED supports the countries in developing climate resilient development plans and economic development strategies. It developed a **framework (CRED approach) that helps to understand and mitigate the economic and social risks due to climate change**. This also contributes to accomplishing national adaptation goals in national climate strategies, adaptation plans (NAPs) and Nationally Determined Contributions (NDCs), while maintaining competitiveness and increasing prosperity.

All steps and model types mentioned in current typologies for adaptation models are required for the **CRED approach**, but the main contribution and focus is on the **implementation of country-specific macroeconomic models**. 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. The targeted outcome is to provide **methods and instruments to analyse and plan climate resilient economic development**. It is tied to three different outputs, capacity building, policy advice and the dissemination of the CRED results.

In the scientific literature, there are various approaches for estimating the macroeconomic impacts of climate change. The CRED approach goes beyond these ones in several ways, especially **considering the specific conditions in emerging economies**. First, results of global and in many cases regionalized climate models are used 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 in this knowledge. Macroeconomic models are the core of this process to evaluate and discuss different adaptation options along with the modelling results.

This report presents experiences and results of the implementation. It provides an **overview of selected approaches and compares experiences in the countries** under investigation. For Georgia, investments in irrigation systems and windbreaks were examined as adaptation options. The analyses show that adaptation measures provide co-benefits: not only can the damages in years with climate change effects be reduced, but also crop yields in every year can be increased. 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 their estimated costs.

The CRED experiences are documented in detail in the national reports for the three pilot countries. A comparison shows a variety of differences, but also similarities in key characteristics in the countries: While **structures of underlying macroeconomic and labour market data in all three countries are similar** although with varying sector classifications, **the climate-related data, economic structures, and policy options are different**.

Two different kinds of macroeconomic models are applied: In Vietnam, a Dynamic General Equilibrium (DGE) model has been implemented with the software MATLAB. The model puts greater emphasis on 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 solution problems, which can complicate its use by model builders. In Kazakhstan and Georgia, similar **macroeconometric economy-energy-emission (E3) models** based on Microsoft Excel are applied. They are more demand side oriented and less price-sensitive in the feedback mechanisms. All three models 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.

GEORGIA	KAZAKHSTAN	VIETNAM
Adaptation ... **in the agriculture sector:** • Investing in rehabilitating and expanding irrigation systems • Investing in wind breaks **in the tourism and infrastructure sector:** • Investing in (re-)construction of coastline protection • Investing in climate resilient roads and bridges	**Adaptation ...** **in the agriculture sector:** • Investing in rehabilitating and expanding irrigation systems • Investing in precision agriculture: the case of parallel driving **in the energy sector:** • Expansion of underground powerlines • Deployment of wind power and energy efficiency improvements in the housing sector	**Adaptation ...** **in the 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. **in housing:** • build houses with reinforced walls and bricks • raise a house on stilts

››› see more in *Table 1*

Integration of modelling results in economic processes requires the consideration of entry points and enabling factors. Entry points are windows of opportunities such as a high-level policy mandate when the modelling can support a national long-term policy strategy. A combination of key factors, or enablers, is required to support the effective use and uptake of climate economic modelling results in economic development. For all three countries, raising awareness of the need to adapt to climate change, information sharing and communication on current and projected climate risks, and capacity development on climate change adaptation and the impacts on economic development have triggered and enabled climate economic modelling.

This report documents the Lessons Learnt and the success factors regarding data, development of modelling tools, capacity building, and integration of results into the policy process. They are in some cases country-specific; others hold for all three countries. A general common understanding, close cooperation, early identification of national partners, clear definition of their roles as model builders or model users, and the early availability of a model framework with which to start quickly are essential. The approaches implemented in the three pilot countries are an excellent basis for this.

In the face of climate change, every country is well advised to take foreseeable changes into account when planning its long-term economic development. Against this background, policy advice for climate resilient economic development is becoming increasingly important. The good news from the CRED project is that it is **feasible to quantify socio-economic impacts of climate change and design specific adaptation measures as part of long-term strategies**. Setting this framework for climate resilient economic development helps to mitigate the economic and social risks due to climate change.

Another advantage of the models is that they can quickly **inform policies on other economic issues and structural breaks**, such as the effects of measures against the COVID-19 pandemic or the impact of the war in Ukraine on Georgia.

In summary, the **CRED** approach encompasses a model-based process that builds on existing knowledge in the respective country and **promotes capacity building**, supports climate resilient economic development, **delivers respective policy advice, and enables institutions in the country to flexibly quantify new climate risks and adaptation measures and make findings usable for the political process**.

1 INTRODUCTION

Climate change poses a major challenge to long-term economic development. On the one hand, the window is closing on limiting global warming to below 2 degrees, preferably 1.5 degrees, above pre-industrial levels, as set out in the 2015 Paris Climate Agreement. The latest IPCC (2022a) report confirms the urgency to act quickly and comprehensively: if the target is still to be reached, climate mitigation efforts such as investments in renewable energies, energy efficiency and reforestation must be increased much faster than in recent years. New technologies and production and consumption patterns must be developed. At the same time, climate change is already underway and will continue to accelerate in the coming 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).

Against this background, the global programme "Policy Advice for Climate Resilient Economic Development" (CRED)[1] aims to support long-term planning to address climate change risks with appropriate adaptation measures. Decision-makers in partner countries are enabled to quantify the impacts of climate change and adaptation measures in the context of macroeconomic long-term development. The CRED programme supports the partner countries in developing climate resilient development plans and economic development strategies. Setting this framework for climate resilient economic development helps to mitigate the economic and social risks due to climate change. This also contributes to accomplishing national adaptation goals in national climate strategies and adaptation plans (NAPs) and Nationally Determined Contributions (NDCs) while maintaining competitiveness and increasing prosperity of all. The CRED programme is implemented in close collabouration with political and implementing partners in Georgia (GEO), Kazakhstan (KAZ) and Vietnam (VIE).

At the end of 2019, CRED launched its capacity building programme and corresponding measures have been implemented in the three pilot countries until 2022. Three national macroeconomic models have been developed in cooperation with national partners to capture the economic effects of climate change and adaptation options in the context of long-term economic development. Staff of leading executing agencies have been trained to use the models independently and to integrate the results into the policy-making process.

This global report presents key experiences and results of the implementation in the three pilot countries Georgia, Kazakhstan and Vietnam relevant for all those who are facing national development planning processes, NDCs, and/or NAPs. Particularly this includes national planning institutions, development cooperation actors, international organizations and other potential users of the approach.

1 *https://www.giz.de/en/downloads/giz2021-en-project-brief-climate-resilient-economic-development.pdf (last accessed October 20,2022)*

THE REPORT PRESENTS:

- A general description of the CRED approach of model-based policy advice that integrates the effects of climate change and adaptation to climate change into long-term policy strategies.
- An overview of selected approaches and comparing experiences in Georgia, Kazakhstan and Vietnam, explaining similarities and differences in terms of data availability and collection, modelling approach, benefits and challenges.
- Lessons learnt for other countries to find a suitable approach for using climate economic modelling results to support climate resilient development.

The three countries under investigation are not only different regarding their landscapes, exposure and vulnerability to climate change and suitable climate change adaptation measures, but also in terms of socio-economic development, modelling experience and data availability. For this, the report investigates the various stages of how the CRED approach was set up and identifies Lessons Learnt for various country-specific contexts, institutional landscapes and settings. This includes first practical steps to anyone, who wants to reproduce the CRED approach: How to introduce the approach, whom to train, where to anchor the knowledge, how to set up the process of identifying the relevant research questions, and how and to whom to communicate the results.

2 THE CRED APPROACH
GENERAL OVERVIEW

For policy making, different instruments, methods and models are needed to support decision making. The macroeconomic evaluation of the consequences of climate change that builds on climate modelling and cost-benefit (micro) analyses of different adaptation measures should be considered together with these analytical steps when designing adaptation policy.

A recent comprehensive desk review for the EU Commission developed an adaptation modelling typology, which ranges from climate system modelling, over hazard, exposure and vulnerability modelling, sectoral models for impact and adaptation assessment to economic models (*Figure 1: Adaptation modelling typology*). All steps and model types are required for the CRED approach. Results from sector models and analyses are used as inputs into the macroeconomic models that are in the focus of this report. The model results will be complemented by other techniques and information available in the countries.

Figure 1: Adaptation modelling typology

Climate system / Social-Economic system / Environmental system

MODELS

Climate modelling (for adaptation)	Hazard, exposure and vulnerability modelling	Sectoral models for impact and adaptation assessment	Economic models for impacts and adaption assessment	Other techniques	How to use the information (principles and methods)
Climate models which provide inputs or risk, impact and adaptation assessments.	Models and techniques which utilise climate variables to develop climate risk assessments. These provide inputs further processed by impact models such as crop and energy models, detailed under 'sectoral models for impact and adaptation assessment'.	These models process ‚hazard, exposure and vulnerability modelling' outputs to quantify the impact of climate change on sectors that provide essential services to society, the environment and the economy. These can support identifiying adaptation options.	Top-down macro-economic models inform the choice of adaptation measures, or mix of measures and policies, often under substantial and non-reducible, deep uncertainty. Other economic assessments test strategies to support the uptake of adaptation measures	Futher analysis, using qualitative or semi-qualitative techniques, that support adaptation assessments.	Scrutiny of analytical „conceptual frameworks" and of methodologies that substantiate them in adaptation analyses.
Country specific input			**Macroeconomic model**	**Policy Integration**	

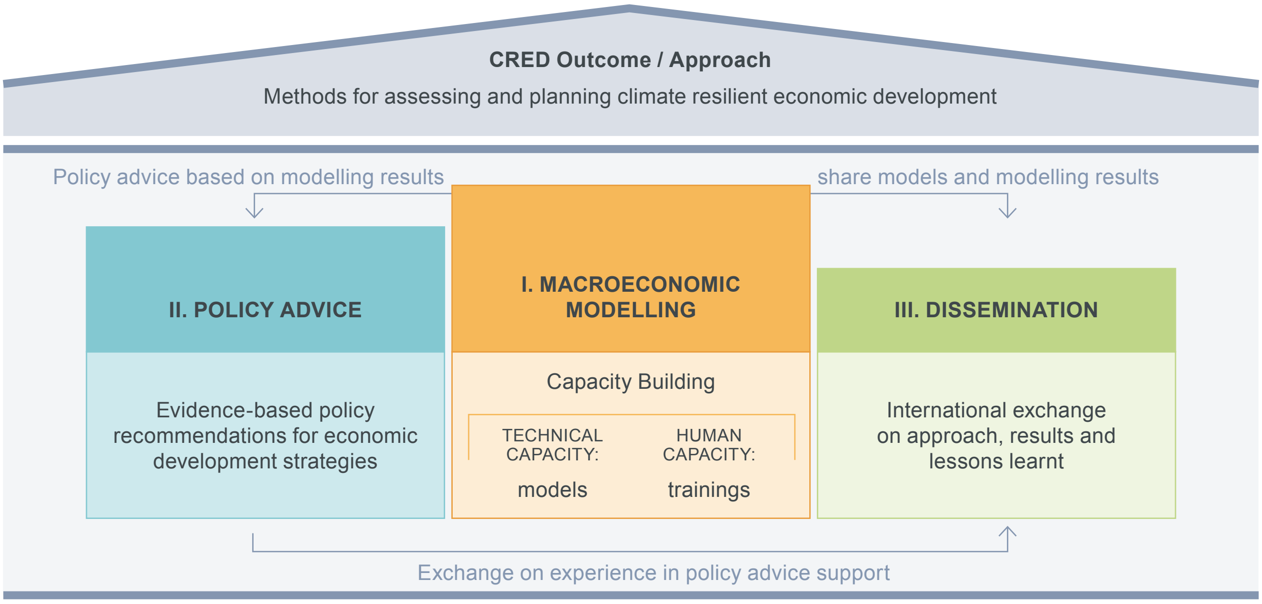
Source: Own illustration based on EU 2021d, p.6

To enable climate resilient economic development, it is essential that countries strengthen their ability to understand, plan for and continuously manage climate risk for their key economic processes. Macroeconomic modelling can make a major contribution to actionable, evidence-based policymaking for enhancing economic resilience. For the analysis of mitigation of climate change, mainly international models are available.[2]
In contrast, there are only a few country models or models at country or even regional level that have been used to quantify the economic impacts of climate change and adaptation measures (Lehr et al. 2020, Vrontisi et al. 2022). Accordingly, in many countries, capacities for the assessment of country-specific climate change impacts on economic development via quantitative modelling are insufficient. Policymakers need reliable economic models for anticipated climate impacts and adaptation options. These are necessary to decide upon effective direct economic policy and fiscal policy instruments that lead to resilient economic development by improving adaptation capacities and reducing the vulnerability of the economy, environment, and population.

The CRED programme supports evidence-based policymaking on adaptation to climate change at the national level. Together with its partners in Georgia, Kazakhstan and Vietnam, the CRED project pilots economy-wide assessments of climate change impacts and respective adaptation measures. Country-specific macroeconomic models have been developed together with national partners. These models provide key information for policy makers: First, the modelling results show how different climate hazards impact the economy up to the year 2050. Second, economy-wide effects of investments in different adaptation options are assessed. This allows to compare a set of adaptation measures and thereby to identify those measures (or a combination thereof) contributing the most to economic development. For example, the energy sector in Kazakhstan is affected by heat waves which increase the electricity demand for cooling and limit the electricity generation from hydropower and thermoelectric power plants. Therefore, it is beneficial to combine adaptation measures – in this case, energy efficiency measures and wind power expansion – to maintain energy security (GIZ,2021a).

The targeted outcome is to provide methods and instruments to analyse and plan climate resilient economic development. This also supports the implementation of the adaptation components of the NDCs. The outcome is tied to three different outputs, which are capacity building, policy advice and the dissemination of the CRED results, illustrated in the *figure 2 below*.

Figure 2: Outcome and outputs of the CRED programme



Source: GIZ (own illustration)

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

BASIS OF THE APPROACH

The approach is initially based on natural scientific knowledge about the effects of climate change as described in *figure 1*. It involves possible future developments that are described and quantified in various scenarios. This includes among others climatic changes in the form of temperature, wind speed and precipitation, both on average and in extremes, which play a major role in the vulnerability as well as impacts such as damage caused by climate change. These changes can trigger other processes, such as the spread of pathogens and their vectors. Climate change can also lead to crop losses, which can trigger hunger and, indirectly, migration movements and conflicts. For socio-economic development, the damages need to be translated into monetary terms. This is a complex process as effects differ by region, depending on natural conditions and socio-economic structures and processes, which change over time. Monetary data on previous damage events in countries proved to be an important source of information in this regard.

In the scientific literature, various approaches to estimating the macroeconomic impacts of climate change are described. Probably the best-known calculations have been made since the early 1990s by Nordhaus (1991), who mapped the linkages between climate change and the global economy in a dynamic model. Based on this, various approaches of impact assessment models (IAMs) have been developed and refined as to how damages can be more differentiated and regionalized. For example, 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. A wide range of quantifications of climate change impacts are also available for the EU and have informed the EU adaptation strategy (EU 2021c). The bio-physical and subsequently socio-economic effects are quantified in a set of different models as part of e.g., the PESETA (Ciscar et al. 2014, Feyen et al. 2020) and COACCH projects (COACCH 2021). However, all these results have been produced in very large projects in terms of both time and funding and cannot simply be replicated in other countries. Rising et al. (2022) state "a large discrepancy between the dire impacts that most natural scientist project we could face from climate change and the modest estimates of damages calculated by mainstream economists." Economic modelling is still struggling with many challenges in this regard according to their recent overview. However, decision-makers in the countries cannot wait until science has answered all questions satisfactorily.

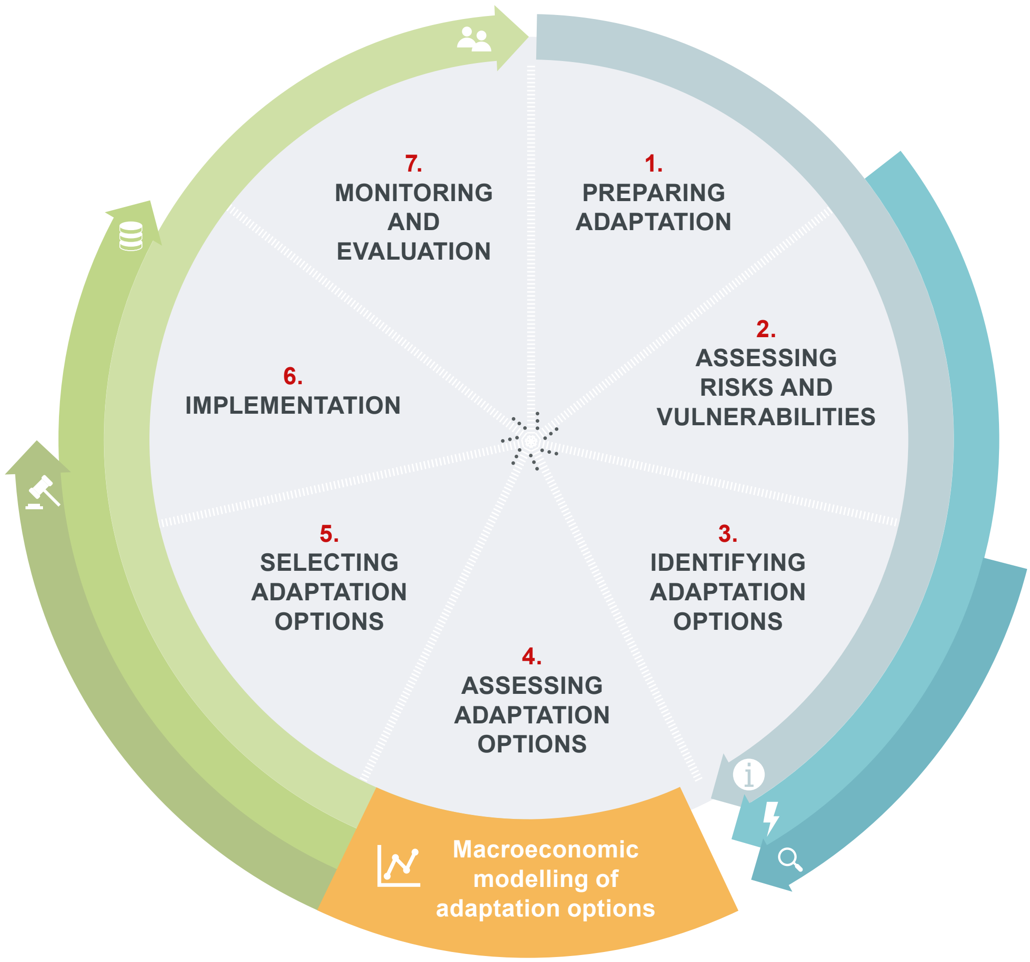
UNIQUE FEATURES OF THE CRED APPROACH

The CRED approach goes beyond these approaches in several ways, especially taking into account the specific conditions in emerging economies. **First** – natural science modelling of climate effects is used in a simplified manner. For this purpose, it is advantageous that many results of global and in many cases regionalized models are available 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 extreme weather events (EWE) can directly be used. Other information can be further processed in sector models such as crop and energy models. **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, evaluate and discuss different adaptation options among each other along the modelling results. This is important because science will make further advances in knowledge in the coming years that can be taken up and directly applied to the specific situation in the countries.

The current results of this process are documented in detail in the national reports of the CRED project[3]. **CRED makes use of a 7-step approach to support adaptation policies at the national level**[4], which is visualized in *Figure 3: Macroeconomic modelling in the adaptation policy cycle*. In phase 1 (blue, step 1-3), the basis for the modelling is created by collecting sectoral and regional data; by assessing the risks and vulnerabilities; and identifying suitable adaptation measures. Data generation includes the translation of climate hazards, vulnerabilities, damages, and climate adaptation options into their impact on socio-economic variables. Phase 2 (orange, step 4) includes the modelling of damages and adaptation options for several sectors and regions. Therefore, the socio-economic model that can process this information has to be developed and maintained. In phase 3 (green, step 5-7), modelling results are combined with additional information. Selected adaptation measures are implemented and can be monitored and evaluated in the future.

Figure 3: Macroeconomic modelling in the adaptation policy cycle



Source: GIZ (2022a) based on ClimateAdapt (n.d.).

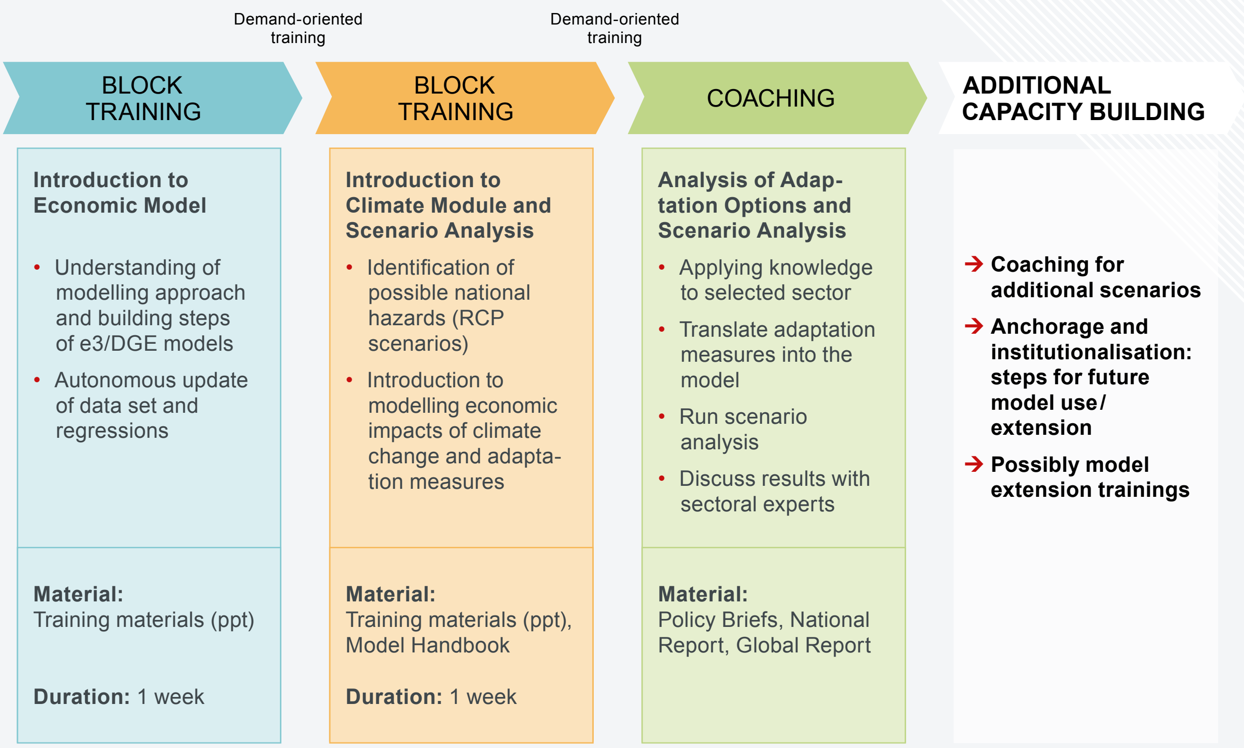
3 *https://www.giz.de/en/worldwide/79266.html (last accessed October 20,2022).*

4 *https://www.giz.de/en/downloads/giz2021-en-cred-macroeconomic-models-for-climate-resilience.pdf (last accessed October 20,2022).*

During the trainings by the CRED team, both model builders and model users were targeted. The former were involved in implementing the national models, given their (macroeconomic) modelling experience and their role in the respective partner institutions. Model users were involved in the training on interpretation of results and simulation analysis, they do not need detailed macroeconomic modelling knowledge, but can contribute specific knowledge about sectors, actors or policy processes. In general, the training in all countries covered, on the one hand, theoretical background and on the other hand, provided practical sessions for the application of the tools. The participants are staff of the partner institutions and other selected candidates from institutions that are involved in the policy process.

The following *Figure 4: Training programme for capacity building* gives an overview of the training and coaching process: First, the basics of the macroeconomic models were taught. Then the procedure of how to integrate the impacts of climate change using scenario analysis were presented. Subsequently, the analysis of adaptation measures was conducted in the form of coaching. At the end, there was a need for additional capacity building for the interpretation of results or wider use of the models. All these steps have been adapted in the countries according to demand and circumstances.

Figure 4: Training programme for capacity building



Source: GIZ (own illustration).

These various steps represent a challenge for successful implementation, both individually and in combination. This is because the process requires various complex skills among national experts and the willingness and ability to cooperate and to progress on a common ground of understanding of all stakeholders and especially of the national implementing partners.

This includes:

- The common understanding of climate and socio-economic data.
- The common understanding of climate and socio-economic modelling and linkages among each other.
- The ability to simulate the socio-economic development in line with political long-term planning in scenario analyses.
- The ability to quantify climate change damages, impacts and adaptation actions in this system context.
- Detailed knowledge of the policy processes for the preparation of long-term strategies (LTS) including NDCs and NAPs.

In all these areas, extensive specialized knowledge is needed for the whole CRED process. Expertise and knowledge are linked to the economic model implementation and its application during the capacity building within CRED, which is focused on making existing knowledge available for the whole process. Beyond the technical implementation, the appropriate institutional framework plays a central role for the success of the approach. The various types of information available at national and international level must be collected and linked in the best possible way. The national institutionalization of model use and maintenance is crucial. This anchoring requires clear responsibilities for major stakeholders. This process is detailed in the case of Georgia in GIZ (2022b). The stakeholders' roles must be clearly defined for a fruitful cooperation in the future. Within the CRED project, a practitioner's guide has been developed by experts from the International Institute for Sustainable Development (IISD) to facilitate these complex processes[5]. The framework identifies nine indicative entry points around planning, budgeting and financing, implementation, monitoring, evaluation, and learning. It gives advice on how to select a promising one. Different factors should be considered for assessing the entry points, from modelling and policy cycle to climate adaptation status. The framework includes eight enabling factors such as leadership, capacities, information and communication and institutional arrangements, which support the effective use and uptake of climate resilient economic modelling. The enablers and entry points reinforce each other and are closely linked. For the transferability of the approach to other countries and the concrete start of the process, the guide provides valuable information on how it can successfully be implemented in a country.

Based on all these steps and information, the CRED approach makes an important contribution to the integrated long-term planning of economic development, climate mitigation and adaptation to climate change, so that the prosperity of the people can be increased due to climate resilient economic development.

5 *https://www.giz.de/en/downloads/giz2021-en-climate-economic-modelling-practitioners-guide.pdf (last accessed October 20,2022)*

3 NATIONAL IMPLEMENTATIONS

→ GEORGIA

→ KAZAKHSTAN

→ VIETNAM

3.1 GEORGIA

Due to climate change climate, hazards and disaster risks as EWE must be regarded as unavoidable in the medium term up to the year 2050. However, the Georgian policy of reducing greenhouse gas emissions (GHG) and adapting to climate change can help to reduce the damage and costs caused by climate change impacts in Georgia as much as possible. Several climate trends in Georgia have already changed during recent decades, e.g., the frequency and severity of EWE like increased heat waves, droughts and precipitation, or increased temperature.

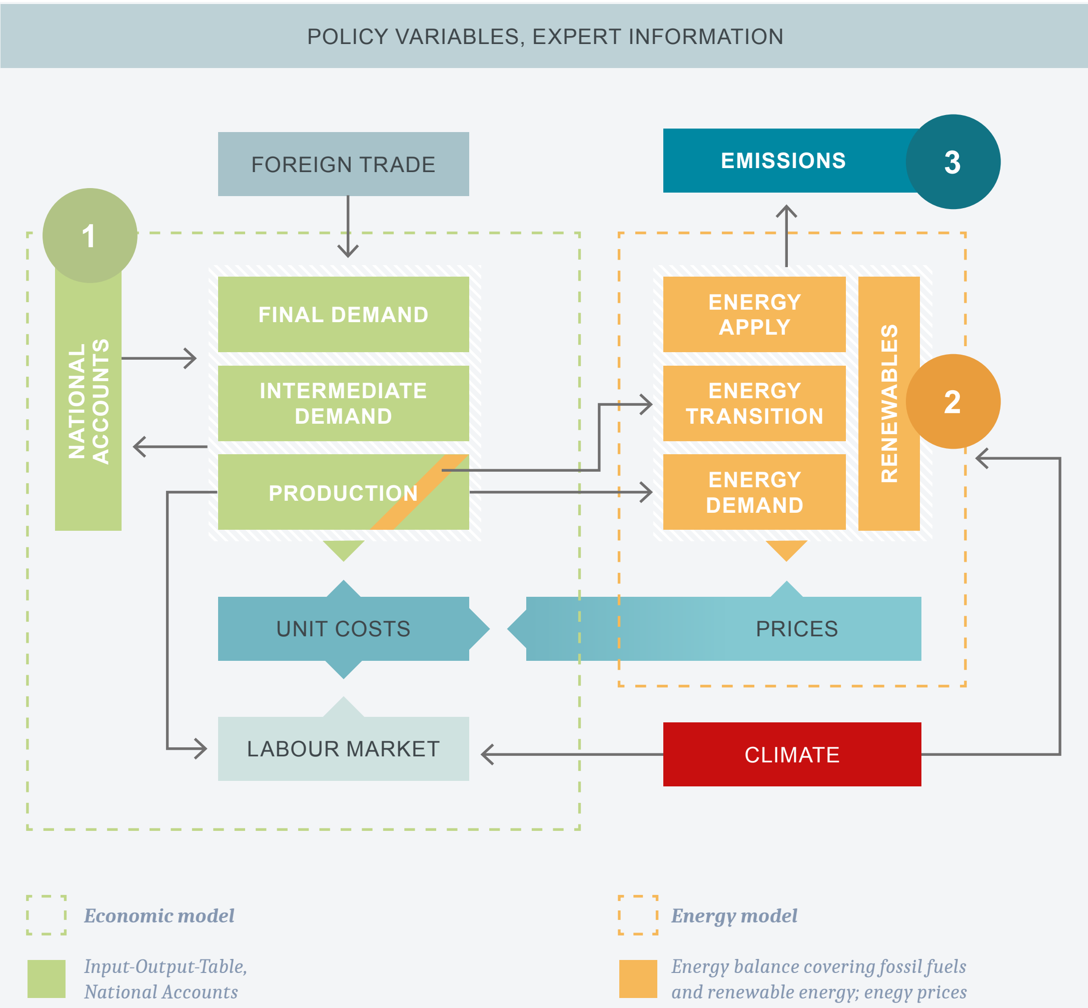
On the night of 13-14th June 2015, intense rainfall resulted in a flash flood, which affected the Georgian capital Tbilisi (see GFDRR et al. 2015). The economic impact was high: transportation was the most affected sector with damages to important streets and routes. The estimated cost of damage to transport was GEL 33.2 million (about 11 million USD), the damages to houses were GEL 16.1 million. Furthermore, the zoo and the water management were affected. Thus, the effects of climate change are striking the Georgian economy, which has undergone a major transformation since the fall of the Soviet Union, growing in double digits due to several economic and democratic reforms. The Tbilisi disaster is an observable sign of the changing climate.

The EWE of the past indicate that there is already a need for climate adaptation today to keep the expected future climate impacts and damage to society, environment and economy low. Being a signatory to different international environmental treaties and agreements (e. g., the United Nations Framework Convention on Climate Change (UNFCCC), and the Kyoto Protocol to the United Nations Framework Convention on Climate Change), Georgia is required to contribute to decreasing GHG emissions, as well as adaptation to climate change in ecosystems and economic sectors (see USAID 2016).

For the implementation, all steps and model types as described in *Figure 1: Adaptation modelling typology* are required for the CRED approach. In particular, results from sector models are used as inputs in the macroeconomic model. The results of vulnerability modelling or accounting and the results of cost-benefit analyses provide the basis for scenario building. For example, cost-benefit analyses on windbreaks from 2019 are available (ISET 2019), which precisely break down the necessary investments and the higher yields in agriculture that can be achieved. The inclusion of the results of the cost-benefit analysis 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, which measures are implemented and how, that have finally to be taken by the government.

To ensure informed policymaking on adaption to climate change, the macroeconomic model e3.ge has been developed in cooperation with the Ministry of Economy and Sustainable Development (MoESD) of Georgia, the Institute of Economic Structures Research (GWS) and the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). The e3.ge model contains three interlinked model parts: the (1) economic model, the (2) energy module and the (3) emissions module. The abbreviation ge denotes the respective country (Georgia). The economic part of the e3.ge model is a macro-econometric (dynamic) Input-Output (IO) model. This modelling allows the determination of climate change effects on macroeconomic indicators like GDP and employment. Furthermore, the model is capable to quantify the economy-wide effects of different adaptation measures to elabourate adaptation strategies that ensure a sustainable development of the economy.

Figure 5: The e3.ge modelling approach



Source: Own figure based on GWS, 2022.

During the CRED programme, Georgian model builders and model users have been trained to anchor the e3.ge model in the country. Model builders are expert staff in the department of Economic Analysis and Reforms Department in the MoESD, which received intense training in model updating, application and extension within the framework of CRED, and the department owns the rights to the model. Model users describes experts from other public institutions in Georgia, currently Ministry of Environmental Protection and Agriculture of Georgia (MEPA) in particular, which use the model for their own issues, such as the development of a new NAP. In the first training sessions, the foundations of the model were explained. This includes the implementation of and interlinkages between the different modules for model builders. Numerous practical exercises were part of the interactive coaching process, again mainly for model builders. In the second training phase, the focus was on implementing the impacts of climate change and adaptation measures to climate change into the model, making increased use of scenario analyses.

Since data forms the basis of the economic model, effort has been put into data research, especially on climate change damages and adaptation. While MoESD provided the necessary data and information for the economic part of the model, a national expert conducted desk research to compile information on climate change effect damages in the past (last 20-30 years) in Georgia and contacted several stakeholders that could possibly share useful information. Throughout the national research it turned out, that there is no single private or public institution where one can find and collect all the required information and data for Georgia. The documentation of climate change damages in monetary terms is unsystematic so far. There are information gaps in the list of occurred EWE (e.g., what happened and when) and moreover, there are gaps or incomplete information on corresponding monetary damages. Moreover, there is only few data available on sector-specific cost-benefit analyses (CBA) for different adaptation measures needed as input for e3.ge.

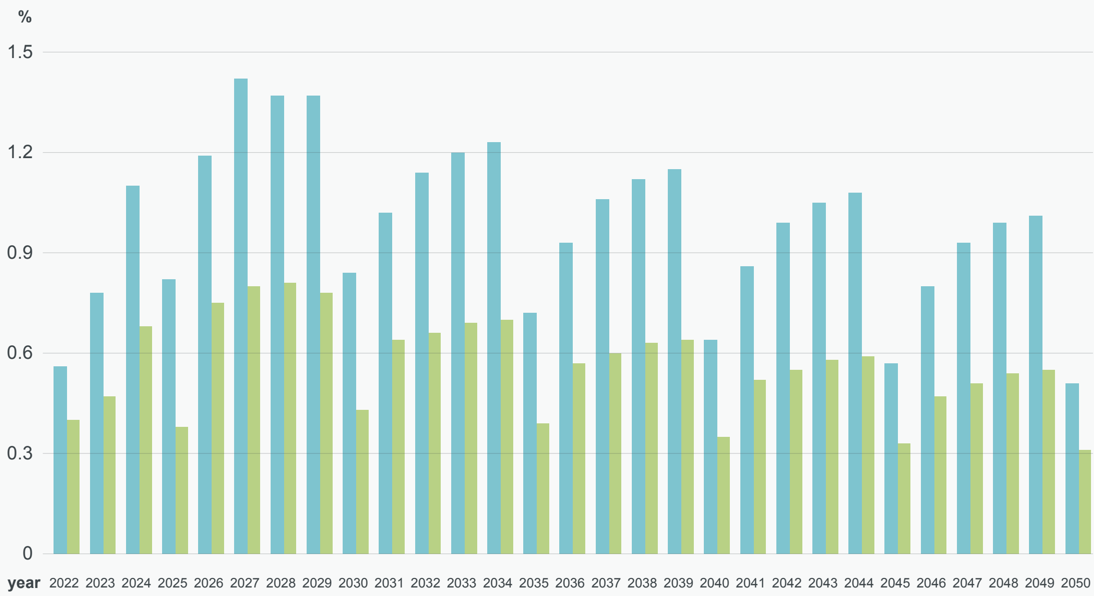
Together with MoESD, agriculture, tourism and infrastructure have been identified as key economic sectors in Georgia. Agriculture plays an important role for the Georgian economy, being characterised by family-based subsistence farming with quite low productivity and low income (World Bank 2018). Furthermore, in the last decade, tourism has been one of the fastest growing economic sectors in the Georgian economy. In the context of climate change, infrastructure is also an important topic. During several sector-specific expert meetings and workshops, a common understanding of the climate change issues in the respective economic sectors and possible adaptation measures has been established.

The e3.ge model has been used to calculate the macroeconomic effects of several adaptation measures for Georgia. In the case of agriculture for example, irrigation systems and wind breaks were examined. For tourism and infrastructure, the (re-)construction of coastline protection and climate resilient roads and bridges were considered. The analyses show that adaptation measures provide co-benefits: not only can the damages in years with climate change effects be reduced, but also crop yields in every year can be increased. Up- and downstream industries benefit, and, in case of tourism, more tourists will travel to Georgia. The results have been published in two policy briefs and a comprehensive report for Georgia (GIZ, 2022b).

EMPLARY RESULTS CALCULATED WITH THE e3.ge MODEL

With mounting impacts of climate change, Georgia's agriculture sector is expected to be increasingly affected by heavy winds and resulting wind erosion especially in dry land areas. In order to evaluate the usefulness of different adaptation options, Georgia's macroeconomic model e3.ge was used to assess the ***economy-wide effects of investments in windbreaks*** amongst other adaptation measures. The *figure below* shows how investments in windbreaks could affect Georgia's GDP and level of employment.

Figure 6: Economy-wide effects of windbreak investments



Source: own figure based on GIZ (2022a)

Compared to a situation without adaptation, investments in windbreaks result in a yearly increase of up to ***1.4% of GDP*** and ***up to 0.8% higher employment rates*** corresponding to up to ***13,000 additional jobs***. Such investments have positive sectoral linkages leading to increased wage levels and higher consumption expenditure of up to 1.2% 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.

The capacity building process in Georgia enabled the model builders to further develop and run the model in the future. This includes regular model updates and its application to other relevant policy questions. For a future use of the e3.ge model by MoESD for other public institutions in Georgia, a concept note has been developed by IISD that describes the procedure (GIZ, 2022a). This facilitates the concrete implementation. In this context, the financing of the corresponding modelling and the tasks associated with the cooperation play an important role. Furthermore, a collabouration between MoESD and the MEPA has been initiated, with a planned usage of the e3.ge model in the upcoming process of updating the NAP in Georgia, a great success for the CRED project. In this context, it should also be mentioned that the e3.ge model, which depicts the structure of the Georgian economy, is also suitable for making short-term statements on the effects of other structural changes such as the COVID-19 crisis and the economic effects associated with measures such as lockdowns. The same applies to the implications of wars or sharp changes in international energy prices.

3.2 KAZAKHSTAN

Kazakhstan committed itself to achieve carbon neutrality by 2060 and thus contributes to limit global warming. However, "Kazakhstan is [also] very vulnerable to various effects of climate change" (UNGA 2020). Climate change affects the environment but also causes immense economic costs, affects key industries and endangers jobs, wealth and life of Kazakh people.

The update of the NDC for the period 2021-2030 is supported by the United Nations Development Programme (UNDP) but not yet approved. In this update, both mitigation and adaptation policies and measures as well as roadmaps on both will be considered[6]. The development of an adaptation roadmap by the Ministry of Ecology, Geology and Natural Resources (MEGNR) aims at raising awareness and to mainstream climate change issues into policy planning[7]. A reference to the CRED concept has been integrated into this draft roadmap, which still must be approved by the government.

The New Environmental Code[8] adopted in 2021 governs climate change adaptation and sets out the priority areas, namely agriculture, forestry, water management and disaster risk reduction. Article 314 further regulates the general requirements for climate change adaptation such as the collection of data and information, the process of planning, development and implementation. These steps are also reflected in the CRED approach, which adds a macroeconomic analysis of climate change impacts and adaptation measures to provide a more comprehensive view of the economy-wide impacts including the direct and intersectoral effects.

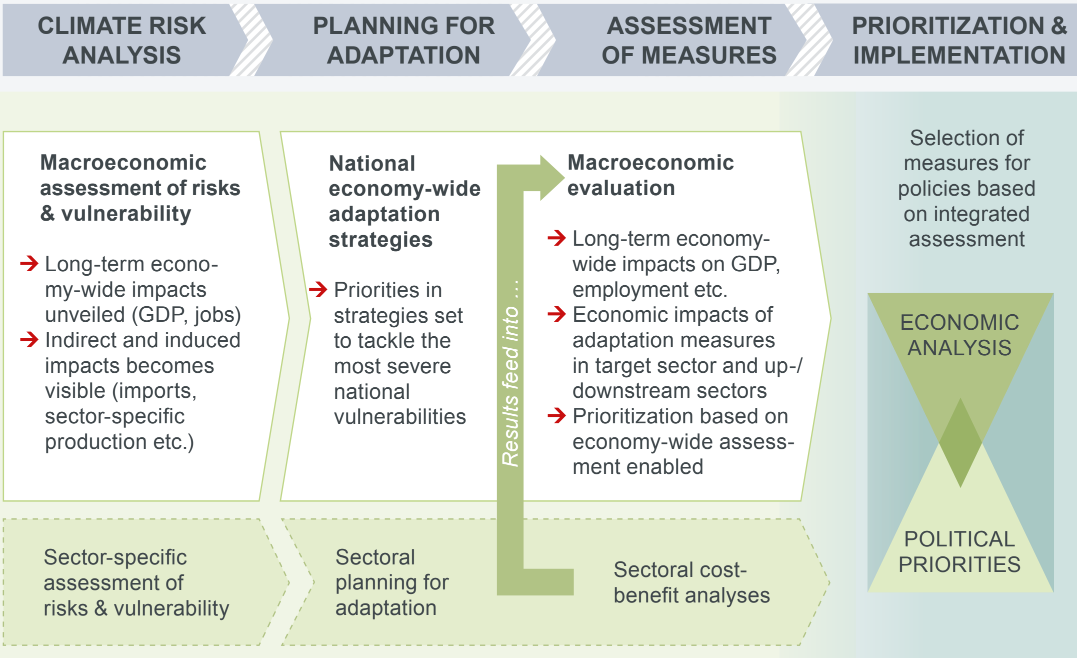
The use of the e3.kz macroeconomic model for Kazakhstan in combination with scenario analysis helps to deal with the inherent uncertainty of climate change and the future developments in general. In scenarios, different assumptions on the frequency, intensity and occurrence of climate hazards are examined as well as various adaptation options. E3.kz shows what could happen under climate change and which adaptation options have positive effects on the economy, employment, and the emissions (win-win options). Comparing the macroeconomic impacts of adaptation options offers one opportunity to prioritize adaptation options for the respective sector. Modelling results reveal possible synergies or trade-offs with other political priorities such as the carbon neutrality by 2060. However, other criteria such as health aspects and biodiversity which are beyond of the scope of the model must be considered as well to get a more comprehensive evaluation and to select appropriate adaptation measures (*Figure 6*).

6 *https://www.kz.undp.org/content/kazakhstan/en/home/projects/sdu/ndc.html (last accessed October 20,2022)*

7 *https://www.undp.org/kazakhstan/stories/ipcc-alarm-report-global-climate-trends-and-forecasts-kazakhstan (last accessed October 20,2022)*

8 *https://wecoop.eu/wp-content/uploads/2021/04/2021-KZ-ENV-Code_full-text_en.pdf (last accessed October 20,2022).*

Figure 7: Added value of macroeconomic modelling for assessing adaptation measures



Source: GIZ 2022c

Climate change and adaptation scenarios consider information and data of the most relevant climate hazards, their sector-specific impacts as well as suitable adaptation options. The Climate Policy and Green Technology Department of the MEGNR is coordinating both mitigation and adaptation policies and is responsible for ensuring cross-sectoral coordination and cooperation for climate action. It is raising relevant research questions related to adaptation supported by sectoral ministries such as the Ministry of Agriculture. The overall long-term development planning is led by the Ministry of National Economy (MNE) with its subordinate institution, Economic Research Institution (ERI), a think tank for economic modelling and advice.

Particularly challenging is the process of data collection of climate damage data as well as sector-specific CBA needed as input for e3.kz (*Figure 6*). The recording of climate damage in monetary terms has so far been unsystematic and rather patchy[9]. Government authorities do not possess full and accurate damage data. Some climate damage data are collected by Kazhydromet and the Committee of Emergency Situations of the Ministry of Internal Affairs. Additional damage data is collected by screening mass media and scientific literature by national experts and GWS. Sector-specific CBAs for adaptation measures are even more rare for Kazakhstan and have been borrowed from other country studies. During several expert meetings, a common understanding of how to integrate climate change impacts into economic modelling has been created between climate and economic modelling experts (amongst others ERI, Zhasyl Damu, Kazhydromet). An advantage was that the implementing partner institution ERI is experienced in IO modelling and econometrics so that the development of the e3.kz model could be built on this experience.

9 *https://climateknowledgeportal.worldbank.org/country/kazakhstan/adaptation (last accessed on 19.09.22)*

The e3.kz macro-econometric IO modelling approach covers several economic sectors, their interlinkages as well as the domestic and foreign drivers for economic growth. Demand and supply of the economy as well as prices are part of the model which allows to integrate various impacts of climate change and adaptation measures. To identify possible synergies or trade-offs of adaptation and mitigation strategies (e.g., the LEDS), the core economic model was extended to an e3 model. The energy module represents the relations within the energy sector in greater detail than in the economic model. It depicts the energy demand, supply and transformation by different fossil fuels and renewables in physical units and allows for a better illustration of the combustion-related CO_2 emissions which are covered in the emission module.

Selected adaptation measures for the key sectors agriculture, energy and infrastructure were examined with e3.kz regarding their economy-wide impacts. The macroeconomic analysis shows that climate change puts food and energy security at risk. Economic growth, jobs and income are endangered not only in directly impacted economic sectors if no adaptation measures are taken. The exemplary analyses for the agriculture[10], energy[11] and infrastructure[12] sector – summarized in three policy briefs – show that adaptation measures provide co-benefits but also shed light on possible trade-offs with other strategies in Kazakhstan (e.g., the LEDS). 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. The same holds true if the investment needs for adaptation are financed by international donors. A comprehensive description of the e3.kz model and the macroeconomic impacts of climate change and adaptation scenarios are part of the national report for Kazakhstan (GIZ, 2022d).

Scenario results provide valuable information for stakeholders, including MEGNR who is leading the NAP development, MNE and sectoral ministries regarding the economic implications of adaptation measures as well as for the Ministry of Finance on the investment needed related to adaption.

10 https://www.giz.de/en/downloads/giz2021-en-kazakhstan-policy-brief-agriculture.pdf (last access November 7, 2022)

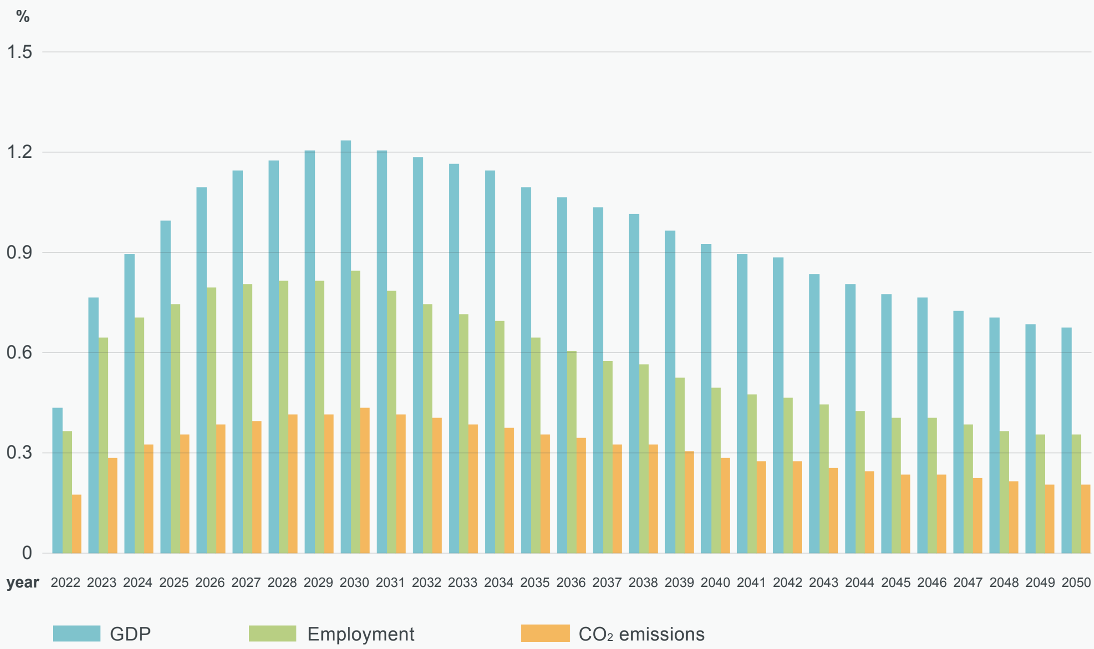
11 https://www.giz.de/en/downloads/kazakhstan-economy-wide-effects-of-adaptation-in-the-energy-sector.pdf (last access November 7, 2022)

12 https://www.giz.de/en/downloads/kazakhstan-economy-wide-effects-of-adaptation-in-infrastructure.pdf (last access November 7, 2022)

EMPLARY RESULTS CALCULATED WITH THE e3.kz MODEL

In the context of adapting to 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 in rehabilitating and expanding irrigation systems in Kazakhstan. The *figure 8 below* shows the impacts of such investments on GDP, employment, and energy-related CO_2 emissions.

Figure 8: Economy-wide effects of irrigation investments



Source: own figure based on GIZ (2022d).

Compared to a situation without adaptation, investments in the agricultural water infrastructure result in a yearly increase of up to ***1.2% of 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. However, a higher growth path leads to an annual rise of energy-related
CO_2 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.

Capacity building is key to anchor the e3.kz model, model updates and further independent application to pressing policy questions. During the CRED project, e3.kz training sessions to (1) understand and develop the model and to (2) perform scenario analysis regarding climate change and adaptation scenarios were conducted for experts in the fields of ecology (Zhasyl Damu) and economy (ERI).

A critical success factor to engage modelers is related to the availability of local project partners and their responsibility for certain tasks which should be supported by approval of higher-level authorities. A crucial success factor for the use of modelling results hinge on buy-in and the commitment by MNE, MEGNR and other users.
Training is successful if a continuous participation is possible and "brain drain" can be avoided. Training of trainers is suggested to keep the knowledge within the local institutions and to provide quicker assistance by local trainers after the project ends. The use of the macroeconomic model for other scenario analyses such as mitigation measures or other economic shocks, such as the analysis of the economic impacts of Russia's attack on Ukraine supports broader knowledge dissemination to other interested parties (e.g., other line ministries) as well as the anchorage and ownership of the model. In this regard, ERI as the owner of the e3.kz model, should clarify the conditions for further use of the model by trained modelers from outside of ERI and/or their conditions for provision of services by themselves to line ministries and other users (GIZ, 2022e).

3.3 VIETNAM

Vietnam is projected to be one of the countries most severely affected by climate change and EWE. Vietnam is particularly vulnerable to rising sea levels. On top of this, the current climate projections for Vietnam show that higher average temperatures will challenge productive dynamics in critical economic sectors such as agriculture and manufacturing. Furthermore, the foreseeable higher intensity of cyclones and typhoons will put increasing pressure on Vietnamese infrastructure and inhabitants. In this sense, policymakers and stakeholders can benefit from having access to evidence-based economic projections that account for climate change to implement suitable policy measures. These may include shifting investment to more climate-resilient sectors and addressing the vulnerability of sectors particularly affected by climate change.

In this context, the government of Vietnam unveiled the National Green Growth Strategy (VGGS) in 2012 for the 2011-2020 period with a vision toward 2050. The VGGS is centred around restructuring the economy to increase the efficiency of natural resource use, reduce GHG through research and development (R&D), and drive economic growth in a sustainable manner. Vietnam is also a signatory to the Paris Agreement and has pledged to become a net-zero emitter by 2050. This shows that Vietnamese policymakers are aware and concerned about the impact of climate change on the social and economic development of the country in the coming decades.

Considering this, GIZ in cooperation with the Halle Institute for Economic Research (IWH) is supporting the Central Institute for Economic Management (CIEM) since 2019 to develop the Dynamic General Equilibrium Model for Climate Resilient Economic Development (DGE-CRED) to predict sectoral and regional economic effects of climate change on the Vietnamese economy (GIZ,2022f).

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. The model differentiates between different regions and sectors to replicate the different climatic conditions experienced in various areas of Vietnam. Moreover, 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 labour and capital productivity. In this sense, climate variables and weather extremes impact production at the regional and sectoral levels. For instance, cyclones can destroy the capital stock used in the construction sector, which can either substitute capital using more labour or lay off workers as they become unproductive without machines.

The model operates under different climate scenarios known as Representative Concentration Pathways (RCPs), which describe different levels of greenhouse gases up to 2100. To get a holistic perspective of the different climate scenarios and examine how key economic indicators evolve under different circumstances, the RCPs are paired with the Shared Socioeconomic Pathways (SSP). The SSP scenarios are used within the IPCC framework and provide a series of projections to examine how society, demographics, and economics might evolve over the next century on a global scale.

The process in which the DGE-CRED model was developed involves several stages, each of them crucial for policy analysis. The first stage is characterized by data collection to get an overview of the situation at hand. Economic variables such as output, prices, or employment levels in the different Vietnamese regions and sectors are of particular interest. Furthermore, reliable projections for climate variables (such as temperature and precipitation) and EWE that correspond with the SSP scenarios are essential components. Finally, the model requires data to compute climate-induced damages on sectors like agriculture, housing, forestry, or transport. The data collection process is crucial to calibrate and operate the DGE-CRED model and, as such, will considerably impact the final results. The team relied on data provided by national experts as well as government statistics. Due to the large amount of detailed data required to operate the DGE-CRED, data gaps for economic, climate and damage variables had to be overcome with own computations or approximations based on international evidence.

In addition to key macroeconomic variables and climate-induced damages to the economy, the DGE-CRED model includes different adaptation options for various productive sectors within the Vietnamese economy. Some of the adaptation designs that the model incorporates include strengthening housing infrastructure so that it can endure EWE or building dikes to avoid the inundation of coastal areas because of rises in the sea level. The adaptation strategies were designed based on sectoral reports produced by national experts. While systematic and detailed, these reports were complex and often hard to break down and apply to the DGE framework.

An important component of the CRED process involves training Vietnamese model builders and users from the CIEM and other institutions with forecasting and simulation capabilities. The goal of the training has been to guide national model developers to operate the DGE-CRED framework and to train model users in order to anchor the CRED model in Vietnam. Model builders were staff from CIEM, that have participated in all training sessions and have a good understanding of the model's functions. Model users can adjust selected scenario inputs and have a thorough understanding of the model's mechanisms and workings. During the training, MATLAB trainers supported the participants with technical assistance. Participants were selected from several institutions under related line ministries, Department of Climate Change (DCC), the Viet Nam Institute of Meteorology, Hydrology and Climate Change (IMHEN) and Institute of Strategy and Policy on Natural Resources and Environment (ISPONRE) under the Ministry of Natural Resources and Environment (MONRE), Development Strategy Institute (DSI) and the National Center for Socio-Economic Information and Forecast (NCIF) under the Ministry of Planning and Investment, Institute of Policy and Strategy for Agriculture and Rural Development (IPSARD) and the Institute for Agricultural Environment (IAE) under the Ministry of Agriculture and Rural Development (MARD), National Economics University (NEU) and Foreign Trade University (FTU).

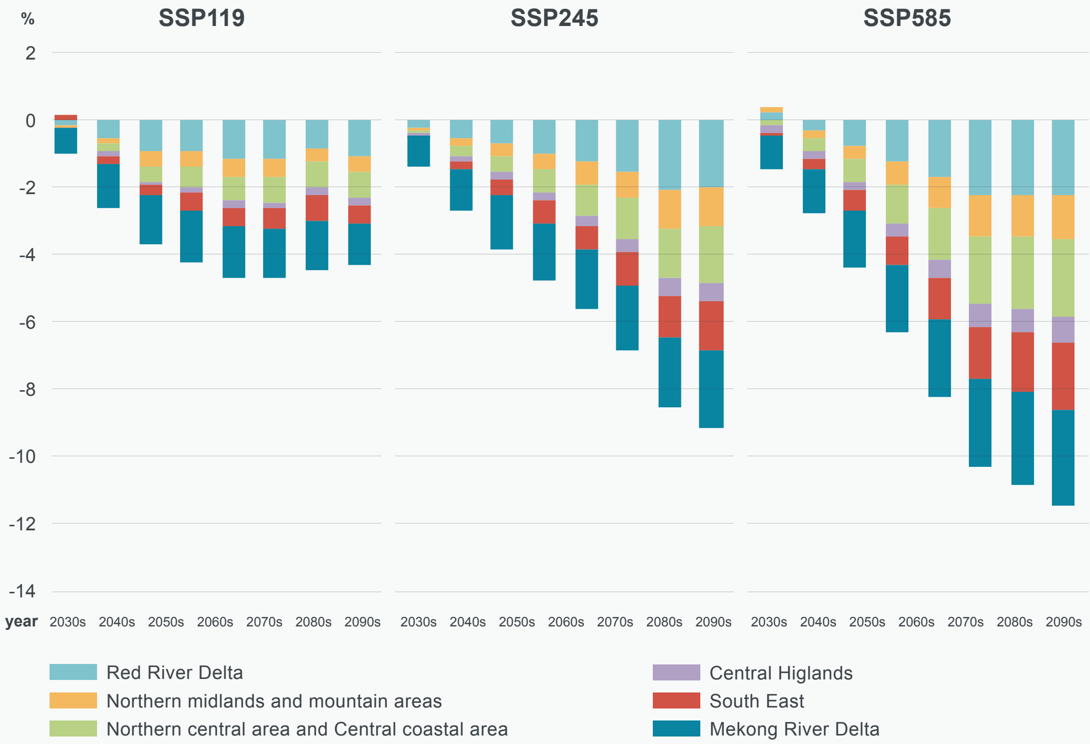
There have been several training sessions. In the first one, attendees became familiar with different modelling approaches and got the opportunity to solve dynamic optimization problems that characterize DGE models. In the following sessions, emphasis was placed on implementing the impacts of climate change and adaptation strategies for climate adaptation into the model. The practical component of the program was an overall success as attendees were given valuable practical lessons on model-building as well as the opportunity to discuss questions with the developers of the DGE-CRED model themselves.

EXEMPLARY RESULTS CALCULATED WITH THE DGE-CRED MODEL

Due to the increasing impact of climate change on Vietnam's long-term economic growth and its consequences, the DGE-CRED model was applied to assess the effects of cli-mate risks and potential adaptation strategies on Vietnam's economy. The model is constructed as a multi-region model, which allows to differentiate across regions to ac-count for various regional climate developments. The paths of climate variables are de-fined with the help of meteorological models based on IPCC's SSP119, 245 and 585, i.e. scenarios with low, medium and high mitigation challenges. The DGE-CRED model compares the effects of the different climate change scenarios (SSP 119, 245 and 585) to a baseline scenario which assumes that climate change has no economic impacts.

Figure 9 below visualizes the respective GDP losses expected under the different climate change scenarios without adaptation action. The simulation results indicate that climate change can reduce Vietnam's annual GDP on average by 5 percent in the 2050s. They also clearly show that the Mekong and Red River Delta are particularly affected by the economic losses, even in the most optimistic scenario (SSP 119), while mountainous areas are less vulnerable due to higher altitudes. Furthermore, the GDP losses only peak in the optimistic SSP 119 scenario during the second half of the 21st century, whereas in more severe climate change scenarios respective GDP losses continuously increase decade by decade until the end of the century if no adequate adaptation ac-tions are taken.

Figure 9: GDP losses in 6 regions from climate change impacts (in percent)



Source: GIZ (own illustration)

EXEMPLARY RESULTS CALCULATED WITH THE DGE-CRED MODEL (CONT.)

Evaluating several adaptation measures under different climate change scenarios, the DGE-CRED model depicts the effects on relevant components in comparison to climate change scenarios without adaptation action.

Figure 10: Impact of investment in dikes as adaptation measure on relevant GDP components under SSP 245 scenario (in percent) compares the impacts on consumption, investments, government expenditure, net exports, housing expenditures and GDP when dikes are being built as an adaptation measure under the SSP 245 scenario in comparison to no adaptation investments. Importantly, the adaptation measure has a positive impact on societal welfare as illustrated by the consistently higher consumption and less housing expenditures for the population in comparison to no adaptation. However, it should be noted here that the construction of dikes is associated with lower GDP and investments in the short, medium and long run under the SSP 245 scenario, as the dikes prevent damages of the capital stock by e.g. floods, which in turn leads to fewer investments in reconstruction. This shows that looking beyond the sole effects on GDP is important for a more holistic understanding of the economic impacts of climate change and respective adaptation investments.

Figure 10: Impact of investment in dikes as adaptation measure on relevant GDP components under SSP 245 scenario (in percent)

Source: GIZ (own illustration)

By the end of this process, the DGE-CRED model became a detailed and complex representation of the Vietnamese economy in the presence of climate-induced damages. However, not all designated sectors of the economy could be implemented into the model due to the lack of sectoral reports and relevant data. In this sense, it is important to mention that the results obtained by GIZ (2022g) should be treated as a frame, but not the overall dimension. This is particularly true for the effects of adaptation measures and their respective CBA. Simulation results indicate that climate change will negatively impact Vietnam's GDP, which is consistent with the literature. The model results imply that lower consumption levels will absorb a reduction in GDP to increase capital stock investments to compensate for lower productivity. In this sense, the challenge for policymakers is to design and implement adaptation measures aimed at reducing the consumption gap. The currently evaluated adaptation measures are not able to reduce the consumption gap in a meaningful way. The main reason for this result is that labour productivity is one of the main hazards to the Vietnamese economy. Among the currently evaluated adaptation measures the upgrading of the dyke system is the most important one. The other adaptation measures are not able to reduce the damages in a meaningful way. However, each adaptation measure itself yields high returns in relation to their estimated costs.

4 COMPARISON OF THE THREE COUNTRY APPROACHES

4.1 MODEL COMPARISON

The implementation of the CRED approach in the three countries has taken place under different conditions. The following comparison in *Table 1: Key features of the three country models* shows a variety of differences, but also similarities in key characteristics in the countries.

The structure of underlying macroeconomic and labour market data is similar in all three countries with varying sector classifications, and the climate-related data are also comparable. However, energy data were used only in Georgia and Kazakhstan, due to the small share of the energy sector and the lack of data in Vietnam.

In Vietnam, a Dynamic General Equilibrium (DGE) model has been implemented with the proprietary numeric computing software MATLAB. The model places greater emphasis on 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 solution problems, which can complicate its use by model builders. In Kazakhstan and Georgia, similar macro-econometric (dynamic) economy-energy-emission (e3) models based on Microsoft (MS) Excel are applied. They are more demand side oriented and less price-sensitive in the feedback mechanisms. All three models provide simulations until 2050, which is already a long-term perspective for economic models, in which human behaviour can change, while climate models that represent natural science relationships can more easily run until 2100. All models divide the economy into different sectors, which is a central requirement for modelling the structural effects of climate change and adaptation measures. Models for Kazakhstan and Vietnam will be respectively have also been regionalized, which was not pursued for Georgia due to missing data and the relatively limited size of the country.

The use of different types of models in the countries has several reasons: Firstly, it was possible to test whether one model type is more suitable or if both model types are suitable for modelling climate resilient development. Both model types have proven to be useful. Secondly, it is important for successful capacity building to start from existing knowledge regarding software and modelling skills in the best possible way. For a country, it may therefore be advantageous to start with either the e3 or the DGE model approach, depending on prior knowledge and available capacities. The example of Georgia shows well that the responsible ministry MoESD as model builder has only limited resources. The e3.ge model should therefore be used for other issues internally as well as externally (currently with the National Bank of Georgia) and together with other institutions (MEPA) also for climate change modelling and adaptation to ensure synergies and thus the permanent use of the model in the country.

The use of different modelling approaches always raises the question of which approach is most appropriate. Apart from the fact that every model developer praises his own model as the best, the answer is unfortunately only of limited help: it depends. 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. They also converge in part because all models have inherent weaknesses in that they can and do only represent a simplification of reality. Especially about climate change, many research questions are also still open. The reader is referred here to EU (2021d), Nikas (2019) and Rising (2022) for further information.

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, sea-level rise does not play a role for Kazakhstan as a landlocked country. For the other climate change impacts, it must be taken into account that certain EWE 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. But the agricultural sector plays an important role in all three countries, as agriculture is 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 measures for which data on costs and benefits have already been collected in the country.

Table 1: Key features of the three country models

	GEORGIA	KAZAKHSTAN	VIETNAM
Available data	• Macroeconomic and sectoral data • Labour market data (employment, wages, labour force) • Energy balances • Limited availability for data for climate scenarios, damage data and CBA of adaptation options	• Macroeconomic and sectoral data • Labour market data (employment, wages, labour force) • Energy balances and prices • Climate scenarios, damage data and CBA of adaptation options	• Macroeconomic and sectoral data • Labour market data (employment, wages) • Climate scenarios, damage data and CBA of adaptation options
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-X13) • Macro-econometric (dynamic) Input-Output model • Extended by environmental aspects such as energy balance, energy prices and emissions • Simulation model with a mid- to long-term perspective (until 2050)	• Excel-based model framework (DIOM-X) • Macro-econometric (dynamic) Input-Output model • Extended by environmental aspects such as energy balance, energy prices and emissions • Simulation model with a mid- to long-term perspective (until 2050)	• 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

13 DIOM-X: Dynamic Input-Output Modelling Framework in Excel

	GEORGIA	KAZAKHSTAN	VIETNAM
Evaluated adaptation measures	Adaptation in the agriculture sector: • Investing in rehabilitating and expanding irrigation systems • Investing in wind breaks Adaptation in the tourism and infrastructure sector: • Investing in (re-) construction of coastline protection • Investing in climate resilient roads and bridges	Adaptation in the agriculture sector: • Investing in rehabilitating and expanding irrigation systems • Investing in precision agriculture: the case of parallel driving Adaptation in the energy sector: • Expansion of under-ground powerlines • Deployment of wind power and energy efficiency improvements in the housing sector Adaptation in infrastructure: • (Re-)construction of storm-proofed houses • "Green Belt" mass afforestation (Re-) construction of climate resilient roads	Adaptation in the 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. Adaptation in housing: • build houses with reinforced walls and bricks • raise a house on stilts Adaptation in forestry: • mixed plantation Adaptation in transport: • roadbed elevation • poly mere asphalt

Source: GIZ (2022a), GIZ (2022d), GIZ (2022f)

The CRED process has taken place in specific policy contexts in each case, which are briefly listed in *Table 2: Key features of the CRED process in three country models*. A political partner institution and an implementation partner were present in all three cases. This ensures the political support and at the same time the implementation of the CRED process. Due to different responsibilities of political actors and due to the overarching issue of economic impacts of climate change and adaptation, a close cooperation of different actors, explicitly or implicitly, is required.

Integration of modelling results in economic processes needs considering entry points and enabling factors (GIZ, 2021b). Entry points are windows of opportunities such as the update of the NAP in Georgia, the establishment of a high-level political mandate as the Ecological code in Kazakhstan or including adaptation in the Kazakh Low Emission Development Strategy, or the Green Growth strategy in Vietnam. A combination of key factors, or enablers, is required to support the effective use and uptake of climate economic modelling results in economic development. For all three countries, raising awareness of the need to adapt to climate change, information sharing and communication on current and projected climate risks, and capacity development on climate change adaptation and the impacts on economic development have triggered and enabled climate economic modelling.

Table 2: Key features of the CRED process in three country models

	GEORGIA	KAZAKHSTAN	VIETNAM
Political partner	• Ministry of Economy and Sustainable Development (MoESD)	• Ministry of National Economy (MNE)	• Ministry of Planning and Investment (MPI)
Implementation partner	• Economic Analysis and Reforms Department, Ministry of Economy and Sustainable Development (MoESD)	• Institute of Economic Research (ERI)	• Central Institute for Economic Management (CIEM)
Entry points	• Establish a high-level political mandate (Update of the National Adaptation Plan in Georgia by MEPA) • Initiate strategic engagement between MoESD and MEPA	• Establish a high-level political mandate (e.g., Ecological code) • Initiate strategic engagement with the Ministry of National Economy on climate change (e.g., LEDS strategy)	• Net zero emission pathway
Enabling factors	• Raising awareness of the need to adapt to climate change • Information sharing and communication on current and projected climate risks • Capacity development on climate change adaptation and the impacts on economic development		
Institutionalization	• MoESD: leadership, model development, model application in the upcoming NAP process • MEPA: providing data and information for different adaptation measures relevant for Georgia	• Climate Policy and Green Technology Department of MEGNR: coordination of mitigation and adaptation policies • MNE: overall long-term development planning • ERI: Economic modelling and advice • Ministry of Finance: Financial planning and decision making	• CIEM and the Department of Science, Education, Natural Resources and Environment (DSENRE) under MPI in the upcoming net zero emission pathway of Vietnam.

Source: GIZ (2022a), GIZ (2022d), GIZ (2022f), GIZ (2021b)

4.2 LESSONS LEARNT AND RECOMMENDATIONS

Valuable experiences have been made in the three pilot countries to varying degrees. Overall, *Table 2: Key features of the CRED process in three country models* shows that the experiences with the processes in the three countries are comparable, although they differ in detail due to the different circumstances and structures. The uniform enabling factors in the three countries can be emphasized. Obviously, awareness raising, information sharing, and communication and capacity building have played a central role in the three countries. At this point, however, an allocation by country is deliberately not made.

The following lessons have been learnt and success factors identified during CRED implementation regarding:

I DATA AND DEVELOPING MODELLING TOOLS:

- Data availability and quality determine the quality of results. The national statistical offices play a major role here.
- Data collection and verification is time-consuming and requires support of national partners (and regarding climate data also international partners).
  It would be good if the country could name a contact person at an early stage who collects the data requests and forwards them internally. The explicit involvement of the respective statistical office in this can facilitate the process.
- Model complexity should be kept low to ensure that the necessary capacities can be successfully built up among the respective partners. However, the model should cover the relevant aspects for the policy questions.
- Model review by national and international experts facilitates the acknowledgement of the model.
- Detailed model handbook with examples eases capacity building. Transparency increases confidence and awareness of possible applications as well as limits of the model (“white box” modelling approach).
- The Excel-based approach of e3 models reduces the typical technical hurdles of model building and application.

II CAPACITY BUILDING:

- Capacities in terms of time and personal resources of local partners are crucial.
  The regular workload of employees at the partner institutions often does not allow for continuous participation in training sessions. It is challenging to build the necessary local capacities to successfully maintain (model builders) and apply the model to urgent questions, as skilled project members could leave the partner institutions (“brain drain”).
- Generally, a distinction must be made for participants that are model builders and model users. The requirements – both regarding time and economic modelling knowledge – for model builders are much higher. In addition to a basic understanding of the model interrelationships, the model users need knowledge about the impact of

climate change and of adaptation measures, whether in one sector or across sectors.

- Regular and shorter online sessions fit better into the daily work of local partners than extensive on-site training sessions. However, a longer training phase of e.g., one week at the beginning of capacity building supports the development of a common understanding early on and to quickly get into a common working mode. This might also motivate participants to collabourate and exchange in the future.
- Capacity building on all relevant modelling aspects and institutional anchoring is key to assure model building and continuous use of the models. Therefore, intensive, regular capacity building (training of trainers, again mainly for model builders, avoidance of "brain drain") is key.
- Assignment of responsibility for data collection, model update, scenario analysis etc., is an important ingredient for the implementation of a new model tool and the future update of the model. Therefore, this task should be explicitly anchored in the institution's personal resources. Since this is crucial for anchoring the model in the country, a simplified diagram showing the data needs and key partners to procure them at the beginning is very useful. If national data sources are not (fully) available / accessible, data from international data suppliers (e.g., Asian Development Bank, World Bank) can be used as a starting point (GIZ,2022d).

III INTEGRATION OF RESULTS INTO THE POLICY PROCESS:

- Interdisciplinary discussion and collabouration need common understanding of terminologies. Therefore, an overview of the modelling goals should be presented at an early stage to experts/institutions that might be relevant for data provision, sectoral expert knowledge, policy making etc. The country reports from the three pilot countries provide a good basis for this and are available as starting points in other countries.
- High-level support for economic evaluation of adaptation options is very important. However, the high-level support should be clarified and stressed before the project starts. Given their time-constraints necessary approval of intermediate process steps can delay the implementation. However, regular updates are useful for a common understanding and cooperation. In Georgia for example, the vice-minister of MoESD has explicitly supported the CRED process and even devoted some time to a high-level meeting.
- Involvement of local project partners and international renowned scientists, increase the awareness of various institutions and policy makers for the project. During the coaching process in Kazakhstan, modelling results were presented and discussed with various stakeholders representing amongst others sector experts e.g., in agriculture and international institutions (e.g., UNDP, ADB) which shared their insights, studies and information regarding climate change adaptation in the country. In Vietnam, several discussions with ADF on the analysis of socio-economic impacts of climate change in Vietnam and adaptation strategies took place[14]. The distinguished Professor Tom Kompas (University Melbourne) has ensured empirical quality of the model.
- Regular seminars and workshop with multiple stakeholders to create space for a common understanding and exchange during the implementation of the model.

14 *https://www.afd.fr/en/gemmes-vietnam-analysis-socio-economic-impacts-climate-change-vietnam-and-adaptation-strategies (last accessed October 20,2022).*

- Cooperation and maintenance of established networks going beyond the project. For instance, the AFD runs the GEMMES project in Vietnam that provided also useful input for the implementation of the DGE-CRED model. GIZ national offices have coordinated respective early exchange successfully.
- Transferring full ownership of the model to the respective model builders in the country not only allows for evaluating but also for continuous monitoring of current and future adaptation options. The proposed institutionalization of the CRED model in Georgia described in GIZ (2022b) is a good example of this.

IV LESSONS LEARNT ACROSS ALL STAGES OF THE CRED APPROACH

- Early feedback from national partners and a general memorandum of understanding of the process between all stakeholders are required to prevent delays.
- The CRED approach and process with its three main pillars – model development, capacity building and policy support regarding adaptation planning – is challenging with respect to coordination and planning as well as time-consuming for all partners involved. In the future, this process could be simplified, for example, by using templates to obtain data also from the pilot countries. Furthermore, a simplified e3 model prototype has been developed under the CRED programme, which can be used for different countries by drawing largely on country-specific international data[15]. This could speed up the model development process. Still, the approach is very successful in terms of collabouration with partners, intensive exchange with experts, dialog between decisionmakers from different fields and evidence-based policymaking with country-specific economic models for climate change adaptation planning. The highly participatory approach is suitable to foster an exchange between field experts and thus, increase the acceptance of methods, tools and results.
- The pilot approach for different countries is a suitable tool to compare different modelling approaches and management and collabouration strategies among different institutions. It is a good starting point for transferring the approach to other countries. If a country has similar political structures, comparable types of models are already in use, and the data situation is similar, these are good prerequisites for building on the successful approach in one of the countries. The CRED approach itself has matured to the point where it can be readily applied to other countries. With the prototype, a first e3 model can be built faster based on international data, which can be replaced by national data in a later stage. Because the conditions are different in every country, country-specific adaptations are necessary in each case regarding climate change and adaptation scenarios.
- *Table 2: Key features of the CRED process in three country models* describes the main features of the successful CRED process in the three countries. Accordingly, the political and implementation partners must be defined at an early stage. Data availability also needs to be clarified soon. At the political level, central strategies are needed as entry points to ensure implementation. Enabling factors support implementation and direct the focus to the issue of climate resilient economic development. Institutionalization is key for the long-term implementation of the approach.
- Regarding the pilot project involving three countries at the same time, it is important to conduct regular meetings with all team members to exchange on both progress and delays, and hence, to derive rapidly suitable approaches in the other countries of the project.

15 See GIZ 2022h for more information on the e3 model prototype.

5 KEY MESSAGES AND CONCLUSIONS

In the face of climate change, every country is well advised to take foreseeable changes into account when planning its long-term economic development. Against this background, **policy advice for climate resilient economic development is becoming increasingly important.** The good news from the CRED project is that it is **feasible to manage climate change and design adaptation measures as part of long-term strategies**. Setting this framework for climate resilient economic development helps to mitigate the economic and social risks due to climate change. This also contributes to accomplishing adaptation goals in national climate strategies. Another **advantage of the models is that they can quickly inform policy on other economic issues,** such as the effects of measures against the COVID-19 pandemic or Russia's attack on Ukraine and the sanctions it triggered.

Within CRED, country-specific macroeconomic models have been developed together with national partners considering the specific conditions in emerging economies. These models are applied for scenario analyses and provide key information for policy makers. The **modelling results show how different climate hazards and adaptation measures impact the economy** up to the year 2050. This allows to **understand the socio-economic impacts of climate change** and to compare a set of adaptation measures and thereby to identify those measures contributing the most to economic development.

Therefore, natural science modelling of climate effects is used in a simplified manner. The impacts of future evolution and intensity of EWE is combined with damage data of the respective hazards in the countries. CRED builds on nationally available data and 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 own countries. National damage data of recent EWE can directly be used. **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. The 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 the modelling results. Overall, developing the macroeconomic modelling tools, capacity building to enable staff in implementing institutions to maintain, apply and update the model also to upcoming policy issues including international economic crises, and the integration of results into the policy process are key for the long-term success of CRED.

Concerning data, the internationally agreed System of National Accounts (SNA) including IO tables for sectoral details are the basis for economic modelling (UN Statistics Division 2018). In general, countries that have already experience with models based on these accounts, should use them as a starting point for model development. The model software should be kept simple to make it easier for national experts to get started. Climate impacts to be investigated and possible adaptation measures result from the natural conditions of a country. A look at international experiences, especially in comparable countries, can help here.

Central to the transfer of experience made and Lessons Learnt in CRED to other countries are the importance of specific entry points and enabling factors for the successful implementation of the approach. Entry points are, for example, political planning processes in the preparation of national long-term strategies or budget and financing planning, also taking into account international financial transfers. Enabling factors are above all political leadership including support for long-term planning, if, for example, the state leadership names combating climate change as a central goal or such as planning processes for NDCs, or NAPs are pending within the framework of international obligations. In this sense, it is important that the same enabling factors were identified (awareness raising, information sharing and capacity development) in the three pilot countries and that in each case a high-level political mandate each regarding climate change and adaptation supported the CRED process. Without this backing, transferability of the approach is likely to be difficult or impossible.

If these conditions are fulfilled in a country, the model approach can be transferred well, as described in detail in the prototype paper (GIZ, 2022h). In the simplest case, a standardized model framework based largely on international data sets is filled in for a new country, so that initial modelling and capacity building can take place after only a few months. Software and CRED approach are the starting point of a longer process in which capacity building and anchoring in the countries are key. Particularly, country-specific conditions must be taken into account, not only with regard to climate change but also with regard to the institutional conditions and the policy landscape in the country, as well as the close cooperation of different stakeholders. Additional factors identified in CRED will support successful implementation: Involvement of national partners from the beginning, high-level support, data availability, capacity building, and knowledge sharing at the international level.

In summary, a **model-based process that builds on existing knowledge in the respective country and facilitates capacity building** in a targeted **manner is a process that promotes climate resilient economic development (CRED)**, delivers respective policy advice and, above all, **enables institutions in the country to flexibly quantify new climate risks and adaptation measures** and make them usable for the political planning and steering process.

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7 APPENDIX: CHECKLIST FOR DATA AND MODEL SELECTION

DATA

- What are reliable sources of national data?
- In which dimension and which legal and technical requirements is it possible to get (easier) access to both official and unofficial data for external foreign consultants? (incl. translations)
- Are the data reliable in particular regarding changes in methodology, revisions etc.?
- Are there any key sectors in the national economy that should be explicitly addressed?
- In which frequency are the data available in general and what is the average time lag for publication?
- Since when are most of the data available (history)?
- In which frequency are forecasts executed (quarterly, biannually, or annually) and for which period (quarters or year)?

TECHNICAL REQUIREMENTS

- Which official software is available at your institution to run forecasts and simulation?
- Which operating system and version (e.g., Windows 11, Mac Monterrey OS (Apple), Linux Mint) are you using?
- Is each computer used for macroeconomic analysis equipped by MS Office (Excel; at least version 2016), EViews, MATLAB, "R"? (If applicable, are there enough licences?)

GENERAL OVERVIEW ON THE MODELS

- Which models are used for long-term projections and policy planning?
- Are there already models (and other instruments) that are regularly used at your institution and other (inter)national institutions to simulate socio-economic effects of climate change and climate adaptation measures in the country?
- Are these models used to support economic policy decisions?
- What type of models are used / planned to be used – small / medium-sized / large macro models or / and micro models?
- Did your institution already obtain assistance from national or international research institutes or organizations to prepare the data and to develop macro models and policy analysis?
- Which goals shall be reached with the models in general?
- Is a demand-side or supply-side approach already implemented?

SECTORAL QUESTIONS

- Which sectors of the economy should be covered?
- Which institution is suitable for collabouration for a particular sector? Both regarding knowledge and influence?
- Which sectoral data is available, in particular input-output table(s)?