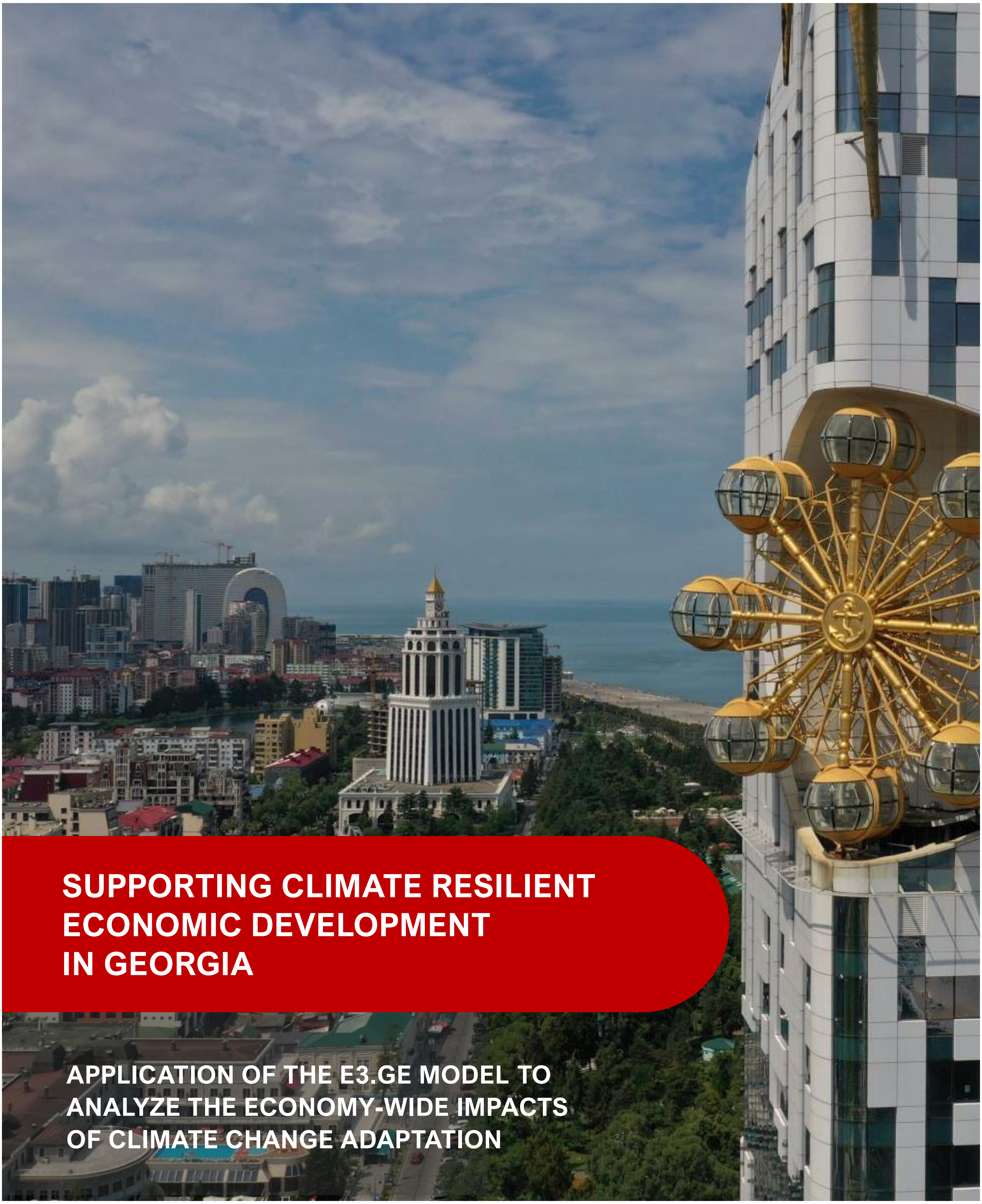


SUPPORTING CLIMATE RESILIENT ECONOMIC DEVELOPMENT IN GEORGIA

APPLICATION OF THE E3.GE MODEL TO ANALYZE THE ECONOMY-WIDE IMPACTS OF CLIMATE CHANGE ADAPTATION

Published by:

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

On behalf of:

Federal Ministry for the Environment, Nature Conservation and Nuclear Safety

of the Federal Republic of Germany

In cooperation with:

MINISTRY OF ECONOMY AND SUSTAINABLE DEVELOPMENT OF GEORGIA

GWS SPECIALISTS IN EMPIRICAL ECONOMIC RESEARCH

SUPPORTING CLIMATE RESILIENT ECONOMIC DEVELOPMENT IN GEORGIA

APPLICATION OF THE E3.GE MODEL TO ANALYZE THE ECONOMY-WIDE IMPACTS OF CLIMATE CHANGE AND ADAPTATION

As a federally owned enterprise, GIZ supports the German Government in achieving its objectives in the field of international cooperation for sustainable development.

Published by:
Deutsche Gesellschaft für
Internationale Zusammenarbeit (GIZ) GmbH

Registered offices:
Bonn and Eschborn, Germany

Address:
Deutsche Gesellschaft für
Internationale Zusammenarbeit (GIZ) GmbH
Köthener Str. 2
10963, Berlin, Germany
T +49 61 96 79-0
F +49 61 96 79-11 15
E info@giz.de
I www.giz.de/en

Programme description:
IKI Global Programme on
Policy Advice for Climate Resilient Economic Development (CRED)

Project Manager:
Stefanie Springorum
stefanie.springorum@giz.de

Authors:
Markus Flaute, Saskia Reuschel, Christian Lutz,
Maximilian Banning, Frank Hohmann
GWS - Gesellschaft für Wirtschaftliche Strukturforschung | Institute of Economic Structures Research, Osnabrück

Contributions:
Sebastian Homm, Mikheil Khuchua, Stefanie Springorum, Anne Weltin | GIZ
Julie Dekens | International Institute for Sustainable Development
Ketevan Chapidze, Vakhtang Tsintsadze, Simon Burchuladze | MoESD

Editors:
Mikheil Khuchua, Tbilisi
Mariam Chkheidze, Tbilisi
Anne Carolin Weltin, Berlin

Design:
Alvira Yertayeva, Nur-Sultan
Mariam Chkheidze, Tbilisi
Atelier Löwentor GmbH, Darmstadt

Photo sources:
Cover page: ©georgiantravelguide.com

The study was conducted by international experts Markus Flaute, Saskia Reuschel, Christian Lutz, Maximilian Banning, Frank Hohmann, Gesellschaft für Wirtschaftliche Strukturforschung | Institute of Economic Structures Research (GWS) in the framework of the IKI Global Programme on Policy Advice for Climate Resilient Economic Development (CRED), implemented by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH on behalf of the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU).

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

Germany, 2022

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AAGR	Annual average growth rate
BAU	Business as usual
CBA	Cost-benefit analysis
CGE	Computable General Equilibrium
CHP	Combined Heat and Power
CRED	Climate Resilient Economic Development
DICE	Dynamic Integrated Climate-Economy-Model
DIM	Disaster Impact Models
DIOM-X	Dynamic Input-Output Models in Excel
EWE	Extreme Weather Events
FUND	Climate Framework for Uncertainty, Negotiation and Distribution
GDP	Gross domestic product
Geostat	National Statistics Office of Georgia
GHG	Greenhouse gas emissions
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GWS	Institute of Economic Structures Research (Gesellschaft für wirtschaftliche Strukturforschung)
IAM	Integrated Assessment Model
ICT	Information and Communications Technologies
IEA	International Energy Agency
IO	Input-Output
IPCC	Intergovernmental Panel on Climate Change
MoESD	Ministry of Economy and Sustainable Development
NAP	National Adaptation Plan
NDC	Nationally Determined Contributions
NPISH	Non-profit institution serving households
PAGE	Policy Analysis for the Greenhouse Effect
PESETA	Projection of Economic impacts of climate change in Sectors of the European Union based on bottom-up Analysis
RCP	Representative Concentration Pathways
RICE	Regional Integrated model of Climate and the Economy
UIB	University of the Balearic Islands
SPEI	Standardized Precipitation Evapotranspiration Index

GLOSSARY

Adaptation	In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate 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 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.
Climate sensitivity	Climate sensitivity refers to the change in the annual global mean surface temperature in response to a change in the atmospheric CO2 concentration or other radiative forcing
Climate variability	Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability).
Climate vulnerability	Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability).
Cost-benefit analysis	Monetary assessment of all negative and positive impacts associated with a given action. Cost–benefit analysis enables 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. Cost–benefit analyses representing society's point of view are important for climate change decision-making, but there are difficulties in aggregating costs and benefits across different actors and across timescales

E3 model	The 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 modeling 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.
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 well-being, 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.

Source: IPCC (2018).

EXECUTIVE SUMMARY

Climate change is one of the most significant and urgent problems for the environmental and socioeconomic development not only in Georgia, but worldwide. Several climate trends in Georgia have already changed during recent decades, e. g., the frequency and severity of extreme weather events like increased temperatures, droughts and precipitation. Climate change affects the Georgian economy in many ways. The direct effects of climate change (e. g., crop losses in agriculture due to drought) also cause indirect (e. g., reduced production in food industry due to fewer primary inputs) and induced (e. g., income losses due to reduced production) effects in the economy. Likewise, the implementation of adaptation measures to climate change has several impacts on the economy. Adaptation to climate change can in each case ensure that the damage of climate change is kept to a minimum and that additional positive impulses are provided to the economy.

Knowledge of the economy-wide effects of climate change and the implementation of adaptation measures is important for Georgia in order to set up an appropriate adaptation strategy that focusses on all economic sectors. Based on an intensive exchange with Georgian ministries, partners and experts, the macroeconomic model e3.ge model has been developed to ensure informed policy-making on adaption to climate change in Georgia. Modeling research allows the determination of climate change effects on macroeconomic indicators like GDP and employment. Furthermore, modeling research is capable to quantify the economy-wide effects of different adaptation measures to elaborate adaptation strategies that ensure a sustainable development of the economy (see USAID 2016).

The most important economic sectors of the Georgian economy were identified and possible adaptation measures targeting these sectors were selected in order to quantify their macroeconomic effects. Regarding agriculture, irrigations systems and windbreaks are analyzed in more detail. Regarding tourism and infrastructure, the (Re-)construction of coastline protection and climate-resilient roads and bridges are analyzed.

Agricultural production heavily depends on climate conditions. The effects of the already ongoing and forecasted climate change on the agriculture sector in Georgia range from the displacement of agri-climatic zones, the reduction of crop productivity due to extreme weather events, the reduction of the agricultural lands' fertility, the reduction of irrigated land areas to a higher demand for irrigation water (see MEPA 2017).

Climate is one of Georgia's main competitive advantages for tourism (see USAID 2016). However, tourism activities are directly related to weather conditions, e.g., temperatures, precipitation, sea turbulence, the stability of beaches (see The World Bank 2020). Moreover, tourism is sensitive to all risks of climate change that may affect urban infrastructure, communications, utilities, and coast protection infrastructure (see UNDP 2013).

The analysis of the adaptation measures in this report illustrates that investments in adaptation provide co-benefits: Damages from climate change can be reduced, and the domestic economy benefits from an increased domestic production, which also creates additional jobs.

The economy-wide impacts are relevant for policymakers to prioritize adaptation measures. The e3.ge model can be used for macroeconomic evaluation of many other adaptation measures. However, this requires the corresponding data on the costs and benefits of the adaptation measures. Other criteria must be considered as well such as health aspects and ecosystem services (e. g., biodiversity, regulation of the water balance) to get a more comprehensive evaluation of a measure, and to formulate an appropriate adaptation strategy.

1 INTRODUCTION

Climate is changing and will continue to do so in the future. Climate change is one of the most significant and urgent problems for the environmental and socioeconomic development not only in Georgia, but worldwide. Several climate trends in Georgia have already changed during recent decades, e. g., the frequency and severity of extreme weather events like increased temperatures, droughts and precipitation. These events are observable signs of the changing climate. The changing of climate is even about to continue in the future. 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.

Being a signatory to different international environmental treaties and agreements (e. g., the United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Protocol to the United Nations Framework Convention on Climate Change), Georgia is required to contribute to decreasing greenhouse gas emissions, as well as adaptation to climate change in ecosystems and economic sectors (see USAID 2016).

Knowledge of the economy-wide effects of climate change and the implementation of adaptation measures is vital for Georgia in order to set up an appropriate adaptation strategy that focusses on all economic sectors. The impacts of climate change will be visible in many economic sectors, and adaptation to climate change can in each case ensure that the damage is kept to a minimum and that additional positive impulses are provided to the economy through their implementation. Modeling research allows the determination of climate change effects on macroeconomic indicators like GDP and Employment. Furthermore, modeling research is capable to quantify the economy-wide effects of different adaptation measures to elaborate adaptation strategies that ensure a sustainable development of the economy. The results of the modeling research can be used for the planning in several economic sectors being affected by climate change, including water resources management, agriculture, tourism, and construction of roads, railways and buildings (see USAID 2016).

The effects of climate change are manifold and various approaches to adaptation exist to counteract these effects. This report focuses on the economic sectors of agriculture and tourism, which are both important for the Georgian economy. Since agriculture is one of the most vulnerable sectors to climate change, actions must be taken. Otherwise, not only food security, but also jobs and income are endangered in the Georgian economy. Tourism as well is vulnerable to climate change in many ways. Irrigation systems and windbreaks for agriculture as well as the (re-)construction of coastline protection and the climate-resilient construction of roads and bridges for tourism and infrastructure are being studied as possible adaptation measures in this report.

In the last decade tourism has been one of the fastest growing sectors in the Georgian economy. While the share of the agriculture sector to GDP has fallen significantly over the last years, still more than 40% of the working population are employed in this sector. The activities in the two sectors mentioned directly depend on the effects of weather and climate. The effects of climate change will also be felt in several other economic sectors (e.g., effects of hot temperatures on labour productivity).

To ensure informed policy-making on adaption to climate change, the macroeconomic model e3.ge model 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 German Agency for International Cooperation (GIZ). The e3.ge model contains three interlinked model parts, the (1) economy module, 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 or so-called dynamic Input-Output model.

The central role of the e3.ge model application is the macroeconomic and sectoral assessment of climate change and adaptation options. These quantifications inform the selection of measures for adaptation and sectoral planning. It supports thus mainstreaming and finally implementing adaptation into development strategies and financial decisions. On this basis, the e3.ge model maps not only the direct effects (e. g., crop losses in agriculture due to drought) but also indirect (e. g., reduced production in food industry due to fewer primary inputs) and induced (e. g., income losses due to reduced production) effects of climate change and adaptation measures in the consistent framework of national accounts and input-output tables. By doing this, the use of the e3.ge model allows for "smarter adaptation: improving knowledge and managing uncertainty", as described by the World Bank (2020a).

By conducting scenario analysis, different adaptation options are evaluated with regard to their economy-wide effects and their implications for the environment. By defining appropriate indicators, adaptation options can be evaluated against each other to find favorable solutions. On the one hand, model results of the climate change scenario show what could happen under climate change scenarios (awareness raising under uncertainty). On the other hand, policymakers can identify those adaptation measures that are highly effective and have positive effects on the economy, employment, and the environment. This approach goes beyond the classic cost-benefit approach, which is usually limited to single sectors.

The global programme Policy Advice for Climate Resilient Economic Development (CRED) supports respective ministries in Georgia as well as in Kazakhstan and Vietnam in developing climate-sensitive development plans and economic development strategies, by:

(1) Developing methods and tools for modelling the economic impacts of climate change.
(2) Capacity building through training and coaching: Supporting the lead executing agencies and implementing partners to become independent users of the macro-economic models.
(3) Supporting the lead executing agencies and relevant stakeholder in integrating the results in policy-making processes and adaptation planning.

Figure 1 gives an overview of the process of the global CRED programme, under which the modelling activities are conducted. In parallel with the collection of data and information on the economy and climate change effects in Georgia, the e3.ge model was developed. For selected sectors and adaptation measures, the macroeconomic effects of climate change and adaptation are calculated within the framework of a scenario analysis. Finally, the results are processed on the basis of different indicators such as GDP and employment and fed into policy making processes in order to support the policy process with quantitative information.

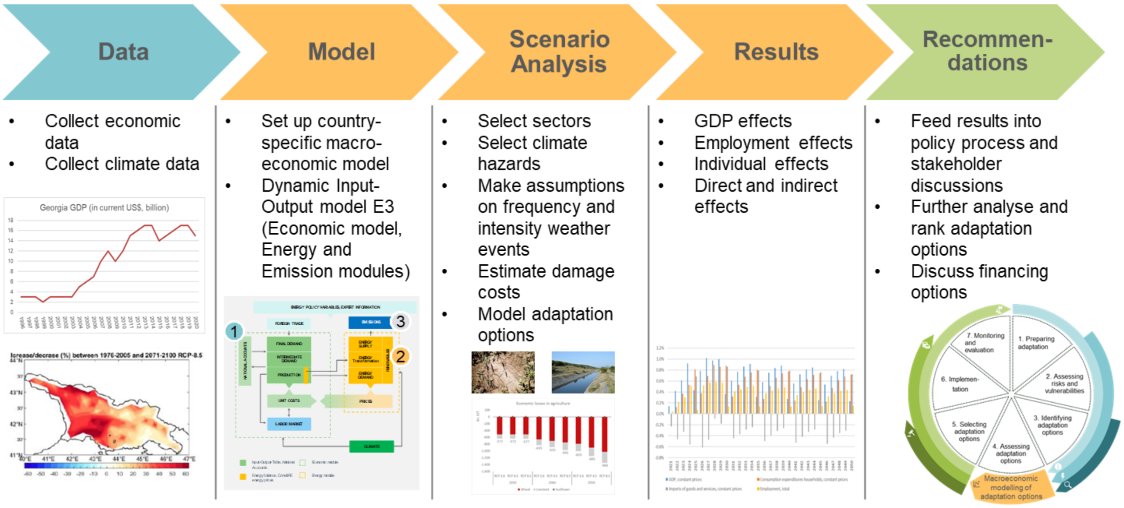


Figure 1: Overview of the CRED process on macroeconomic modelling for evidence-based policy making

Source: GIZ.

This report is organized as follows:

Chapter 2 focuses on the modeling approach itself. After giving an overview of the different existing modeling approaches in the literature to estimate the macroeconomic effects of climate change, chapter 2.2 will briefly present the e3.ge approach and its model building blocks. Chapter 2.3 describes the technique of scenario analysis.

For a better understanding of the impacts of future climate change on the economy, chapter 3.1 focuses on the development and current situation of Georgia's economy. Furthermore, future climatic threats for Georgia are analyzed (chapter 3.2). A description of the economic damage caused by climatic events in the past in chapter 3.3 gives a first impression of the monetary damages that can be expected in the future.

Chapter 4 describes in a nutshell the assumptions and results of the reference scenario, which serves as a basis for the climate change (and adaptation) scenarios.

Chapter 5 brings together economic modelling and climate change to quantify the future economic effects on the Georgian economy. In the context of case studies, the individual biophysical effects of climate change are monetized for selected extreme weather events to implement them in the e3.ge model. The model calculates the economy-wide effects for Georgia. Several economic indicators (e.g., GDP, production level, employment) are analyzed for each case.

After climate change effects have entered the e3.ge model, chapter 6 focuses on different adaptation measures in sectoral studies. Agriculture and tourism are both very important sectors for the Georgian economy. For both sectors, two adaptation measures are included in the e3.ge model to calculate the economy-wide impacts of adaptation.

Chapter 7 illustrates possible entry points for macroeconomic modelling in the policy making process and highlights its benefits and ways for institutionalization.

Chapter 8 points out the key messages and concludes.

2 MODELLING APPROACH

2.1 APPROACHES FOR MODELLING ECONOMY-WIDE EFFECTS OF CLIMATE CHANGE

2.1.1 INTERNATIONAL APPROACHES FOR MODELLING ECONOMY-WIDE EFFECTS OF CLIMATE CHANGE

Various approaches to estimate the macroeconomic effects of climate change are described in the literature. Probably the best-known calculations have been made since the early 1990s by William Nordhaus. They led to the development of one of the first integrated assessment models (see Nordhaus 1992), which attempted to represent the interrelationships between climate change and the global economy in a dynamic model, and were honoured with the Nobel Prize in 2018. Other models followed, such as the FUND model[1] run by Richard Tol, or RICE as a regionally specified variant of DICE. These models have in common that they are subject to neoclassical utility maximization and that the damages of climate change, summarized in a damage function, are a side condition to reach an equilibrium. In these models, climate change-induced damages are represented in more or less complex empirically determined dependencies on climate change indicators. One variant is a directly estimated influence of increased temperature on the target variable. More sophisticated variants estimate individual damage functions for individual climate indicators, such as drought, heat, heavy rainfall, or floods for different economic sectors such as agriculture, the energy sector, or tourism (PAGE in the Climate Cost project, also FUND by Anthoff et al. 2011).

There is extensive scientific discussion on these models, revolving around the validity of discount rates, the optimal social discount rate (Weitzman 1998), fat tails of the distribution function of climate risk (Hwang et al. 2016), and other scientifically exciting questions and challenges. The models used do not know explicit time and show states of the economy in an initial equilibrium, which are compared to an equilibrium after taking into account climate impacts or additionally adaptation measures. These approaches have contributed significantly to the estimation of economic impacts at the global level.

While greenhouse gas (GHG) emissions contribute everywhere to global warming, climate change and adaptation impacts differ much more at the national, regional or even local level. To account for this, global models have been regionalized in top-down ways (see, for example, RICE, or Ricke et al. 2018). Increasingly, however, studies can be found in the literature in which climate change-related damages and adaptation costs are estimated and quantified in bottom-up methods. Examples can be found for the European member states in the studies conducted by the Joint Research Center of the EU under the acronym PESETA (meanwhile up to PESETA IV, see Feyen et al. 2021), for Austria in the COIN study[2] by Steininger et al. (2015), for the EU COACCH (2021) project, for European islands in the SoClimpact project[3], in the impact assessment for the EU 2021 adaptation strategy (European Commission 2021a) or for Germany in the studies EconCCAdapt[4] and most recently in Lehr et al. (2020). In addition, many individual sector-specific studies are available.

Applied macroeconomic analysis of climate change is a complicated task which is increasingly met with a combination of bottom-up sector specific models and macroeconomic models (Ciscar et al. 2012; Ciscar

---

[1] See http://www.fund-model.org/
[2] See https://coin.ccca.ac.at/
[3] See https://soclimpact.net/
[4] See https://www.oekonomie-klimawandel.de/

et al. 2014; Bosello & Parrado 2020; Nordhaus 2017; Schinko et al. 2020). Because climate change is a global phenomenon, most applications have focused on large scale aggregation of geographical regions. However, downscaled modelling provides useful policy insights from a regional perspective based on unique vulnerabilities and socioeconomic characteristics.

Macroeconomic models can be used for modelling the impacts of climate change and climate change adaptation. Macroeconomic top-down models can be linked with the detailed results of sector models or bottom-up models. The national accounts form the basis of an macroeconomic model. In addition, the interdependences of different economic sectors are described in input-output tables. Using national accounts and input-output data, the sectoral impacts and second-round effects of climate change as well as adaptation measures and instruments can be recorded.

In principle, three basic types of macroeconomic models can be distinguished according to the underlying philosophy and understanding of the interaction of an economy: Computable General Equilibrium models (CGE), static Input-Output models (IO) and (macro)econometric Input-Output models (IOE – Econometric Input-Output models, according to Máñez et al. 2016). In the context of the economic analysis of climate change effects, these economic models are combined with climate models to create Integrated Assessment Models (IAM), in which climate models are linked to CGE models using a loss function, and Disaster Impact Models (DIM), in which the economic effects of catastrophic events on the regional economy are assessed and in which a regionalisation of CGE or IO models takes place.

Computable General Equilibrium (CGE) models

Computable General Equilibrium (CGE) models are based on the microeconomic theory of Léon Walras. Representative households and companies optimize their benefit or profit. Behavioural parameters are calibrated with literature values for a base year in such a way that key variables are well represented in this year. The models assume complete immediate substitution and price adjustment and they do not have any historical time. The model solution after the policy measure has been set and the new equilibrium reached can be compared with a basic simulation. The new model solution, in which a more expensive good is used less according to the assumed substitution elasticities, describes a new equilibrium at the end of all adaptation processes. Prices drive the results to a large extent as well as efficient allocations of resources. CGE models are more suitable for long-term issues and under the assumption of functioning markets.

CGE models are a frequently used tool to evaluate policy measures (Sue Wing 2004). Policies such as the introduction of a tax or price changes act as an exogenous shock to the economy, which then rebalances itself through its own balancing mechanisms. The models are based on the assumptions of the neo-classical economy and – in their simplest form – do not reflect market imperfections, external effects, unemployment, etc. More advanced models take some imperfections into account.

Static Input-Output (IO) models

The input-output account consists of three input-output tables and the supply and use table. The input-output tables provide a detailed insight into goods flows and production links both within the national economy and with other countries (United Nations 2018; Miller & Blair 2009). If this accounting system is translated into matrix notation, the result is a system of equations for which the economist of the same name, Wassily Leontief, was awarded the Nobel Prize in 1973. In a IO model, a policy measure that leads to higher prices increases the costs of all consumers who cannot switch to other products in the short term. In the case of extreme weather events, this approach is more suitable for the assessment than the assumption of immediate substitution possibilities (for homogeneous goods) in a CGE model. It is also possible that due to the temporary loss of production, other delivery routes or production sites may be permanently chosen, thus allowing short-term changes to persist. This can be easily modelled in the static IO model by specific changes to individual parameters. However, long-term adaptation processes cannot be represented in a static IO model. Adaptation costs are then rather overestimated.

Disaster Impact Research is a common field of application for IO analysis. There is a large number of research projects in which analyses and assessments of the effects of catastrophic events, such as floods or hurricanes, are undertaken. In many of these studies, IO models are used to estimate the direct costs of reconstruction and also the indirect costs resulting from the triggered change in demand (e. g. Haimes & Jiang 2001, Bockarjova et al. 2004, Cochrane 2004, Okuyama et al. 2004). By means of these models, in addition to the direct physical damage (to buildings, etc.) reported by insurance companies and indirect demand-side effects caused by "shock-like" changes in demand for intermediate, capital and consumer goods, the effects of catastrophic events on the various economic sectors can be analysed (Máñez Costa et al. 2016).

(Macro)econometric (or dynamic) input-output models

Dynamic IO models take time into account. In macro-econometric IO models, the behaviour parameters are econometrically estimated on the basis of time series data. Substitution elasticities can also be zero if no significant correlation has been shown in the past. They reflect the economic development year after year and can therefore also reflect the temporal progress of the effects of policy measures or instruments. The models are used for a medium-term period (often until 2030, partly until 2050), because the assumption of behavioural constancy, which fixed parameters necessarily implicitly entail, is less and less valid with increasing distance in time. Of course, this is also a general problem of using socio-economic models for long-term simulations.

2.1.2 MODELLING APPROACH CHOSEN FOR GEORGIA

Based on the international experiences, it is obvious that various approaches for modelling the economic impacts of climate change and adaptation exist. So far, there is no one fits all solution. Each approach has its advantages and limitations (Keen 2020, Keppo et al., 2021). For this reason, several models that complement each other are sometimes used at the same time (e. g. Feyen et al. 2020, Lehr et al. 2018).

In principle, key requirements for an economic model to be able to map climate change can be defined as follows: it needs to capture the main economic impacts (e. g. productivity and income losses), sectors (e. g. agriculture, energy, infrastructure) that are directly affected by climate change and must take into account supply chains. Additionally, such an economic model has to consider long-term macroeconomic developments not only with respect to future climate change impacts but also the adjustment reactions in the years subsequent to a climate event.

For Georgia, the macro-econometric (dynamic) IO modeling approach is a suitable solution. International experiences as well as other climate change adaptation projects of GWS show that this approach fulfills the necessary requirements and can be successfully implemented (Aaheim et al. 2015, Lehr et al. 2016, 2018, 2020). In combination with scenario analysis technique, the modeling approach is suitable to study both the wider economic impacts (e. g., changes in economic indicators such as GDP and employment) of climate change effects and climate change adaptation. In contrast to static models – which compare a situation before and after a change (comparative static analysis) – the proposed dynamic simulation model is time-dependent and contains the economic development and transition processes. Furthermore, the requirements for data and model approach are kept moderate for a sustainable solution. The model can be easily understood by model developers and model users, which is important for the subsequent ownership of the model. The model approach is flexible, can be expanded in many ways and allows for integrating expert input. The model is not a "black-box". It includes the data, model code and results combined in one Excel workbook.

The following chapter 2.2 describes the Georgian macro-econometric IO model e3.ge, which will then be used for the evaluation of climate change effects and adaptation measures on the Georgian economy (see chapters 5 and 6).

2.2 THE GEORGIAN E3.GE MODEL

A macro-econometric IO simulation model for Georgia has been developed to analyse the overall macroeconomic impacts of climate change and sector-specific adaptation measures. This so-called e3.ge model (economy, energy, emissions; Georgia) uses the model building framework DIOM-X, which was developed for creating dynamic Input-Output models in Excel. Thus, the model is built in the programming language Visual Basic for Applications (VBA), which is part of Microsoft Excel. All parts of the e3.ge model are stored in one single Excel file. Figure 2 shows a screenshot of the model worksheet in the model Excel file. Data, information, scenario assumptions and results are all stored in separate worksheets and can easily be used and updated.

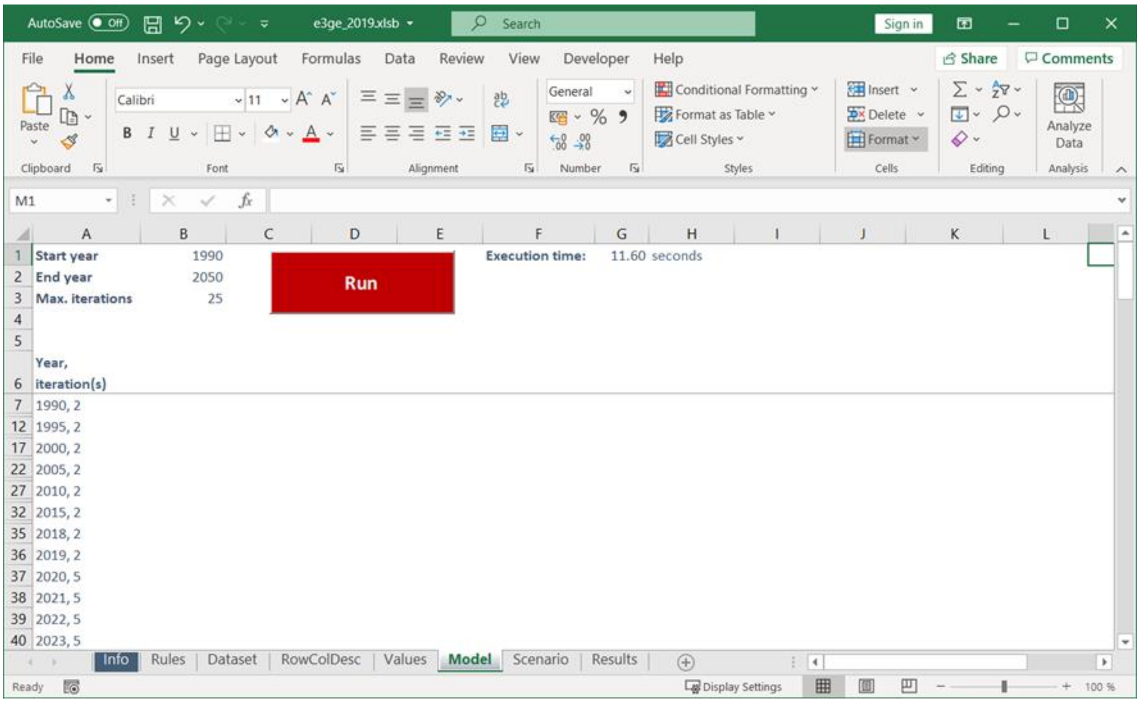


Figure 2: Model worksheet

Source: Own figure.

The core of an E3 model is a set of equations which describe the various model inter-dependencies. The number of variables and equations does not allow for an explicit solution of the equations system but requires an iterative solution algorithm. A model by definition is always a simplification of a (real world) counterpart. Thus, an E3 model depicts the relevant relations within an economy and between the other E3 model parts but omits detail that is not necessary for the main topic the model tries to address. The approach to store the full data set, framework and model code in a single workbook ensures that all aspects of the model can be examined, verified and – if necessary – extended.

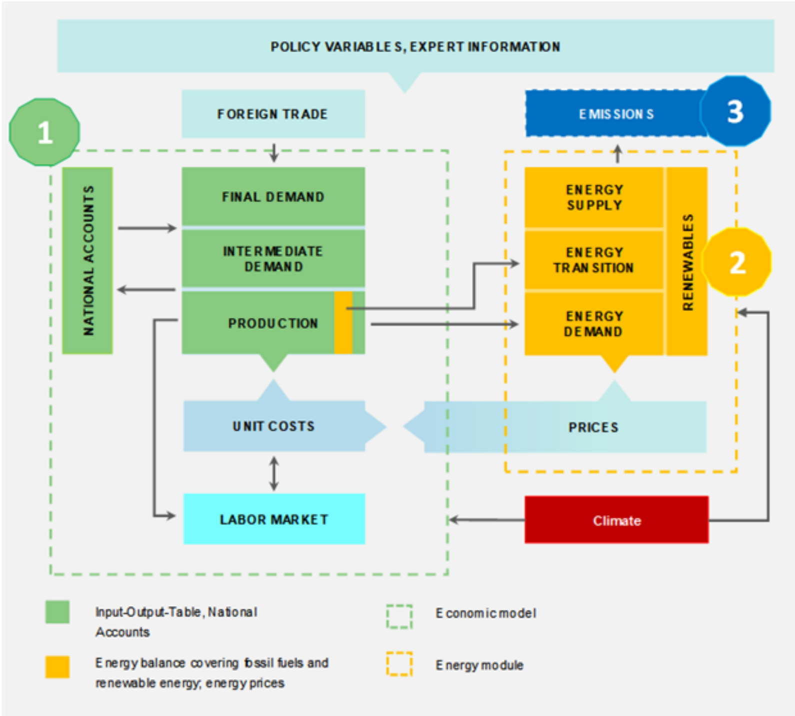


Figure 3: The e3.ge modelling approach

Source: Own figure based on GWS, 2022.

Figure 3 shows the structure and interlinkages in the e3.ge modelling approach. The e3.ge model contains three interlinked model parts, (1) the economy model, (2) the energy module and (3) the emissions module. The central part of the economic model are the input-output tables (sectoral data) and national accounts (macroeconomic data) depicting the key industries and supporting industries, their interlinkages as well as the domestic and foreign drivers for economic growth. The labor market is part of the model to monitor the impacts on jobs. The foreign trade section contains the country's imports and exports at a sectoral level. Unit costs and prices are calculated within the model. Energy balances, which include energy supply, transformation and demand for various energy carriers, are at the center of the energy module. Energy demand is determined by the economic activity. The emissions module comprises the energy-related CO_2 emissions. Climate change effects (e. g., the destruction caused by heavy precipitation, effects of heat on labor productivity) and adaptation measures (e. g., irrigations systems, windbreaks) are being added to the model and can trigger various economy-wide effects.

2.3 SCENARIO ANALYSIS

Scenario analysis is a method for dealing with the different kind of uncertainties of the future. Different assumptions on how the future might evolve can be tested. However, scenarios should not be considered as precise forecasts. Instead, they show possible development paths that are reactions to the assumptions made.

Scenario analysis helps to analyze and quantify the impacts of “what-if” questions, e. g. “What” will happen to the economy, “if” an extreme weather event occurs or adaptation measures are introduced? Typically, such an analysis is done before a policy measure is introduced (ex-ante analysis) to explore possible reactions within the economy.

Scenarios are consistent sets of quantified assumptions describing the future development. “If” describes assumptions in the scenario settings which are injected into the model. “What” comprises the economy-wide impacts and consequences resulting from the assumptions made. Thus, a scenario helps to better understand what could happen and who or what is affected and how. For instance a climate change scenario will be built from assumptions on the frequency of expected future extreme weather events (e. g. a heat wave occurs every 10 years) and their respective damages and effects on the economy (e. g. reduced labor productivity, increased demand for health care services).

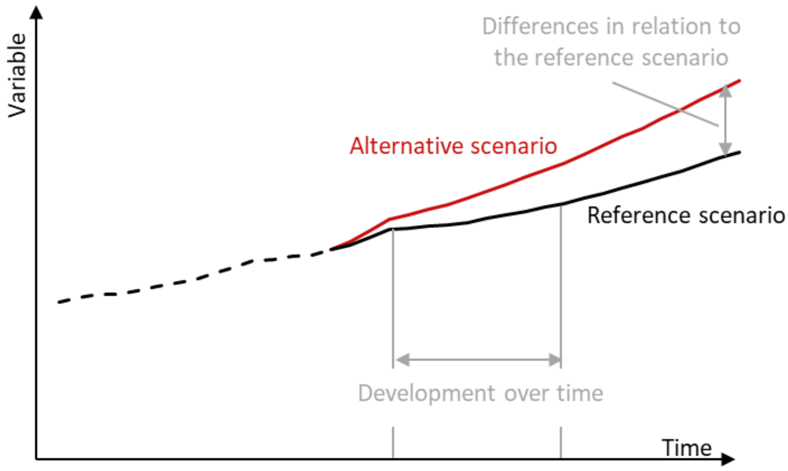


Figure 4: Comparative scenario analysis

Source: Own figure.

Depending on the question to be answered and the application purpose of a model (climate change, adaptation to climate change, but also expansion of renewable energies, energy efficiency, fiscal changes such as taxes or price changes), various policy options can be analyzed. Comparing the results from different scenarios (see Figure 4) helps to identify the option which is appropriate for a particular issue. Policy-makers need to identify and prioritize the criteria (e. g. growth or employment effects) that are most important.

Table 1: Description of scenarios for climate change and adaptation

Scenario	Description
Business-as-usual (BAU) or Reference scenario	The reference scenario is laid out as a business-as-usual scenario. This scenario extrapolates the **economic relationships observed in the past** into the future. Model variables, model parameters and assumptions are carefully selected in order to provide a reliable projection and a solid **basis for other scenario analyses**. Such a scenario does not include consideration of climate change and adaptation.
Climate change scenario	A scenario with climate change, which contains **additional assumptions on the economic damages and losses caused by climate change**. The scenario is based on the reference scenario. The macroeconomic effects of climate change can be determined from the deviations between the climate change scenario and the reference scenario.
Adaptation scenario	A scenario with climate change and adaptation to climate change, which contains the aforementioned additional assumptions on the economic damages and losses caused by climate change and the **assumptions on one or more adaptation measures**. Thus, this scenario is based on the climate change scenario. The macroeconomic effects of adaptation can be determined from the deviations between the adaptation scenario and the climate change scenario.

Source: Own table.

All alternative scenarios are calculated for future years, so that differences between the business-as-usual (BAU) scenario only occur afterwards. In order to get the macroeconomic effects of the alternative scenario, the deviations between the alternative scenario and the BAU scenario are calculated (time-related relative and absolute as well as intertemporal). The differences between the scenarios can then be attributed to the different assumptions in the scenarios and the triggered reactions in the model.

The e3.ge model is used to simulate the economic effects of different climate change scenarios and adaptation measures in Georgia. To do so, first of all, scenarios including the effects of climate change have to be compared to a scenario without any structural changes. This so-called reference scenario (or business-as-usual scenario, BAU) reflects the continuation of the economy under a development of the determining exogenous factors, such as oil price development. Thus, for the analysis of the economic impacts of climate change, a scenario **with** climate change is compared to a scenario **without** climate change, namely the reference scenario.

In a further step, various scenarios are created that depict adaptation measures to climate change. Since climate change can no longer be denied and its consequences should also be included in a reference scenario to be assumed for the future, the analysis of the economic effects of adaptation to climate change is carried out between a scenario **with** climate change **and** adaptation to a scenario **with** climate change only. From this comparison, the economic effects of the adaptation measure alone can be derived from the model calculations. The changes result in deviations of core economic variables such as GDP, employment or changes of production in certain economic sectors. The deviations can be interpreted as the result of the effects analyzed.

The climate change and adaptation scenarios identify certain model variables, which change under the respective event and measure. Only variables characteristic for climate change and adaptation can be altered, all other exogenous settings remain, hence the name ceteris paribus analysis. The economic simulation then gives results for economic indicators such as employment, GDP or production under the new circumstances of the scenario. The changes of these indicators can be interpreted as results of the respective climate change event or adaptation measure respectively, and answers the question “what happens to GDP, if we invest GEL X million in this adaptation measure?”.

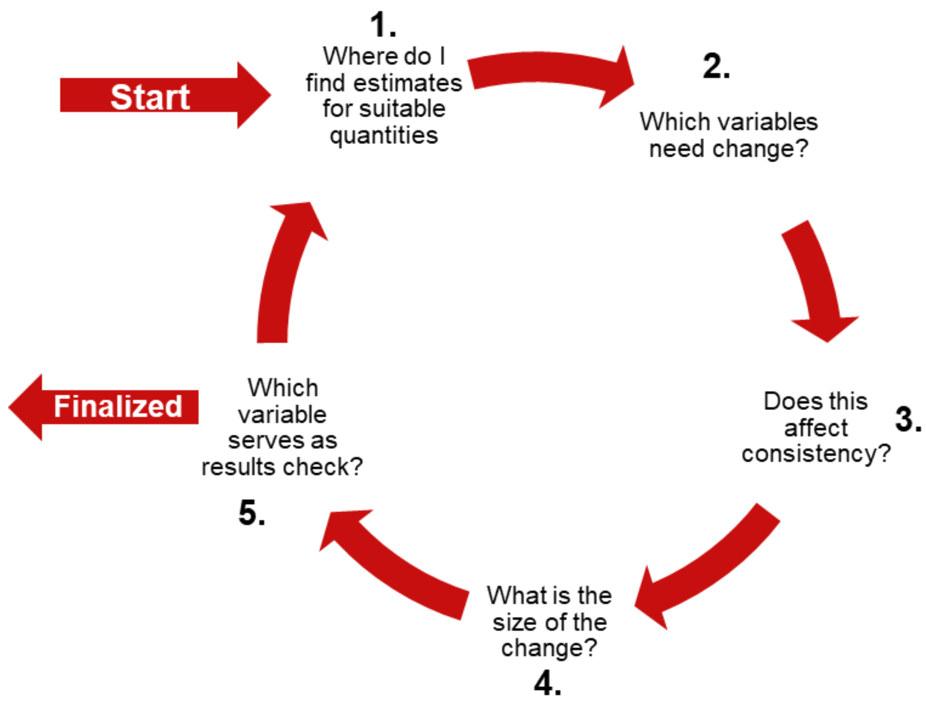


Figure 5: Steps of building a scenario

Source: Own figure.

Building a scenario helps to think about the question at hand. The possible steps that need to be taken for scenario building are shown in Figure 5.

(1) A first starting point is to consider where possible information and data needed for the respective scenario can be found. The sources for this are manifold, e.g. literature, news, newspaper, online magazines can be used. All assumptions and data should be documented.

(2) Once the respective data is at hand, that data needs to be related to the appropriate variables in the model. Specifically, this involves identifying which variables in the model need to be changed to reflect the desired effects of the respective scenario.

(3) While on the one hand there are variables that are exogenously given into the model or are estimated, on the other hand there are variables that result from calculations and definitions in the model. While the former can be changed well by adding effects of climate change and adaptation, it is not possible to do so for the latter ones without further ado, since this would eliminate the consistency of the model.

(4) Before looking at the respective results of the scenario, one has to think about the possible size of changes expected due to respective scenario tweaks. This step helps to identify whether the results are plausible or not.

(5) After having identified the respective variables for the results check, the scenario is either finished and the model user prepares the results, or the model user revises the scenario and searches for further data and information and starts the corresponding cycle from the beginning.

Chapter 5 and 6 will use the scenario technique to evaluate the economic effects of climate change and adaptation to climate change on the Georgian economy. To do so, the economic impacts of different climate change events will be implemented in the e3.ge model and analyzed. Furthermore, different adaptation measures will be analyzed on a sectoral level (namely agriculture and tourism).

3 CLIMATE CHANGE AND ITS EFFECTS IN GEORGIA

3.1 COUNTRY INFORMATION

Georgia is located in the South Caucasus region, east of the Black Sea and south of the Great Caucasus. It boarders Russia to the north, Turkey and Armenia to the south and Azerbaijan to the east. Georgia is covering an area of 67,000 square kilometers with around 3.7 million inhabitants in 2019. Around 60% of the population is living in urban areas, more than 1.1 million people live in the capital city Tbilisi (GEOSTAT 2020). Figure 6 shows the population development from 1990 to 2020. In the first years of independence, the population increased to a peak of almost 5 million in 1993, after that the population began to decline, dropping to 3.7 million in 2020.

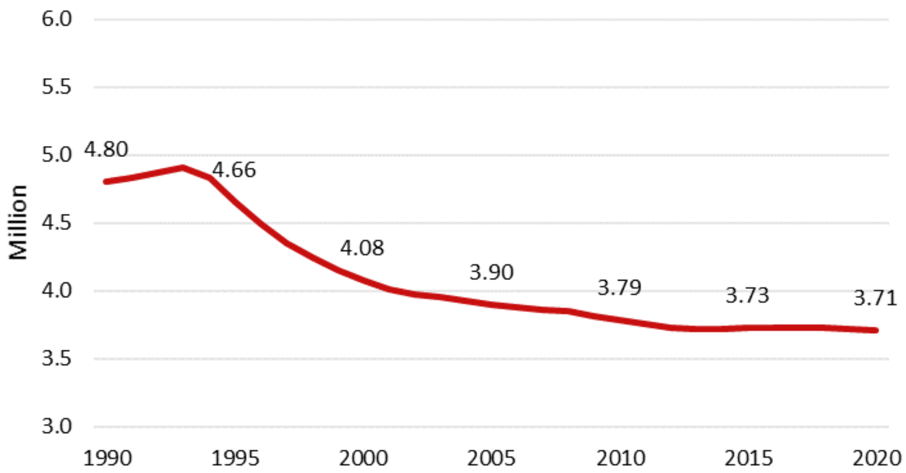


Figure 6: Population 1990 – 2020

Source: Own illustration, data from World Bank (2021) and GEOSTAT (2021b).

Since the secession of the Soviet Union in 1991, Georgia has undergone major transformations. Several structural reforms focussing on the creation of a liberalised economic environment have been implemented such as reconstruction of the public sector, deregulation for business, reduction of corruption, simplifying of tax and trade related rules and procedures (World Bank 2018). This led to a certain reputation and improvements in international rankings (MoESD 2019). For instance, in terms of business environment Georgia is placing seventh out of 190 countries in the World Banks Doing Business Ranking (World Bank 2020c). In addition, Georgia pursued a western oriented policy with closer ties to the European Union (EU). In 2016 the EU-Georgia Association Agreement came into force, including a Deep and Comprehensive Free Trade Agreement (DCFTA), which strives for political association and economic integration. In this context Georgia has made several commitments in the fields of democracy, rule of law, human rights and fundamental freedoms, good governance, market economy and sustainable development (Official Journal of the European Union 2014). A number of further measures and reforms have already been implemented, but at the same time challenges requiring further effort remain (European Commission 2021b). For further progress on the European path, reform commitments to consolidate democracy and reform of the judiciary with regard to independence and accountability, management of public finances, the labour market and energy efficiency are seen as significant (European Commission 2021b). Another challenging issue is also to ensure an inclusive, green and sustainable recovery from the COVID-19 crisis and to accelerate digitalisation (European Commission 2021b; World Bank 2020b). Thus, structural reforms are considered necessary to improve the investment climate and trade potential and as well as the resilience of the Georgian economy (European Commission 2021b). The existing challenges are summarised under the concepts of sustainable growth and job creation; trade logistics and connectivity have been identified as main productivity constraints (World Bank 2018).

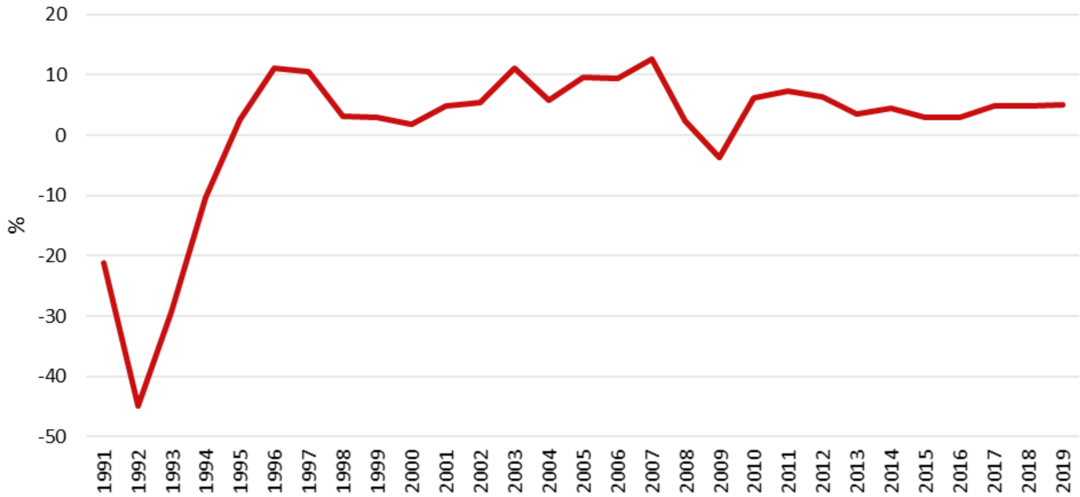


Figure 7: Georgia: Real GDP growth rate (% p.a.) between 1991 and 2019

Source: Own illustration, data from World Bank (2021).

Figure 7 shows the development of real GDP growth rate between 1991 and 2019. After independence and the breakup of the Soviet Union in 1991, Georgia experienced a deep economic crisis, which is considered the most severe of the former Soviet states (World Bank 2018). In 1995 a new currency, the Georgian Lari (GEL), was introduced. The following period is characterised by economic recovery; a certain stability was achieved with the first reforms (World Bank 2018). Since the Rose Revolution in 2003, Georgia's transition was initiated with comprehensive structural reforms aiming to improve the business environment, liberalize trade, upgrade infrastructure and strengthen public finances (World Bank 2018). The decline in 2008/2009 was due to the global financial crisis as well as the conflict with the Russian Federation (World Bank 2018). Over the past decade Georgia's economy grew robustly, at 4.8% p.a. between 2010 and 2019 (GEOSTAT 2021a).

Despite the economic and human development poverty and unemployment still pose a challenge, although trends are decreasing. It is stated that in 2019 19.5% of the population has been living under absolute poverty line compared to 37.7% in 2010 (GEOSTAT 2021b). The unemployment rate declined from 27.2% in 2010 to 17.6% in 2019 (GEOSTAT 2021b). In 2019 Georgia ranked 61st on the Human Development Index – a composite statistic of life expectancy, educations and income indices – with a value of 0.812 (UNDP 2020).

In 2019 Georgia's gross domestic product (GDP) was approximately GEL 49,252.7 million (approx. USD 17.4 billion) and the GDP per capita amounted to GEL 13,239.4 (USD 4,696.2) (GEOSTAT 2020). More than half of the GDP was generated in Tbilisi (GEOSTAT 2021b). Economic growth was based primarily on domestic demand and the use of productivity gains and first-generation reforms (World Bank 2019). Figure 8 shows the GDP by categories of use: Private consumption accounts for more than 70% of GDP, government final consumption for about 13% and gross capita formation for about 25%. Imports of goods and services amount to 63.8% and exports of goods and services to 54.8%, leading to net exports of -9% (GEOSTAT 2021a)

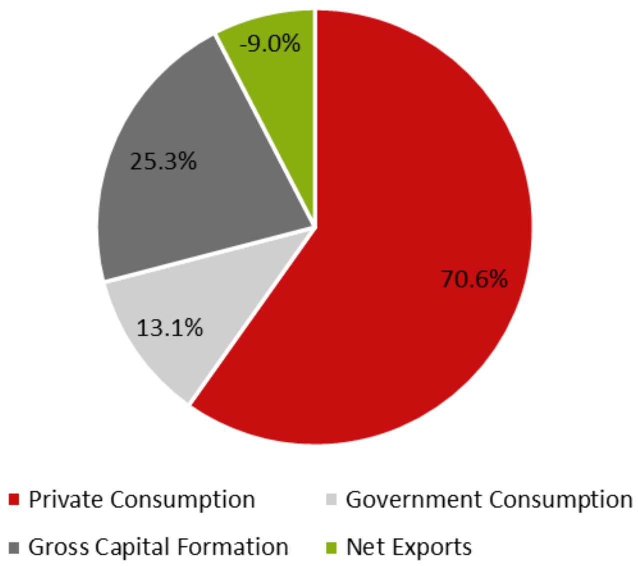


Figure 8: GDP by final use (2019)

Source: Own calculations, based on data from GEOSTAT (2021a).

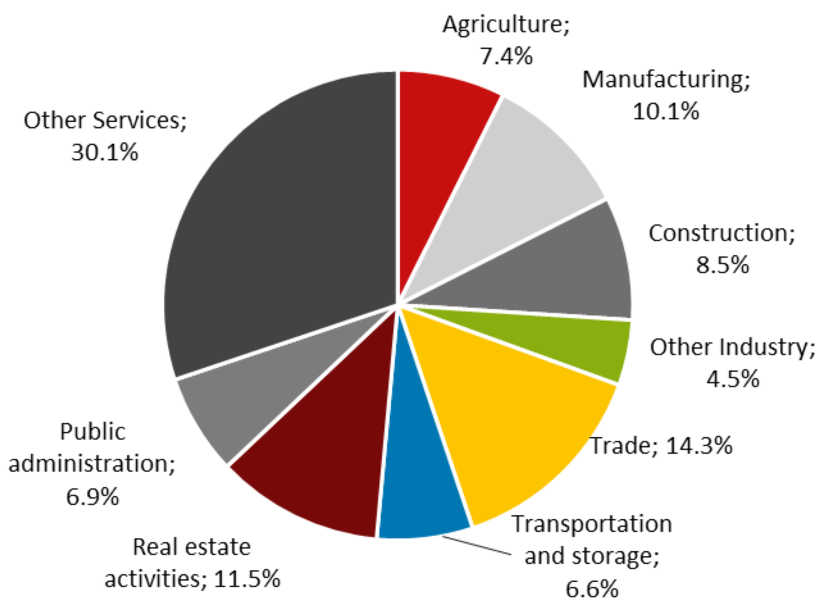


Figure 9: Structure of GDP by sector (2019)

Source: Own calculations, based on data from GEOSTAT (2021a).

Figure 9 shows the structure of GDP by sector in 2019. Main sectors of the Georgian economy are trade (14.3%), real estate activities (11.5%), manufacturing (10.1%), construction (8.5%), agriculture (7.4%), public administration (6.9%) and transportation and storage (6.6%) (GEOSTAT 2021a).

In the last decade, tourism has been one of the fastest growing economic sector in the Georgian economy. Tourism revenues to GDP was 21.6% in 2019, out of which 18.7% is international tourism revenues and domestic tourism revenues is 2.9% (see GEOSTAT). With its diverse landscape from the Black Sea coast to vineyards to mountains combined with its rich cultural heritage Georgia has an ideal baseline for tourism. In 2019 international traveller trips exceeded 9 million for the first time of which about two thirds were tourists. With a share of 75%, the majority of visitors come from the neighbouring countries Azerbaijan, Russia, Armenia and Turkey (GNTA 2020). Tourism contains a variety of segments: Beaches, nature, adventure, wine and food, and city breaks. Tbilisi attracts the most tourists and in view of the increasing number the share has remained stable. Nature and adventure as well as wine and food tourism are described as growing sectors, while the classic beach and casino tourism is stagnating (World Bank 2019). Despite the recent development there is still further potential that could be leveraged (World Bank 2018). These includes attracting more tourists from outside the region or improving the development of touristic infrastructure in rural areas, where many natural and cultural assets are located. Furthermore, bridging specific skill gaps in hospitality and developing quality standards is recommended (World Bank 2018).

Agriculture in Georgia is characterised by family-based subsistence farming with quite low productivity and low income (World Bank 2018). The share of the agriculture sector to GDP has fallen significantly over the last years, from 22% in the year 2000 to 7.4% in 2019. It is anticipated that the share will fall to around 7% by 2025 (MoA 2017). 20% of the employed persons in Georgia are employed in agriculture. However, own-account workers and contributing family workers even increase the number of persons working in agriculture. Furthermore, agriculture accounts for 75% of rural employment and 45% of rural income in Georgia (MoA 2017). Beside the self-employed semi-subsistence farmers, also an agri-business sector and a number of larger commercial farms provide employment (MoA 2017). Agriculture is a traditional sector in Georgia, more than 40% of the territory consists of agricultural lands. Agriculture contains plant growing and animal husbandry. Traditional crops include grapes, wheat, maize, fruit, wine and tea. Main types of livestock breeding are bovine animals, pigs, sheep and goats and poultry. There are few commercial activities, e.g. in high-end niche sector of viticulture. The development of the agricultural sector has been accelerated in recent years also by international programmes (World Bank 2018). It is one of the greatest challenges for the Georgian agriculture sector to improve productivity, increase farm incomes, and reduce rural poverty (MoA 2017).

Figure 10 shows the distribution of employed persons by economic activity for the years 2017 and 2020. The overall labour force decreased from 1.641 million persons in 2017 to 1.523 million persons in 2020. The number of employed persons decreased from 1.286 million persons to 1.241 persons respectively, resulting in an employment rate of 78.4% in 2017 and 81.5% in 2020. While the employment in the agricultural sector decreased (22% versus 20%), there has been growth in the service sectors.

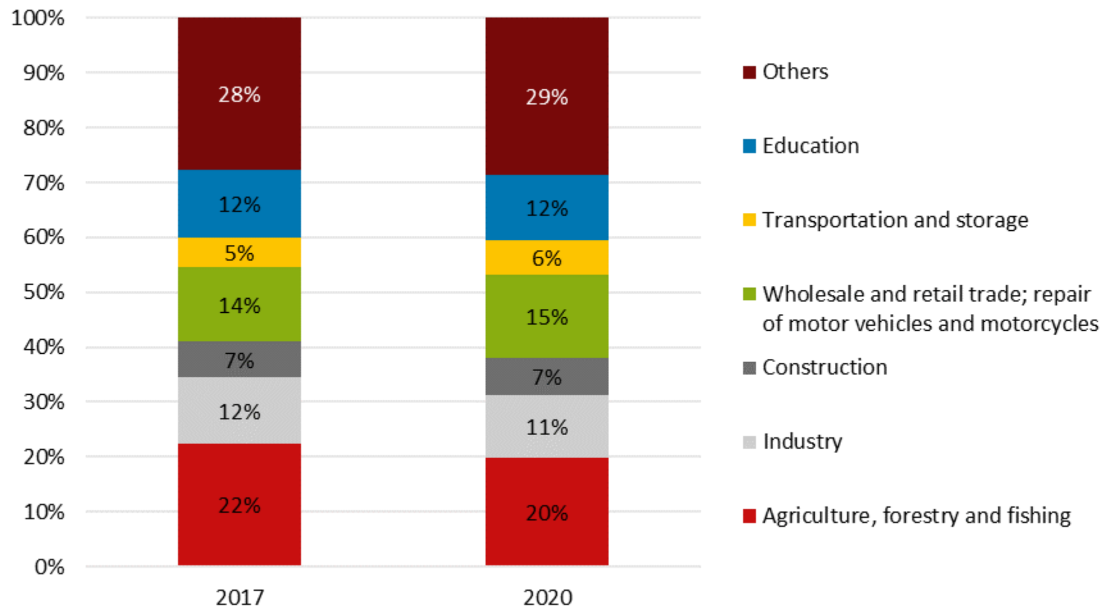


Figure 10: Distribution of employed persons by economic activity

Source: Geostat

3.2 CLIMATIC THREATS

Georgia is a mountainous country: more than 80% of the territory is mountainous, and 20% of the country is located at 2,000m or more above sea level (World Bank 2020b). These natural conditions facilitate the occurrence of floods, debris flows, landslides and avalanches, mostly in the mountainous parts of the country and along the major rivers (UNDP 2014). The average annual temperature ranges between 14°C to 15°C and the annual rainfall is between 1,500mm and 2,500mm. Due to its geographical location between the Black and Caspian seas with a complex mountainous terrain, Georgia concentrates a wide variety of landscapes and climatic zones in a very small area (USAID 2016). The Black Sea provides a distribution of moderate temperatures and large amounts of precipitation, whereas the Caucasus protects Georgia from cold air masses from the north. At the Black Sea coast the climate is humid subtropical, while the East is a moderately humid subtropical area. In South Georgia the climate is ranging from moderately humid to dry in mountainous areas. Due to the different climatic zones and landscapes, the effects of climate change differ in the individual regions (USAID 2016).

Climate is changing and will continue in the future. Climate change is a long-term change in the average weather patterns. These changes have a broad range of observed effects. The climate variability includes all the variations in the climate within smaller timeframes (month, year). The climate variability is altering, meaning that aspects of climate (e. g., temperature, precipitation) differ from an average.

Since the 1960s, different climate trends have already been observed in Georgia. Temperatures in the west and the east increased, as well as the number of hot days, particularly in the lowlands. While precipitation in the mountainous areas in the west increased, precipitation from the mid to the east decreased. During the same period, Georgia's glacier mass decreased by 30%. Besides the long-term changes in climate, extreme weather events such as extreme precipitation causing landslides, mudflows and droughts as well as more frequent floods occurred (USAID 2017).

Climate projections expect increasing average annual temperatures in the range of 1.6 to 3°C in the period 2041-2070 and a further increase in the period from 2071 to 2100 (compared to the baseline period 1971–2000). The lowest increase in temperatures is expected in the Black Sea coastal area. Furthermore, an increase in the number of hot days (maximum temperature over 25°C) and more frequent heat waves during summer are expected. The number of frost days is decreasing, especially in the mountain regions where a decrease by up to 71 days (period 2071-2100) is expected. Glacier melt proceeds, a complete loss of the glacier mass in projected by 2160. Changes in precipitation differ: While in eastern Georgia precipitation will decrease, it will remain almost unchanged along the coastal zone. In addition, an increase in extreme weather events leading to an increased risk of flash floods, mudflows, landslides and droughts is expected (USAID 2016).

Navarro and Jorda Sanchez (2021) provide time series data for significant areas, cities or infrastructures in Georgia, illustrating the evolution of climate hazard indicators in Georgia for the RCP8.5 scenario and the RCP2.6 scenario[5]. The evolution is indicated by the number of days per year or the number of events per year. For each period, the evolution is estimated as the difference between the average over the period (2011-2040, 2041-2070) and the historical average (1976-2005). The following events are covered:

- Droughts
- Extreme temperature
- Heatwaves
- Extreme precipitation
- Extreme wind
- Wildfires.

A detailed description of the definition and estimation of climate hazard indicators is described in the report by Navarro and Jorda Sanchez (2021).

Figure 11 exemplary shows the percentage change of extreme precipitation events in future periods compared to the historical period (1976-2005). Maps in the left (right) column shows the results for the RCP 8.5 (2.6) for different time periods. The events are increasing in time, for example, in the South and West of Georgia.

For the RCP2.6 evaluating adaptation measures are redundant due to comparable small damages from climate change events. Kahn et al. (2019) show that the effects of climate change on the economy in Georgia can even be positive in a RCP2.6 scenario, which implies that the historic trend of climate change is worse than the RCP2.6 scenario.

[5] The Representative Concentration Pathways (RCP) 8.5 (2.6) is the most pessimistic (optimistic) scenario assuming a global temperature increase of +4.8°C (+2°C) compared to the preindustrial level. The evolution of the number of EWE under the RCP 4.5 could not be provided by UIB. For analyzing economic impacts of climate change and adaptation only the RCP 4.5 and 8.5 are meaningful. For the RCP 2.6 evaluating adaptation measures are redundant due to comparable small damages from climate change events. Thus, the number of climate change events for the RCP 4.5 can simply be calculated as a mean value of the RCP 8.5 and RCP 2.6.

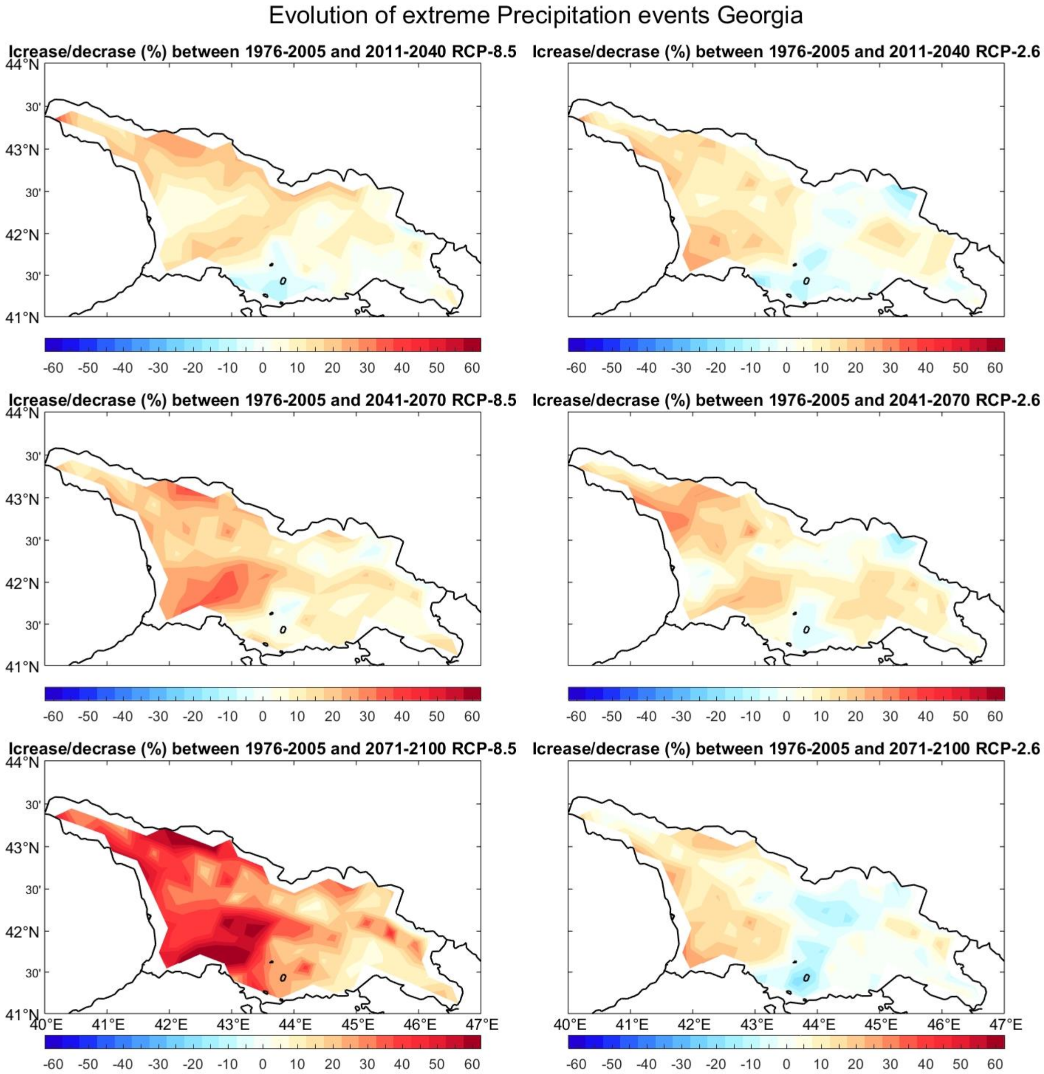


Figure 11: Evolution of extreme precipitation in Georgia for RCP 2.6 and 8.5 until 2100

Source: Navarro and Jordà (2021), UIB

Table 2 contains the average annual growth rates of the number of events per year for selected locations in Georgia. These growth rates represent the interface between climatic developments and economic damages in the future. For the modeling of climate change scenarios (see chapter 5), it is assumed that an increased number of extreme events leads to increased economic damages on a 1:1 basis. Accordingly, the growth rates calculated here are used to extrapolate the economic damages into the future. While the growth rates for extreme precipitation and extreme wind are 0.2% in total for Georgia for the different decades, the number of temperature based extreme events (drought, heatwave, extreme temperatures) is growing with higher rates. It is assumed that the damages caused by these events will increase likewise. For the RCP 2.6 evaluating adaptation measures are redundant due to comparable small damages from climate change events (see Figure 11).

Table 2: Average annual growth rates of the number of events per year for selected locations in Georgia

		RCP 8.5 (high scenario: global temperature increase of +4.8°C)							
		Tbilisi	*Kutaisi*	*Telavi*	*Gudauri*	*Batumi*	*Kvemo_Karti*	*Enguri_Dam*	*Georgia*
Drought	*2021-2030*		7,2%			0,7%		7,6%	3,2%
	2031-2040		5,7%			1,1%		5,8%	5,1%
	2041-2050	22,8%	4,5%	15,1%	21,4%	1,4%	19,2%	4,6%	8,4%
Heatwave	*2021-2030*	2,6%	3,2%	3,1%	3,1%	2,4%	2,7%	3,2%	2,9%
	2031-2040	2,2%	2,8%	2,6%	2,7%	1,9%	2,3%	2,8%	2,4%
	2041-2050	1,9%	2,5%	2,3%	2,4%	1,6%	2,0%	2,5%	2,1%
Extreme Temperatures	*2021-2030*	3,3%	3,2%	3,7%	3,7%	3,7%	3,4%	3,2%	3,5%
	2031-2040	3,0%	2,8%	3,3%	3,3%	3,2%	3,0%	2,9%	3,1%
	2041-2050	2,6%	2,5%	2,9%	2,9%	2,8%	2,7%	2,6%	2,7%
Extreme Wind	*2021-2030*	0,2%	0,4%	0,2%	0,3%	0,1%	0,0%	0,0%	0,2%
	2031-2040	0,3%	0,3%	0,2%	0,3%	0,0%	0,1%	0,0%	0,2%
	2041-2050	0,3%	0,3%	0,3%	0,3%	0,0%	0,2%	0,0%	0,2%
Extreme Precipitation	*2021-2030*	-0,2%	0,2%	0,3%	0,0%	0,4%	0,0%	0,3%	0,2%
	2031-2040	-0,2%	0,3%	0,3%	-0,1%	0,4%	0,0%	0,2%	0,2%
	2041-2050	-0,2%	0,3%	0,3%	-0,1%	0,4%	0,0%	0,2%	0,2%
Wild Fire	*2021-2030*								
	2031-2040						14,3%		14,3%
	2041-2050						7,2%		8,8%

Source: Own calculations based on data from Navarro and Jordà (2021), UIB.

Table 3 provides an initial overview of selected impacts of climate change on different infrastructures and sectors. Transport and energy as well as health and tourism are considered.

Table 3: Possible impacts of climate change on infrastructure and sectors

	Transport	Energy	Health	Tourism
Temperature changes	• Melting road surfaces and buckling railway lines • Damages to roads due to melting of seasonal ground frost or permafrost • Changing demand for ports as sea routes open due to melting of arctic ice	• Reduced efficiency of solar panels • Reduced output from thermal plants due to limits on cooling water temperatures • Increased demand for cooling	• Vector-borne infectious diseases • Health hazards caused by heatwaves • Changes in fitness and activity level • Increased demand for health care services • Deaths	• Reduced winter season in alpine ski resorts • Extended summer season for seaside tourism • Adverse health effects during heatwaves and due to increased occurrence of waterborne diseases
Sea-level rise	• Inundation of coastal infrastructure, such as ports, roads or railways	• Inundation of coastal infrastructure, such as generation, transmission and distribution		• Increased erosion at waterfront structures and of popular tourist beaches • Increase in overtopping and flooding rates of tourism facilities • Losses to tourist assets

	Transport	Energy	Health	Tourism
Changing patterns of precipitation	• Disruption of transport due to flooding • Changing water levels disrupt transport on inland waterways	• Reduced output from hydropower generation • Disruption of energy supply due to flooding • Insufficient cooling water	• Problems in water quality • Water-borne disease outbreaks • Deaths and injuries • Decrease in service reliability	• more frequent occurrence of avalanches in hiking and trekking areas • disruption of transport and other services at beach destinations through mudslides and landslides
Changing patterns of storms	• Damage to assets, such as bridges • Disruption to ports and airports	• Damage to assets - e.g. wind farms, distribution networks • Economic losses due to power outages	• Accidents • Deaths and injuries • Decrease in service reliability	• closure of tourist attractions and closure of transport • damages to coastal resorts, tourism equipment, trees and natural attractions • loss of tourism infrastructure

Source: Adapted from OECD (2018), World Bank (2020b) and WBG and ADB (2021).

Climate change not only causes direct damage to infrastructures, but also leads to indirect economic losses, for example through interruptions in transport or energy supply (OECD 2018). The indirect losses often even exceed the direct infrastructure damage, which is why climate-resilient infrastructures are of particular importance (OECD 2018). Climate change affects human health through different impact pathways. There are both direct and indirect disease impacts such as accidents and deaths or changes in certain disease risks, but also indirect social and economic risks such as loss of jobs and livelihoods, for example, through reduced food yields, property loss or infrastructure damage (EEA 2017).

The economic activities in Georgia are affected by different climate threats. Agricultural production heavily depends on climate conditions. The effects of the already ongoing and forecasted climate changes on the agriculture sector in Georgia range from the displacement of agri-climatic zones, the reduction of crop productivity due to extreme weather events, the reduction of the agricultural lands' fertility, the reduction of irrigated land areas to a higher demand for irrigation water (see MEPA 2017). Thus, climate change negatively impacts the economic and social welfare and increases both sector and economy development risks.

Climate change will lead to an increase in extreme weather phenomena, above all drought and heavy precipitation. Other problems like salinization due to evaporation, better wintering of diseases, and increased wind erosion can also be related to climate change. On the one hand, some of these developments can have advantages for agriculture (such as a longer vegetation period, which enables to harvest several times a year, and making agriculture possible in regions not previously considered). On the other hand, however, there are also disadvantages, for example, earlier flowering makes fruit trees more susceptible to late frosts and the risk of spreading plant-damaging diseases increases. Hot temperatures also mean more stress for crops. In the long term, climate change could reduce the yields because the crops are no longer well enough adapted in their previous location.

With regard to tourism, climate is one of Georgia's main competitive advantages, including temperature ranges, natural settings, recreational properties and diverse landscapes, which are enabling a set of tourism activities (see USAID 2016). However, tourism is strongly affected by climate change. Tourism activities are directly related to weather conditions, e.g., temperatures, precipitation, sea turbulence, and the number and seasonal distribution of sunny days (see The World Bank 2020b).

Furthermore, climate change has an impact on tourist assets, including infrastructure, tourist attractions, and transportation systems. Thus, several threats from climate change may arise, such as the flooding of streets, interruption of the provision of power, failure of cooling systems, damaged roads, interruption of the provision of water, malfunctioning of wastewater (see The World Bank 2020b). While these threats directly have an impact on infrastructure, they also have an impact on tourism in Georgia, since tourism depends on a well-developed and functioning infrastructure. Moreover, damaged infrastructure can lead to further economic implications, as supply chains may be disrupted, industrial buildings may be damaged, and thus production losses and further disruptions may occur.

Besides these risks of climate change, tourism in Georgia is also facing some opportunities. The summer season of seaside tourism may be extended due to the forecasted increase of air temperature, accompanied with warming of sea water, decreasing of precipitation and increasing of the number of sunny days (see CZ-NAP 2020, World Bank 2020b,).

3.3 OVERVIEW PAST EVENTS AND MONETARY DAMAGES

Section 3.2 provided an initial overview of the climatic threats that could affect Georgia. In order to better understand the modeling studies on the economic effects of climate impacts and adaptation measures carried out in the remainder of this report, this chapter provides a synopsis of past climate change events and their monetized damages. The events and damages presented here result from a cooperation with the Georgian partner TBSC Consulting. TBSC 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 a useful data.

The following hazards were covered through the research:

- Droughts
- Storms or strong winds
- Heavy rains
- Landslides and mudflows
- Floods
- Heat waves
- Coastal storms or coastal floods
- Glacial melt

- Hailstorms.

All possible sources of information (state agencies, public media coverage, international and local publications, private sector entities) on the above-mentioned information were addressed and all feasible efforts were made to collect and records on: a) the occurrence of the event and b) estimated damage (both monetary and non-monetary, where available).

The analysis of past events and their monetary impact provides an initial indication of the damages that can be expected from future extreme weather events in Georgia. However, it must always be taken into account that the amount of monetary damage depends in particular on the regional scale in which and the extent to which the extreme weather event occurred. For example, it makes a difference whether a heavy rain event, which basically has a rather regional limited impact, takes place in an urban area or whether the rain pours down in a rather rural area. In the former case, the damage is likely to be significantly higher, as e.g. buildings are flooded and damaged and household goods become unusable (e. g., the heavy precipitation event of Tbilisi in 2015), whereas in the latter case, e.g. agricultural yields may be affected.

The analysis also illustrates that the damage patterns between the individual extreme weather events are quite similar, but can differ significantly in magnitude. This is also an important finding, since the adjusting screws for setting extreme weather events in the model (see chapter 5) are thus similar.

Throughout the TBSC research it turned out, that there is no single private or public institution where one can find and download the required information and data entirely. World Bank (2017) also points out that data on historical damage and losses resulting from natural disasters in Georgia are scarce. There are information gaps in the list of occurred extreme weather events (e.g. what happened and when) and moreover, there are gaps or incomplete information on corresponding monetary damages. The most comprehensive databases used can be found at the National Environmental Agency (NEA), the Hydro-Meteorology department and the Department of Geology at NEA.

Table 4 summarizes the monetary damages from extreme weather events in Georgia for the years 1995 to 2020. Depending on the data sources used and the respective extreme weather event, the quality of the data is better or worse. Only some damages can be reported annually. Also, a clear allocation of monetized damages cannot always be made (see the extreme event in Tbilisi in the year 2015: monetary damages are reported under heavy rain, flood and mudflow). It is therefore not possible to sum up the individual yearly losses of the extreme weather events to get the monetary damages of climate change for the respective year.

Table 4: Reported monetary damages in million GEL for different extreme weather events for the years 1995 to 2020.

Year	Storm or Strong Wind	Strong Wind - Insured Loss	Coastal Storm	Heavy Rain	Heavy Rain - Insured Loss	Drought	Flood	Flood - Insured Loss	Hail	Hail - Insured Loss	Landslide	Mudflow
1995	0.5						3.2		12.7		72.5	52.7
1996	4.0					17.0	25.5		17.0		44.1	14.8
1997	1.0					26.0	34.0		33.0		57.5	24.8
1998	72.0					6.0	2.0		22.0		40.5	12.1
1999	3.5					0.6			5.4		10.6	4.0

Year	Storm or Strong Wind	Strong Wind - Insured Loss	Coastal Storm	Heavy Rain	Heavy Rain - Insured Loss	Drought	Flood	Flood - Insured Loss	Hail	Hail - Insured Loss	Landslide	Mudflow
2000	1.0					450.0	2.0		5.8		12.9	2.6
2001	0.1					21.0			10.4		13.5	23.4
2002	2.5								6.8		13.2	22.0
2003	0.1								8.3		13.5	3.7
2004	1.8			3.0					3.0		122.5	23.3
2005	1.4		1.0	0.2			13.7		69.0		75.7	7.1
2006	0.3			1.5		5.0			6.2		54.6	7.0
2007	1.1		0.6	0.7					5.0		14.9	8.4
2008	2.9					4.5	6.0		2.9		31.1	9.7
2009	8.4			2.0		6.0	1.0		9.5		46.1	12.0
2010	2.5					45.0	2.4		6.9		15.5	3.9
2011	0.0			0.4			21.0				9.4	6.6
2012							50.0		0.4		19.5	35.9
2013	0.8		3.0	5.5		0.1			0.4		32.4	33.8
2014	0.8			3.0			3.0		0.2	3.1	47.1	115.2
2015		3.4		200.2	1.3		200.0		15.0	81.5	67.6	246.7
2016	0.1	0.7		1.0	0.9		3.0			54.9	41.7	21.1
2017	6.4	2.6					5.0	0.3		14.1	53.5	26.6
2018	8.0	3.6						0.5		7.0	49.7	42.6
2019	0.2	1.3		50.0			53.0	0.2		11.0	29.6	33.3
2020	0.3	2.2		45.0			50.0	0.1		11.9		
SUM	**119.7**	**13.8**	**4.6**	**312.4**	**2.2**	**581.2**	**474.9**	**1.0**	**239.9**	**183.4**	**989.1**	**793.0**
per year	5.0	2.3	1.5	26.0	1.1	52.8	27.9	0.3	12.0	26.2	39.6	31.7

Source: Own calculation, based on data from TBSC.

Keeping in mind that allocating damages to one hazard only is not possible, landslides and mudflows have each had the highest reported damages in the past. For landslides, these damages add up to almost GEL 1,000 million over the years 1995 to 2020, for mudflows it is almost GEL 800 million. High accumulated reported damages can also be found for droughts (GEL 581 million) and floods (GEL 475 million), followed by heavy rain (GEL 312 million), hail (GEL 240 million), strong wind (GEL 120 million) and coastal storms (GEL 5 million).

Looking at Table 4 in more detail, it is noticeable that the respective loss totals for the individual extreme weather events are strongly influenced by individual particularly strong reported losses in each case. For landslides it is the year 2004 (GEL 122.5 million), for mudflows, heavy rain and flood it is the Tbilisi disaster of 2015 (approx. GEL 200 million), for drought it is the year 2000 (GEL 460 million) and for wind it is the year 1998 (GEL 72 million). Thus, these numbers already reflect the fact that there are so-called 1 in 100 years major events, which are significantly more devastating than the average events.

Table 5 summarizes disaster losses for the time period from 1991 – 2015 as recorded in the international EMDAT database (see World Bank 2017). UNDP (2014) points out, that over the last 40 years, 70 percent of the country has experienced disasters from hydrometeorological and geological hazards. The losses incurred between 1995 and 2013 as a result of landslides, floods, drought, storms, avalanches, and hail were calculated at GEL 2.7 billion, which is pretty much in line with the reported monetary damages as shown in Table 4.

Table 5: Reported historical disasters in Georgia, 1991 – 2015.

Disaster	Time period	Events (number)	Total deaths	People affected (number)	Total damage (million US$)
Flood	1995–2015	14	61	153,078	82
Earthquake	1991–2009	4	15	30,212	350
Storm	2001–2013	3	0	8,668	91
Drought	2000	1	-	696,000	200

Source: Adapted from World Bank (2017).

Table 6: Illustrative impacts of past hazards in Georgia

	Heavy rain	Floods	Strong wind	Drought or water shortage	Hail	Landslide, mudflows	Forest fires
Agriculture and Forestry	Damaged crops	Damaged crops	Damaged crops	Damaged crops	Damaged crops		Lower fire / trees were not damaged
	Flooded vineyards	Flooded fields	Knocked down trees	Damaged vineyards	Damaged vegetables		Grass and dried leaves were burned
	Killed cattle	Killed cattle		Delayed Vegetation	Damaged fruits		
	Damaged irrigation systems			Damaged Irrigation canals and systems			
		Damaged agricultural lands					Open area, forest not damaged

	Heavy rain	Floods	Strong wind	Drought or water shortage	Hail	Landslide, mudflows	Forest fires
Transport and Buildings	Damaged bridges	Damaged bridges	Destroyed bridges			Damaged bridges	
	Damaged roads	Damaged roads	Damaged buildings			Damaged roads	
	Flooded houses	Damaged houses	Damaged roofs		Damaged roofs	Damaged houses	
	Damaged railway line	Stopped train traffic					
	Damaged cars	Damaged cars	Damaged cars				
	Damage to household items						
Energy and Water	Damaged power lines	Cut power lines	Cut power lines			Damaged power lines	
	Damaged oil pipelines	Destroyed oil and gas pipelines	Cut gas pipelines			Damaged pipelines	
	Damaged drinking water wiring					Damaged water supply system	
		Destroyed dams					
		Operation of Hydro power was delayed		Hydro Power Plants affected			
Industry	Flooded industry						

Source: Adapted from TBSC.

Table 6 illustrates which individual categories of damage are addressed by each hazard. The categories are similar in each case, but the individual biophysical effects (too much water due to heavy rain, too strong wind) have different impacts on the specific damage and the amount of damage. Agriculture is at the mercy of nearly all climatic damage events. Both crops on the fields and animals can suffer damage. Fruits and vegetables can suffer damage from both too much water and too little water, from heat and drought, from too much wind, from hail, as well as from fire. Animals also suffer damage from too much water or from little water and drought.

Different types of infrastructure are each affected by the different extreme weather events. Bridges, roads, buildings, and grid-based infrastructure such as electricity, gas/oil, and water supply are hit in different ways. While roads and bridges are washed out and their foundations are damaged by heavy rain, a storm, for example, causes superficial damage due to fallen trees or other objects. Extreme heat warms and expands the material of roads, causing them to blow up. Household goods and cars also get damaged in different ways.

While industry and production sites can be affected directly by extreme weather events like precipitation, strong wind or floods, they can also be affected indirectly by cut power lines or damaged infrastructure.

Without electricity, machines cannot produce, and damaged infrastructure may cause a delay in the supply chain, which both can lead to a production loss.

4 DEVELOPING A REFERENCE SCENARIO

The reference scenario is laid out as a business-as-usual scenario. It yields the basis for all further scenario analyses and evaluations. Thus, the parameters and settings must be carefully selected in order to provide a solid basis for the other scenarios. As described in section 5.1, the dependencies observed in the past are used to project the development of the Georgian economy to the future. For this report, the data base in the model ranges up to the year 2019. However, new data is published on a regular basis and needs to be implemented in the model. So far, the model does not contain any information on the COVID-19 pandemic crisis in the years 2020/2021 and the recovery process in the forthcoming years. The economic crisis caused by the pandemic is neither a cyclical nor a structural event (see Kakulia and Kapanadze 2020), an thus needs to be integrated in the e3.ge model explicitly. As, for example, consumption variables are estimated (e.g. on the basis of the GDP of the previous year) and other variables (if neither estimated nor calculated by definition or being tweaked) may remain constant over time, there is a clear need to actively create a reference scenario that addresses the following three points:

1. The pandemic impacts in the Georgian economy in the year 2020
2. The economic recovery in the year 2021 and the following years
3. The possible future path for the Georgian economy until the year 2050

Although the e3.ge model is only a simplified representation of reality, the economy of the e3.ge model should be comparable to the developments observable in reality and assumed in national ministries and other well-known institutions (e.g., International Monetary Fund, IMF). Since the different model forecasts are based on different assumptions, they all have slightly different results. Thus, a perfect harmonization between well-known forecasts and the e3.ge model results is not possible and is not feasible at all. By tweaking the right variables, the e3.ge model can process the additional information and take into account the aforementioned points throughout model runtime. The number and type of variables to be tweaked need to be carefully selected, since the more variables are tweaked for the reference scenario, the less the model's own dynamics come into play. However, it is necessary that the model performs a GDP growth path that is comparable to other studies. Likewise, in a second step in the next case studies, the reference scenario will be taken to integrate the effects of climate change and adaptation, which are not automatically to find in the future projections as well (see section 5.1).

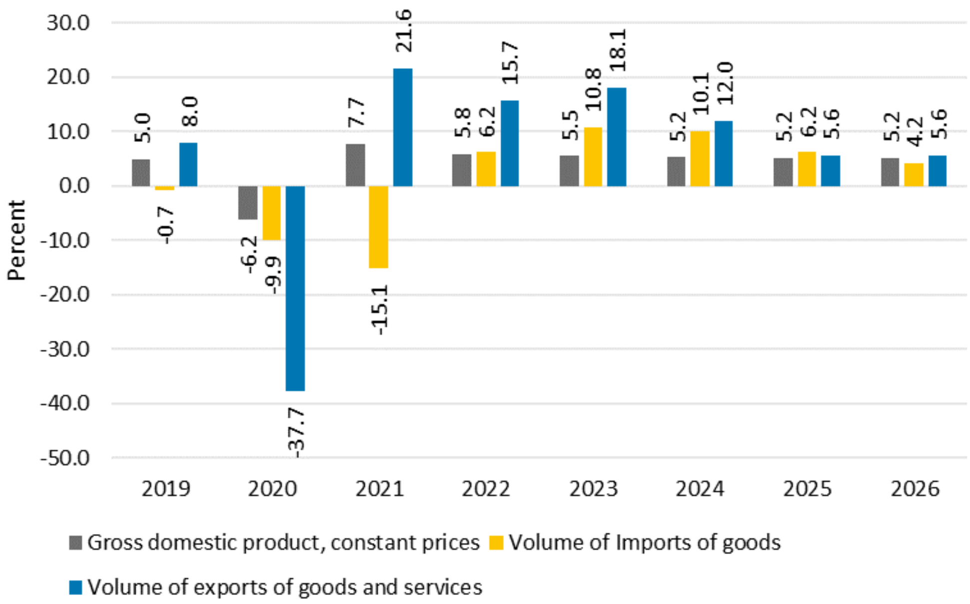


Figure 12: Expected growth rates of Gross domestic product, exports and imports for the years 2019 – 2025, in percent

Source: Own figure, based on data from IMF.

Figure 12 gives a first impression on the expected growth rates for important economic variables for the near-term future, provided by the IMF. The pandemic impact on the economy is massive and significantly disrupts the economic growth that has been observable in the past (see Figure 7). For the year 2020, the IMF predicts a drop in GDP of more than 6%, and the Georgian Ministry of Economy and Sustainable Development foresees a similar drop of up to 6%. This decline is followed by an economic recovery in 2021 and the following years, assuming a positive economic growth also for the long-term future. The course of the pandemic has a massive impact on the economic development in 2021. While official authorities in Georgia assume economic growth of 3.5%, the IMF assumes an increase by 7.7%. Exports are decreasing by 37% in 2020, the first year of the pandemic , imports are decreasing by 10% respectively. The recovery takes several years, with double-digit growth rates for exports and imports.

Also the other components of GDP, namely consumption expenditures of households and government, gross fixed capital formation and changes in inventories, need to be addressed to implement the pandemic impacts and the recovery process. Anti-crisis economic recovery plans focus on additional consumptions expenditures of the government throughout the pandemic year 2020 and the years after, but also on additional investment in infrastructure and buildings, to stimulate the Georgian economy. Likewise, the Georgian government developed a package of measures to address the economic impacts of the anti-pandemic restrictions on citizens and businesses, e.g. subsidies, grants, benefits, postponing of various financial obligations (see Kakulia and Kapanadze 2020). Due to this, it is assumed that private households are not changing their consumption patterns during the pandemic. Moreover, it is assumed that additional expenditures of GEL 670 million will be made throughout the year 2021, which also result, for example, from tax reductions.

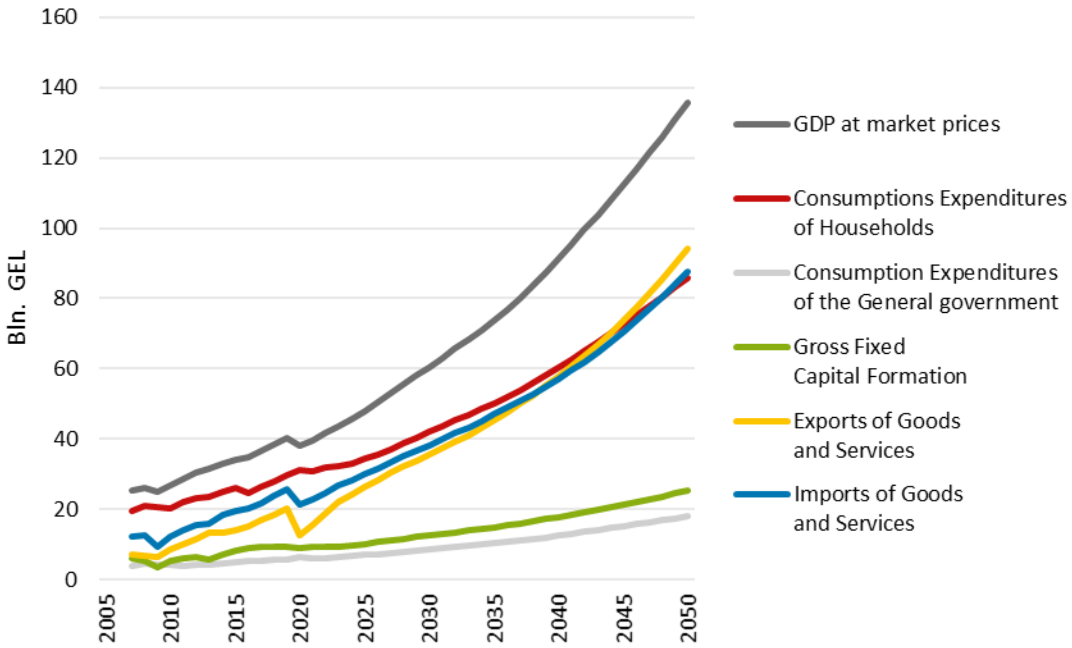


Figure 13: Reference scenario, projection of GDP and components, real values, in billion GEL

Source: Own figure based on e3.ge results.

Figure 13 shows the projection of the Georgian GDP and its components for the reference scenario up to the year 2050. The economic development in the reference scenario is positive: All components of the GDP have a positive development, interrupted by the negative impacts of the pandemic in the year 2020. After the recovery, the Georgian economy is supposed to grow both due to increasing exports of goods and services and increasing consumption expenditures. Likewise, the imports are also increasing over time. Table 7 summarizes the economic development by calculating the average annual growth rates for the GDP and its components of final demand. Especially exports in constant prices are growing significantly over time, with an average annual growth rate of 7% in the years 2020 to 2050. The recovery from the pandemic causes high growth rates for exports. The exports are growing faster than the other final demand components. But also the consumption expenditures of households and the government are growing at an average of 3.4% and 3.6%, respectively. Overall, the GDP is growing at an average of 4.3% throughout the years 2020 to 2050. This economic development is in line with the development that was visible in the past (see Figure 7).

Table 7: GDP and components of final demand in constant prices – Average annual growth rates (AAGR)

	2007-2019	2020	2021-2030	2030-2040	2040-2050	2020-2050
GDP	3.9%	-5.9%	4.9%	4.2%	4.1%	4.3%
Consumptions Expenditures of Households	3.7%	4.5%	3.5%	3.7%	3.6%	3.4%
Consumption Expenditures of the General government	3.4%	6.9%	4.2%	3.8%	3.8%	3.6%
Gross Fixed Capital Formation	3.5%	-4.7%	3.4%	3.6%	3.5%	3.5%

Exports of Goods and Services	9.0%	-38.5%	9.5%	5.0%	5.0%	7.0%
Imports of Goods and Services	6.3%	-17.1%	6.0%	4.1%	4.4%	4.8%

Source: Own figure based on e3.ge results.

However, such strong economic growth can only be achieved if the accompanying economic circumstances make such growth possible. Table 8 shows the corresponding increases in production for 16 different industries. The increasing production levels require that the corresponding labor force is available or that significant improvements in productivity occur. The increasing demand for energy must also be met.

Table 8: Production for 16 industries in constant prices – Average annual growth rates (AAGR)

	2007-2019	2020	2021-2030	2030-2040	2040-2050	2020-2050
Agriculture, hunting and forestry	1.9%	-12.7%	5.0%	4.2%	4.0%	4.3%
Mining and quarrying	8.4%	-39.4%	9.8%	5.7%	5.9%	7.5%
Manufacturing	4.8%	-13.1%	6.4%	5.0%	4.9%	5.4%
Production and distribution of electricity, gas and water	5.7%	-21.5%	3.6%	3.7%	4.0%	3.7%
Construction	7.4%	-14.7%	2.9%	3.6%	3.3%	3.3%
Wholesale and retail trade; repair of motor vehicles and personal and household goods	5.4%	-15.0%	5.3%	4.2%	4.1%	4.6%
Hotels and Restaurants	13.4%	-43.3%	8.0%	4.7%	4.8%	6.0%
Transport and communication	2.9%	-17.8%	6.7%	4.7%	4.7%	5.4%
Financial intermediation	9.8%	-7.2%	4.8%	4.1%	4.0%	4.3%
Real estate, renting and business activities	14.9%	-16.4%	4.4%	4.0%	3.8%	4.0%
Public administration	-1.2%	19.5%	3.7%	3.7%	3.4%	3.3%
Education	6.0%	-2.9%	3.4%	3.6%	3.3%	3.2%
Health and social work	5.0%	6.9%	1.9%	3.6%	3.3%	3.2%
Other community, social and personal service activities	5.3%	-22.9%	6.3%	4.4%	4.3%	5.1%

Source: Own figure based on e3.ge results.

Looking at the production values at constant prices (see Table 8), the positive development in the tourism sector is noticeable. The sector *Hotels and Restaurants* has already grown strongly in the past and will also be the sector with the strongest growth in the future in the reference scenario (average annual growth rate of 6% in the period from 2020 to 2050). However, it was also this sector that suffered the greatest losses in the pandemic (-43.3% in the year 2020), as travel no longer took place. For this sector in particular, the recovery will also depend to a large extent on how quickly vaccinations are carried out worldwide and thus travel restrictions are lifted again. The pandemic has caused production to decline in almost all sectors, with only *Public administration* and *Health and social work* having an increase in production in the year 2020. Other sectors develop quite well over time with the highest growth rates in some industries as *Manufacturing, Transport and communication,* and *Mining and quarrying*. However, while the *Manufacturing* and *Transport* sectors play a major role in the future, the sector *Mining and quarrying* is the smallest one. It is also those two sectors, which are expected to grow more strongly than in the past.

Table 9: Labor market indicators – AAGR

	2010-2019	2020	2021-2030	2030-2040	2040-2050	2020-2050
Employment, total	-0.3%	0.1%	-0.2%	-0.4%	-0.2%	-0.3%
Unemployment, total	-1.3%	-6.4%	-6.2%	-1.7%	-4.5%	-1.3%

Source: Own table based on e3.ge results.

The labor market in Georgia is determined by the development of the population and, in particular, by the development of the working-age population (20–64 years old). The UN forecasts predict a sharp decline in the Georgian population in the future. From over 5.4 million people in 1990, the population decreased to under 4 million people in 2020. It is assumed that there will be a further decline to about 3.5 million people by 2050. Thus, the increasing economic activity and production goes along with a decreasing number of skilled workers. Accordingly, the economic growth shown in Figure 13 can only be realized if there is a significant improvement in productivity, and thus more can be produced with the same or even reduced labor input. For modeling purposes, it is assumed that this increase in productivity will take place.

Figure 14 illustrates that the level of employment remains almost constant, while the unemployment is steadily decreasing. The overall population is decreasing.

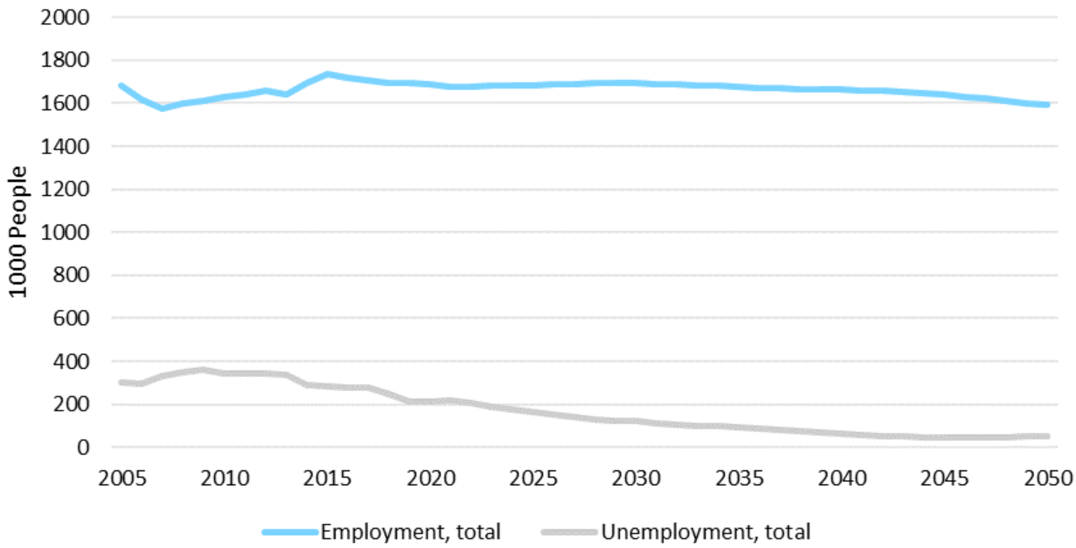


Figure 14: Labor market data in 1000 People for the years 2005 – 2050

Source: Own figure based on e3.ge results.

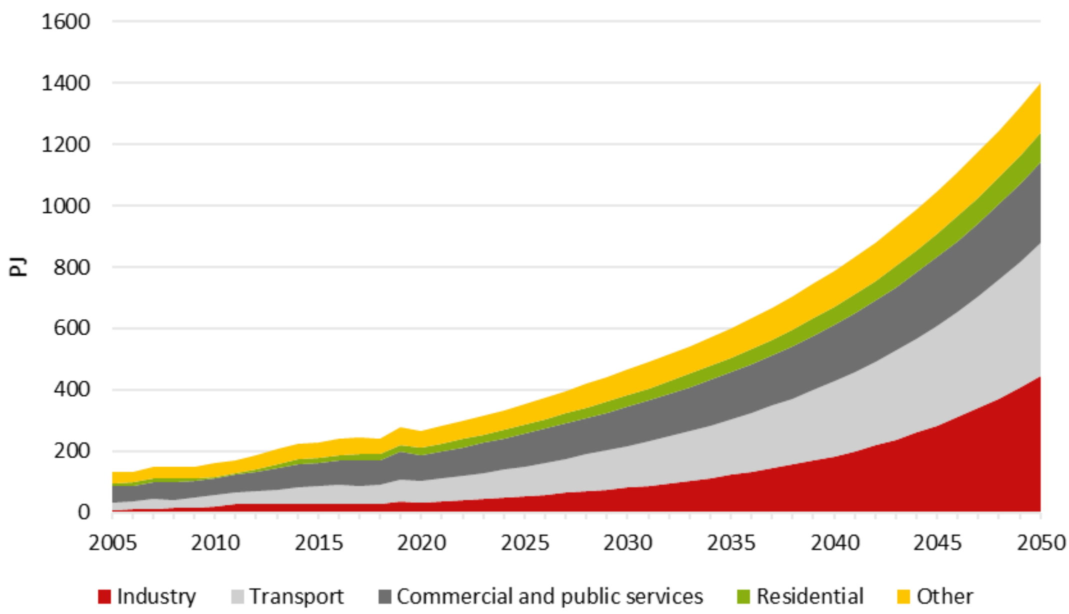


Figure 15: Final energy consumption by sector in PJ for the years 2005 – 2050

Source: Own figure based on e3.ge results.

The assumptions regarding energy supply and demand as described above are a strict continuation of past developments and the status quo of today (Figure 15). Therefore, final energy consumption continues to grow faster than GDP. Overall, the final energy consumption is growing at an average of 6.0% p. a. between 2020 and 2050 (GDP: 4.3%, respectively). Especially in industry (9.1%) and transport (6.3%) the long-term growth rates are very high. Final energy consumption by households is increasing at an almost constant growth rate of less than 4.0% p. a. over time. Industry will need more than ten times as much final energy under this scenario as was needed in 2020. Energy consumption in the transport sector increases and will need more than six times as much final energy as was needed in 2020. Corresponding to the final energy consumption, the CO2 emissions are increasing over time, not presuming a stronger use of renewable energy in final energy demand.[6] The transport sector is the sector with the highest CO_2 emissions. Due to the high shares of hydro power for generating electricity, the CO_2 emissions of the energy industries are rather small (see Figure 16).

[6] The calculation of CO_2 emissions in this report can only be approximated with the emission factors for CO_2 by sector and fuel type of Kazakhstan. Unfortunately, there is no corresponding information available for Georgia in the official reporting of UNFCCC. Once the data is also available for Georgia, the model can be adjusted accordingly. However, a comparison of the corresponding emission factors for different countries shows that they are at a similar level in each case.

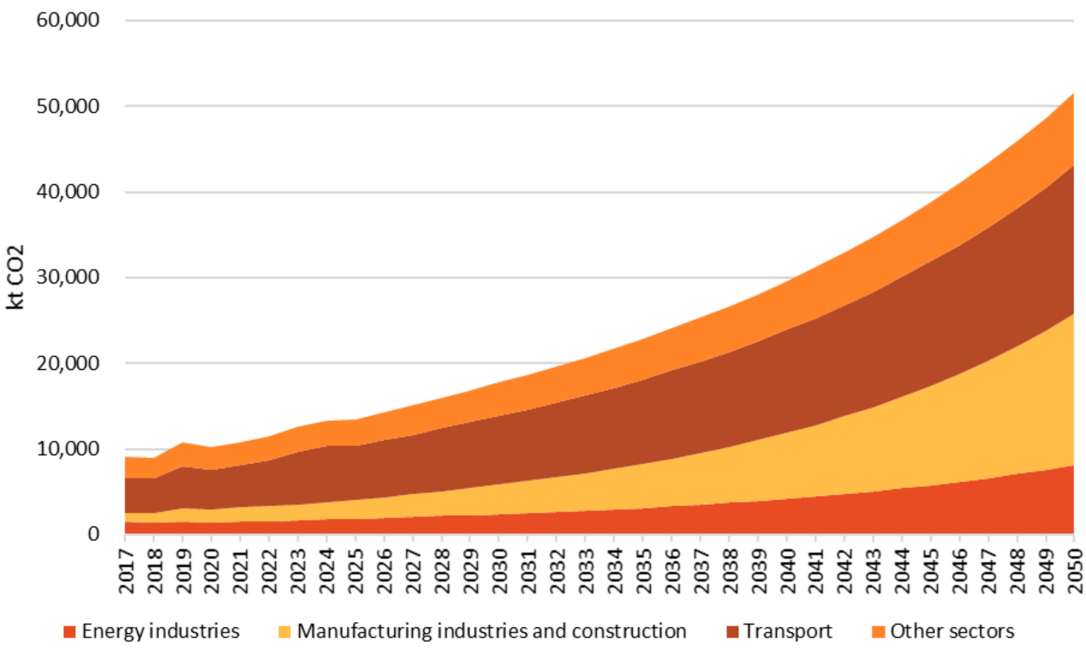


Figure 16: CO_2 emission by sectors, 2017-2050

Source: Own figure based on e3.ge results.

This reference scenario sets the basic framework for the further modeling activities. In the next sections, effects of climate change are implemented into the described scenario framework in order to create scenarios with climate change.

5 ECONOMICS OF CLIMATE CHANGE

5.1 IMPLEMENTING CLIMATE CHANGE IMPACTS IN THE E3.GE MODEL

Climate change affects the world and the life of people in many ways, including manifold effects and reactions on the economy, either directly or indirectly. There are interactions and feedbacks between these individual effects. Future responses (mitigation or adaptation) and societal changes, in turn, influence the extent of climate change effects and thus its effects on the economy. All in all, it is a very demanding task to represent these interactions and relationships in simulation models. Statements about the future can only be made with a high degree of uncertainty, which increases the further one looks into the future (Brasseur et al. 2017).

Nevertheless, in this chapter climate change is integrated into the macroeconometric e3.ge model to calculate the economic damages and effects that may result in the future. The approach is to focus initially on the above mentioned relevant extreme weather events (see chapter 3.2). Thereby, with the support of information and insights gained in expert workshops in Georgia throughout the model building process, different effects are integrated on a sectoral level, e.g. the effects of heat waves on agriculture or tourism. The interlinkages in the modeling framework are about to calculate the overall macroeconomic effects out of the respective sectoral changes.

As described in chapter 2.2, the e3.ge model contains three interlinked model parts, namely the economy model, the energy module and the emissions module. But why does the model need to be extended to include the damages caused by climate change in order to calculate the economic effects of climate change and adaptation in the future? Doesn't the model already contain information and data on climate change?

As the model is calculating on an annual basis and extrapolating historical time series data into the future, the effects of climate change are not automatically found in future projections. Although there are some events with very high damages that are even visible in the macroeconomic data (e.g. the severe drought in the year 2000 affected almost 700,000 people, and its adverse effect on agriculture and electricity generation by hydropower stations reduced GDP by 5.6 percent; see World Bank 2017), the modeling of future impacts of climate change on the national economy needs a link between future climate projections and sectoral economic damages (see chapter 3.2) so that the model can be hit by different climatic threats. The increase in frequency and intensity of climate change events in the future play an important role. While it is already difficult to quantify these increases for the respective climate change events from a scientific modeling perspective, it is even more difficult to quantify their economic consequences (Brasseur et al. 2017). Since no official and comprehensive data set exists, the economic damages must be derived from single past climate events in the country and serve as a benchmark.

However, these damages could have been avoided or reduced by investing in adaptation measures. Furthermore, this money could have been spent on productive uses rather than on repairs and restoring the status quo (so called defensive spending). Since the effects of climate change are expected to increase in frequency and extent, comprehensive estimates of the damages due to extreme weather events in different areas and sectors of the national economy need to be first integrated in the e3.ge model.

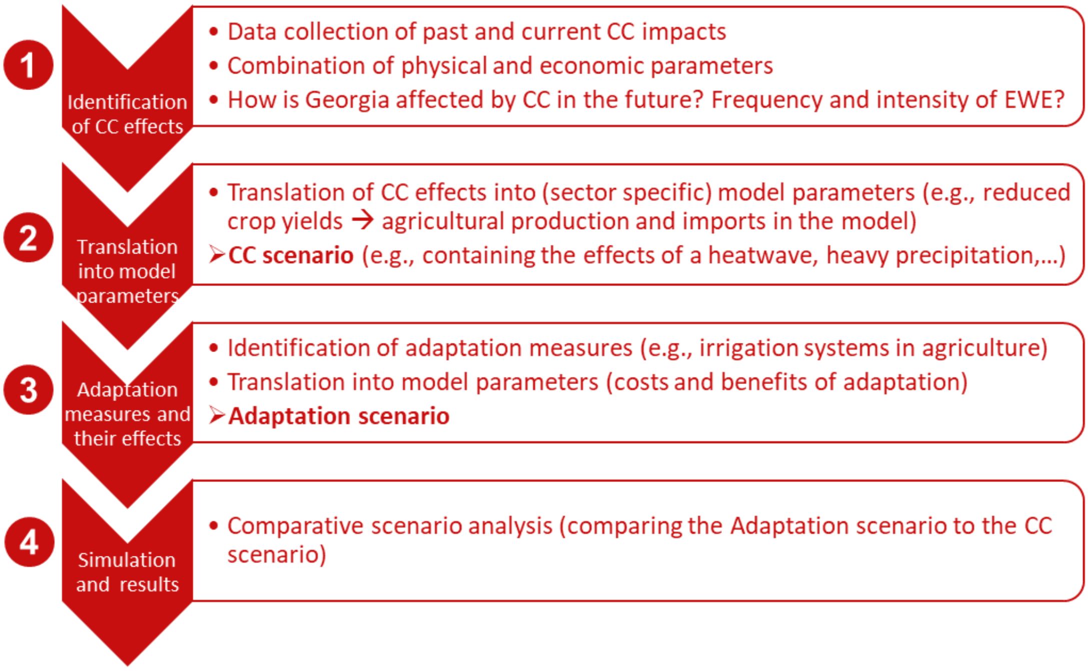


Figure 17: Integration of climate change and adaptation in an economic model; proceeding in four steps

Source: Own illustration, adapted from Lehr et al. (2020).

Figure 17 illustrates the approach of implementing climate change (and later adaptation to climate change) in the e3.ge model. Therefore, a functional connection between the climate information for the future (see chapter 3.2) and the economic consequences (see chapter 3.3) has to be derived. To do so, four steps are taken:

1. After agreeing on the extreme weather events to be expected in the future in the respective country, the next step is to derive the possible explicit biophysical and economic effects for each extreme weather event. This is done, for example, by evaluating literature, insurance data, websites, etc. The evaluations and research of TBSC mentioned above (see chapter 3.3) also contribute to the identification of the individual effects. For this step, it may be necessary to combine physical and economic parameters (e.g., increased electricity consumption weighted by electricity price). In particular, data and information from climate change-related events in the past are an essential aid for the identification and valuation of the effects. It is this information in particular that is incorporated into the economic model.
2. In a second step, the identified biophysical and economic effects need to be translated into model parameters. To do so, the detailed analysis on future development of climate change events are used to create a time series of damages for the respective extreme weather events. These time series are then assigned to specific variables in the e3.ge model. The structure of the model may require translations to be made. For example, some variables in the model cannot be directly influenced by climate change because they are residuals or definitionally dependent on other variables. Accordingly, a decline in domestic production, for example, can be integrated in the model via increased imports. After having finished this second step, the economic model contains climate change effects and can be used to evaluate these respectively.
3. The third step, which will be explained in chapter 6, comprises the identification of adaptation measures and their translation into the e3.ge model.
4. Finally, a scenario-analysis (see chapter 2.3) is being performed to evaluate the economic effects of climate change and adaptation to climate change.

Figure 18 provides an overview on how to implement climate change impacts at sectoral level.

Figure 18: Extreme weather events and their sectoral impacts

Source: Own figure.

Since there is not that one database that contains all the data needed to integrate climate change in the e3.ge model, different sources were used to gather all the information and data:

- Meteorological experts from the National Environmental Agency in Georgia (Meteorological information and data; exchange with climate experts from UIB)
- Climate scientists and experts from the University of the Balearic Islands (evaluation of international climate models and scenarios; development of the number of extreme weather events and gradual changes in Georgia in the future)
- Local partners in Georgia from TBSC (detailed analysis of past extreme weather events; non-monetary and monetary damages)
- European Climate Damage and Adaptation Platforms PESETA, Climate-Adapt
- Desk research (internet, scientific papers, newspapers, reports)
- Evidence from other countries (e.g. Germany)
- Fruitful discussions within the CRED project
- Own assumptions

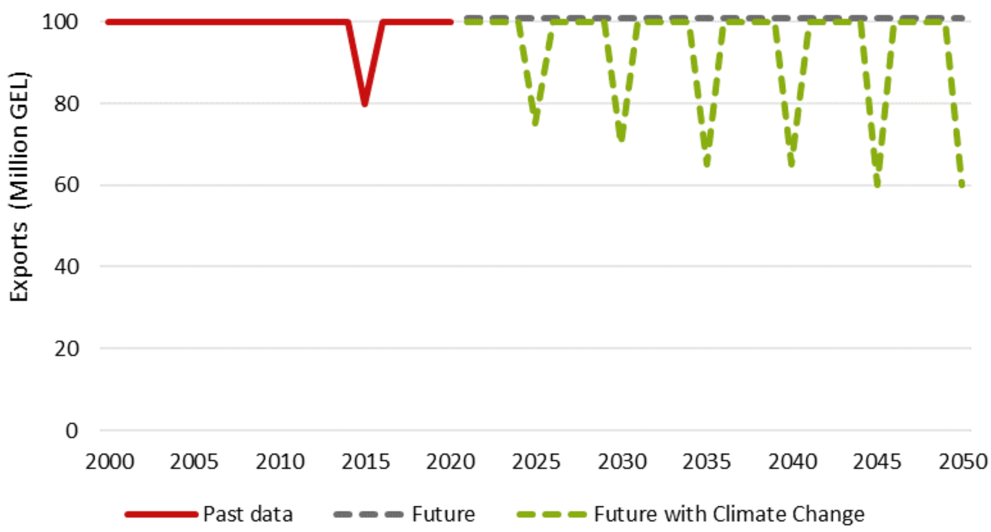


Figure 19: Example for the forward projection of exports and integration of climate change effects

Source: Own figure.

Figure 19 illustrates the necessity to explicitly integrate climate change effects into the economic model. The example illustrates exports of 100 Million GEL for all past years, except for the year 2015. In 2015, there is an exemplary decline in exports of 20% due to climate change effects, but exports recover the year after. Econometric estimations, linear trends, but also the course of the time series itself, lead to the assumption that future development of exports may also settle somewhere around 100 Million GEL. Extrapolating past values would thus ignore the fact that without adaptation to climate change, export losses due to climate change would occur with greater frequency and to a much greater extent. Instead of assuming a future development of the exports illustrated with the orange line, the assumptions about the effects of climate change must be explicitly considered. The green line shows only one possible example. Depending on the frequency and amount of damages assumed, the recovery process may take longer than just one year, which could result in a downward movement, from which it becomes increasingly difficult to get out. The same is true for the other direction, as some of the climate change events also cause positive economic reactions (see section 5.1).

The following case studies on different extreme weather events and their respective damages (or gains) calculate the economy-wide effects of climate change. The analysis is not limited to the isolated evaluation of individual climatic hazards, but can also consider several climatic hazards in aggregation at a time.

In the next subsections, case studies exemplary illustrates the economy-wide impacts in terms of e. g. economic growth, jobs and CO_2 emissions of selected extreme weather events calculated with the model e3.ge. All scenarios are based on the RCP 8.5 scenario which is the most pessimistic scenario in terms of concentrations of GHG in the atmosphere assuming a global temperature increase of +4.8°C compared to the preindustrial level. In contrast, RCP 2.6 is the most optimistic scenario with a global temperature increase of +2°C compared to the preindustrial level considering that all countries follow the Paris Agreement and drastically reduce the GHG emissions since the beginning of the 21st century. The intensity (or number per year) of the climate hazards for selected areas are taken from the UIB projections which are given for the RCP 8.5 (and RCP 2.6) scenario (see chapter 3.2).

The selection of the cases under consideration is based on intensive exchange and the joint development process of the model with Georgian ministries, partners and experts. In this context, the identification of climatic threats (see chapter 3.2) and the knowledge of past events and monetary damages (see chapter 3.3) have provided the direction for the scenarios to be considered. The scenarios were jointly developed step by step in trainings and coaching sessions. Assumptions have been discussed with sectoral experts and policy makers throughout different workshops. However, these scenarios are a first starting point for the analysis of the economy-wide effects of climate change and adaptation. By varying assumptions and inputs for the model, justified new developments can be calculated and compared to each other. The overall process leads to a reduction of the uncertainty regarding the macroeconomic effects of climate change and adaptation. The reference scenario (chapter 4) sets the basis for modeling the economic impacts of climate change. In the next sections, effects of selected climate hazards are modelled applying scenario analysis.

These scenarios are the starting point for analyzing the macroeconomic impacts of climate change and adaptation. The analysis of different "what-if" scenarios helps to reduce the uncertainty regarding the macroeconomic impacts of climate change and adaptation.

5.2 EFFECTS OF EXTREME WEATHER EVENTS ON THE GEORGIAN ECONOMY

5.2.1 ECONOMY-WIDE IMPACTS OF HEATWAVES

Scenario assumptions and implementation

There are plenty of definitions for a heatwave in the literature. They differ on the temperature threshold and the minimum length where daily maxima exceed the upper temperature threshold (see also chapter 3.2). Heatwaves are a direct consequence of climate change and it is assumed that the frequency and severity will increase significantly in the future. The effects of a heatwave can be manifold: Infrastructure, industrial productivity, and electricity generation and distribution infrastructure are possibly affected, to only mention some of them. This chapter is about to describe the economic effects of heatwaves. As described in chapter 2.3, the heatwave scenario builds on the reference scenario but contains additional information on climate change effects of a heatwave that impact characteristic variables.

As a starting point, the biophysical effects of a heatwave need to be determined. Biophysical effects of a heatwave directly affect different economic sectors as shown in Figure 20. The identified economic effects must be underpinned with data and information so that they can be integrated into the model.

Sector	Impact	Source
	People suffering from high temperatures cause a higher demand for health care services (+1.6%)	Own assumption based on estimations for Germany (Hübler 2014)
	High temperatures cause a higher demand for beverages (+5%)	Own assumption based on evidence from Germany for the heatwave in 2018
	Irrigation systems get damaged or blow up and must be repaired (GEL 1 million)	Own assumption
	Grapes may get burned due to very strong sunlight (decreasing wine exports by GEL 50 million)	Own assumption based on evidence from France
	Losses in harvest due to scarcity of rain and water (-10%)	PESETA Project
	Production losses due to less productive workers working outside, but also in hot buildings	Based on ILO 2019
	Higher electricity demand for cooling reason (+6.0%)	Own assumption
	Increased price levels (+10%) due to interrupted transport routes and lower yielding harvest	Own assumption

Figure 20: Economic effects of a heatwave

Source: Own figure.

To take into account the fact that there will be an increasing number of heatwaves with a greater severity in the future, assumptions must be made as to how the respective extreme event will develop in the future and what impact this will have on the amount of damages. Navarro and Jorda Sanchez (2021) provide the respective information (see chapter 3.2).

Table 10: Average annual growth rates of the evolution of the number of heatwave events in Georgia for the RCP8.5 Scenario, in percent

	Tbilisi	Kutaisi	Telavi	Gudauri	Batumi	Kvemo Karti	Enguri Dam	Georgia
1980-2005	18.0%	4.2%	15.7%	6.9%			4.0%	8.9%
2006-2020	3.5%	3.8%	4.1%	3.9%	3.7%	3.7%	3.7%	3.8%
2021-2030	2.6%	3.2%	3.1%	3.1%	2.4%	2.7%	3.2%	2.9%
2031-2040	2.2%	2.8%	2.6%	2.7%	1.9%	2.3%	2.8%	2.4%
2041-2050	1.9%	2.5%	2.3%	2.4%	1.6%	2.0%	2.5%	2.1%

Source: Own calculations based on data from Navarro and Jorda Sanchez (2021), UIB.

The respective average annual growth rates shown in Table 10 are taken to calculate the increase in future damages caused by a heatwave. For example, the number of heatwave events in Tbilisi is increasing every year in the decade of 2031 to 2040 at an average of 2.2%. By selecting a future frequency of heatwave events (e.g., every 5 years, see Figure 21), a timeseries of damages can be calculated and implemented in the e3.ge model.

Scenario results

Results from the e3.ge model indicate the following future impacts of heatwaves in Georgia:

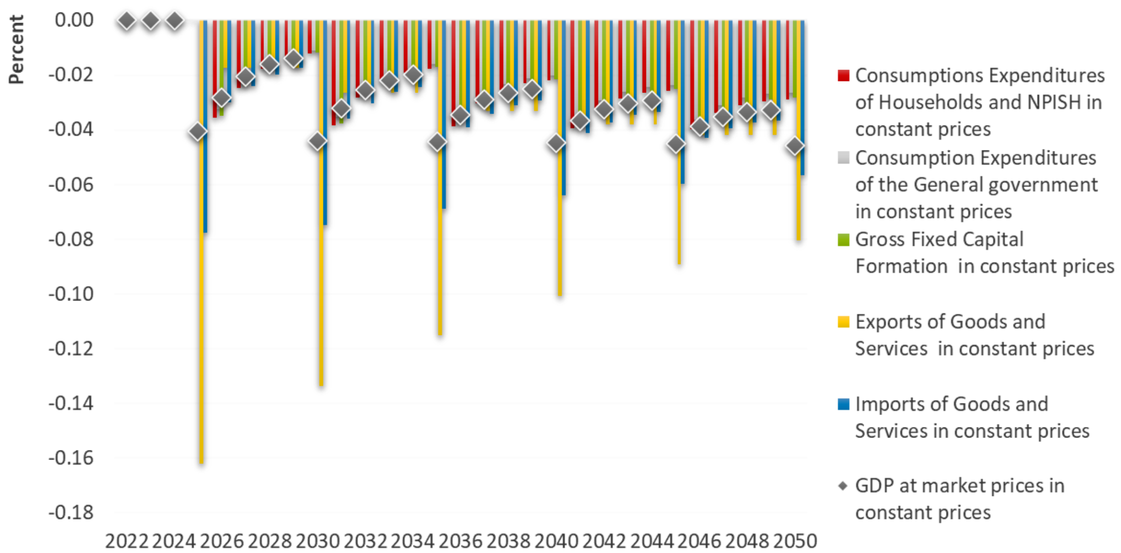


Figure 21: Macroeconomic effects of reduced wine exports, 2022-2050, deviations from the "Baseline" scenario without climate change in percent

Source: Own figure based on e3.ge results .

Wine production: The overall effects of the reduction of wine exports in years with a heatwave (every 5 years, starting in 2025) on GDP is negative (see Figure 21). Decreasing exports cause a reduction in production, which also causes a reduction in imports, according to the import shares of the respective sectors. The impact lasts for several years (e.g. lagged reactions in consumption due to GDP changes in the previous year), causing also negative effects in the following years. The increasing damages to grapes cause for an increasing absolute reduction of exports over time.

Labor productivity: Using ILO data on working hours lost due to heat stress (ILO 2019), every sector is affected in a different way by high temperatures: the agriculture and construction sector have a high reduction in gross output, because people working outside are most affected by heatwaves. The services sectors are less affected. The reduction in labor productivity causes a negative effect on the GDP in the years with a heatwave and also in the years in between. In years with a heatwave, the production is reduced and imports are higher. This impact causes a lagged reaction in consumption, causing also negative effects in the following years.

Additional consumption: The additional consumption of beverages, health care services and energy have a positive effect on the economy. The increase of 1.6% in consumption expenditures for health care services in years with a heatwave call not only for an increased production in the human health services sectors, but also in those sectors delivering intermediate inputs to it, like the pharmaceuticals production and wholesale and trade sector. Once again, this increased production calls for additional imports, and a lagged reaction in consumption expenditures due to the prior increase in GDP. Although the additional consumption causes a positive effect on the economy, these consumption expenditures should be considered as defensive spending. This money is spent to get the people in a condition they would have had without a heatwave. People suffering from heat and needing additional health care services should of course not be valued in a positive way. It would always be better if the heatwave would not happen.

Agriculture: Higher prices for agricultural products have a direct impact on consumption expenditures, causing them to decrease. Likewise, imports are getting relatively cheaper. Both effects cause a decrease in GDP. Since the increase in prices for agricultural products by 10% is relatively high, the effect on the GDP is also high.

Irrigation systems: The additional investment in irrigation systems is very small, but is also causing a positive effect on the gross fixed capital formation and the other GDP components, resulting in small increase in GDP.

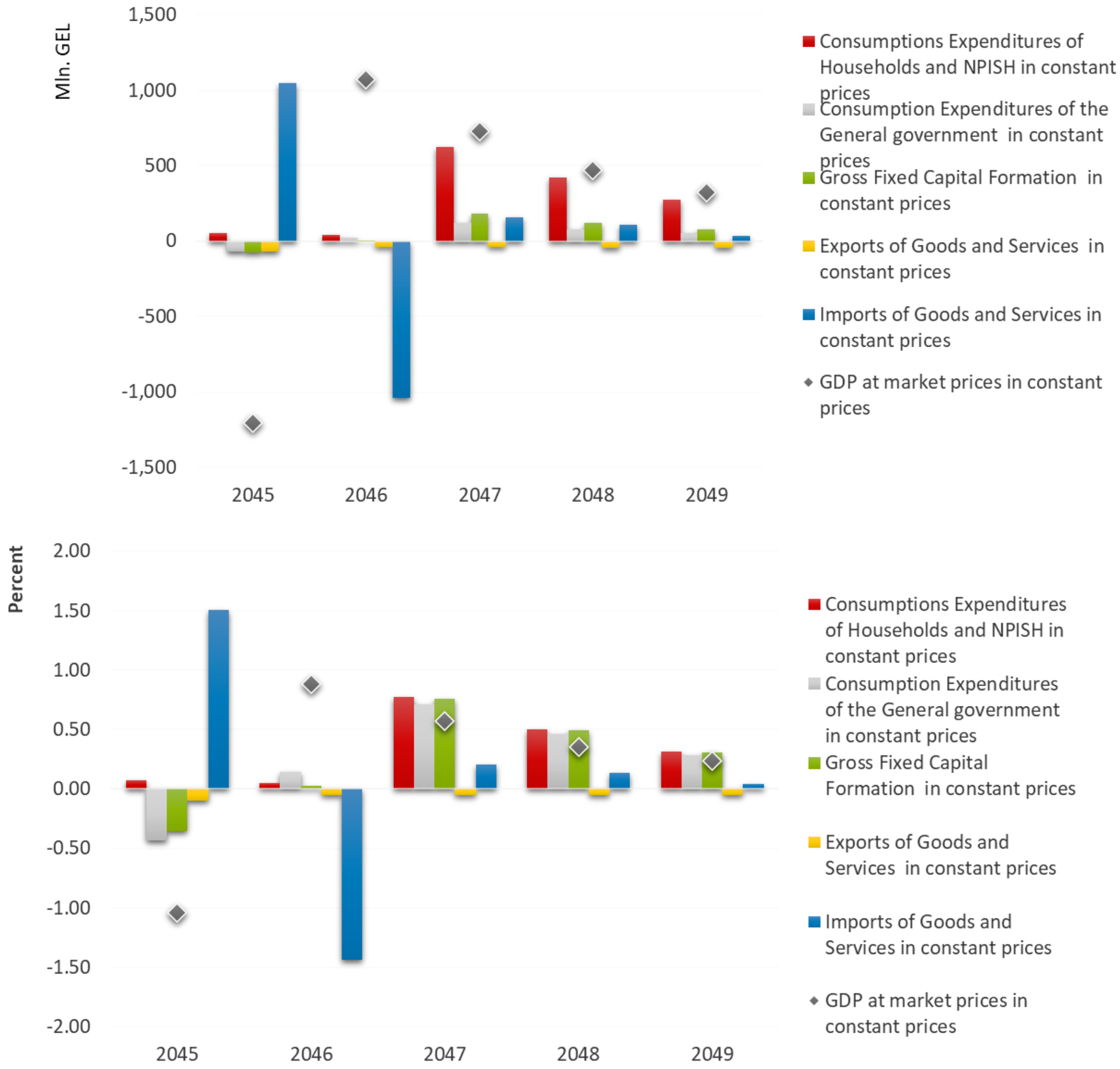


Figure 22: Macroeconomic effects of the "Heatwave" scenario, selected years, deviations from the "Baseline" scenario without climate change in Mln. GEL (top figure) and percent (bottom figure)

Source: Own figure based on e3.ge results.

As seen above, there are negative as well as positive effects, caused by the different economic relevant impacts. In total, the economic model takes all the relevant impacts and reactions into account. Figure 22 shows the overall economic effects for a heatwave in the year 2045 and the following years. In the year 2045, the heatwave hits the economy. The imports increase by more than 1.5% in 2045 (GEL 120 million, respectively) due in particular to the decline in production in the agricultural sector. Agricultural products must be replaced by additional imports. The overall effect on the consumption expenditures of households in the year 2025 is slightly negative (-0.27%, GEL -1,000 million). While on the one hand, additional consumption comes from health care services, energy and beverages, the negative impact comes from second round and induced effects due to the reduced production activity, since less people have a permanent job (employment decreases by more than 1%) and therefore the overall income of households is lower, which reduces the consumption expenditures. Both effects result in a negative impact on the GDP

(-1% in 2045; GEL -1,200 million, respectively). This negative GDP effect calls for a decrease of consumption expenditures in the year 2046, which in turn also has an impact on the imports. Finally, after the shock from climate change in 2045, there are also effects in the following years that settle back down and the model returns to its original path before the next shock comes from the next heat wave in the year 2050.

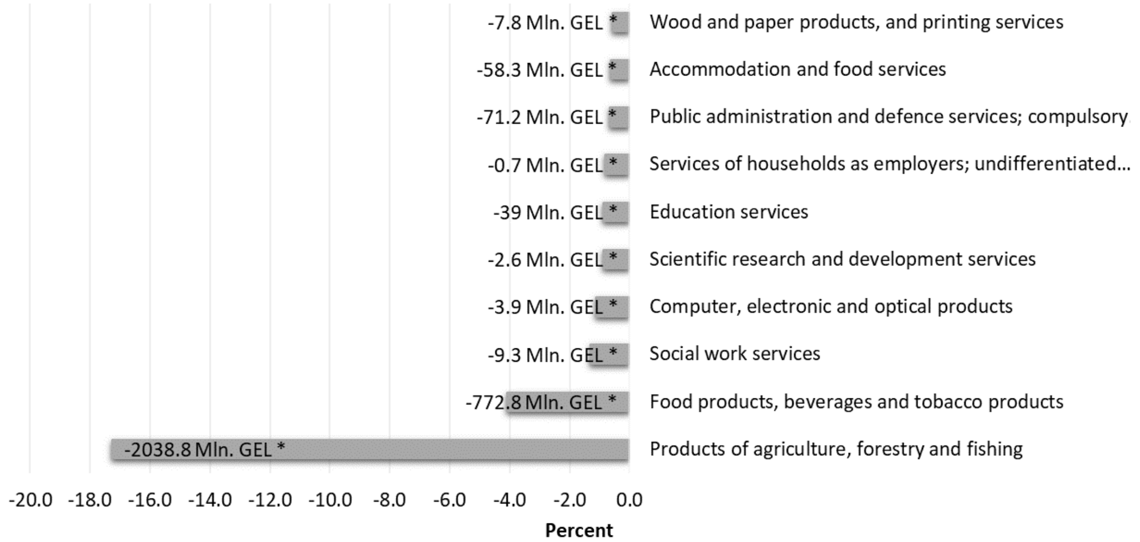


Figure 23: Effects of "Heatwave" scenario: Top-10 relative deviations of Gross output (year 2045) from the "Baseline" scenario without climate change in percent and Mln. GEL

Source: Own figure based on e3.ge results[7].

Figure 23 highlights the effects of a heatwave in the year 2040 on gross output on a sectoral level. In years with hot temperatures, production is in particular constrained in the agriculture and energy sector. Other sectors that are not directly affected by the hot temperatures are also influenced via economic interlinkages. For example, the food production industry records a lower production level because less agricultural products are available to be processed.

The negative impacts on the GDP are caused by:

- Reduced exports,
- Reduced labor productivity,
- Increased prices,
- Decrease in hydro power production.

The positive impacts on the GDP are caused by:

- Additional consumption,
- Additional investment.

The largest effects are caused due to:

- Increased prices for agricultural products,
- Decrease in hydro power production.

[7] Here and in the following graphs, the (*) highlights the fact, that the sectoral order in the figure is based on the relative deviations. The absolute deviations could also lead to a different order in each case. They are therefore only listed for information purposes.

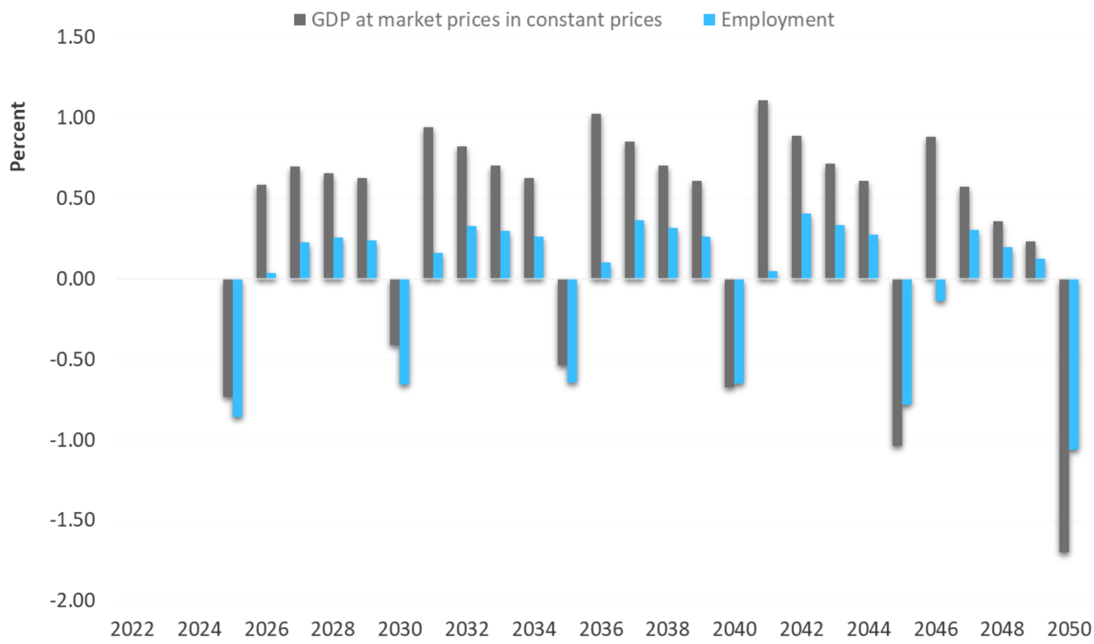


Figure 24: Effects of the "Heatwave" scenario on GDP and Employment, 2022-2050, deviations from the "Baseline" scenario without climate change in percent

Source: Own figure based on e3.ge results.

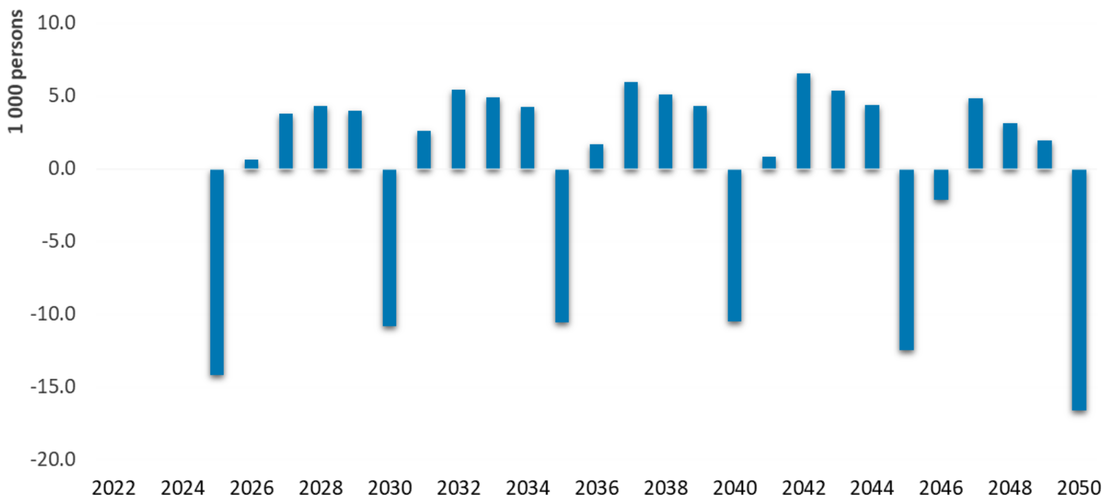


Figure 25: Effects of the "Heatwave" scenario on Employment, 2022-2050, deviations from the "Baseline" scenario without climate change in 1,000 persons

Source: Own figure based on e3.ge results.

Employment is developing in line with economic development. In the years with a heatwave, employment is lower by up to 16,000 people (-1.1%, see year 2050).

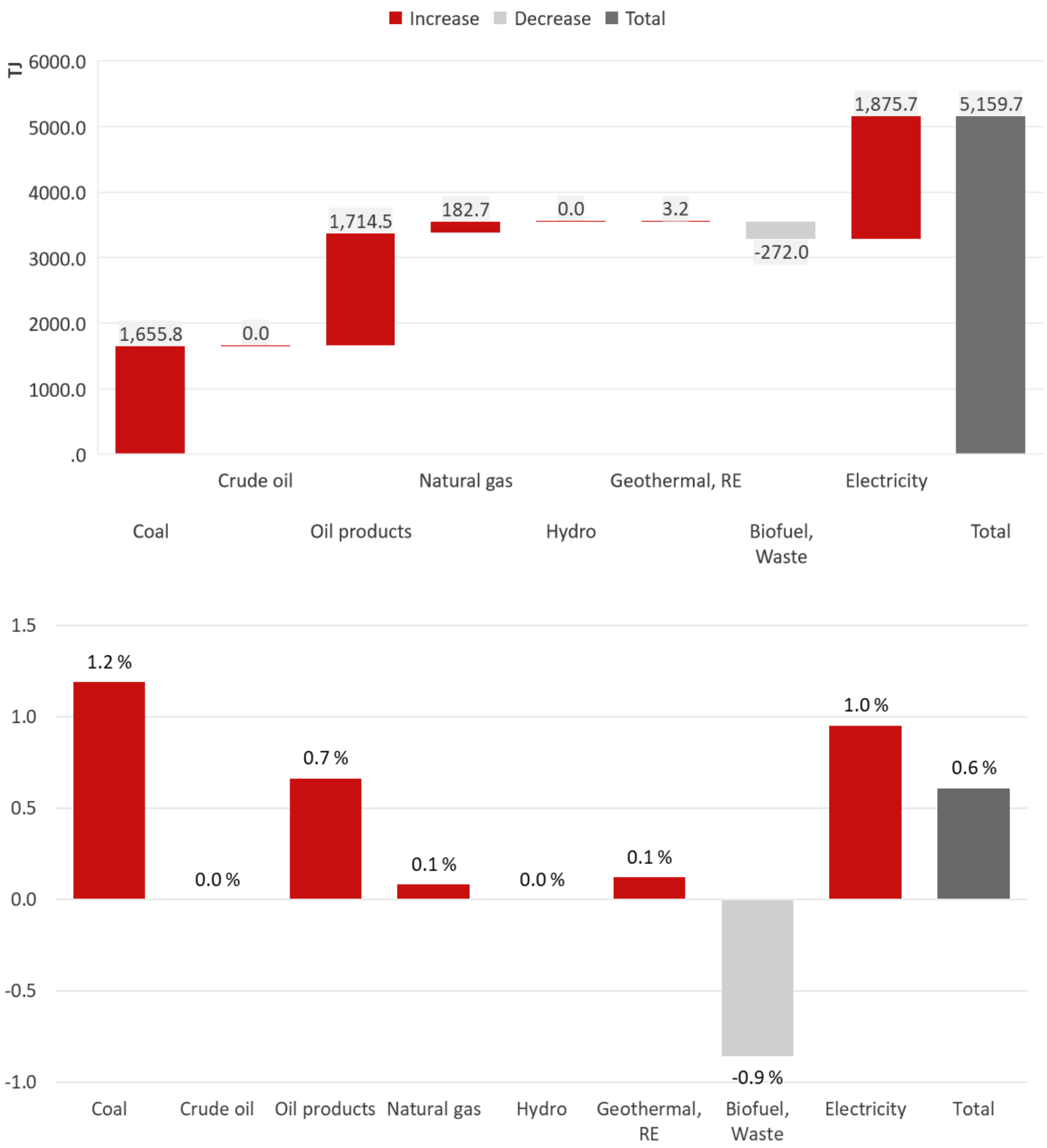


Figure 26: Effects of the "Heatwave" scenario on final energy consumption, 2045, deviations from the "Baseline" scenario in TJ (top figure) and percent (bottom figure)

Source: Own figure based on e3.ge results.

While production is decreasing in some sectors, it is increasing in other sectors. Besides the additional consumption of electricity for cooling reasons, other energy intensive sectors (basic metals, transportation) also have a higher output, which in turn leads to a higher demand for energy (see Figure 26) and likewise for higher CO_2 emissions (see Figure 27).

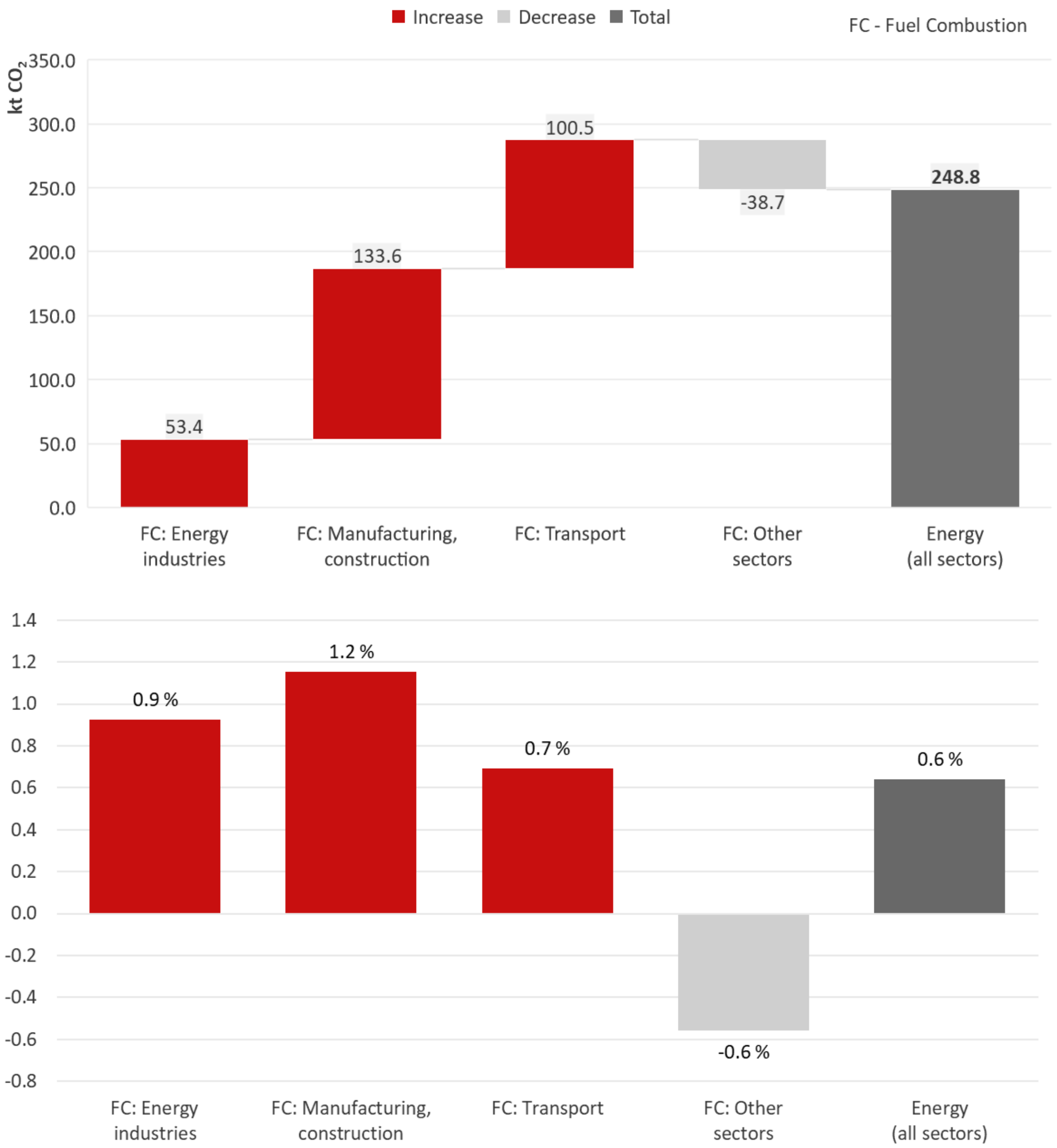


Figure 27: Effects of the "Heatwave" scenario on CO_2 emissions, 2045, deviations from the "Baseline" scenario in kt CO_2 (top figure) and percent (bottom figure)

Source: Own figure based on e3.ge results.

5.2.2 ECONOMY-WIDE IMPACTS OF EXTREME PRECIPITATION

Extreme precipitation refers to instances during which the amount of rain experienced in a location substantially exceeds what is considered as "normal". There are plenty of definitions for extreme precipitation in the literature, which differ in location and the amount of precipitation per unit of time. Heavy rain can occur anywhere and lead to rapidly rising water levels and (or) flooding. The intensity of extreme precipitation events is known to increase with global warming. The economic effects can be manifold and differ depending on where the rain falls. Thus, extreme precipitation events can have considerable impacts on society, economy and also the ecosystem. However, the damages and effects of such an event are also influenced by non-climatic factors: Population density, land-use changes and sealed surfaces are just some of the factors that influence the impact of heavy rainfall. An assessment of future projections of extreme precipitation events is important for policy makers to take appropriate measures.

As a starting point, the biophysical effects of extreme precipitation events need to be determined. Biophysical effects of extreme precipitation events directly affect different economic sectors as shown in Figure 28. The identified economic effects must be underpinned with data and information so that they can be integrated into the model.

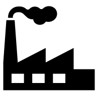
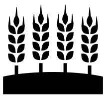
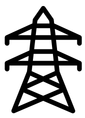
Sector	Impact	Source
	Buildings get damaged and need to be reconstructed (GEL -14.5 million)	Tbilisi Disaster Needs Assessment 2015
	Infrastructure gets damaged and need to be reconstructed (GEL -32 million)	Tbilisi Disaster Needs Assessment 2015
	Water and sanitation system gets damaged and need to be reconstructed (GEL -2.7 million)	Tbilisi Disaster Needs Assessment 2015
	Household goods need to be replaced (GEL -1.6 million)	Tbilisi Disaster Needs Assessment 2015
	Cars are flooded and need to be replaced (GEL -1.2 million)	Tbilisi Disaster Needs Assessment 2015
	Production losses due to interrupted supply chains and flooded production sites (-1%)	Own assumption
	Crop losses due to flooded fields (-5%)	PESETA Project
	Electricity system and oil and gas pipelines get damaged and need to be reconstructed (GEL -1 million)	Own assumption
	Increased price levels due to interrupted transport routes and damaged buildings and infrastructure	Own assumption

Figure 28: Economic effects of extreme precipitation

Source: Own figure.

On the night of 13-14 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, with transportation being the most affected sector. The estimated cost of damage to transport was GEL 33.2 million, the damages to houses were GEL 16.1 million. Furthermore, the zoo and the water management were affected. A loss of production activity in different sectors is being assumed. These damages are considered as benchmarks and are entered into the e3.ge model at a frequency of 10 years in order to calculate the economic effects of heavy precipitation.

To take into account the fact that there will be an increasing number of extreme precipitation events with a greater severity in the future, assumptions must be made as to how the respective extreme event will develop in the future and what impact this will have on the amount of damages. Navarro and Jorda Sanchez (2021) provide the respective information (see chapter 3.2).

Table 11: Average annual growth rates of the evaluation of the number of extreme precipitation events in Georgia for the RCP8.5 Scenario, in percent

	Tbilisi	Kutaisi	Telavi	Gudauri	Batumi	Kvemo Karti	Enguri Dam	Georgia
1980-2005	-0.2%	0.1%	0.3%	0.1%	0.5%	0.0%	0.4%	0.2%
2006-2020	-0.2%	0.2%	0.3%	0.0%	0.4%	0.0%	0.3%	0.2%
2021-2030	-0.2%	0.2%	0.3%	0.0%	0.4%	0.0%	0.3%	0.2%
2031-2040	-0.2%	0.3%	0.3%	-0.1%	0.4%	0.0%	0.2%	0.2%
2041-2050	-0.2%	0.3%	0.3%	-0.1%	0.4%	0.0%	0.2%	0.2%

Source: Own calculations based on data from Navarro and Jorda Sanchez (2021), UIB.

The respective average annual growth rates shown in Table 11 are taken to calculate the increase in future damages caused by an extreme precipitation event. By selecting a future frequency of extreme precipitation events (e.g., every 10 years), a timeseries for damages can be calculated and implemented in the e3.ge model.

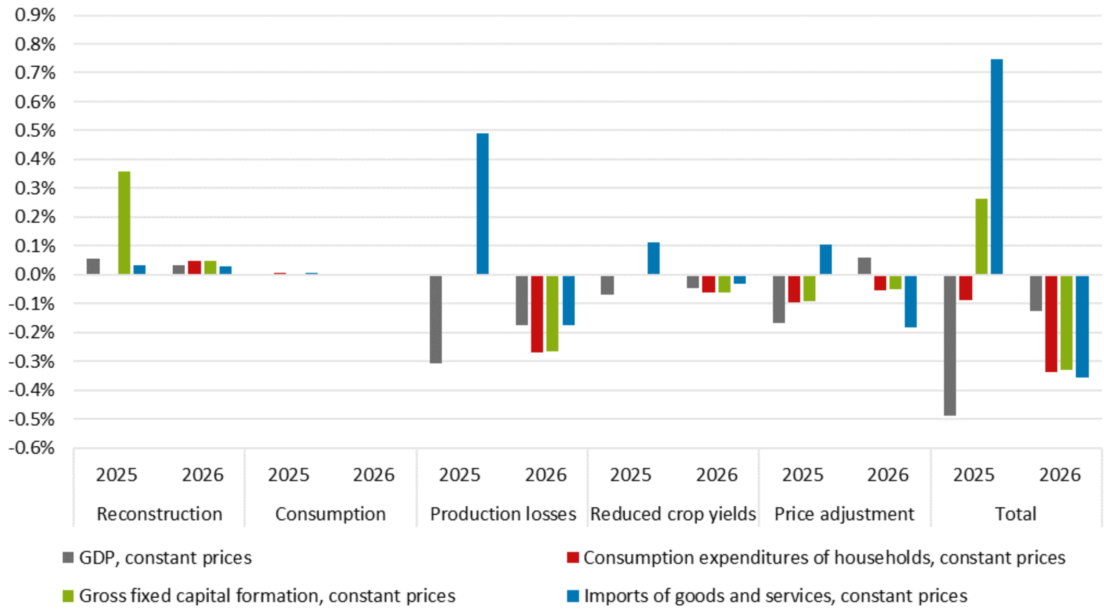


Figure 29: Macroeconomic effects of the "Precipitation" scenario, 2025 and 2026, deviations from the "Baseline" scenario without climate change in percent

Source: Own figure based on e3.ge results.

Figure 29 compares the macroeconomic effects of the individual effects described in Figure 28 and their aggregate impact on the economy for the year 2025 and 2026. Both positive and negative effects can be observed as a result of the extreme precipitation event in 2025. The reconstruction of destroyed infrastructure, buildings, network infrastructure and pipelines leads to additional construction investments. Gross fixed capital formation for reconstruction is therefore positive and has a positive effect on GDP. Additional consumption expenditures also has a small but positive effect on GDP. The negative effect results from the production losses, the decline in the crop yields and the increase of prices. Increased imports are the result of the mentioned effects, which have a negative impact on GDP. The mood in the economy in the year of the damage also has an effect on the following years (as can be seen for the year 2026 as an example). While a positive GDP effect in the year with the extreme precipitation event also leads to an increase in consumption and investment in the following years and thus to further positive GDP effects, the negative GDP effect also leads to negative economic activity in the following years. The following Figure 30 illustrates the overall effects of the extreme precipitation event in the year 2025 on the components of GDP in the following years.

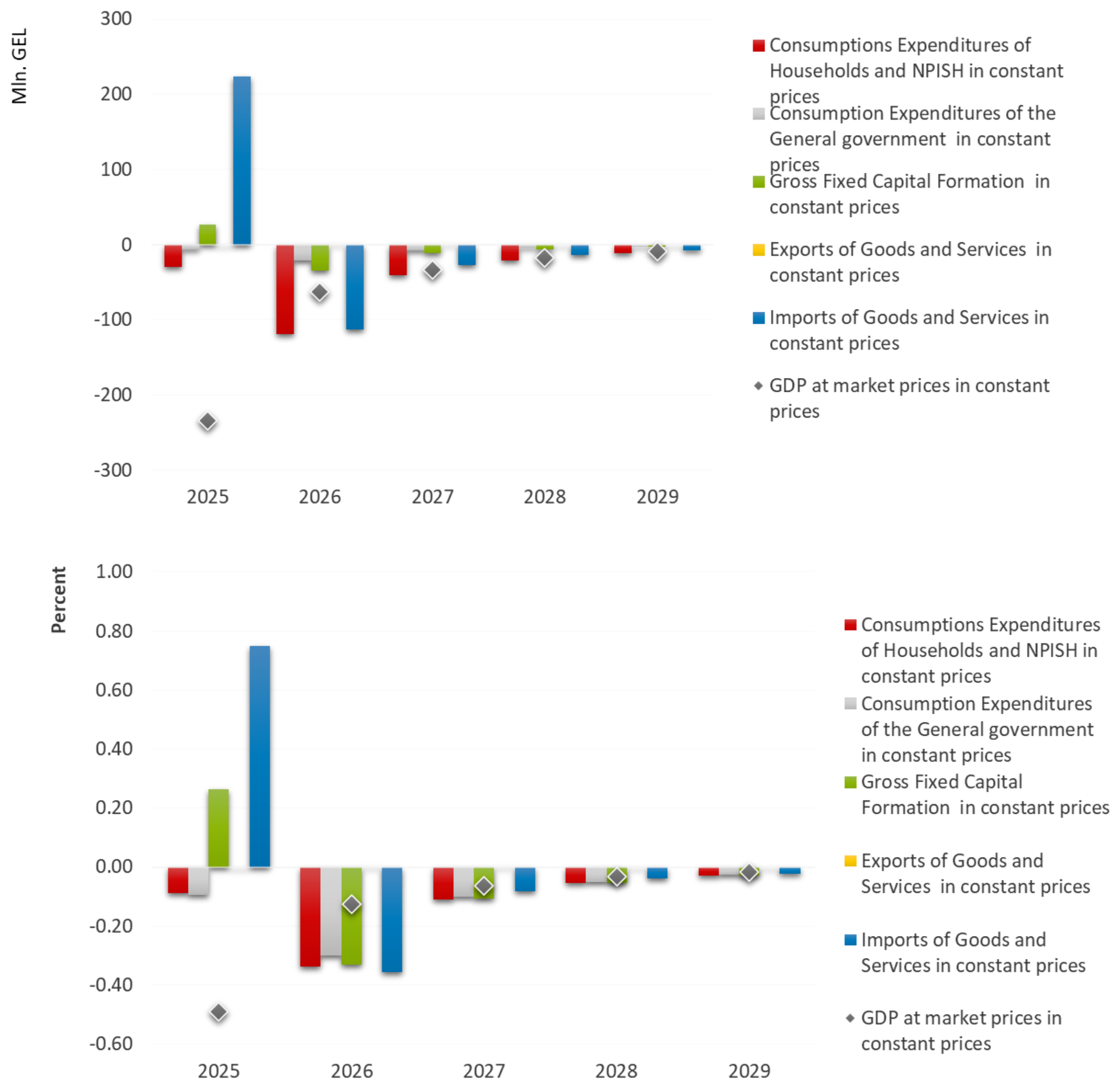


Figure 30: Macroeconomic effects of the "Precipitation" scenario, selected years, deviations from the "Baseline" scenario without climate change in Mln. GEL (top figure) and percent (bottom figure)

Source: Own figure based on e3.ge results.

The precipitation event in the year 2025 has a negative impact on the GDP. The effect is about GEL -250 million (-0.5%). In the following years, this negative GDP impact causes additional negative impacts on the economy (e. g., consumption expenditures of private households -0.3% in 2026, gross fixed capital formation -0.3% in 2026). The effects are decreasing over time and in 2029, the GDP effect is close to zero.

Despite the assumed growth rates for damages of about 0.2% p.a. for the individual decades (see Table 11), the relative effects on the components of GDP differ only very slightly between the extreme precipitation events in 2025, 2035 and 2045. One reason for this is that overall economic output is also increasing over time (see Figure 13), with consumption and investment activities also increasing. In relative terms, the rising losses thus lead to similarly high relative deviations in comparison.

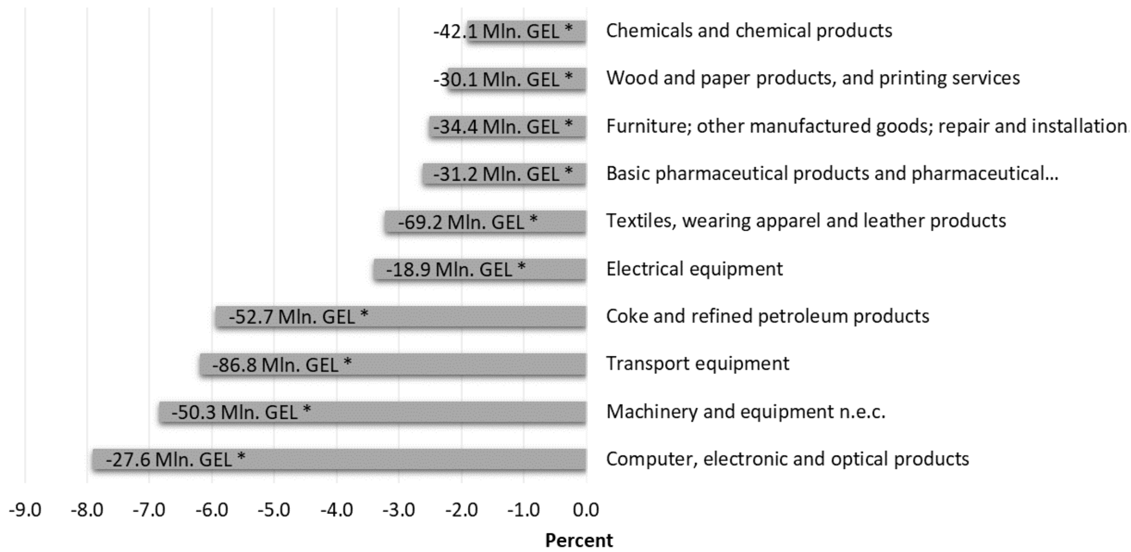


Figure 31: Effects of "Precipitation" scenario: Top-10 relative deviations of Gross output (year 2045) from the "Baseline" scenario without climate change in percent and Mln. GEL

Source: Own figure based on e3.ge results.

Figure 31 highlights the effects of a precipitation event in the year 2045 on gross output on a sectoral level. In years with heavy precipitation, production losses due to interrupted supply chains and flooded production reduce the gross output. On the one hand, these are effects on the different sectors and on the other hand, the production is decreasing due to sectoral interlinkages.

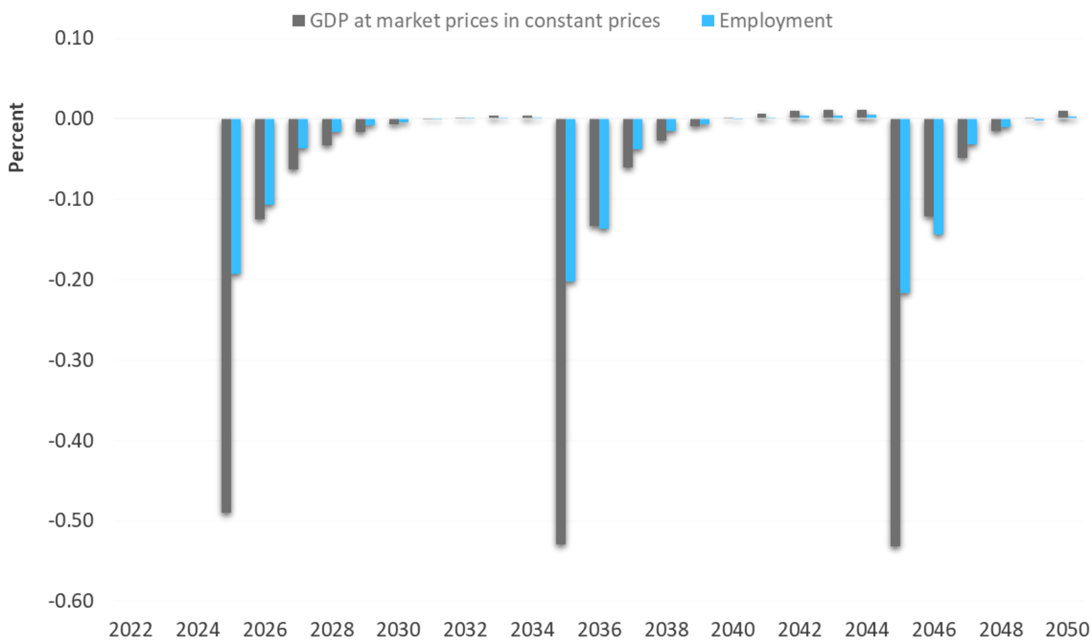


Figure 32: Effects of the "Precipitation" scenario on GDP and Employment, 2022-2050, deviations from the "Baseline" scenario without climate change in percent

Source: Own figure based on e3.ge results.

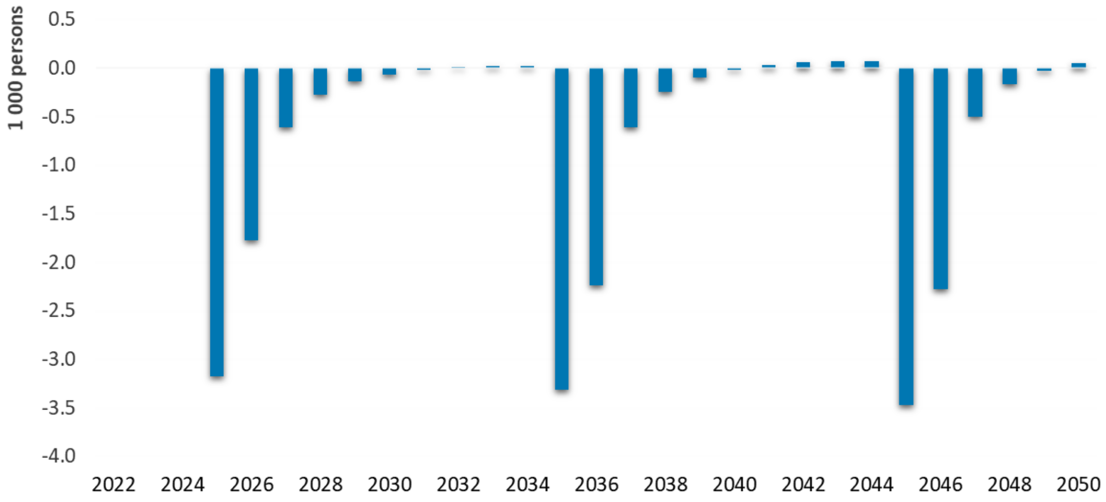


Figure 33: Effects of the "Precipitation" scenario on Employment, 2022-2050, deviations from the "Baseline" scenario without climate change in 1,000 persons

Source: Own figure based on e3.ge results.

Due to the loss of production and the reduced crop yields, fewer people are employed, so that the overall employment effect is negative, especially in the years with the extreme precipitation events, which, however, can be partially compensated by the additional employment in the construction sector. Overall, employment is reduced by up to 3,000 people (see Figure 33). In the following years, the economy slowly recovers so that employment returns to its previous level.

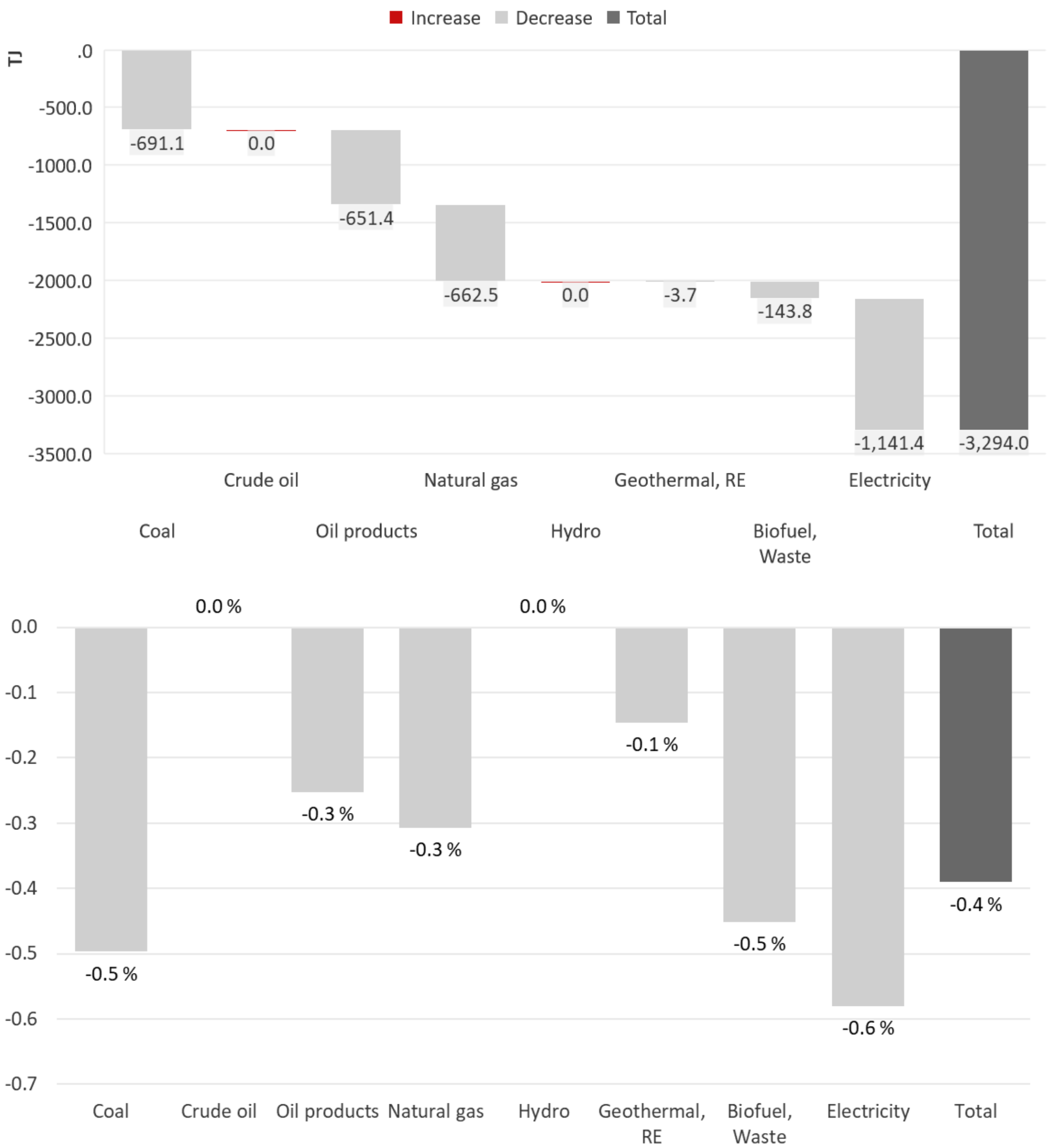


Figure 34: Effects of the "Precipitation" scenario on final energy consumption, 2045, deviations from the "Baseline" scenario in TJ (top figure) and percent (bottom figure)

Source: Own figure based on e3.ge results.

The lower economic activity results in less final energy demand which is 3,200 TJ resp. 0.4% lower in 2045 compared to a Baseline scenario (see Figure 34). Energy demand by fossil fuels decreases accordingly to the use of demanding sectors such as the manufacturing industries.

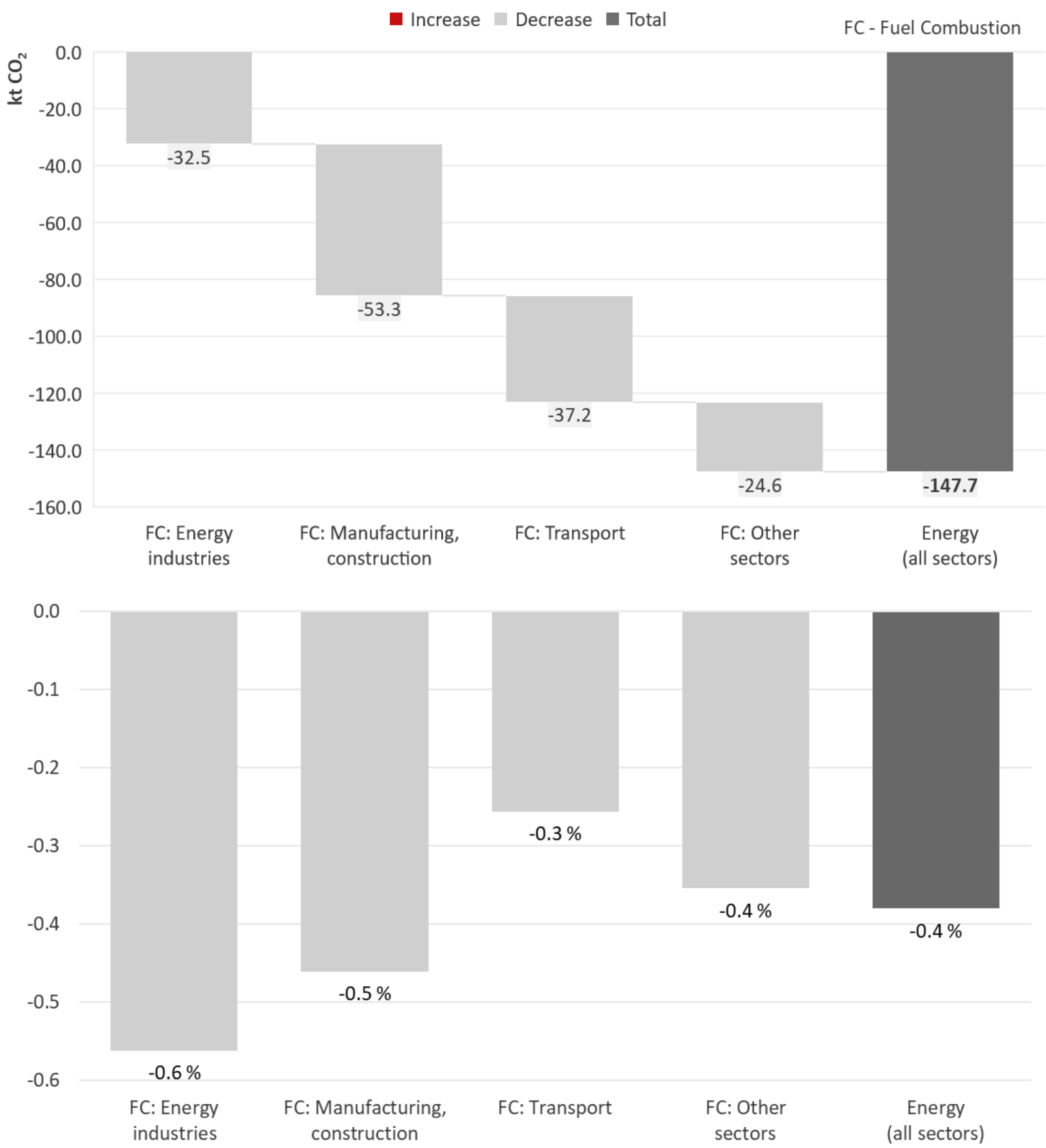


Figure 35: Effects of the "Precipitation" scenario on CO_2 emissions, 2045, deviations from the "Baseline" scenario in kt CO_2 (top figure) and percent (bottom figure)

Source: Own figure based on e3.ge results.

CO_2 emissions in manufacturing, construction and other sectors decrease due to lower production (see Figure 35).

5.2.3 ECONOMY-WIDE IMPACTS OF EXTREME WIND

Extreme wind refers to wind of great violence, which can cause considerable damage and destruction. While an extreme precipitation event takes place on a more local scale, the impact of an extreme wind event is felt more widely. However, the damage that can be caused by a strong wind is very similar to that caused by a heavy rain, but the amount of damage is lower.

Table 6 gives an overview over the categories of damages resulting from the respective extreme weather events in the past. While the reported damages from heavy rain sum up to over GEL 300 million (time period 1995 to 2020), the damages from heavy wind sum up to GEL 119 million (see Table 4). Furthermore, the calculated average damages per year are GEL 26 million for a heavy rain and GEL 5 million for a heavy wind. However, the categories of damages from strong wind are very similar to those of heavy rain. Thus, the damages for wind can be calculated with the information available from the past events. While the damages caused by rain and wind are different (wetness versus destruction), similar buildings, goods, and products are affected. Thus, similar variables are addressed in the economic model. The above mentioned monetary effects of heavy rain are scaled for the extreme wind event and used as initial damages in present.

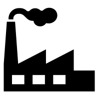
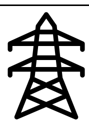
Sector	Impact	Source
	Buildings get damaged and need to be reconstructed (GEL -3 million)	Calculated with information for heavy rain
	Infrastructure gets damaged and need to be reconstructed (GEL -6.5 million)	Calculated with information for heavy rain
	Household goods need to be replaced (GEL -0.3 million)	Calculated with information for heavy rain
	Cars get damaged and need to be replaced (GEL -0.2 million)	Calculated with information for heavy rain
	Production losses due to interrupted supply chains and damaged production sites (-0.2%)	Calculated with information for heavy rain
	Crop losses due to heavy wind (-1%)	Calculated with information for heavy rain
	Electricity system and oil and gas pipelines get damaged and need to be reconstructed (GEL -0.2 million)	Calculated with information for heavy rain
	Increased price levels due to interrupted transport routes and damaged buildings and infrastructure	Calculated with information for heavy rain

Figure 36: Economic effects of extreme wind

Source: Own figure.

The growth rates in Table 12 are used to calculate the damages caused by extreme wind events in the future. By selecting a future frequency of extreme wind events (e.g. every 10 years), a timeseries for damages can be calculated and implemented in the e3.ge model.

Table 12: Average annual growth rates of the evolution of the number of extreme wind events in Georgia for the RCP8.5 Scenario, in percent

	Tbilisi	Kutaisi	Telavi	Gudauri	Batumi	Kvemo Karti	Enguri Dam	Georgia
1980-2005	-0.1%	0.5%	0.0%	0.4%	0.4%	-0.3%	0.0%	0.1%
2006-2020	0.1%	0.4%	0.1%	0.4%	0.2%	-0.1%	0.0%	0.2%
2021-2030	0.2%	0.4%	0.2%	0.3%	0.1%	0.0%	0.0%	0.2%
2031-2040	0.3%	0.3%	0.2%	0.3%	0.0%	0.1%	0.0%	0.2%
2041-2050	0.3%	0.3%	0.3%	0.3%	0.0%	0.2%	0.0%	0.2%

Source: Own calculations based on data from Navarro and Jorda Sanchez (2021), UIB.

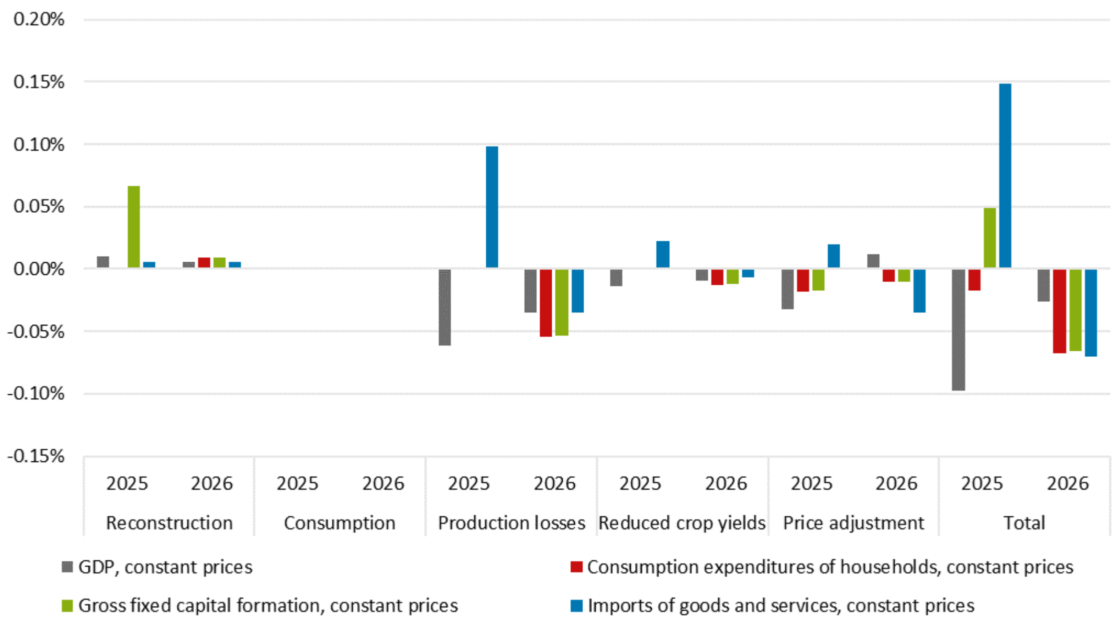


Figure 37: Macroeconomic effects of the "Wind" scenario, 2025 and 2026, deviations from the "Baseline" scenario without climate change in percent

Source: Own figure based on e3.ge results.

Due to the lower damage caused by a wind event, the economic effects are also smaller (see Figure 37). However the direction of the effects is the same as in Figure 29.

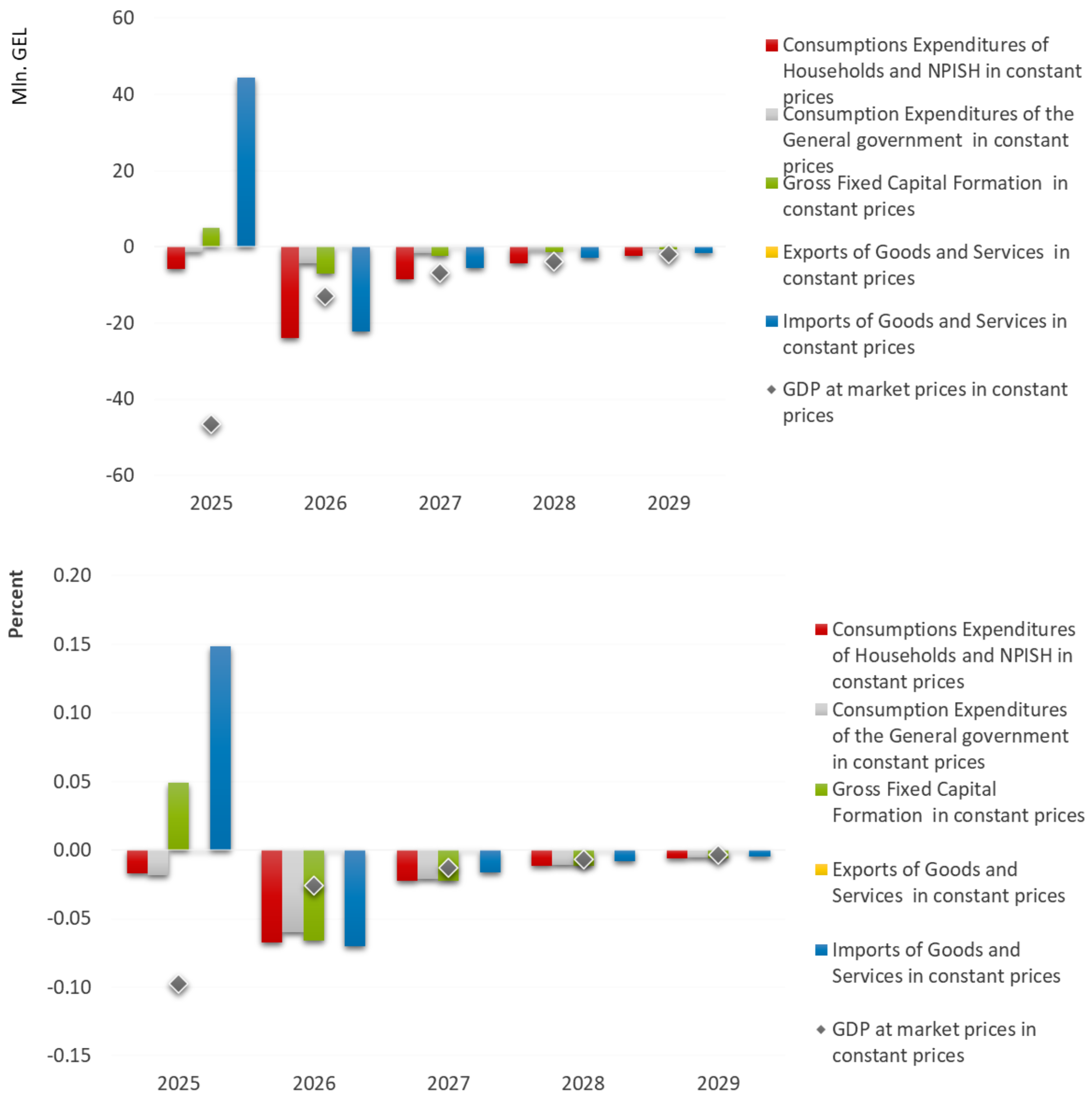


Figure 38: Macroeconomic effects of the "Wind" scenario, selected years, deviations from the "Baseline" scenario without climate change in Mln. GEL (top figure) and percent (bottom figure)

Source: Own figure based on e3.ge results.

Due to the reduced production activity in the different economic sectors, the employment gets a negative effect. Fewer workers are needed. Sectoral employment declines by over 0.1% (Manufacturing, Electricity, Transport). The construction sector benefits from the reconstruction of damaged buildings and infrastructure, resulting in a positive employment effect (see Figure 40 for the year 2025).

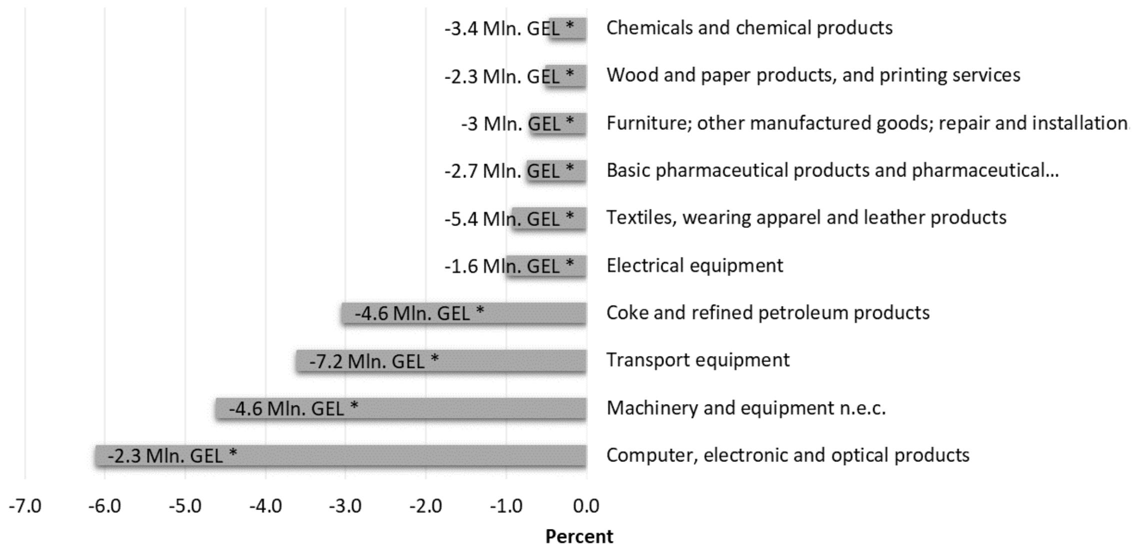


Figure 39: Effects of "Wind" scenario: Top-10 relative deviations of Gross output (year 2025) from the "Baseline" scenario without climate change in percent and Mln. GEL

Source: Own figure based on e3.ge results.

Figure 39 highlights the sectoral effects of a heavy wind event in the year 2025 on gross output. While the sectors affected are the same as in the precipitation event, the amount of damages is smaller in the "Wind" scenario, also causing smaller effects of the gross output.

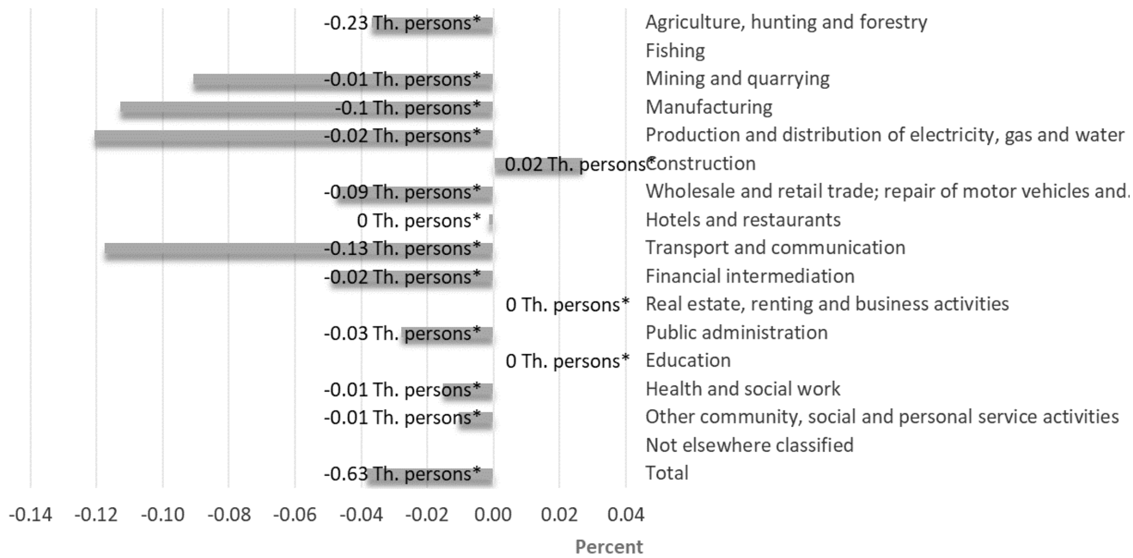


Figure 40: Employment effect of extreme wind on sectoral level in the year 2025

Source: Own figure based on e3.ge results.

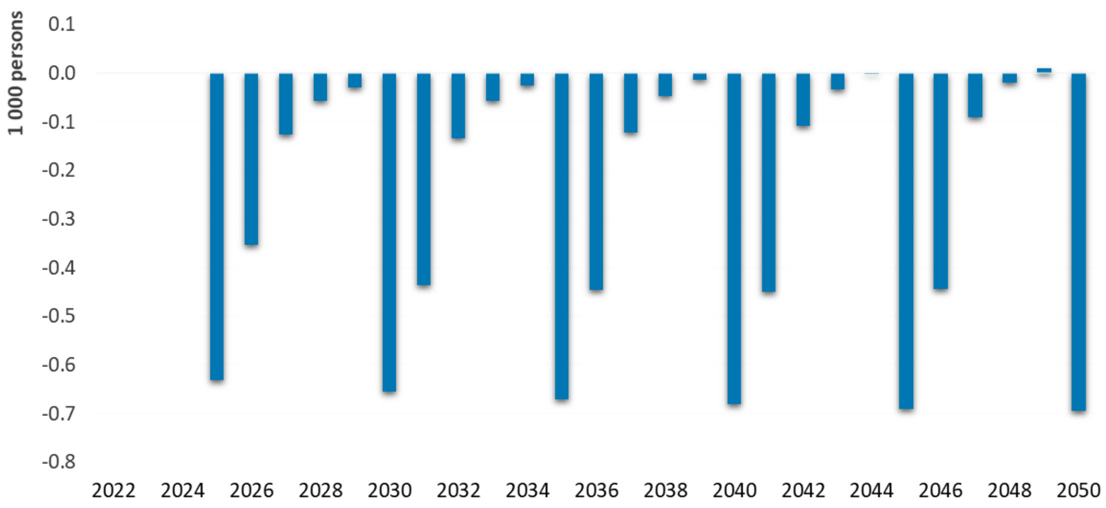
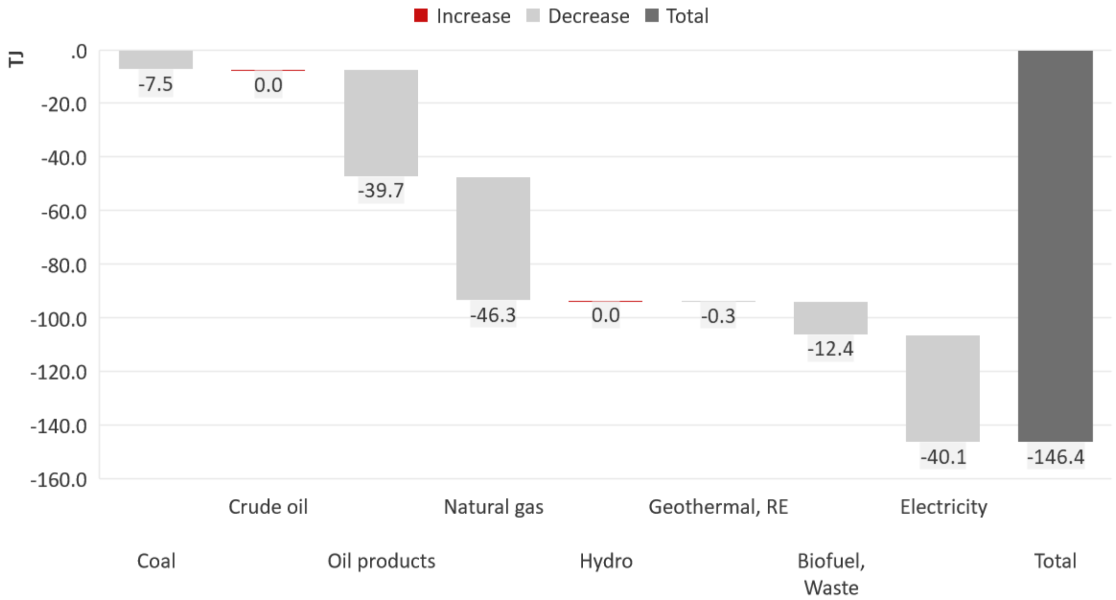


Figure 41: Effects of the "Wind" scenario on Employment, 2022-2050, deviations from the "Baseline" scenario without climate change in 1,000 persons

Source: Own figure based on e3.ge results.

Overall, employment is reduced by up to 700 people (see Figure 41). In the following years, the economy slowly recovers so that employment returns to its previous level.



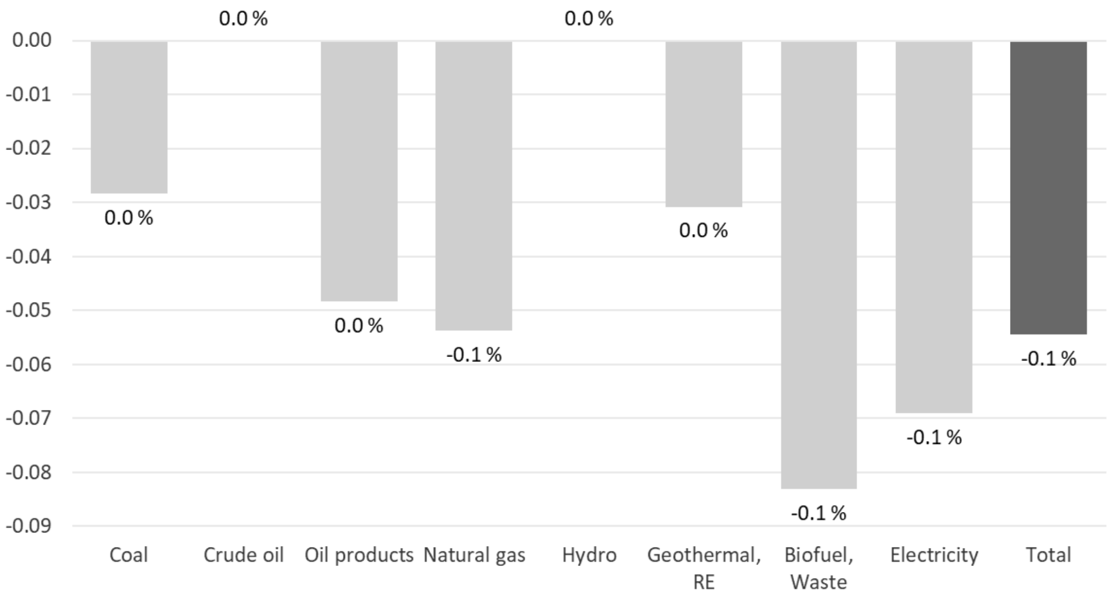


Figure 42: Effects of the "Wind" scenario on final energy consumption, 2025, deviations from the "Baseline" scenario in TJ (top figure) and percent (bottom figure)

Source: Own figure based on e3.ge results.

The lower economic activity results in less final energy demand which is 146 TJ resp. 0.1% lower in 2025 compared to a Baseline scenario (see Figure 42). Energy demand by fossil fuels decreases accordingly to the use of demanding sectors such as the manufacturing industries.

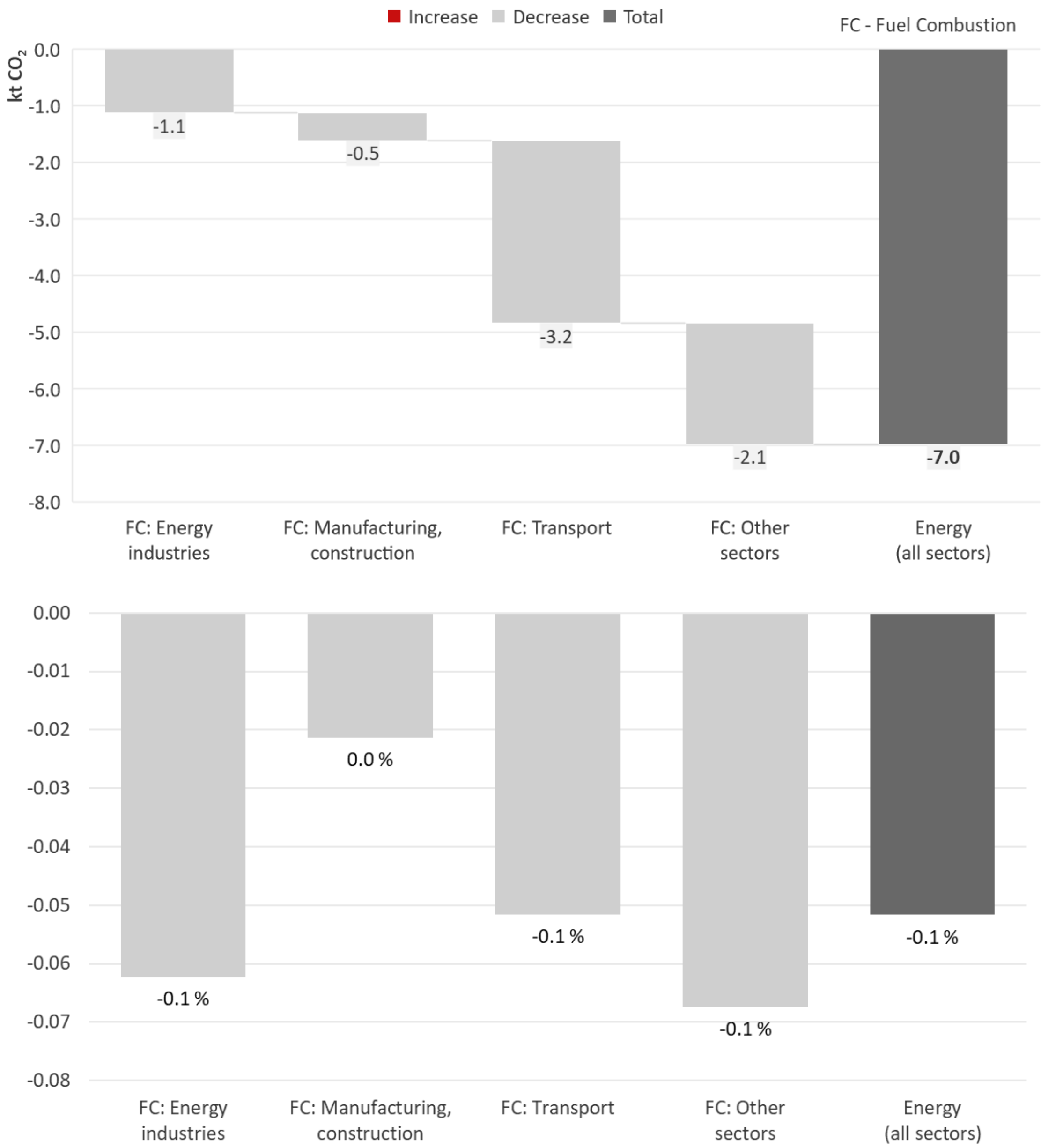


Figure 43: Effects of the "Wind" scenario on CO_2 emissions, 2025, deviations from the "Baseline" scenario in kt CO_2 (top figure) and percent (bottom figure)

Source: Own figure based on e3.ge results.

CO_2 emissions in manufacturing, construction and other sectors decrease due to lower production (see Figure 43).

5.2.4 IMPACTS OF SEA LEVEL RISE ON TOURISM

Rising sea levels pose potential threats to tourism. Tourism infrastructure is often located close to beaches. Sea level rise has a direct impact on this infrastructure, and thus on tourism flows. The effects of climate change on the consumption of all goods and services demanded by tourists need to be implemented in the economic model to take climate change impacts like sea level rise into account. These goods and services are for example accommodation and foods service activities, transportation services, arts and entertainment services.

Table 13 summarizes the average annual impacts of climate change on tourism expenditures for different European regions as calculated in the PESETA[8] project. Assuming the same climate conditions as in Southern European countries, Georgia could face an average annual decrease in tourism expenditures of 11% in the distant future (2071 – 2100). Assuming an increase of the impact of climate change on the tourism expenditures from the beginning of 2025, this results in an impact of climate change on tourism expenditures of 11.5% in 2070. Despite the reduction in tourism expenditures due to climate change, the respective economic sectors continue to grow, but with reduced growth rates compared to the baseline.

Table 13: Impact of climate change on tourism expenditures (average annual changes in %, 2071 – 2100, 2° scenario)

	EU	Northern Europe	UK & Ireland	Central Europe North	Central Europe South	Southern Europe
Changes in tourism expenditures	-5%	-1%	0%	-4%	-5%	-11%

Source: Adapted from Ciscar et al. (2014).

According to the results of the e3.ge model, climate change could lower tourism revenues by up to 1% of GDP per year in Georgia in the year 2050. The demand decrease of tourists leads to changes in demands for intermediate goods from the respective industries and services, and thus to demand changes throughout the economy. The results are in line with the results of Barrios and Ibañez (2013), who conclude a decrease in tourism revenues by up to 0.45% of GDP for the Southern EU Mediterranean countries in the years 2071 to 2100. Accordingly, the decrease in Georgian tourism revenues by up to 1% of GDP in 2050 highlights once again the importance of tourism for the Georgian economy (tourism revenues to GDP was 21.6% in 2019) and the need to take climate change and adaptation into account when planning the future policy strategies.

[8] Projection of Economic impacts of climate change in Sectors of the EU based on bottom-up Analysis

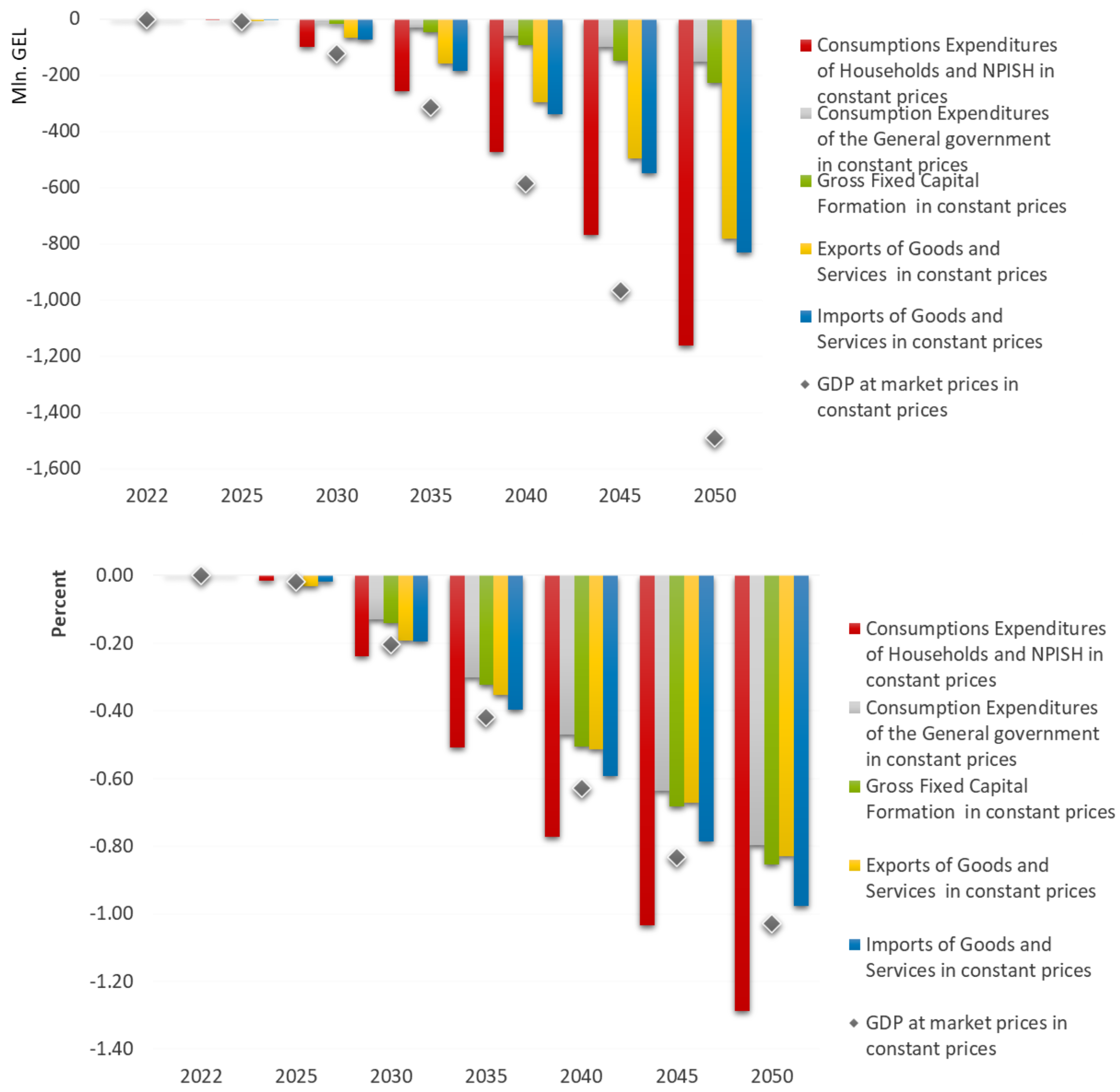


Figure 44: Macroeconomic effects of the "SLR" scenario, selected years, deviations from the "Baseline" scenario without climate change in Mln. GEL (top figure) and percent (bottom figure)

Source: Own figure based on e3.ge results.

Figure 44 illustrates the possible economic effects of reduced tourism expenditures due to sea level rise for selected years. As a result of the absence of tourists, both consumption expenditures by private households and exports of tourism-related goods and services are decreasing. As a result of the annual intensification of the negative climatic conditions, more and more tourists stay away over time, leading to an overall negative trend over time. The consumption expenditures by private households are being reduced by more than 1.2% in the year 2050 (more than GEL -1,000 million) and the exports are being reduced by more than 0.8% in the year 2050 (more than GEL -220 million). This causes an overall reduction to the GDP by more than 1.0% in the year 2050 (GEL -1,400 million, respectively).

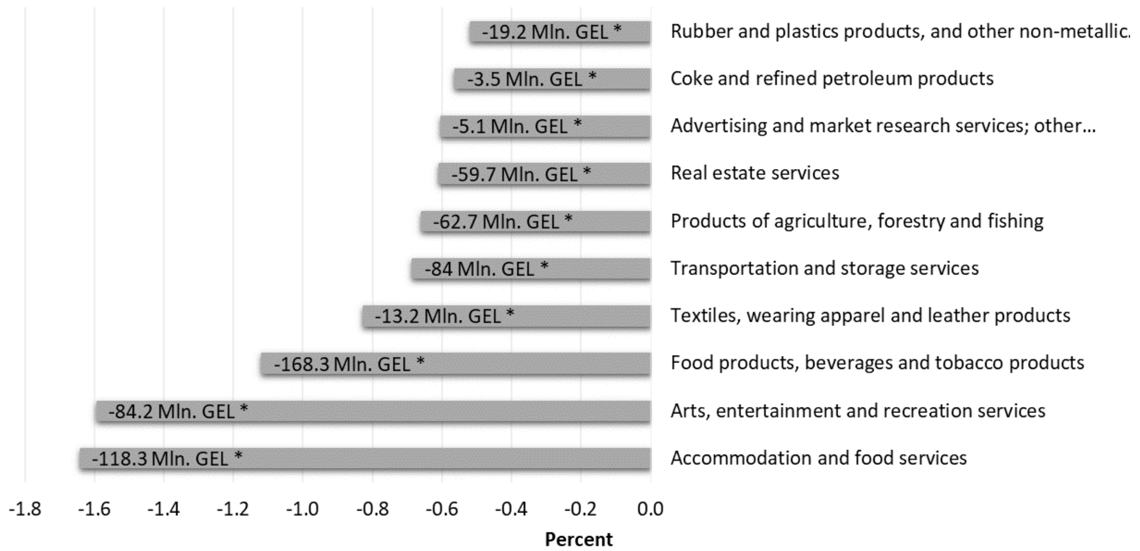


Figure 45: Effects of reduced tourism expenditures due to sea level rise: Top-10 relative deviations of Gross output (year 2040) in percent and Mln. GEL

Source: Own figure based on e3.ge results.

As tourists stay away and demand for tourism-related goods and services declines, the production of goods and services is also decreasing. Figure 45 illustrates as an example the effects of reduced tourism expenditures on sectoral gross output for the year 2040 for the 10 most affected (relative terms) economic sectors. Accommodation services (-1.6%; GEL -118 million), entertainment services (-1.6%; GEL -84 million)), food products (-1.1%; GEL -168 million), textiles (-0.8%; GEL -13 million) and transportation services (-0.7%; GEL -84 million) face the greatest production losses in relative terms. Depending on the overall gross output of the sectors, these relative changes are accompanied by different absolute deviations in the gross output. Figure 45 contains the absolute effects of the reduced tourism expenditures on the gross output in the corresponding bars. In absolute terms, food products (GEL -168 million), accommodation and food services (GEL -118 million) and entertainment services (GEL -84 million) face the greatest production losses in absolute terms.

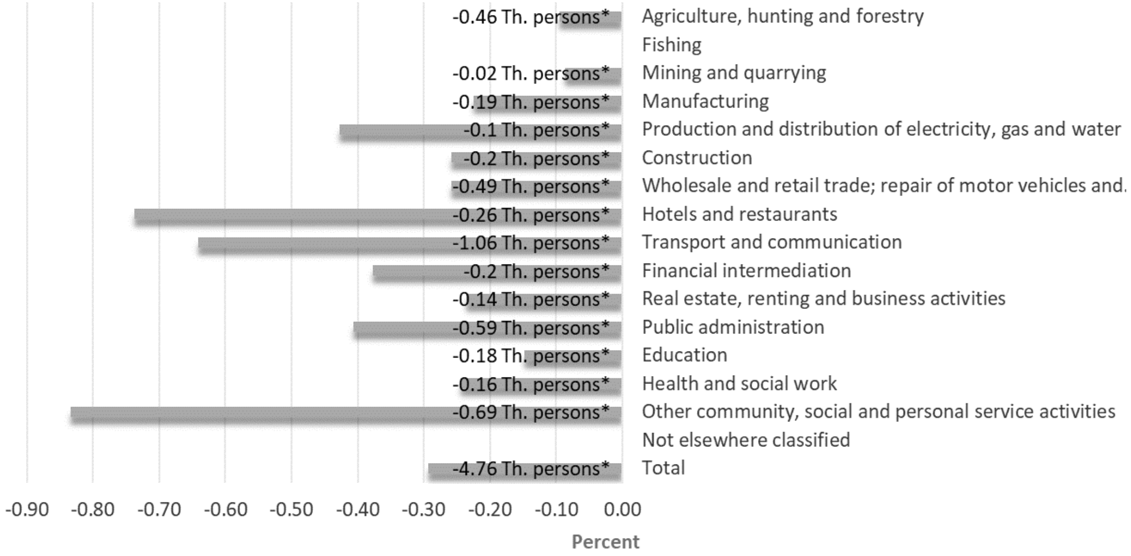


Figure 46: Employment effect of "SLR" on sectoral level in the year 2040, deviations from the "Baseline" scenario

Source: Own figure based on e3.ge results.

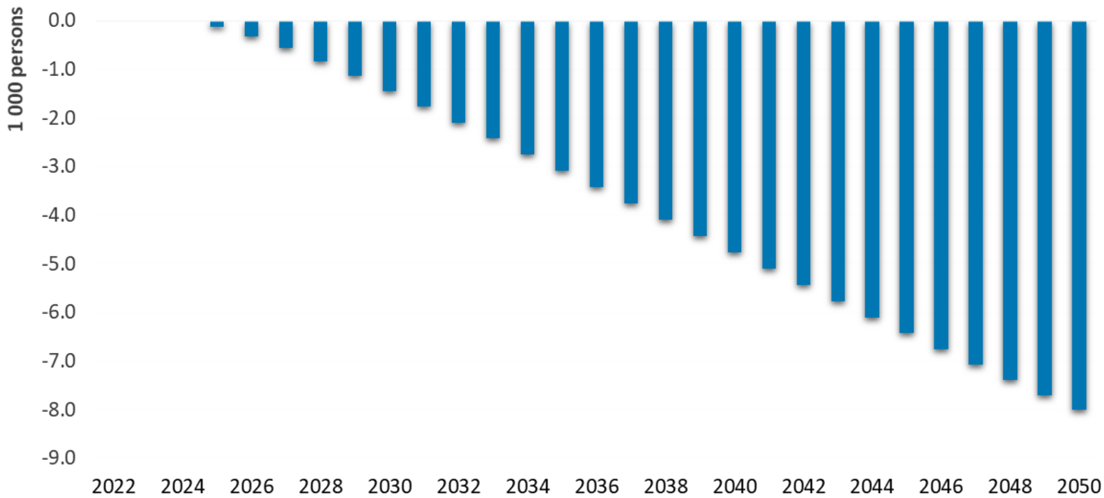
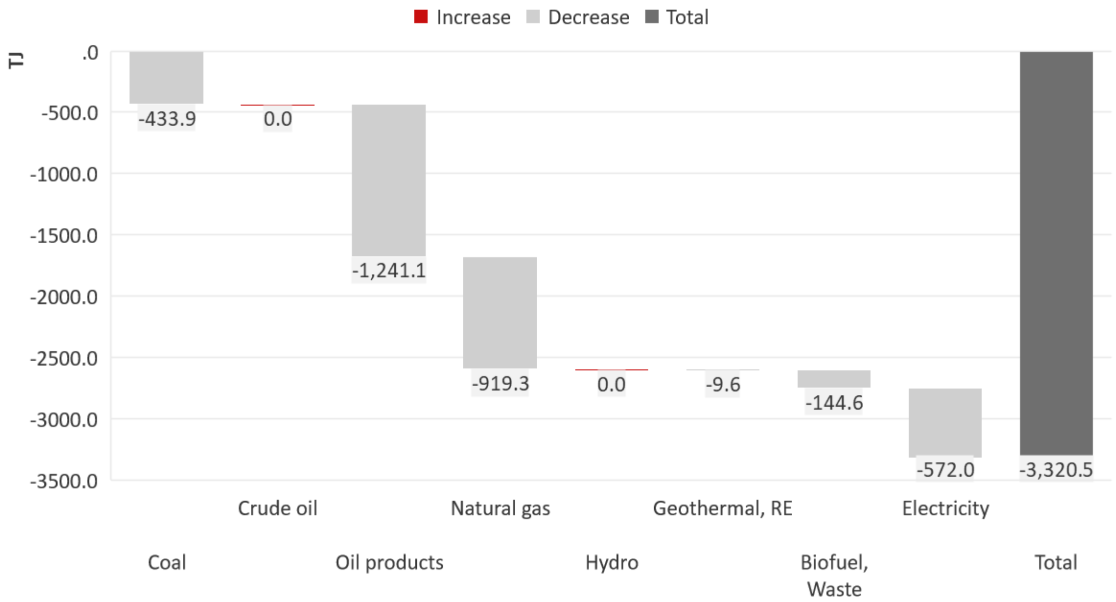


Figure 47: Effects of the "SLR" scenario on Employment, 2022-2050, deviations from the "Baseline" scenario without climate change in 1,000 persons

Source: Own figure based on e3.ge results.

The negative effects on the employment are described in more detail in Figure 46. Not only the economic sectors directly related to tourism face a decrease in production activity and, consequently, a decrease in employment, but also the demand for intermediate goods from the respective industries decreases, resulting also in a decreasing production (see Figure 45) and a decrease in employment. Figure 46 illustrates the sectoral employment effects for the year 2040 as an example. The largest decreases in employment are found in accommodation services (-0.74% in 2040), transportation services (-0.64%) and other services (-0.83%). However, there is also a significant decrease in employment in the other sectors. Overall, employment is reduced by up to more than 8,000 people (see Figure 47). Assuming that the effects of climate change continue to increase, the negative effect on employment continues to grow.



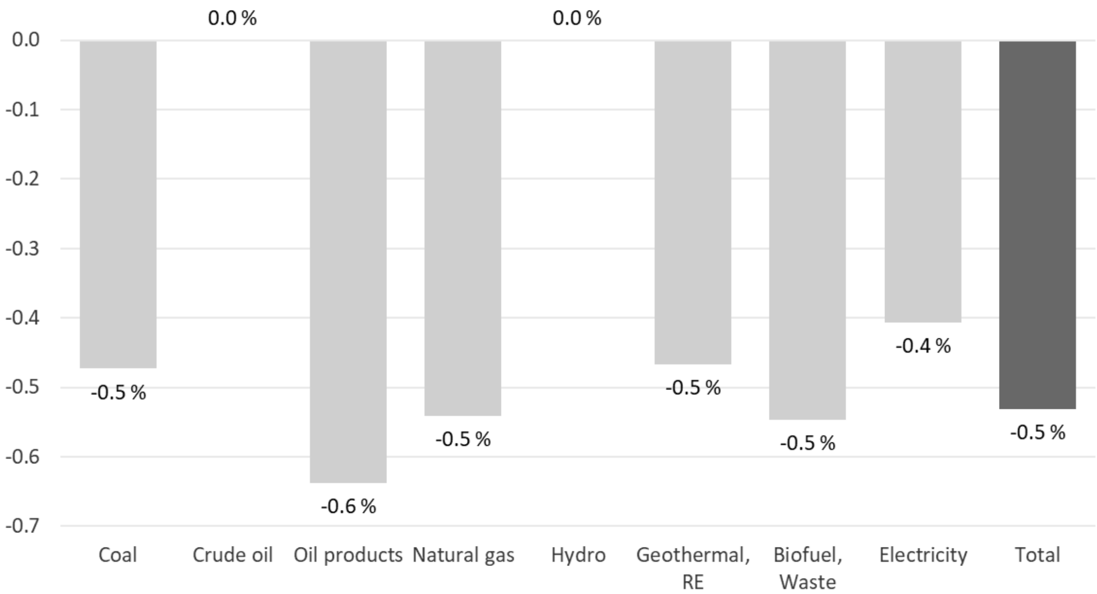


Figure 48: Effects of the "SLR" scenario on final energy consumption, 2040, deviations from the "Baseline" scenario in TJ (top figure) and percent (bottom figure)

Source: Own figure based on e3.ge results.

The lower economic activity results in less final energy demand which is 3,300 TJ resp. 0.5% lower in 2040 compared to a Baseline scenario (see Figure 48). Energy demand by fossil fuels decreases accordingly to the use of demanding sectors.

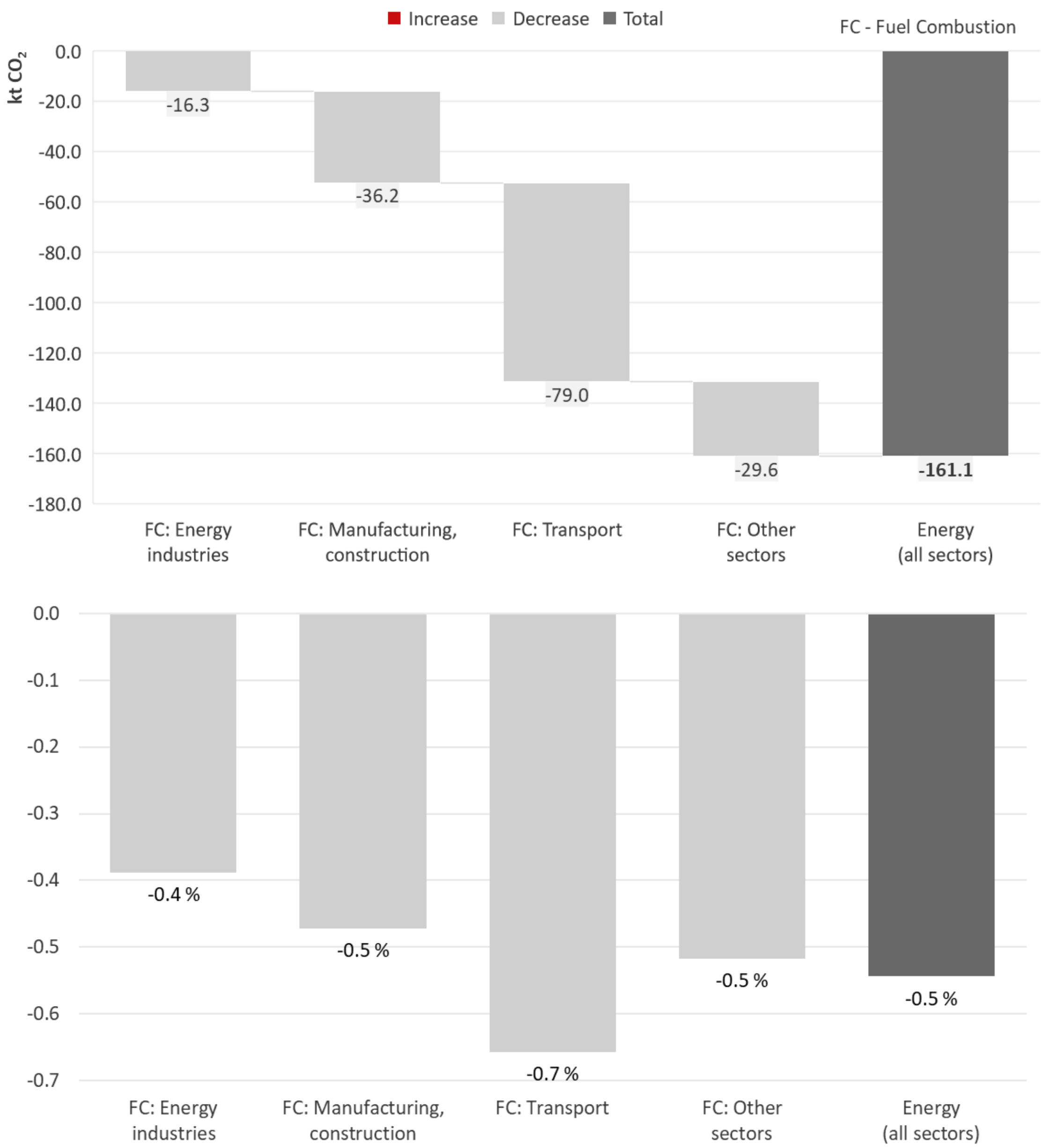


Figure 49: Effects of the "SLR" scenario on CO_2 emissions, 2040, deviations from the "Baseline" scenario in kt CO_2 (top figure) and percent (bottom figure)

Source: Own figure based on e3.ge results.

CO_2 emissions in manufacturing, construction and other sectors decrease due to lower production (see Figure 49).

6 ECONOMICS OF ADAPTATION TO CLIMATE CHANGE

Studies on how to deal with global climate change have focused on the reduction of GHG emissions for a long time. Thus, the number of respective studies dealing with a model-based evaluation of adaptation measures is rather small. A variety of definitions of adaptation to climate change exist. In general, adaptation to climate change can be defined as a "set of organization, localization and technical changes that societies will have to implement to limit the negative effects of climate change and to maximize the beneficial ones" (Hallegatte et al. 2011). The United Nations Framework Convention on Climate Change (UNFCCC) defines adaptation as “adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities”. (UNFCCC 2013). However, adaptation measures are difficult to assess due to the following reasons (see also Lehr et al. 2020):

1. Uncertainty about the impacts of climate change:

Accurately predicting future climate change impacts is difficult. Adaptation measures based on an average temperature increase of 3°C, for example, turn out to be too complex and costly if the temperature rises by 1.5°C only. On the other hand, measures that refer to a global warming of 1.5°C on average are almost meaningless if the temperature rises by 3°C. Similarly, it is uncertain what impacts climate change will have on ecosystems and how communities on the local level will be confronted with the results (Eisenack 2009, Hallegatte et al. 2011).

2. Climate is changing dynamically:

Since the climate will change continuously, the adaptation measures need to be long-term with the possibility of modification, which complicates planning (Hallegatte et al. 2011).

3. Socio-economic systems react slow:

Socio-economic systems react slow to adaptation in technical, institutional, regulatory, and cultural terms. Due to the long-term time horizon, mankind cannot learn from experience or through learning-by-doing processes (Hallegatte et al. 2011).

4. Adaptation to climate change sometimes requires fundamental reorientation:

Often it is not possible or practical, both financially and technically, to adapt boundary conditions to climate change and otherwise pursue the same activities as before. In some cases, it will be necessary for regions to turn away from previous activities and adopt new alternatives.

5. Adaptation takes place on a regional scale:

The willingness of individual regions to invest in adaptation measures is likely to be higher than the willingness to undertake efforts to reduce GHG emissions, since the benefit can be directly attributed to the investing region. Region and topography play a major role in evaluating adaptation measures. In some cases, adaptation measures take place at a small-scale level (counties, cities).

6. Data for modeling adaptation are often more incomplete and subject to greater uncertainty than data for modeling mitigation.

World Bank (2020a) provides a guide for designing strategies for climate change adaptation to help ministries of finance or economy – who oversee the wider economic system – approach adaptation challenges. It provides concrete examples and information to decision makers to guide them through the principles of adaptation and to design and formulate appropriate policy strategies.

The modeling of adaptation measures poses new challenges to researchers. The data needed to evaluate adaptation measures are often not sufficiently available, so that assumptions have to be made which are associated with a high degree of uncertainty.

However, the macroeconomic analysis of different adaptation measures is key to prepare an adaptation strategy in Georgia. Thus, the e3.ge model developed is suitable to accomplish this task. The following analysis gives an economic evaluation of different adaptation measures on a sectoral level.

Figure 50 focusses on the steps to be taken to implement an adaptation strategy. These steps are guided by several key questions that need to be answered. The assessment of the macroeconomic impacts of possible adaptation measures is highlighted in the figure. Thus, the macroeconomic evaluation of possible adaptation measures is key to formulate an adaptation strategy.

Although the financial and economic impacts are relevant for policymakers to prioritize adaptation measures, other criteria must also be considered such as health aspects and ecosystem services (biodiversity, regulation of the water balance) to get a more comprehensive evaluation of a measure, and to formulate an appropriate adaptation strategy. The economic effects should only be one possible basis for decisions on the selection of adaptation measures in Georgia.

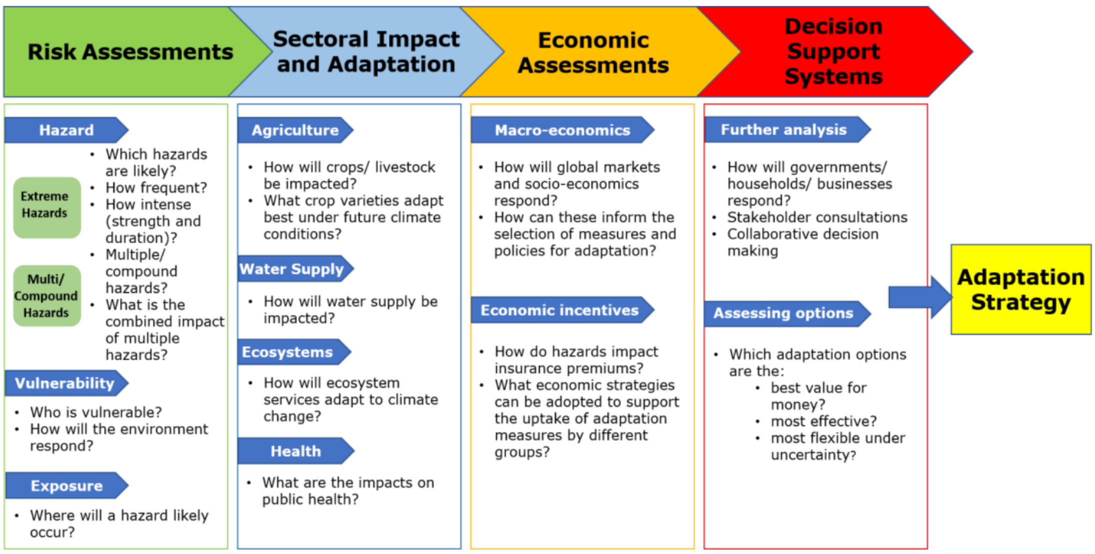


Figure 50: Steps and questions to support the development of climate adaptation strategies

Source: European Commission (2020), p. 6

In the step of risk assessment, possible risks and vulnerabilities from climate change need to be identified (see chapter 5). In the second step, the identified climate risks need to be assessed with respect to their direct impact on certain sectors of the economy. Close contact with field experts is advisable and beneficial in this context.

In the third step, the identified sectoral impacts and adaptation measures are subject to an economic evaluation. An economic model such as e3.ge can be used to estimate the macroeconomic effects. It helps to quantify not only the direct effects on the economy, but also the indirect and induced impacts in other sectors and the total economy to evaluate adaptation options. By using the model for scenario analysis (see Table 1), the macroeconomic effects of different adaptation options can be compared.

Based on these results, policy makers provide decision support by prioritizing the available adaptation options and condensing the available model results for review by high level authorities.

6.1 INTEGRATION OF ADAPTATION TO CLIMATE CHANGE IN THE E3.GE MODEL

The implementation of adaptation measures in the e3.ge model is not appropriate for all adaptation measures. There should be clear criteria for selecting those adaptation measures to be analyzed with a macroeconomic model. The following criteria provide a starting point for filtering the adaptation measures for model application. Thus, it should be noted that if an adaptation measure has not been chosen to be implemented in the model, it still can be important for the comprehensive adaptation strategy and provide positive impacts.

1. Relevance in policy processes and need for action

A first important aspect is the relevance of the adaptation measure for policy processes. If the need for action due to the climate risk or in an economic sector is particularly high, then adaptation measures that address these risks should rather be considered. As it has been shown above, for example, the agriculture and tourism are very relevant for the economy in Georgia. Accordingly, adaptation measures that have an impact on these two sectors may be particularly relevant for a detailed analysis.

2. The measures must be appropriate to the climate impacts and field of action studied.

Only those adaptation measures should be analyzed with regard to the macroeconomic effects that are appropriate to reduce the impacts of climate change under investigation. Thus, an adaptation measure for agriculture should have a positive impact on crop yields, for example.

3. The (expected) macroeconomic effects are relevant

A third important criteria is the expectation about the macroeconomic effects. The use of the macroeconomic model only makes sense if the expected macroeconomic effects are relevant and, in particular, if interactions between different economic sectors are expected. The macroeconomic relevance may result from both the costs or the benefits of the adaptation measure.

4. Combination of adaptation measures and instrument and possibility to map it into the macroeconomic model

Table 14 provides an overview of the different types of adaptation instruments that can be used by the government to enable the implementation of the adaptation measure. The instruments are a possibility of the government to prescribe, regulate, initiate or create incentives for adaptation measures. Not all types of instruments can easily be translated into model parameters. While the economic adaptation instruments (price instrument, direct subsidy) can be directly implemented to the macroeconomic model, other instruments need more clarification or assumptions. For example, a command and control instrument is treated as binding, meaning that all people comply to the regulation. A voluntary agreement is considered to have been fulfilled. Thus, additional assumption may be needed with regard to the respective adaptation measure. Instruments do not necessarily already have to be available for the evaluation of the adaptation measure.

Table 14: Possibilities of modelling adaptation measures and instruments

Type of adaptation instrument	Map into macroeconomic model
Command and control	The regulation is treated as binding
Planning	If this results in a physical/monetary change, it is mapped.
Price instrument	Prices are implemented
Direct subsidy	Subsidy is regarded as successful
Voluntary agreement	The agreement is considered to have been fulfilled
Management of information and knowledge	If this results in a physical/monetary change, it is mapped.
Provision of basic data	If this results in a physical/monetary change, it is mapped.
Inspection	If this results in a physical/monetary change, it is mapped.

Source: Own table.

5. Data availability of costs and benefits for the adaptation measures

Data and information is needed for the costs and benefits of the possible adaptation measures. Starting point are ideally country- and sector specific cost-benefits-analysis of investments into particular adaptation options which already show suitable solutions for the respective sectoral climate change related issue. Costs and benefits (e. g., in terms of damage reduction or additional benefits like increase in harvest) of the measures need to be quantified and then fed into the e3.ge model. Both costs and benefits cause several macroeconomic effects. If no country and sector specific data is available, best-practice adaptation options of comparable situations in other countries may serve as an initial indication.

The filtered list of adaptation measures can be used to formulate the scenarios. These scenarios should be formulated in a way that the model results provide the information needed to answer the key questions identified in the preparation process.

In review of Figure 17, the steps 3 and 4 will be performed in the following sections. The following scenarios are being analyzed regarding the macroeconomic effects of different adaptation measures.

Table 15: Scenarios analyzed with the e3.ge model

Adaptation measure	Climate change impact	Economic sectors affected
Irrigation systems	Severe droughts	Agriculture
Windbreaks	Wind	Agriculture
(Re-)construction of coastline protection	Sea level rise	Tourism related sectors
Climate-resilient roads and bridges	Sea level rise and heavy precipitation	Tourism related sectors

Source: Own table.

6.2 ECONOMY-WIDE EFFECTS OF ADAPTATION MEASURES – SECTOR STUDIES

6.2.1 ADAPTATION IN AGRICULTURE

6.2.1.1 Current situation of Agriculture

Agriculture is one of the most important economic sectors in Georgia, employing about 20% of the active population (plus e.g. own-account workers and contributing family workers), but only having a share in GDP of 8.4% in 2020. This share has fallen significantly over the past decades (see USAID 2017). However, the dependence on agriculture is likely to continue into the medium-term future, and it is one of the greatest challenges to improve its productivity, increase farmers' incomes and reduce rural poverty (see MoA 2017). Agriculture is one of the most vulnerable sectors to climate change in any country's economy, maybe the most important in Georgia (see MoE 2015). Thus, climate change increases sector development risks and negatively impacts economic and social welfare (see MEPA 2017). Consequently, the Georgian Agriculture Development Strategy (2015-2020) (see MoA 2015) focused on three inter-linked challenges: ensuring food security through improvement of productivity and incomes, adaptation to climate change, and promotion of climate change mitigation. To assist the government in the implementation of the agriculture strategy, the National Adaptation Plan of Georgia's agriculture sector to Climate Change (AgriNAP) becomes an integral part of the Agriculture Development Plan.

6.2.1.2 Options for adaptation in Agriculture

There are several ways for farmers to adapt to the expected changes due to climate change. The cultivation of adapted varieties and new crop types in connection with adapted cultivation methods can contribute to soil conservation and water saving, reducing the possible effects of climate change. Other options for adaptation include efficient irrigation systems (e.g., drip irrigation), fertilization to realize higher yields, and improved crop protection to limit pests and diseases. Improved weather forecasting and early warning systems for extreme weather events can also help to limit the damages caused by climate change. Frost protection measures (e.g., frost protection irrigation), hail protection nets, hail guns and windbreaks are further structural adaptation measures. Insurance against crop failures compensates farmers, but the foregone harvest needs to be compensated in other ways (e.g., by increasing imports).

6.2.1.3 Investing in Irrigation systems

The rehabilitation and modernization of irrigation systems is key to support a greatly expanded horticultural crop production (see MoA 2017). Since the temperatures in Georgia will continue to rise and the estimated precipitation varies greatly, irrigation systems can sustain high yields in the future. The irrigation strategy in Georgia "encompasses the rehabilitation of decayed irrigation infrastructure and the development of a modern data-based professional and participatory irrigation management capacity" (see MoA 2017). The irrigation strategy contains several information on cost and benefits.

In the climate change scenario, severe temperatures are assumed to occur every 5 years, starting in 2025. The effects on agriculture are increasing over time due to the intensifying climate change. The rehabilitation of existing gravity irrigation schemes is done by construction works (e.g., canals, drainage, reservoirs). Water-saving technologies (e.g., drip irrigation systems) will be imported from abroad (China, or higher quality from Turkey and Israel, see MoA 2017). The local construction industry is needed for rehabilitation and installation of the irrigation systems. The benefits of irrigation systems include an increased agricultural productivity and thus increased crop yields in years without severe heat and drought, and reduced damages in years with extreme temperatures. Water availability does not seem to be constraining (see MoA 2017).

Table 16: Cost-Benefit-Analysis of irrigation systems; Input for the e3.ge model

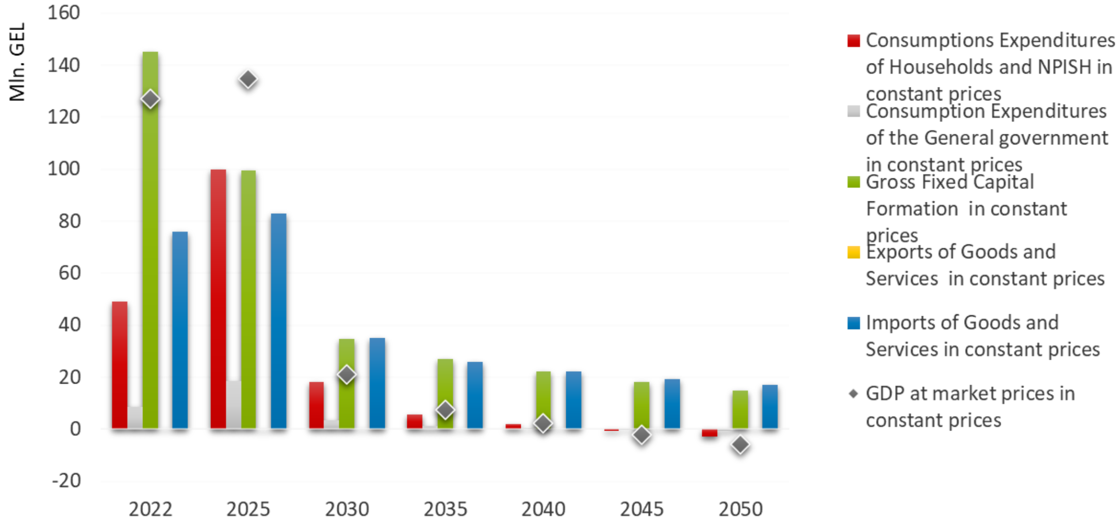
	Investments or Benefits
Rehabilitation investment in irrigation systems	• 2021 to 2025: in total 700 million GEL • 2026 to 2050: 50 million GEL p.a.
Allocation of investment	• 2021 to 2025: 85% irrigation channels, 15% drip irrigation systems • 2026 to 2050: 25% irrigation channels, 75% drip irrigation systems
Increased crop yields from irrigation	• 2021 to 2025: steady growth up to 15% p.a. • 2025 to 2050: 15% p.a.

Source: Adapted from MoA 2017.

However, if the farmers must buy irrigation systems, they will pass their costs to the consumers by increasing the prices of agricultural products. If the government subsidizes the irrigation systems, it may have to reduce its investments elsewhere.

In addition to the direct effects (construction works, material imports, increased agricultural production), these effects account for further second-round and induced effects, e.g., an increase in production in upstream and downstream sectors of agriculture and construction as well as for price and income effects, which in turn influence consumption expenditures.

Model results



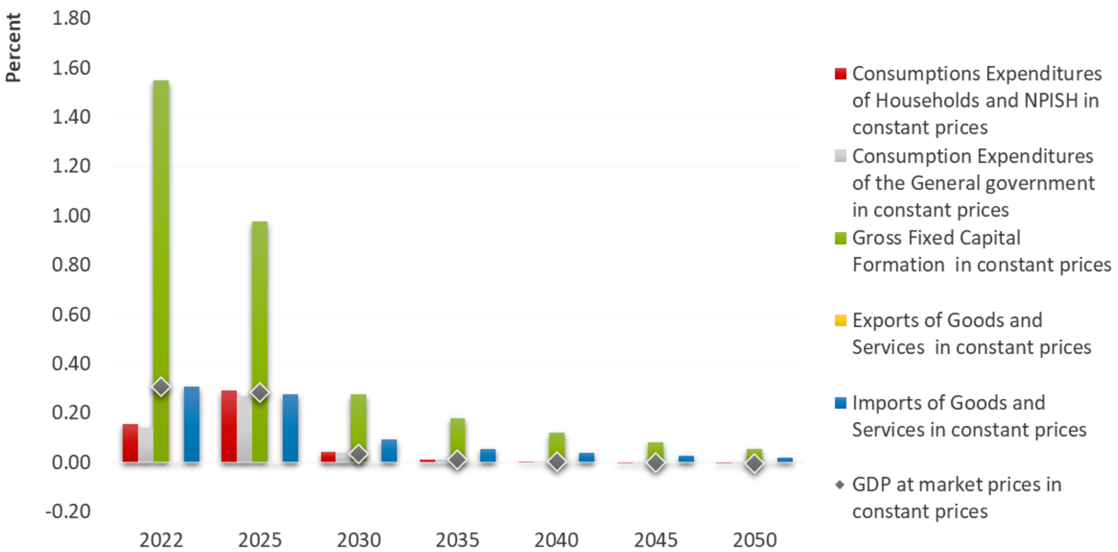
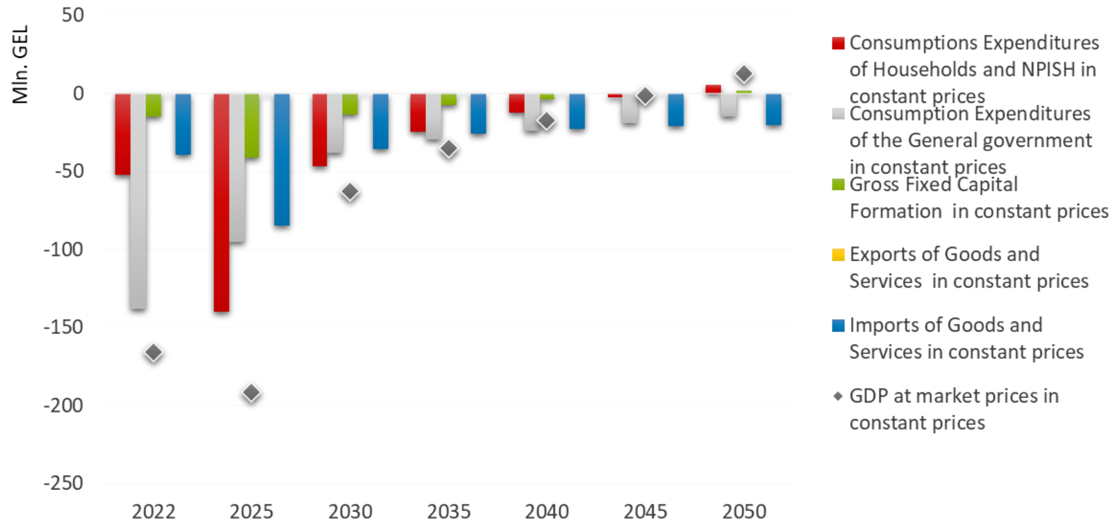


Figure 51: Macroeconomic effects of the additional investment in construction and machinery in the "Irrigation" scenario, selected years, deviations from a "Drought" scenario in Mln. GEL (top figure) and percent (bottom figure)

Source: Own figure based on e3.ge results.

Figure 51 illustrates the economic effects of the investment in both construction activity and additional machinery equipment according to the assumptions in Table 16. Starting with high investments in construction (reflecting the irrigation strategy), the investments in the following years serve to maintain the quality. After the rehabilitation of the irrigation channels in the year 2025, the annual construction investment is small, but still positive. The additional investment in construction has a positive impact on the economy and the GDP. Since almost 100% of machinery products are imported, imports increase in line with investments in machinery. No local production takes place. The overall impact on the GDP is positive and after the year 2025 small, since the amount of investment is reduced. In the year 2025, GDP is higher by GEL 140 million (+0.28%) and in the year 2050, the effect on the GDP is slightly negative, since the products are being imported.



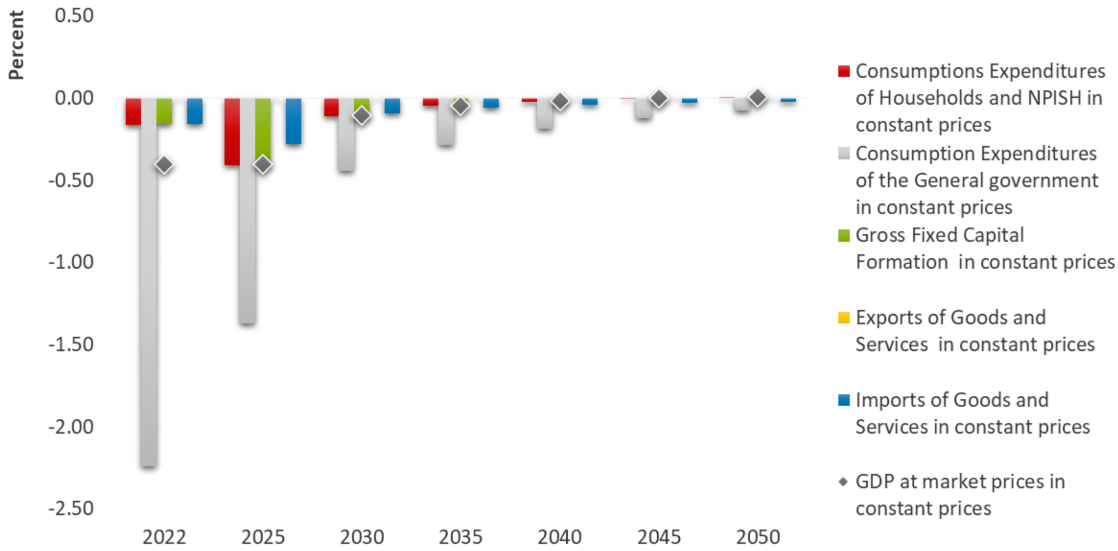


Figure 52: Macroeconomic effects of reduced government expenditures in the “Irrigation” scenario, selected years, deviations from a “Drought” scenario in Mln. GEL (top figure) and percent (bottom figure)

Source: Own figure based on e3.ge results.

If the government subsidizes irrigation systems, other governmental expenditures must be reduced. The previously mentioned investments (construction, machinery) are deducted 1:1 from other consumption expenditures. Thus, Figure 52 illustrates the isolated effect of a reduction in government consumption expenditures. The effect on the GDP is negative (GEL -200 million in 2025; -0.4%) and getting smaller over time, since the amount of investment is decreasing.

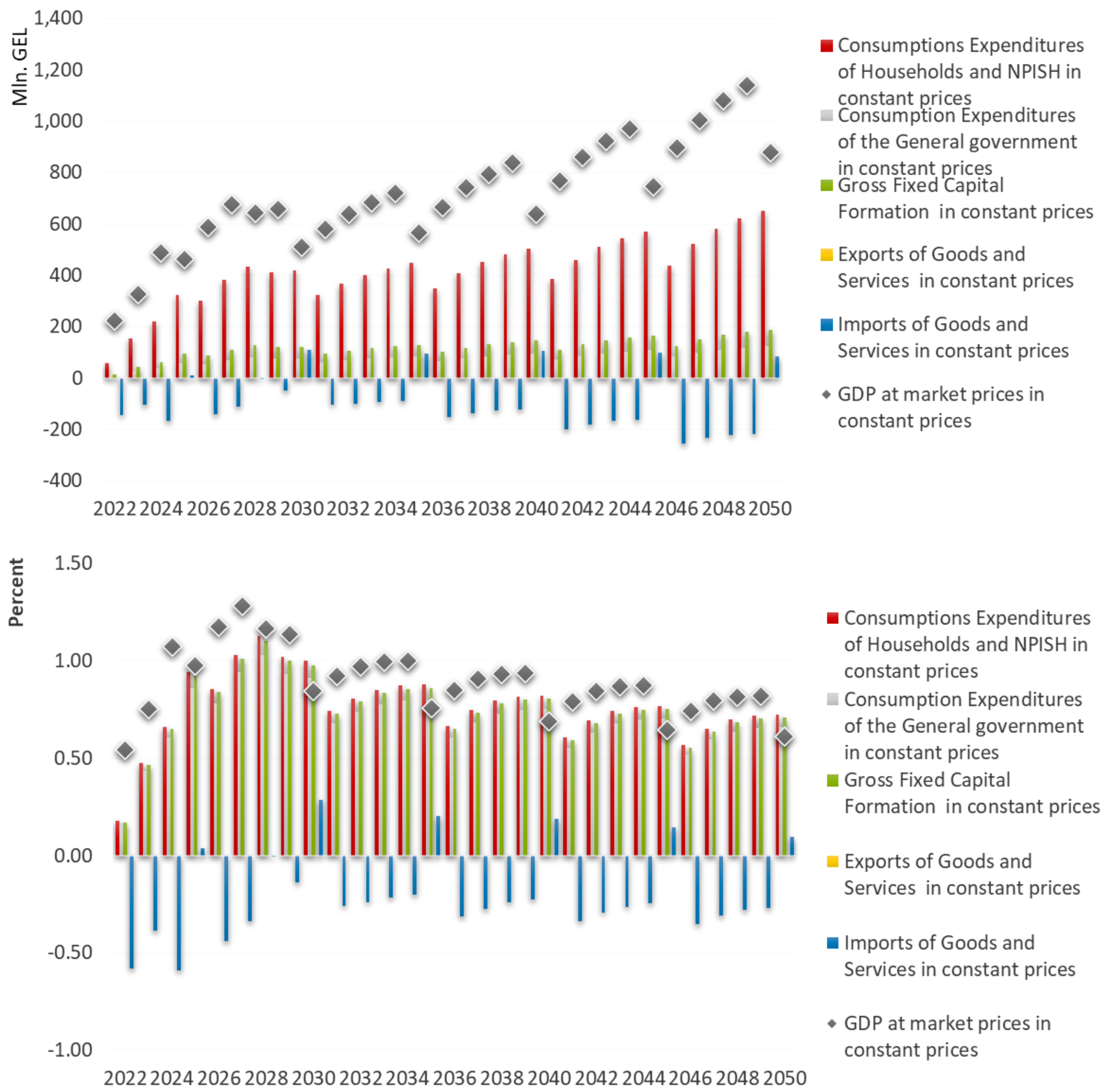


Figure 53: Macroeconomic effects of increased productivity in agriculture in the "Irrigation" scenario, selected years, deviations from a "Drought" scenario in Mln. GEL (top figure) and percent (bottom figure)

Source: Own figure based on e3.ge results.

The highest impact on the economy stems from the increasing productivity in agriculture. In years without a drought (every 5 years, beginning in 2025), the irrigated arable land becomes larger and therefore the crop yield increases. In years with a drought, the damages are reduced. Compared to the scenario with only climate change (see Table 1), the imports of agricultural products can be reduced and the production in the agricultural sector increases. The overall effect on imports results on the one hand from additional imports due to higher consumption and investment and on the other hand from reduced imports of agricultural products. The production is increasing not only in the agricultural sector, but also in those sectors delivering inputs for the agricultural sectors and those sectors using agricultural products as an input. The positive impact of the increased productivity in agriculture is the main determinant of the overall macroeconomic effects (see Figure 54).

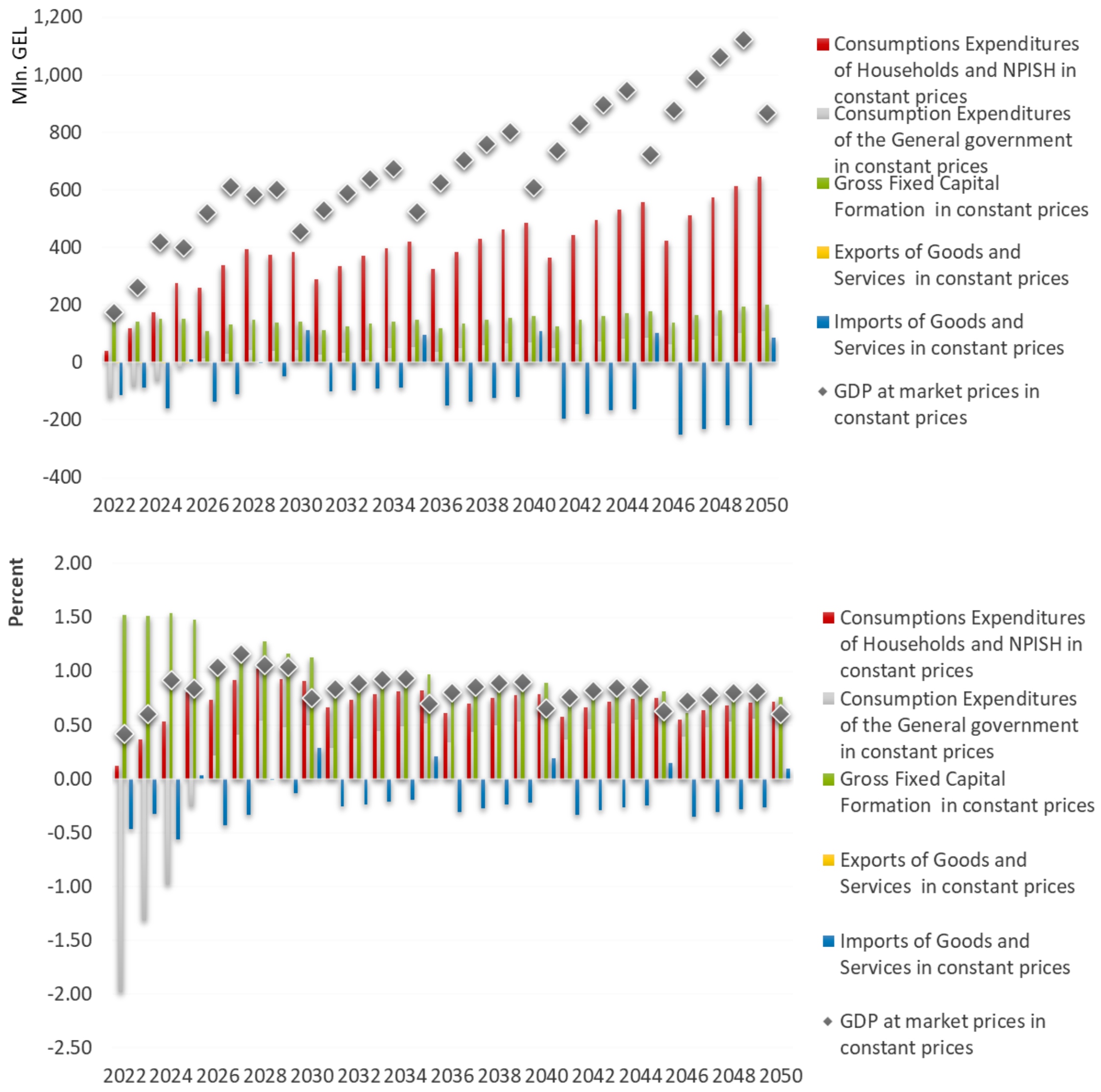


Figure 54: Macroeconomic effects of the "Irrigation" scenario, selected years, deviations from a "Drought" scenario in Mln. GEL (top figure) and percent (bottom figure)

Source: Own figure based on e3.ge results.

The GDP increases by up to 1% (up to GEL 1,000 million) in one year in the period under review (see Figure 54). The positive effects on GDP from additional investment result in lagged positive effects on consumption and investment, which in turn also have a positive impact on other economic sectors and thus on the GDP. The consumption expenditures increase by up to 0.9% (up to GEL 640 million) in one year in the period under review. Since the government subsidizes the irrigation systems, the government's consumption expenditures are reduced elsewhere. The biggest economic effects are to be expected from the increase in production in agriculture due to the additional irrigation. Although there are still crop losses due to droughts and high temperatures, damages can be significantly reduced.

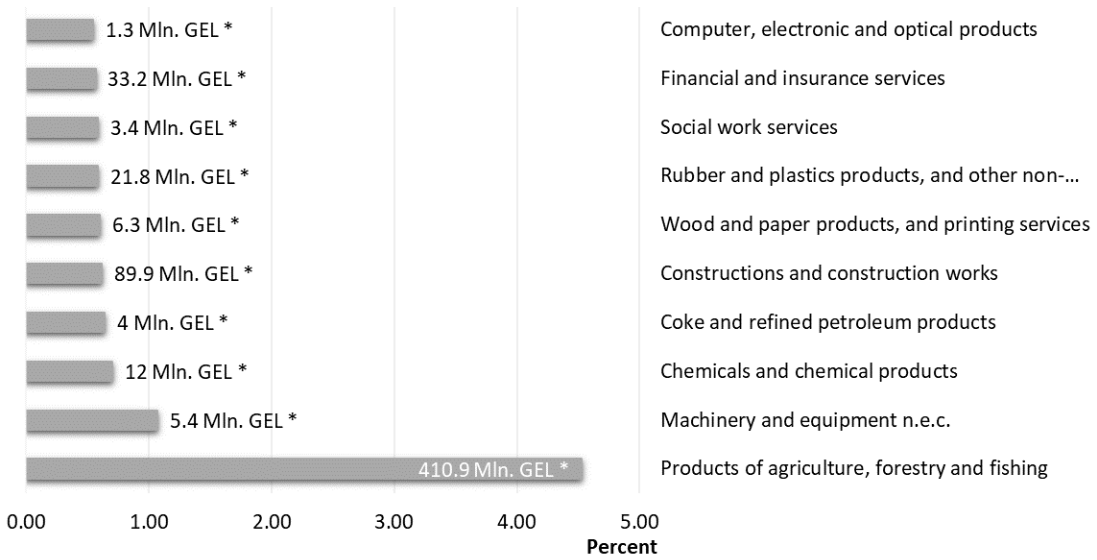


Figure 55: Effects of "Irrigation" scenario: Top-10 relative deviations of Gross output (year 2040) from a "Drought" scenario in percent and Mln. GEL

Source: Own figure based on e3.ge results.

Figure 55 highlights the effects on gross output of different sectors for the year 2040. Agriculture is benefitting the most from the implementation of irrigation systems (+5.5%; GEL 410 million in 2040). Also the sectors providing inputs for the agriculture sector benefit (machinery, chemicals).

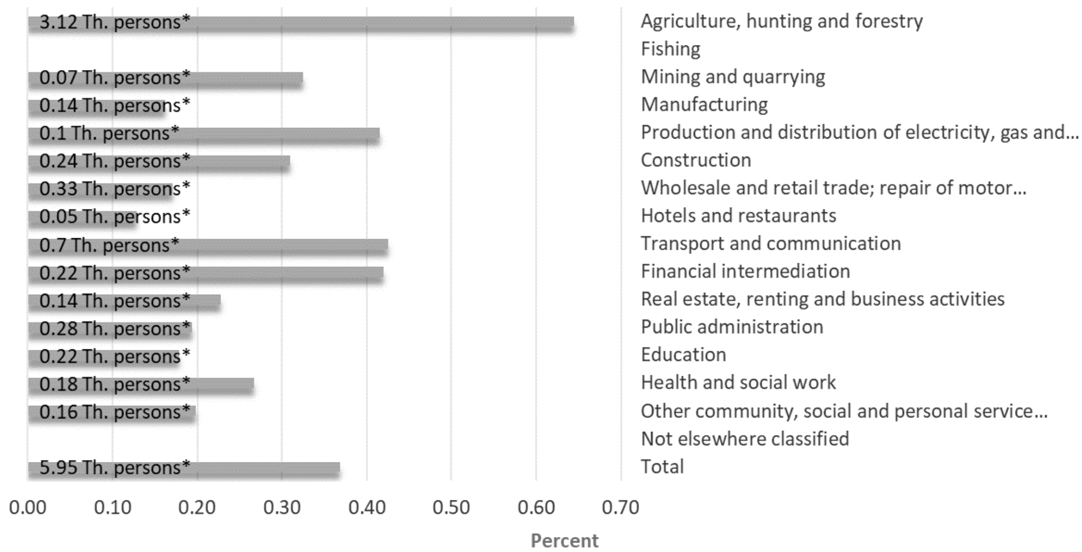


Figure 56: Employment effects of the "Irrigation" scenario on sectoral level in the year 2040, deviations from a "Drought" scenario

Source: Own figure based on e3.ge results.

The implementation of the adaptation measure irrigation systems in agriculture has also positive effects on employment. Up to 10,000 additional people can be employed. This corresponds to an increase of up to 0.6% in one year in the period under review. Analogous to the effects mentioned above, this additional employment takes place in different economic sectors: on the one hand directly in the agricultural sector, but on the other hand also in the sectors for additional consumption and in the transportation sector.

Since the model assumes an increasing productivity in the respective economic sectors, the additional employment decreases over time but remains clearly positive. Figure 56 illustrates the sectoral employment effects for the year 2040. All sectors experience a positive employment effect, which is greatest in the agricultural sector. In the year 2040, the overall employment is higher by more than 0.35% (6,000 people). The employment is increasing by more than 10,500 people per year (see Figure 57).

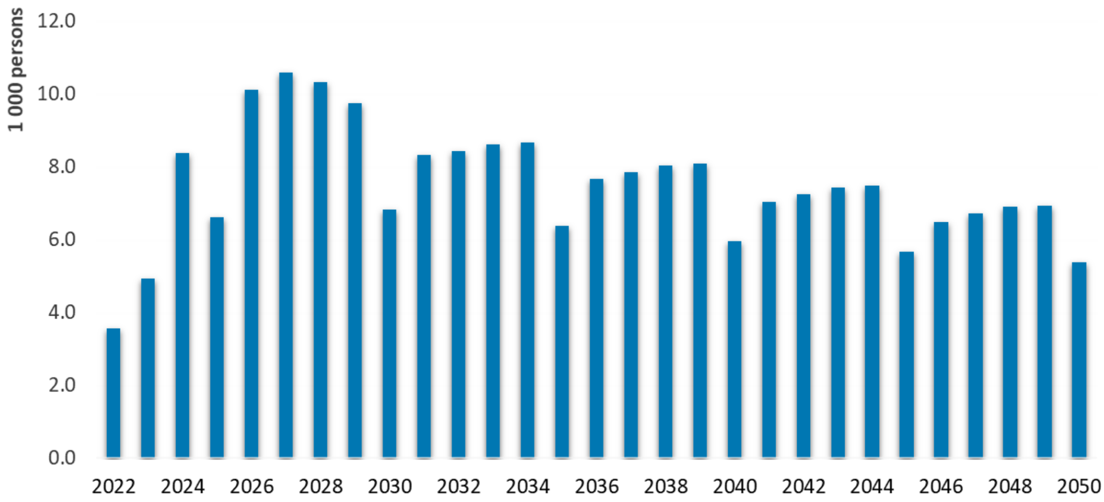
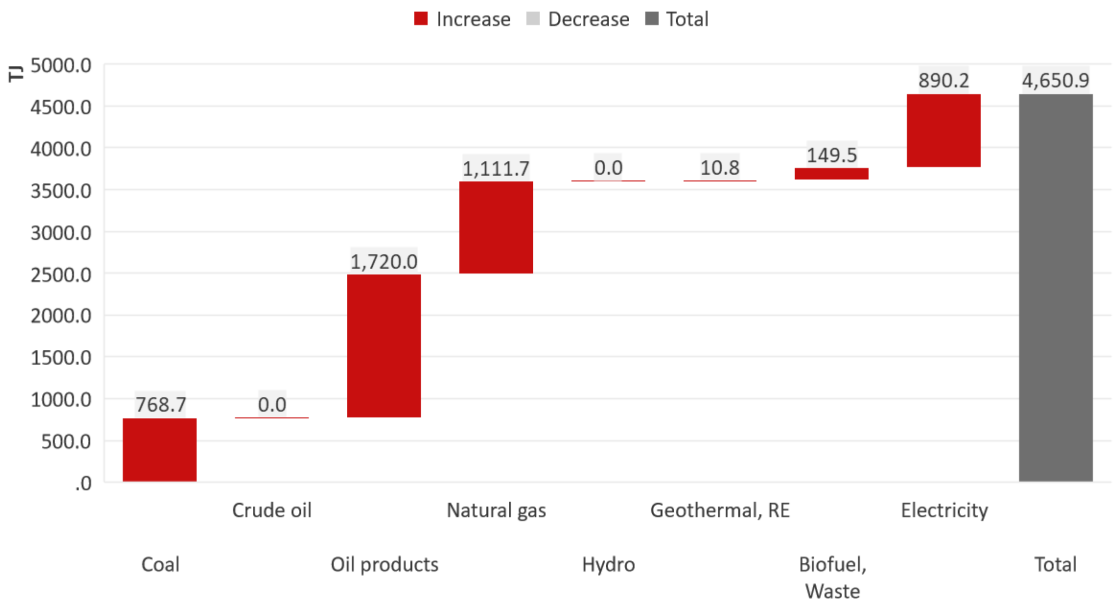


Figure 57: Effects of the "Irrigation" scenario on Employment, 2022-2050, deviations from a "Drought" scenario in 1,000 persons

Source: Own figure based on e3.ge results.

The higher economic activity shows on the one hand positive impacts on income and thus spending opportunities of households and investment plans of companies (see Figure 54). On the other hand, energy demand and CO_2 emissions increase as long as additional mitigation options are not considered. In 2040, the overall effect on the GDP is positive (+0.65%). Total final energy consumption in this year shows high deviations with 4,600 TJ (+0.7%) (see Figure 58). However, the effect in the other years are even higher since the impacts on GDP are even higher.



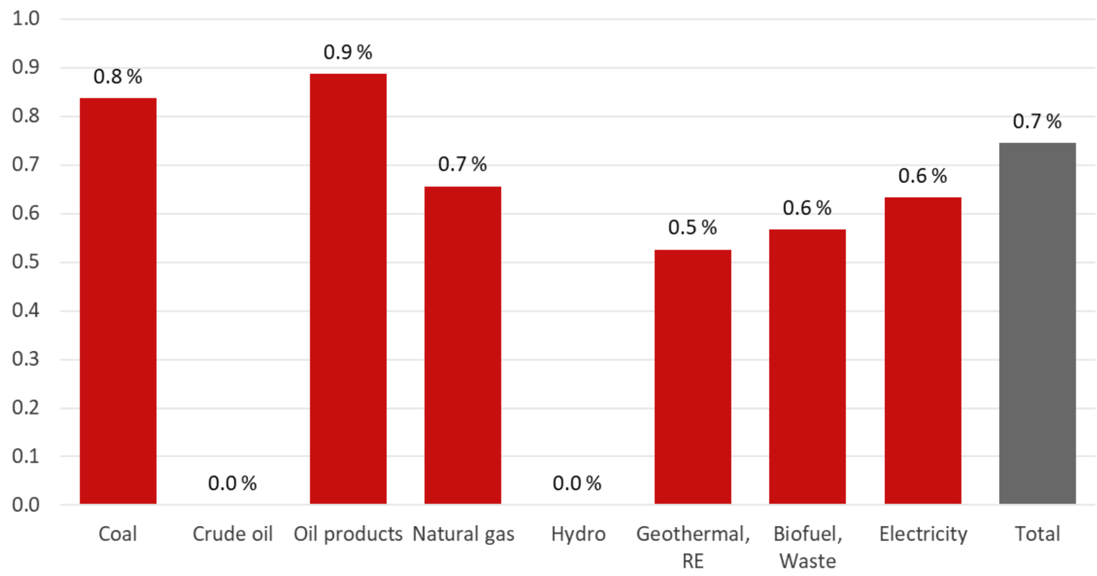


Figure 58: Effects of the "Irrigation" scenario on final energy consumption, 2040, deviations from the "Drought" scenario in TJ (top figure) and percent (bottom figure)

Source: own figure based on e3.ge results.

The changes for the various energy carriers are dependent on the fuel-specific energy consumption in the economic sectors. Agriculture and construction as well as up- and downstream industries are mainly benefitting from this adaptation measure causing in particular a higher demand for oil products (1,700 TJ; 0.9%), natural gas (1,100 TJ; 0.7%) and electricity (890 TJ; 0.6%).

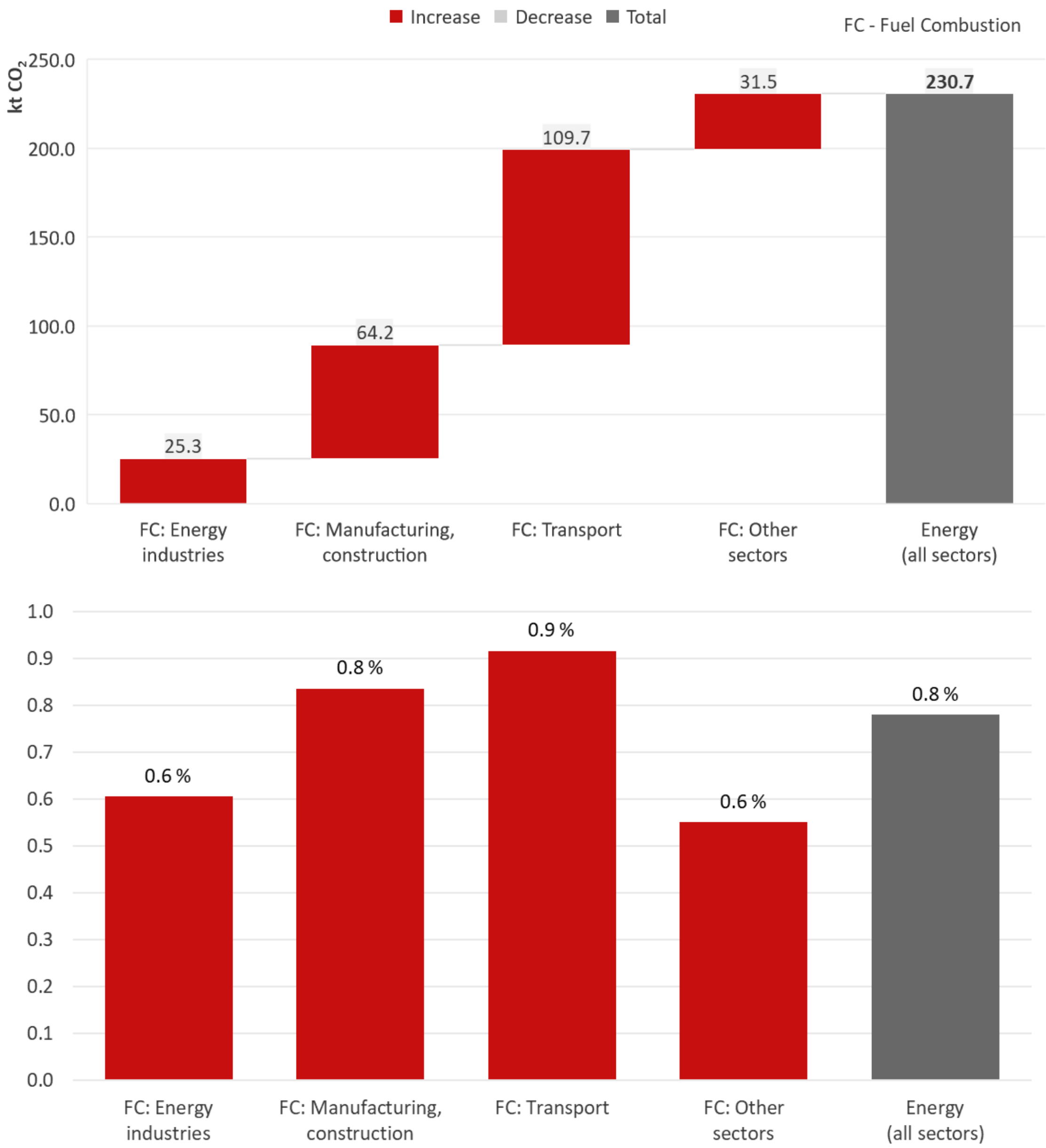


Figure 59: Effects of the "Irrigation" scenario on CO_2 emissions, 2040, deviations from the "Drought" scenario in kt CO_2 (top figure) and percent (bottom figure)

Source: Own figure based on e3.ge results.

The impact on CO_2 emissions follows the use of fossil fuels in the respective sectors as shown in Figure 58. Combustion-related CO_2 emissions are at max. (in 2040) 0.2 Mt (resp. 0.8%) higher than in the "drought" scenario without adaptation.

6.2.1.4 Investing in Windbreaks

Wind erosion is a problem especially in dry land areas. The wind removes and transports soil material and causes land degradation. As a result, the crop yields are reduced. Windbreaks can reduce wind speeds over fields, which protects the soil and thus provides additional protection for the plants in the fields. Thus, when designed for wind reduction purposes, windbreaks can enhance crop production, improve crop quality, reduce fruit rubbing, decrease fruit drop, increase water-use efficiency, and offer control of blowing snow and dust, to mention some of the positive effects (see Smith et al. 2021). The windbreaks usually consist of trees and bushes that are placed at the edge of the fields or between the fields (see IBiS 2019). While these windbreaks were already implemented during Soviet times, they have been cut down by local people and used as firewood during the energy crises in the 1990s. Today, fire and grazing cattle are the biggest threats (see IBiS 2019). However, the restoration of the windbreaks is one key element to adapt to the effects of climate change. This restoration could be done in a way that the new trees and bushes are climate-resilient and even multifunctional, not only providing protection from the wind but also providing additional food security through the introduction of fruit species. This combination of protection and production can be a significant incentive to reactivate the windbreaks (see Smith et al. 2021). However, the reactivation and re-construction of the windbreak system is very costly. Since the income level in agriculture is low, the role of the government becomes crucial. Not only does the planting of windbreaks require financial resources, but there is also a need for further machinery and irrigation products to maintain the windbreaks. Field experiments showed that rehabilitation of windbreaks without additional watering in subsequent years (at least in the first two years) is not possible (see IBiS 2019).

Beginning in 2025, heavy wind is assumed to occur every 5 years, which destroys 5% of the annual crop yield. In addition, an annual loss in crop yields of 1.5% due to wind erosion is being assumed. The installation of windbreaks calls for seedlings and additional plastic tubes to protect the trees. These seedlings are planted by local workers, providing agricultural services. Irrigation systems are also installed. The benefits of windbreaks include an increased agricultural productivity and, thus, increased crop yields in years without heavy wind, and reduced damages in years with heavy wind.

Table 17: Cost-Benefit-Analysis of windbreaks; Input for the e3.ge model

	Investments or Benefits
Investment in windbreaks	• Plants: 6 million GEL p.a. • Plastics: 4 million GEL p.a. • Agricultural services: 5.2 million GEL p.a. • Machinery: 2 million GEL p.a.
Increased crop yields from windbreaks (p.a.)	• Maize: 18% • Wheat: 15% • Barley: 25% • Potato: 15% • Fodder crops: 20% • Vegetables: 15% • Others: 15% • Total (weighted by share in agriculture): 17.8%

Sources: Adapted from Geostat (2019); Moore (n.d.).

However, if the farmers have to buy windbreaks, they will pass their costs to the consumers by increasing the prices of agricultural products. If the government subsidizes the windbreaks, it may have to reduce its investments elsewhere.

As with the irrigation systems, the implementation of windbreaks also accounts for further second-round and induced effects, e.g., an increase in production in upstream and downstream sectors of agriculture as well as to price and income effects, which in turn have an effect on consumption expenditures.

Model results

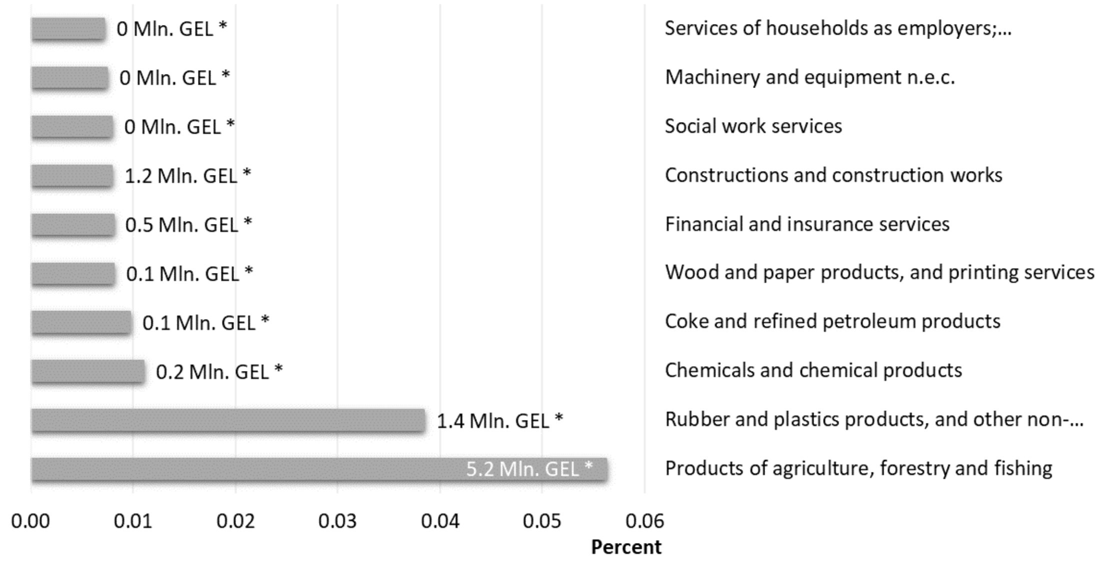
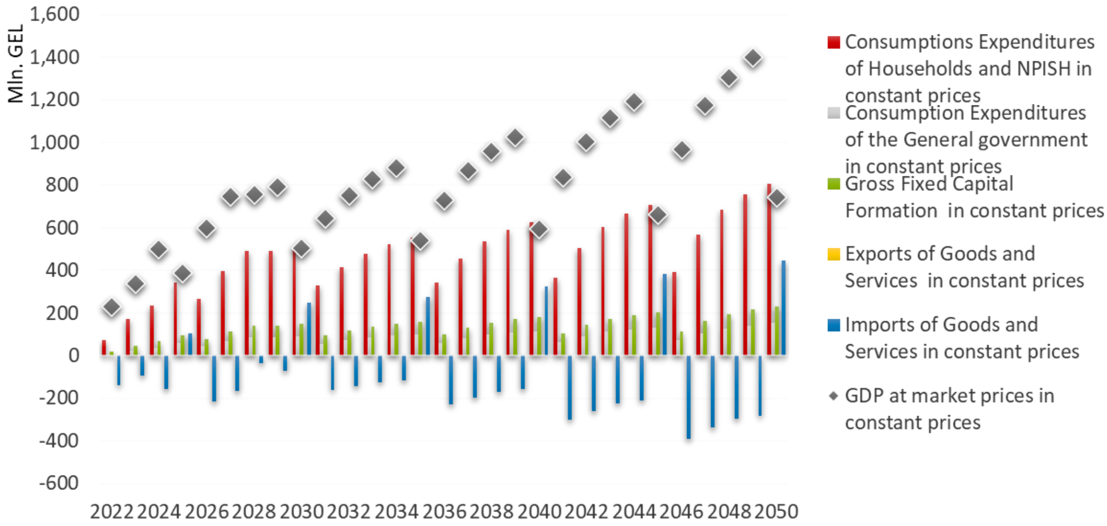


Figure 60: Effects of investment in additional plants and plastic for windbreaks: Top-10 relative deviations of Gross output (year 2040) compared to the "Wind" scenario in percent and Mln. GEL

Source: Own figure based on e3.ge results.

Compared to the scenario with the adaptation measure irrigation systems, the investment in windbreaks lead to different economic interactions. On the one hand, the agricultural sector experiences an increase in production due to increased yields, but on the other hand also because the plants required for the windbreaks (seedlings) are grown domestically. Furthermore, the additional agricultural services for planting the new trees have a positive impact on the agricultural sector. The plastic covers required for planting the windbreaks increase production in the rubber and plastic sector, which is also largely produced domestically (see Figure 60 for the example of the year 2040).

In comparison to the irrigation systems, the effects of windbreaks on the productivity in agriculture is slightly higher (15% increased crop yields from irrigation systems, 17.8% from windbreaks; see Table 16 and Table 17). Thus, this higher productivity has even a more positive impact on the economy.



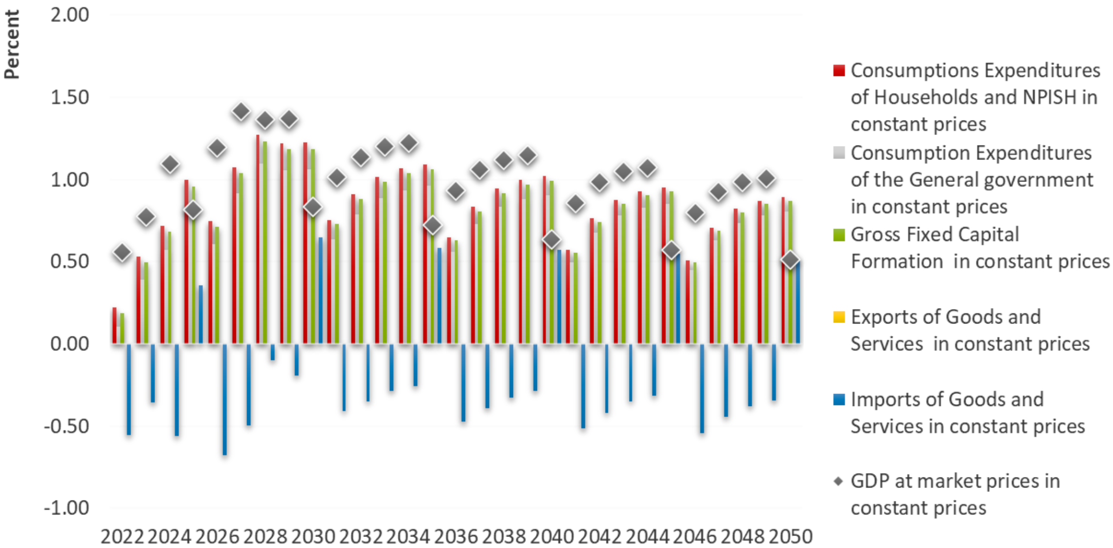


Figure 61: Macroeconomic effects of the “Windbreaks” scenario, selected years, deviations from a “Wind” scenario in Mln. GEL (top figure) and percent (bottom figure)

Source: Own figure based on e3.ge results.

In total, the GDP increases by up to 1.4% (GEL 1,400 million) in one year in the period under review (see Figure 61). The annual investment in planting the windbreaks has a positive but small effect on the GDP. While on the one hand the increased demand for seedlings calls for a higher production in the agricultural sector, also the additional agricultural services increase the production in the respective sector. The greatest economic effects are to be expected from the increased crop yields in agriculture due to the windbreaks. The overall effect on imports results on the one hand from additional imports due to higher consumption and investment and on the other hand from reduced imports of agricultural products. The consumption expenditures increase by up to 1.1% in one year in the period under review.

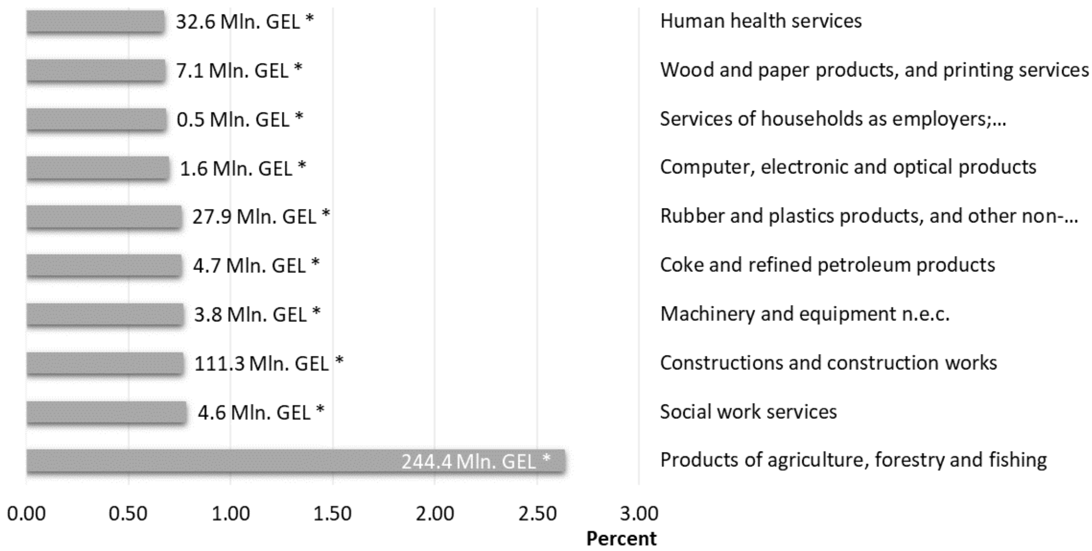


Figure 62: Effects of "Windbreaks" scenario: Top-10 relative deviations of Gross output (year 2040) from a "Wind" scenario in percent and Mln. GEL

Source: Own figure based on e3.ge results.

As with the irrigation systems, the production is increasing not only in the agricultural sector but also in those sectors delivering inputs for the agricultural sectors and those sectors using agricultural products as an input, resulting in higher employment rates and more people having higher wages (e.g., for consumption purposes).

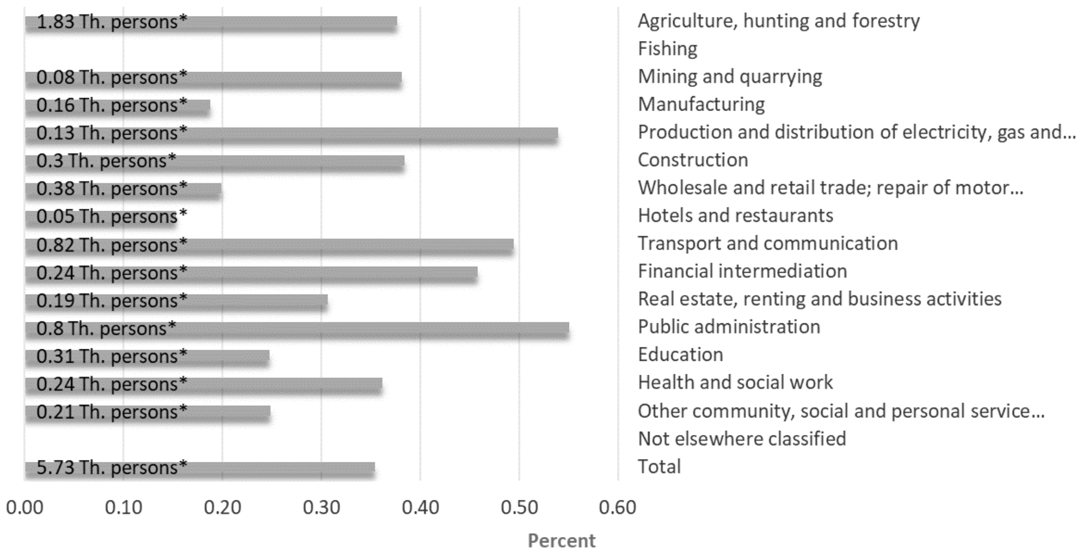


Figure 63: Employment effects of the "Windbreaks" scenario on sectoral level in the year 2040, deviations from a "Wind" scenario

Source: own figure based on e3.ge results.

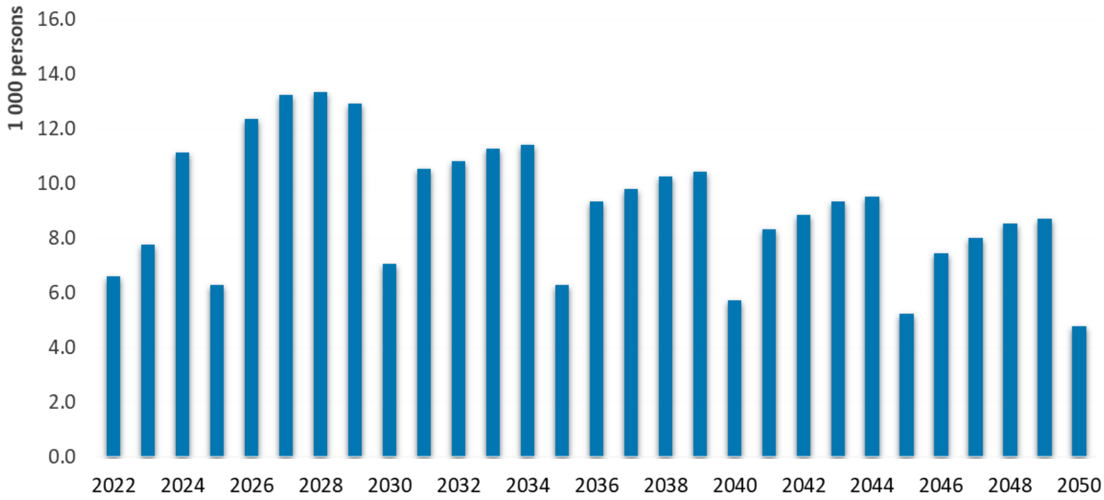


Figure 64: Effects of the "Windbreaks" scenario on Employment, 2022-2050, deviations from a "Wind" scenario in 1,000 persons

Source: own figure based on e3.ge results.

The employment is increasing by more than 12,000 people per year (see Figure 64). Figure 63 provides information on the changes in employment on a sectoral level for the year 2040.

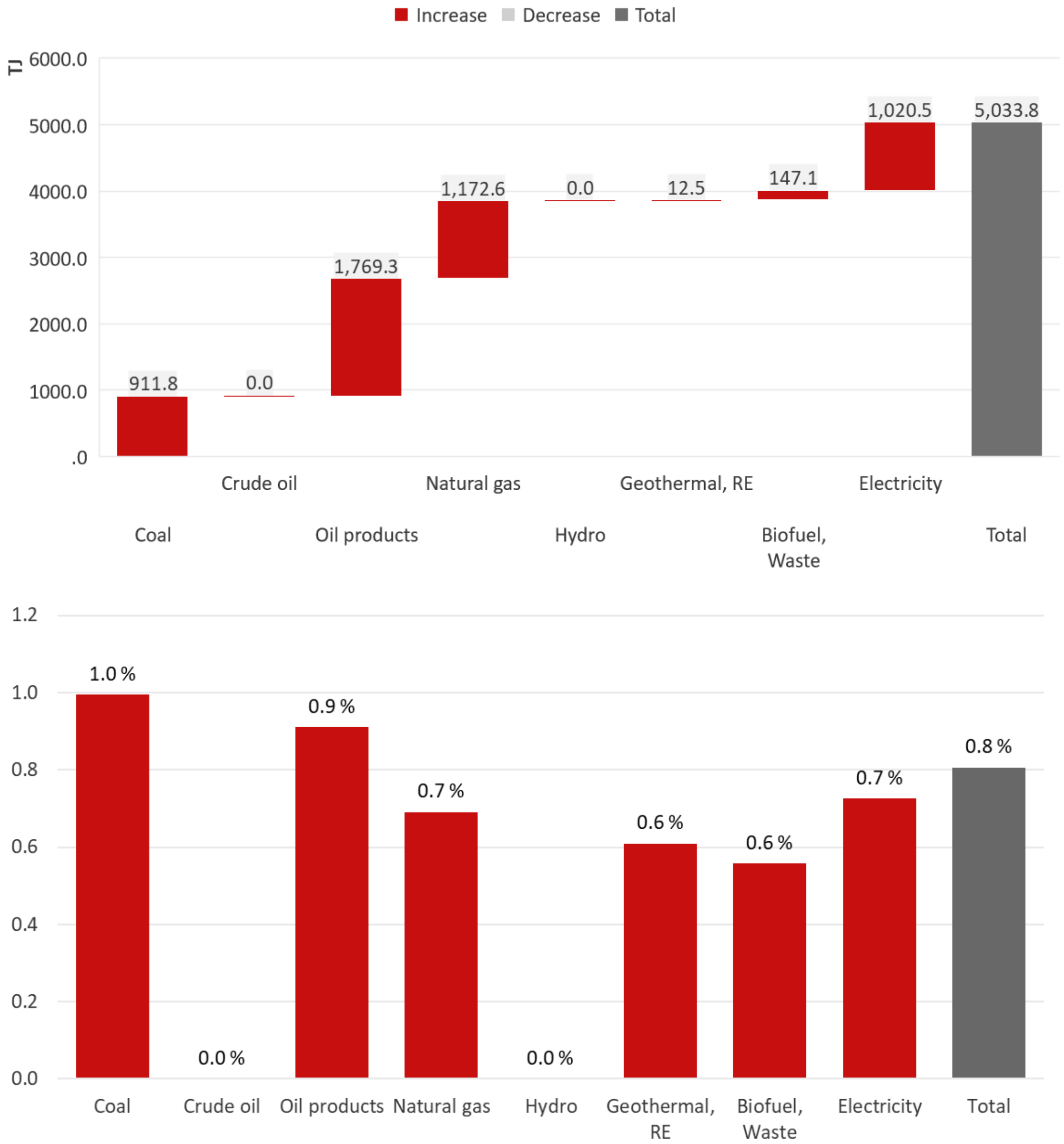


Figure 65: Effects of the "Windbreaks" scenario on final energy consumption, 2040, deviations from the "Wind" scenario in TJ (top figure) and percent (bottom figure)

Source: own figure based on e3.ge results.

Since the largest economic effect in the windbreaks scenario also stems from the increased productivity in agriculture like in the irrigation scenario, the final energy consumption increases in the same way. In total, the energy consumption in the year 2040 is higher by more than 5,000 TJ (+0,8%) (see Figure 65). This also causes an increase in energy related CO2 emissions by 0.8% (see Figure 66).

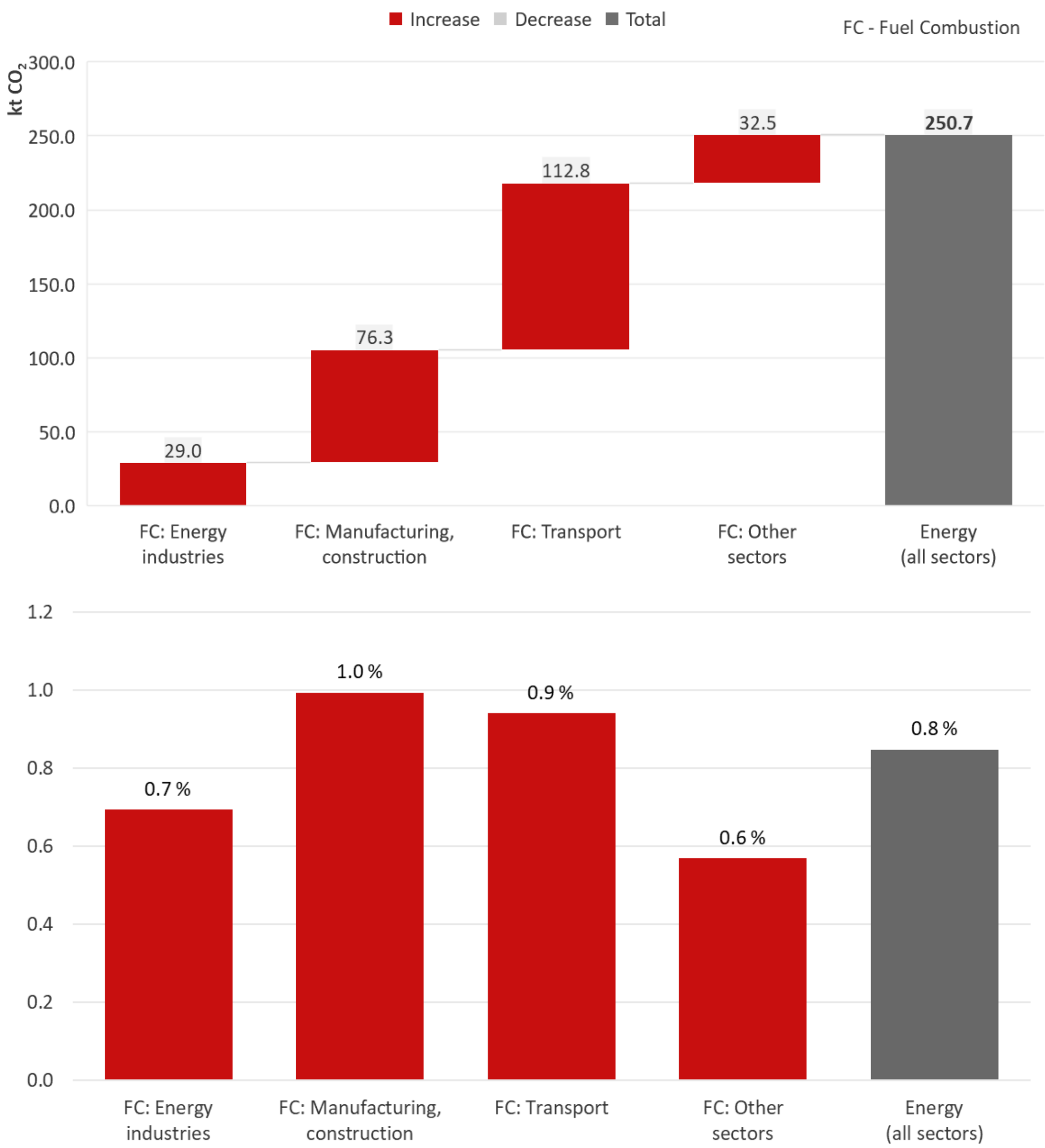


Figure 66: Effects of the “Windbreaks” scenario on CO_2 emissions, 2040, deviations from the “Wind” scenario in kt CO_2 (top figure) and percent (bottom figure)

Source: own figure based on e3.ge results.

6.2.1.5 Key messages

The consequences of climate change are already noticeable and will become more frequent and more severe. Since agriculture is one of the most important economic sectors in Georgia, and agriculture is one of the most vulnerable sectors to climate change, actions must be taken. Modelling results will help to understand which planned adaptation measures (or a combination thereof) are better suited in terms of economy-wide impacts. Thus, adaptation options which are supposed to be beneficial for the agriculture sector should be examined regarding their impacts for the whole economy before implementation. Policymakers should be aware of what could happen to manage adaptation strategies and to initiate a climate resilient economic development.

The results of the scenario analysis with the e3.ge model provide an economic evaluation of two adaptation measures. The two adaptation measures under consideration, irrigation systems and windbreaks, were already used in Soviet times to increase productivity in agriculture. With the experience from the past, the still existing remnants of the infrastructure as well as the application of new technologies, the crop yields and productivity in agriculture can be increased even with regard to the effects of climate change.

Both adaptation measures analyzed with the e3.ge model show that investments in adaptation provide co-benefits: not only can the damages in years with climate change effects in the agricultural sector be reduced, but also the crop yields in every year can be increased and the up- and downstream industries benefit. The domestic economy gets positive impacts resulting from an increased domestic production, which in turn calls for additional jobs. However, it is important where the products come from since imports reduce performance in the domestic GDP. Other adaptation measures like site-adapted selection of species, the cultivation of drought-resistant species, an improved soil coverage, the adaptation of crop rotations and a water-efficient soil cultivation add up to this and can further enhance these positive effects.

Combinations of adaptation measures such as the expansion of irrigated land, the use of water harvesting, and water-efficient infrastructure is very important if water is scarce. Adaptation measures providing small(er) benefits at low(er) costs are also important, in particular for small-scale farmers who do not have huge financial resources.

Financing of adaptation measures through international funds was not assumed. Given the promises of the industrialized countries to support climate protection measures such as adaptation measures with USD 100 billion per year in the future, the prospects for (partial) funding of the measures are good. In this case, the macroeconomic effects of the measures would be even better.

The direct comparison of the adaptation measures implemented in the e3.ge model requires the consideration of all scenario assumptions (e. g., underlying costs and benefits of adaptation, period of investment, Who takes the financial burden?). These assumptions should also be taken into account when interpreting the results. Thus, the macroeconomic results cannot be condensed to only one indicator to evaluate the usefulness of one or the other adaptation measure.

Comparing the two analyzed adaptation measures, the irrigation system initially requires higher investments (2021 to 2025: in total GEL 700 million). At the same time, the yield in the “Windbreaks” scenario is slightly higher (17.8% vs. 15%). However, the effects on yields still can be vice versa in years with an extreme event (heatwave vs. wind; see Figure 23 and Figure 39 for the year 2040). Even taking into account the sectoral development, different targets emerge. Should primarily agriculture be supported in the implementation process (e. g., by implementing windbreaks), or should the construction sector also benefit (e. g., by implementing irrigation systems)? Depending on that decision, different sectors will be stimulated regarding production and thus employment.

However, since the future is uncertain with respect to climate change and the economy, the results are subject to uncertainties themselves and should be considered as an information that can serve as a starting point for the development of an adaptation strategy.

6.2.2 TOURISM AND INFRASTRUCTURE

6.2.2.1 Current Situation of Georgian Tourism

Tourism is one of the priority sectors of the national economy and (at least before the pandemic) one of the fastest-growing industries in Georgia (see USAID 2016). During the past decade, Georgia's tourism growth has increased on average by more than 12.8% per year (see TBC 2019). Between 2009 and 2016, the tourism growth was one of the fastest globally (see The World Bank 2018). In 2018, the tourism revenues made up 36% of Georgia's total exports. Moreover, the international visitors contributed to the consumption in several economic sectors, namely accommodation (84% contribution in spending), food and beverages (20%), culture and entertainment (51%), and transportation (16%) (see TBC 2019 and TBC 2020). On the other hand, revenues from domestic tourism only accounted for 4.2% of Georgia's GDP. Shopping contributed the largest share of revenues (33.5%), followed by served food and drinks (23.0%), and domestic ground transportation services (17.6%) (see TBC 2019). However, Georgia's tourism still relies mainly on tourists from neighbouring regions and countries (see The World Bank 2018).

The number of international visits peaks in summer. The visitors to the coastal region of Georgia are attracted by seaside resorts, local cuisine, historic monuments, cultural diversity, and national parks (see The World Bank 2020b). Cultural heritage is one of the main resources for tourism and tourism revenues (see USAID 2016). Since Georgia is located in different climate zones, there is also the possibility for winter tourism, which is still developing, but already providing the comparative balance between summer and winter tourism (see TBC 2019). Georgia has the ambition to become a four-season touristic destination by offering the appropriate activities (e.g., hiking, climbing, cycling, wine tasting, skiing etc.) (see CZ-NAP 2020).

In 2010, the Georgian National Tourism Administration (GNTA) was established as a legal entity of public law under the Ministry of Economy and Sustainable Development. Besides others, its goals are to ensure the development of sustainable tourism, to improve visitors' experiences and to maximize their expenditures to significantly contribute to the national economy (see GNTA 2018). To increase the value and importance of the tourism sector in Georgia, a 10-year vision and strategic plan was implemented by GNTA: The Georgian Tourism Strategy 2025 sets benchmarks and strives to achieve important objectives (e.g., protection of Georgia's natural and cultural heritage, attraction of higher spending markets, expansion of public and private sector investment in the tourism sector). However, the tourism strategy does not list adaptation to the expected climate change explicitly as strategic priorities.

Prior to the COVID-19 pandemic, strong growth has been forecasted for the tourism sector, enabled also by the aforementioned tourism strategy. However, the severe travel restrictions during the global pandemic have made tourism in particular one of the most affected economic sectors worldwide. While first forecasts at the beginning of the pandemic still assumed a rapid recovery from the consequences of the pandemic, it is currently apparent that the pandemic will continue to dominate daily life in 2021 and probably beyond. Tourism is still restricted and only possible under the COVID-19 safety rules. Thus, the recovery process is still ongoing and the return to 2019 level is more than questionable. For the year 2020, TBC (2020) projected a drop in tourism inflows by 65%. Hotel revenues were projected to be down by even 85%. While domestic tourism restarted already in the last year, it is not associated with large revenues. Accordingly, the return of international tourism is needed and will depend heavily on how vaccination strategies develop worldwide and how the virus continues to mutate.

6.2.2.2 Options for Adaptation in Tourism and Infrastructure

The aim of adaptation to climate change in tourism is to maintain the tourist attractiveness of a destination even under future climate risks and conditions. Climate-resilient infrastructure is crucial to that. Several options exist to adapt tourism and infrastructure to climate change. While on the one hand, the improvement and building of climate resilient infrastructure account for structural building activities, also softer measures such as information campaigns and warning systems can also serve to adapt to the climate impacts in the tourism sector. Thus, adaptation measures can be grouped into two categories: 1) structural adaptation measures (e.g., changing the composition of road surfaces so that they are resilient to high temperatures, building seawalls etc.) and 2) management adaptation measures (e.g., early warning systems, insurances, monitoring of existing assets, changing maintenance patterns) (see OECD 2018).

Infrastructure relevant for tourism purposes needs to be adapted to climate change. Already existing infrastructural facilities like accommodation, utilities, roads, beaches etc. should be maintained and retrofitted by adaptation activities to make them climate resilient. New infrastructure assets should be planned, designed, built, and operated to account for the climate changes that may occur over their lifetimes (see OECD 2018). To do so, buildings and infrastructure need to be less exposed to the natural hazards and risks, e.g., by establishing new building standards, a beach and dune nourishment, and setbacks in the coastal development (see The World Bank 2020b). The structural stabilization of the shoreline is one major adaptation measure to adapt to the coastline erosion. This infrastructure for stabilization could on the one hand include traditional infrastructure, such as hard defences, and on the other hand also natural infrastructure, such as wetlands and other nature-based solutions (see OECD 2018). The construction and development of new infrastructural facilities should be located at places recommended by the coastal protection service. This could be supported by a destination development plan. New tourist areas should be based on sustainable development principles. Further adaptation measures increase the human safety, healthy ecosystems, diversified livelihoods and planning (see The World Bank 2020b). The establishment of a monitoring system to analyse future climate impacts as well as the establishment of a warning system that warns the population and tourists of future extreme weather events. Planning and capacity building that addresses specific local needs increases the ability to respond to the effects of extreme weather events (see The World Bank 2020b).

Adaptation could also lead to co-benefits regarding social and environmental aspects, e.g., by using green infrastructure. Ecosystem-based approaches (or “green”) can provide an effective complement or substitute for traditional built (or “grey”) infrastructure, providing on-the-ground climate adaptation and also providing environmental benefits (see OECD 2018 and The World Bank 2020b).

However, tourism flows are not a one-dimensional decision based only upon climate, but they depend on multiple factors such as political system and stability in the respective destination country and its neighbouring countries, infrastructure, possible activities etc. Accordingly, an analysis to determine the impacts of an adaptation measure to climate change is associated with high degrees of uncertainty.

6.2.2.3 (Re-)construction of coastline protection

Climate change will impact tourism flows and activities and needs to be considered when creating adaptation strategies and national action plans related to the tourism industry (see CZ-NAP 2020). Erosion of seacoast and sea-level rise are the most manifested impacts of climate change. Adaptation to these impacts is one of the most resource-intensive interventions. To retain the commercially important beaches and to protect the infrastructure located on the coastline, it needs to be stabilized (see CZ-NAP 2020), e.g., by (re-)construction measures. However, sea-level rise also has an impact on assets and infrastructure, which can only be evaluated if the hazards are analyzed spatially and temporally in detail. Furthermore, the possible loss of valuable ecosystems through coastline protection needs to be evaluated but goes beyond this analysis.

Model results

The investment in the construction of coastline protection measures leads to additional construction activities and a reduction in the decrease in tourism-related consumption expenditures both of domestic and foreign visitors. Since each construction measure to protect the coastline needs to be planned and carried out individually, the cost estimate cannot be generalized. Beginning in 2025, an annual investment of GEL 100 million is assumed, reducing the loss of tourism flows by additional 0.025% p.a. The individual economic effects of the respective assumptions are explained in more detail.

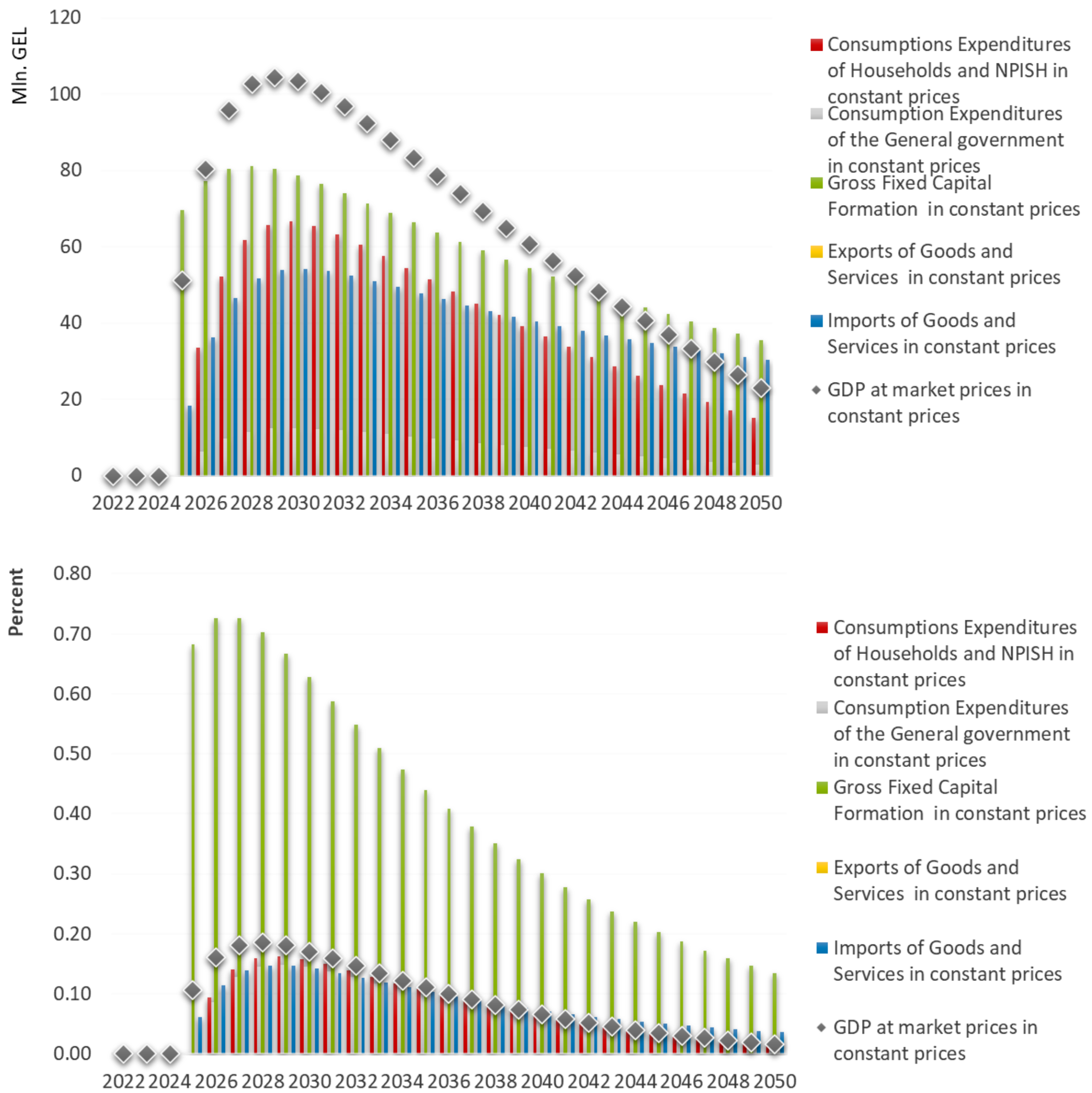


Figure 67: Macroeconomic effects of additional investment in the "Coastline protection" scenario, selected years, deviations from a "SLR" scenario in Mln. GEL (top figure) and percent (bottom figure)

Source: own figure based on e3.ge results.

Figure 67 illustrates the isolated economic effects generated by the annual investment of GEL 100 million in nominal values in construction activities. Gross fixed capital formation is increasing by up to 0.7%, which in turn has a positive impact on the GDP. Likewise, the positive impact on the GDP calls for additional investment and consumption expenditures, which in turn also have a positive impact on the GDP (in total up to 0.2%; GEL 100 million). However, due to an increasing price level, the overall effects are getting smaller in the distant future.

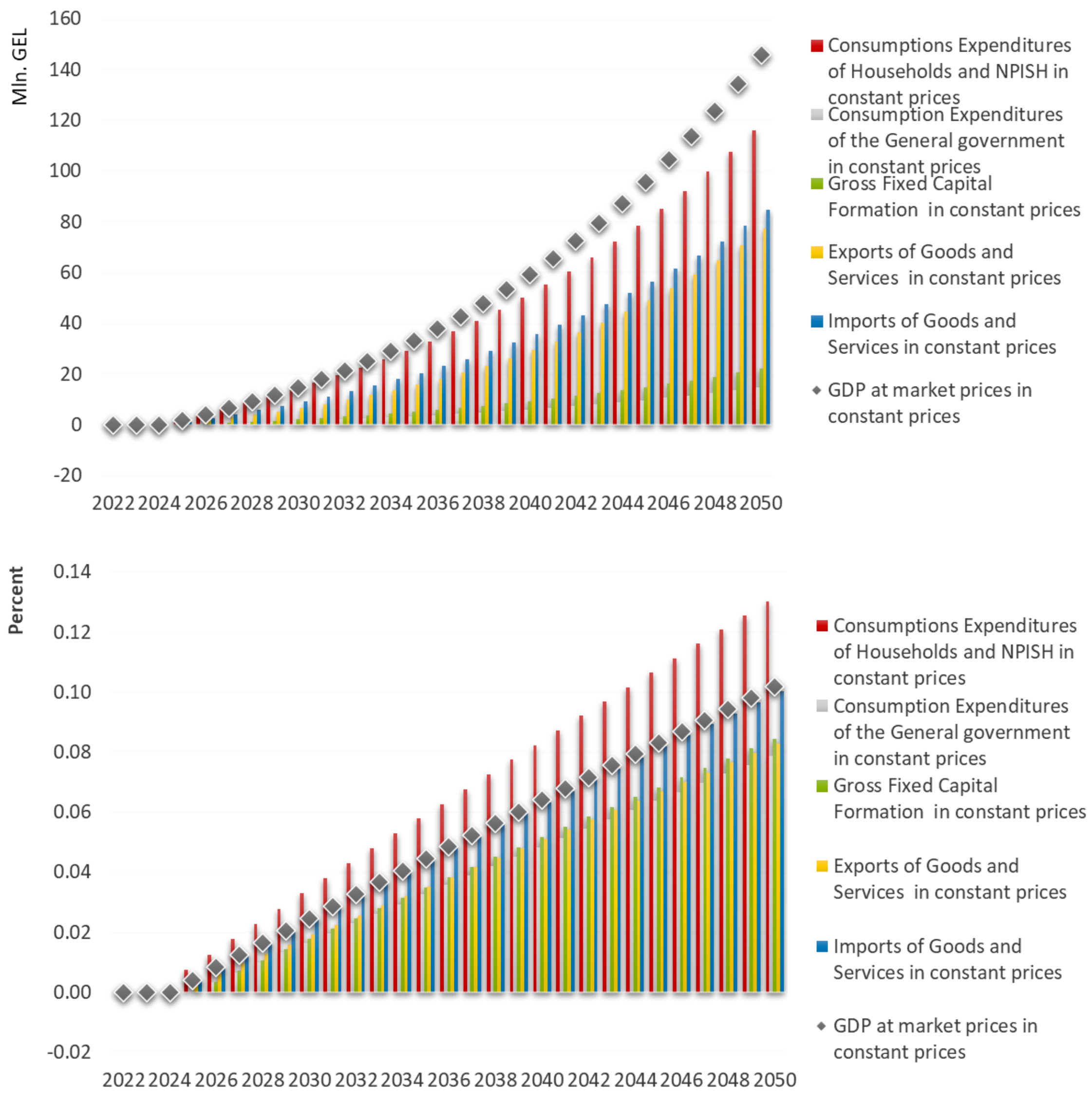
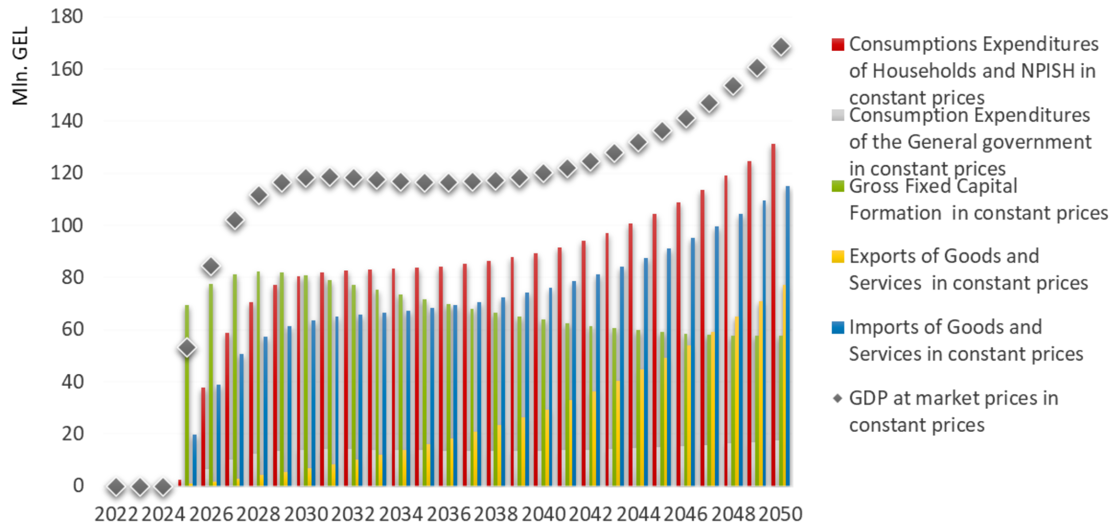


Figure 68: Macroeconomic effects of additional tourism expenditures (additional 0.025% p.a.) in the "Coastline protection" scenario, selected years, deviations from a "SLR" scenario in Mln. GEL (top figure) and percent (bottom figure)

Source: own figure based on e3.ge results.

Compared to the scenario with climate change and no adaptation measures, there are more tourists visiting Georgia in the scenario with the adaptation measure (re-)construction of coastline protection. Thus, the additional tourism expenditures have a positive impact on the economy, since exports and consumption expenditures of households are increasing (see Figure 68). Up to the year 2050, the GDP increases by more than 0.1% (GEL 150 million).



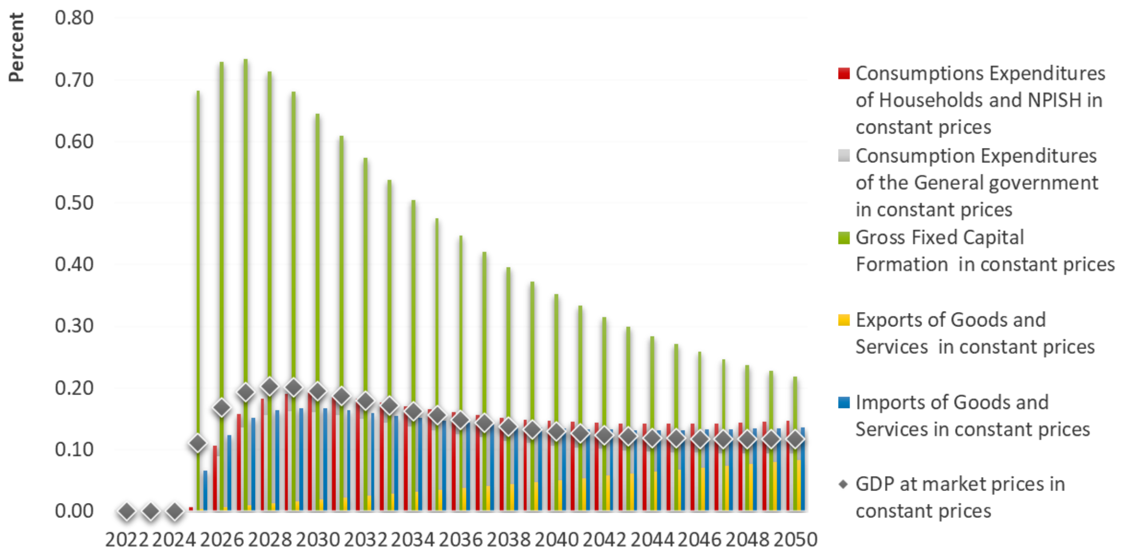


Figure 69: Macroeconomic effects of the "Coastline protection" scenario, selected years, deviations from a "SLR" scenario in Mln. GEL (top figure) and percent (bottom figure)

Source: own figure based on e3.ge results.

Figure 69 illustrates the overall economy-wide effects of implementing the adaptation measure (re-)construction of coastline protection. The macroeconomic effects result from the interplay of the two previously explained effects of additional investment and an increase in tourism expenditures. GDP increases by more than 0.1% (up to GEL 170 million) against the SLR scenario (see Figure 69). The annual investment in construction of coastline protection has a positive effect on GDP. The additional construction work also calls for additional intermediate goods necessary to build the coastline protection. Compared to the baseline scenario with climate change only, the consumption expenditures of tourists increase due to the adaptation measure, because more people are visiting the country. The positive effects in tourism and construction result in additional positive effects on consumption and investment, which in turn also have a positive impact on other economic sectors and thus on the GDP. In total, the consumption expenditures of households increase by up to 0.2% (GEL 120 million) in a single year and the exports of goods and services increase by up to 0.08% (GEL 80 million) (see Figure 69). Production is increasing not only in the construction and tourism related economic sectors but also in those sectors delivering inputs to these sectors, resulting also in higher employment and more people having higher wages (e.g., on disposal for additional consumption purposes). The construction sector is experiencing the greatest increase in production (e.g., 0.4% in the year 2040; GEL 60 million, see Figure 70), followed by tourism-related sectors.

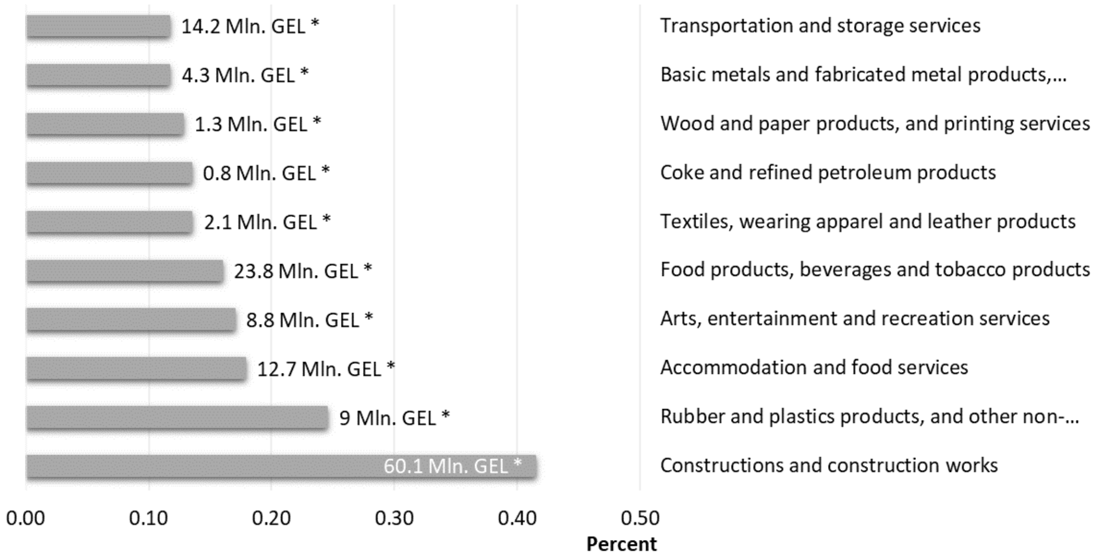


Figure 70: Effects of the "Coastline protection" scenario: Top-10 relative deviations of Gross output (year 2040) compared to the "SLR" scenario in percent and Mln. GEL

Source: own figure based on e3.ge results.

Up to 1,200 additional people can be employed when investing as assumed in the (re-)construction of coastline protection (see Figure 72). This corresponds to an annual increase of up to 0.08% (see Figure 69). Analogous to the effects mentioned above, this additional employment takes place in different economic sectors: construction, tourism related sectors and the supplying sectors. Since the model assumes an increasing productivity in the respective economic sectors, the additional employment decreases over time but remains clearly positive. Figure 71 illustrates the sectoral effects on employment exemplarily for the year 2040.

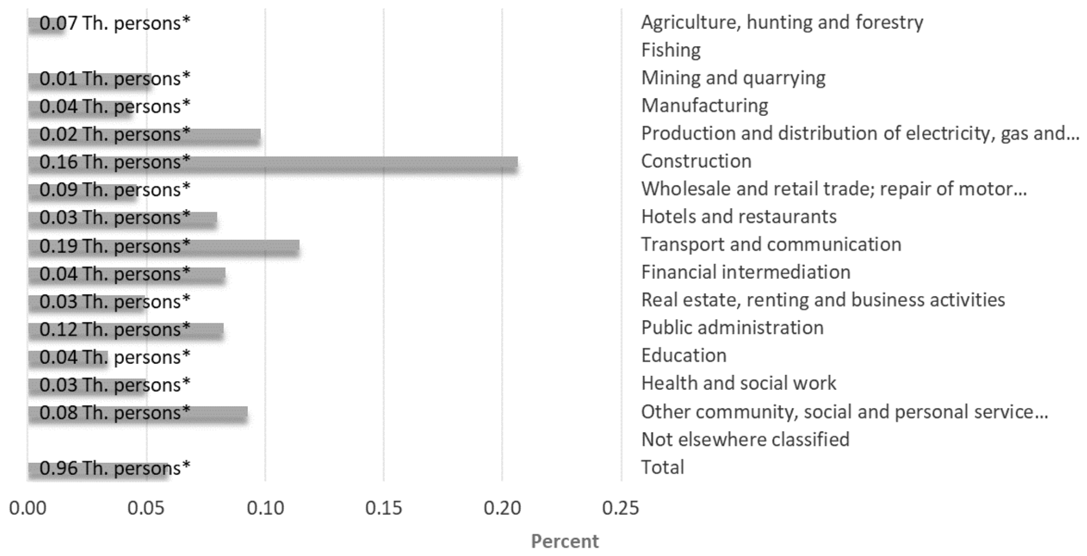


Figure 71: Employment effects of the “Coastline protection” scenario on sectoral level in the year 2040, deviations from a “SLR” scenario

Source: own figure based on e3.ge results.

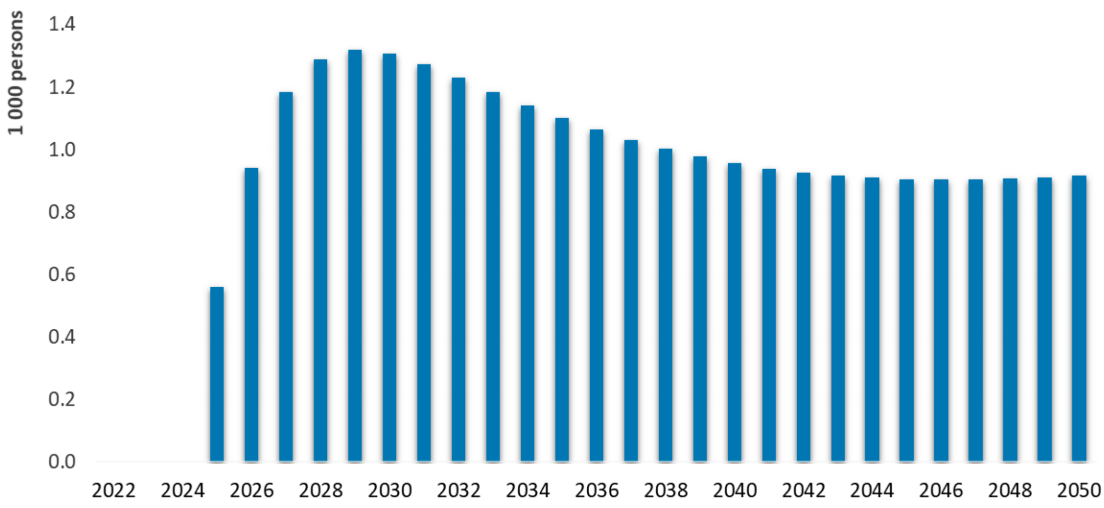


Figure 72: Effects of the “Coastline protection” scenario on Employment, 2022-2050, deviations from a “SLR” scenario in 1,000 persons

Source: own figure based on e3.ge results.

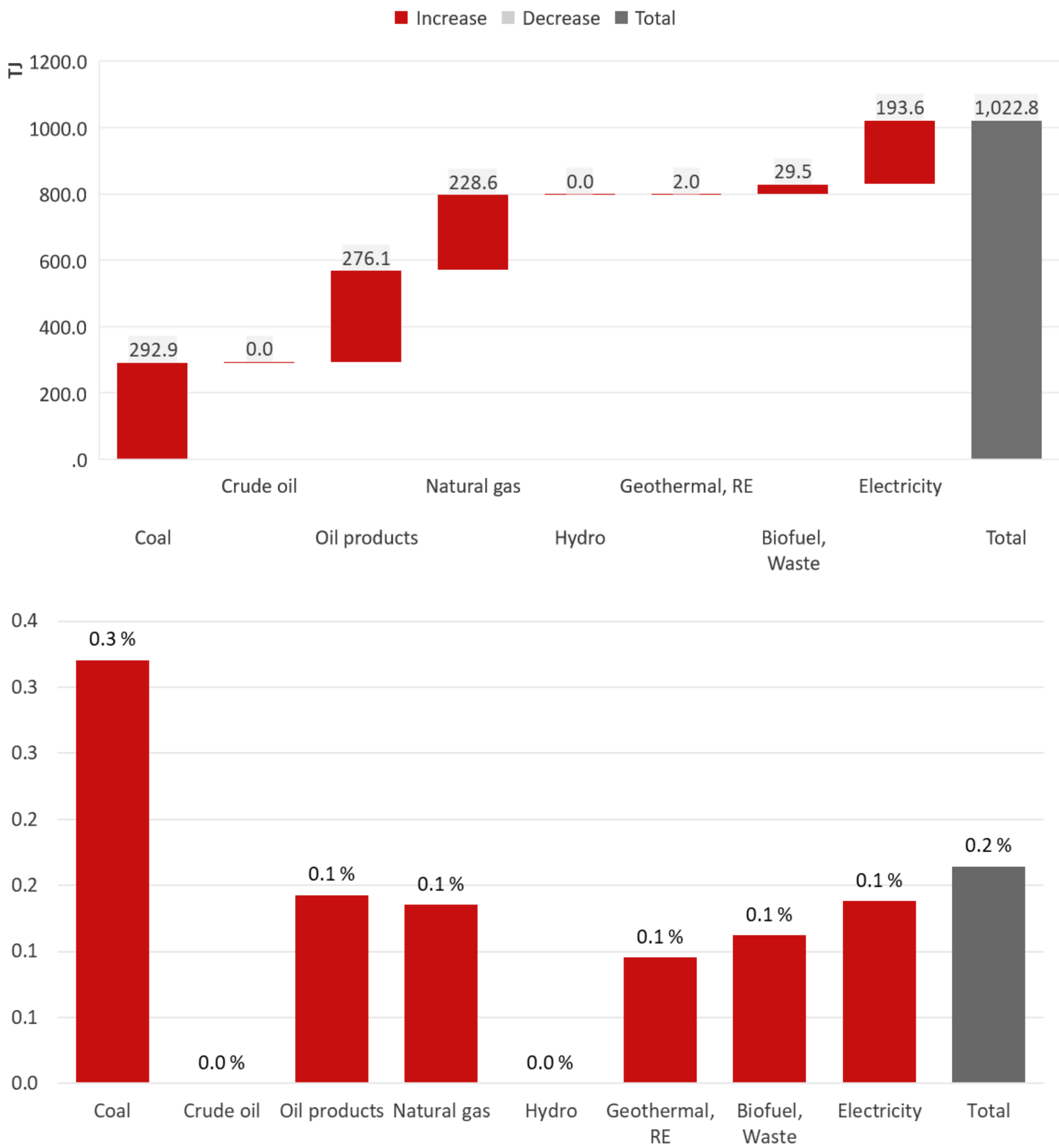


Figure 73: Effects of the "Coastline protection" scenario on final energy consumption, 2040, deviations from the "SLR" scenario in TJ (top figure) and percent (bottom figure)

Source: own figure based on e3.ge results.

The final energy consumption is higher by more than 1,000 TJ in the "Coastline Protection" scenario compared to a SLR scenario. This increase stems from the investment of GEL 100 million in the construction of coastline protection and the consumption expenditures of tourists. Compared to the adaptation measures in agriculture, this increase in energy consumption is rather low, but the economic effects are also much lower in this scenario (effect on GDP 0.2% compared to 1.5% in the windbreaks scenario). Thus, the lower economic activity also causes less increased energy consumption and correspondingly less higher CO_2 emissions. A comparison between the individual measures must therefore always also take into account the economic activity and must not relate solely to the emissions.

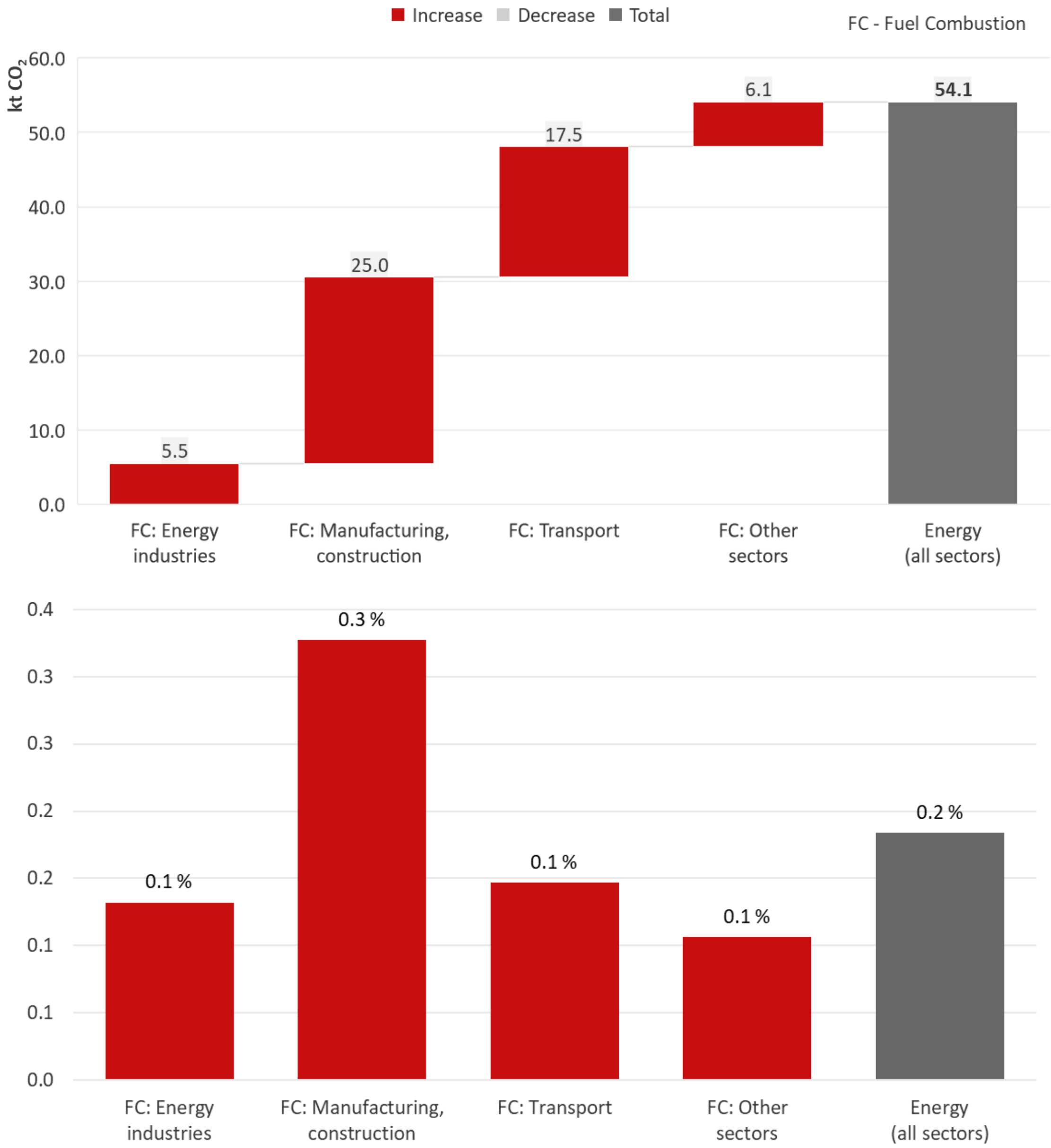


Figure 74: Effects of the "Coastline protection" scenario on CO_2 emissions, 2040, deviations from the "SLR" scenario in kt CO_2 (top figure) and percent (bottom figure)

Source: own figure based on e3.ge results.

6.2.2.4 Climate-resilient roads and bridges

Georgia's transport infrastructure is of low quality (see OECD 2021). According to OECD (2021), transport projects with an investment volume of more than USD 10 billion are currently being implemented to modernize the transport infrastructure: the investments consist primarily of roads (around USD 6.6 billion) and port projects (USD 2.5 billion), while investments in railways (USD 2.1 billion) and intermodal projects are comparatively smaller (USD 83 million). The Government of Georgia has made the maintenance of existing road systems a high priority on its agenda (see OECD 2021). Several risks related to climate change exist which also impact infrastructure: an increased intensity of rainfall could lead to flooding and consequently to erosion of road and railroad foundations, and higher temperatures and heatwaves could lead to a higher deterioration of roads (see CZ-NAP 2020). Thus, not only infrastructure is vulnerable to climate change, but also economic activities based on it are therefore vulnerable to the failure and disruption of this infrastructure. Accordingly, the economic effects can be manifold, ranging from interruption of production processes due to delay in the supply chain to decreasing flows of tourists. By reinforcing and updating road infrastructure, roads and bridges could be built more resilient to climate change impacts and, thus, the negative impacts of damaged infrastructure could be reduced. However, while sea level rise is relevant for infrastructure situated close the coastline, extreme weather events (e.g., heavy precipitation) can occur locally, thus infrastructure is affected to a different degree in each case.

In addition to tourism related impacts of climate change mentioned above, the effects of heavy precipitation are being implemented in the e3.ge model (see chapter 5.2.2). In addition to the reduction in tourism revenues, heavy precipitation causes negative GDP effects in the years with an extreme event. These additional negative impacts are caused by production losses due to heavy precipitation, which cause additional imports. The overall decreasing production has a negative impact on employment. In years with an extreme precipitation event, climate change could lower GDP by 1.4%.

To analyse the macroeconomic effects of the adaptation measure ***construction of climate resilient roads and bridges***, information on the costs and benefits of the respective measure is needed. GFDRR et al. (2015) provides information on the cost to not just rebuild the damaged assets, but to build them back better. These additional needs can be used as a benchmark for costs of the adaptation of roads and bridges for the evaluation of the macroeconomic effects. As an assumption, GEL 50 million p.a. will be invested in climate resilient roads and bridges, starting in 2025. To do so, the adaptation measure is financed by the government and public spending is reduced elsewhere.

Table 18: Road damage and reconstruction costs (millions of GEL)

Roads	Damage	BBB[9] needs	Reconstruction
Chabua Amirejibi H'way	17	5	= 22
Bagebi-Tskhneti Road	2	5	= 7
Tbilisi roads affected by floods	8	12	= 20
Tskhneti-Akhaldaba Road	4	11	= 15
Vere River's embankments	1	9	= 10
Total	33.2	42	= 75.2

Source: Adapted from GFDRR et al. (2015).

Again, there is a high degree of uncertainty associated with estimating the benefits of the respective adaptation measure. While climate-resilient roads may increase the tourism expenditures, they may also cause a reduced level of damages in years with an extreme event because they are able to better drain water. Thus, the benefits can only be estimated by assumption.

Model results

The macroeconomic effects of additional investment of GEL 50 million p.a. are positive. The effects are similar to those described in the Figure 67, but differ in amount, as less is invested in this scenario. However, the government spending are reduced elsewhere to finance the additional road works.

[9] Building Back Better (BBB) is a strategy aimed at reducing the risk to the people and communities in the wake of future disasters and shocks. The BBB approach integrates disaster risk reduction measures into the restoration of physical infrastructure, social systems and shelter, and the revitalization of livelihoods, economies and the environment.

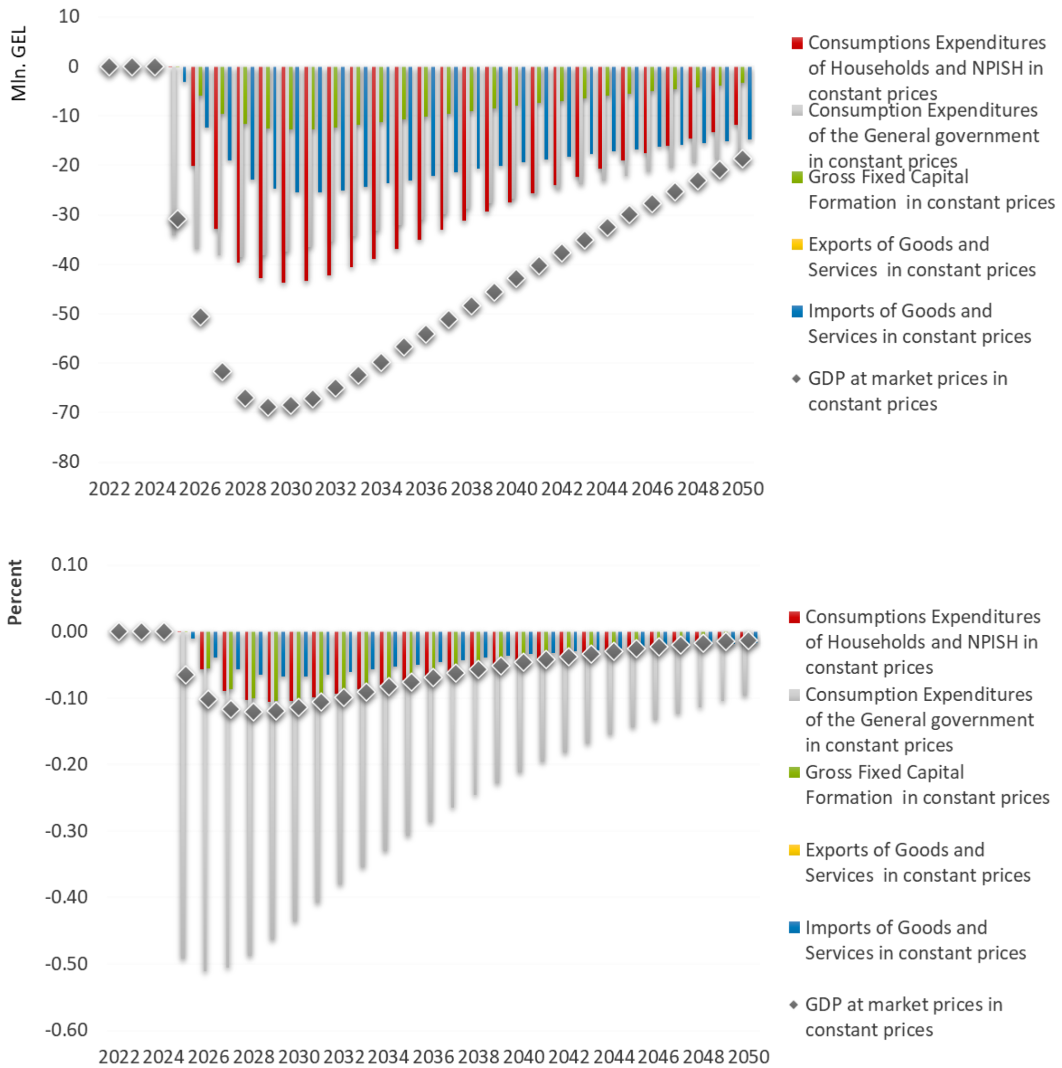


Figure 75: Macroeconomic effects of reduced consumption expenditures by the government (GEL 50 million p.a., nominal) in the "Roads and Bridges" scenario, selected years, deviations from a "CC" scenario in Mln. GEL (top figure) and percent (bottom figure)

Source: own figure based on e3.ge results.

Figure 75 illustrates the macroeconomic effects of reduced consumption expenditures of the government for public administration. The reduction in consumption expenditures has a negative impact on the GDP, which in turn has a negative impact on the other investments and consumption expenditures of households. The overall impact of the two aforementioned effects is slightly negative.

Since the climate resilient roads and bridges may also have a positive impact on the number of tourists in the country, tourism expenditures are increasing. In comparison to Figure 68, the effects are also positive but smaller, since additional 0.01% p.a. of tourism expenditures are being assumed.

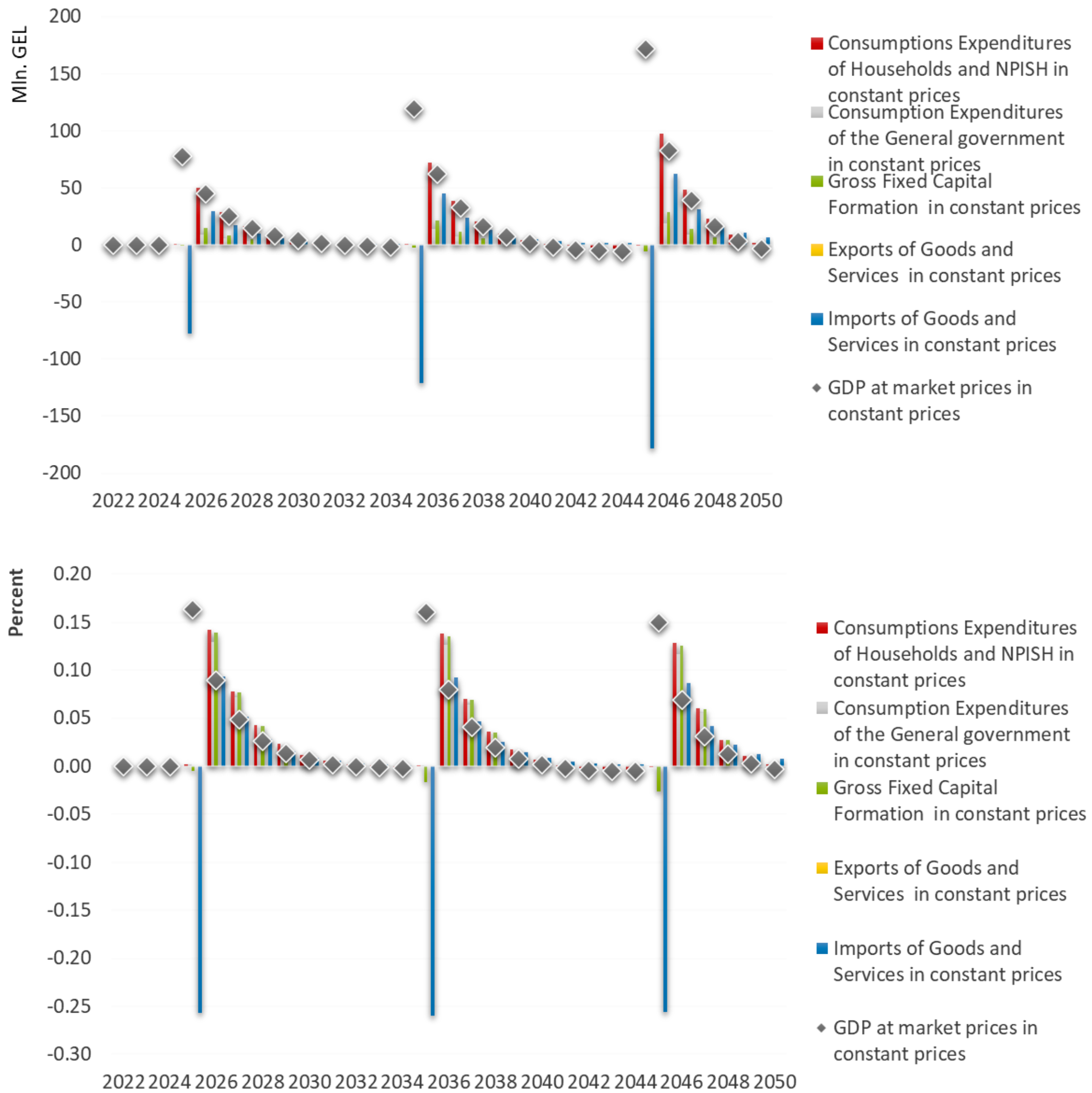
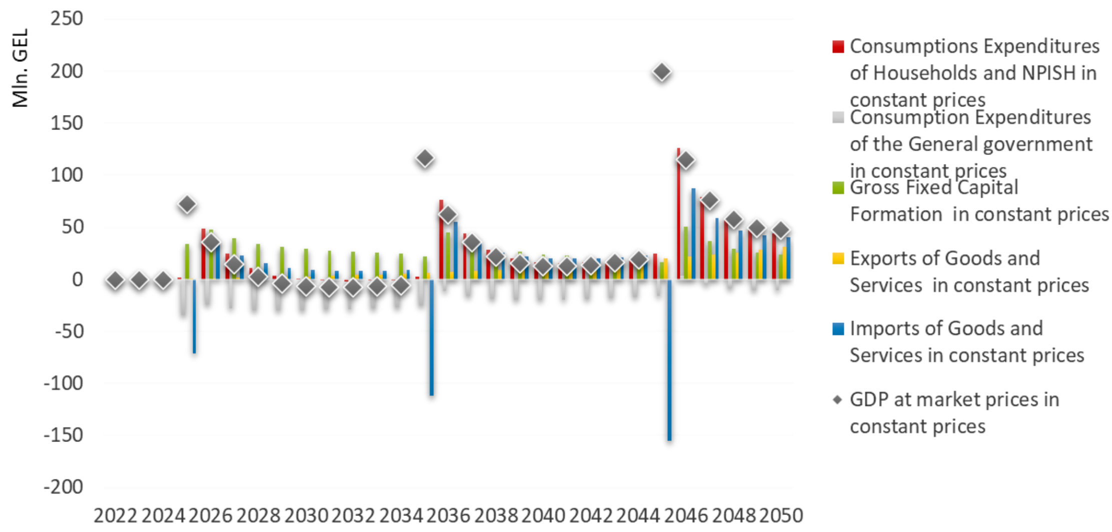


Figure 76: Macroeconomic effects of the reduction of damages from precipitation in the "Roads and Bridges" scenario, selected years, deviations from a "CC" scenario in Mln. GEL (top figure) and percent (bottom figure)

Source: own figure based on e3.ge results.

The climate resilient roads and bridges ensure that there is less damage in years with an extreme weather event (heavy precipitation). In particular, production losses in industry are lower, thus fewer imports are needed (see years 2025, 2035 and 2045 in Figure 76). Increased production provides a positive impact on the GDP. As extreme weather events occur as shocks in the model, the effects slowly run out. Another possible assumption could be that climate-resilient roads lead to additional transport options and, thus, to a positive stimulus for the economy even in the years without an extreme weather event. However, an estimation of this effect is subject to high uncertainty, so this is not considered in the modeling.



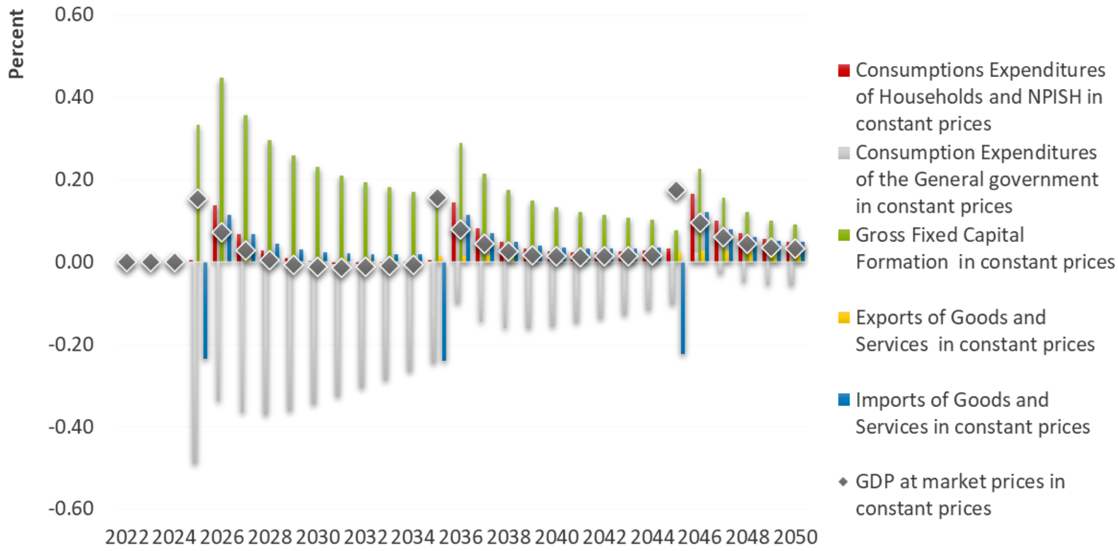


Figure 77: Macroeconomic effects of the "Roads and Bridges" scenario, selected years, deviations from a "CC" scenario in Mln. GEL (top figure) and percent (bottom figure)

Source: own figure based on e3.ge results.

Overall, the GDP increases by up to 0.17% (GEL 200 million) in a single year in the period under review (see Figure 77). The annual investment in construction of roads and bridges has a positive effect on the GDP. Depending on the assumption, other government consumption expenditures may be redirected to finance the additional construction investments. In the years 2025, 2035 and 2045, the higher production activity and reduced damages to transport infrastructure both cause a positive GDP effect compared to the scenario without adaptation. Thus, the imports of goods and services are reduced by more than 0.2% in the respective years (see Figure 77). The positive impact on the GDP causes a reaction in consumption and investment, which is also positive. Due to the modern road infrastructure, more tourists visit the country. Thus, compared to the scenario with no adaptation, a positive GDP effect is being generated from the higher level of consumption expenditures of tourists and higher exports. Once again, this positive GDP effect causes additional consumption and investment in the following years. Assuming that government consumption expenditure is reduced to finance the additional investment in construction, the overall effect on the GDP and employment is negative at the beginning of the period under review. In the more distant future, more and more roads and bridges will be designed to be climate resilient, so that the positive impacts on GDP and employment will increase over time. Up to 1,000 additional people can be employed. However, the decrease in demand for public administration is causing employment in this sector to fall, while it is rising in the other sectors (see Figure 78).

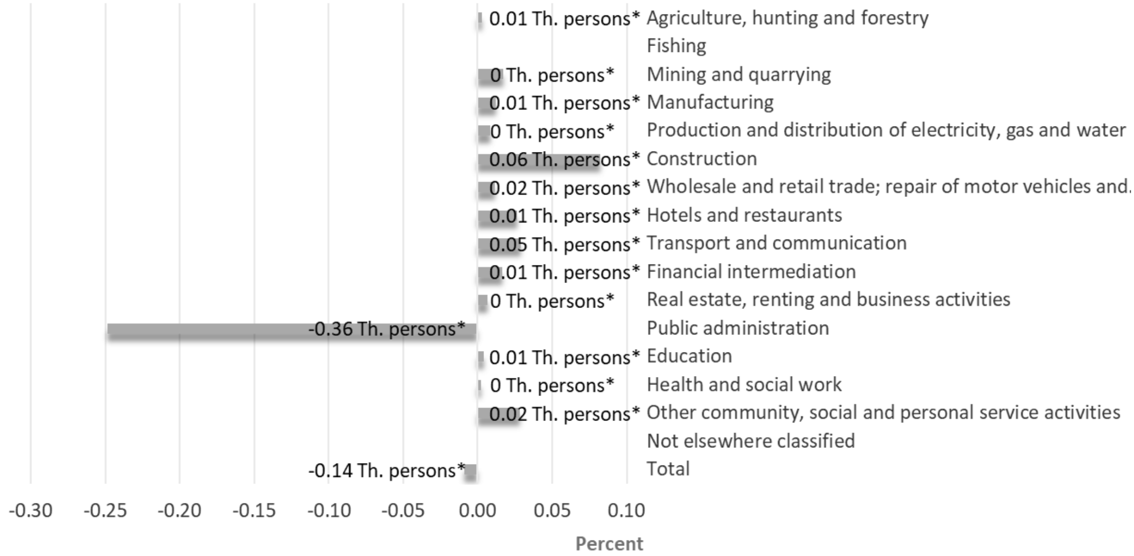


Figure 78: Employment effects of the "Roads and Bridges" scenario on sectoral level in the year 2040, deviations from a "CC" scenario

Source: own figure based on e3.ge results.

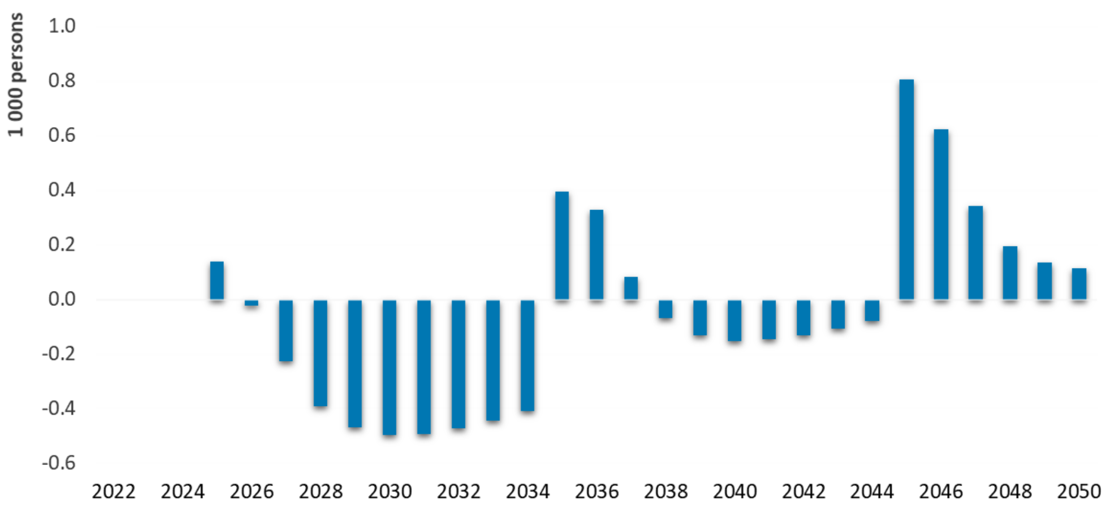


Figure 79: Effects of the "Roads and Bridges" scenario on Employment, 2022-2050, deviations from a "CC" scenario in 1,000 persons

Source: own figure based on e3.ge results.

With the additional construction activities and an increasing number of tourists over time visiting the country, the additional employment in the tourism-related sectors outweighs the losses of employment in public administration. Thus, the overall effect on employment stays positive in the distant future (see Figure 79).

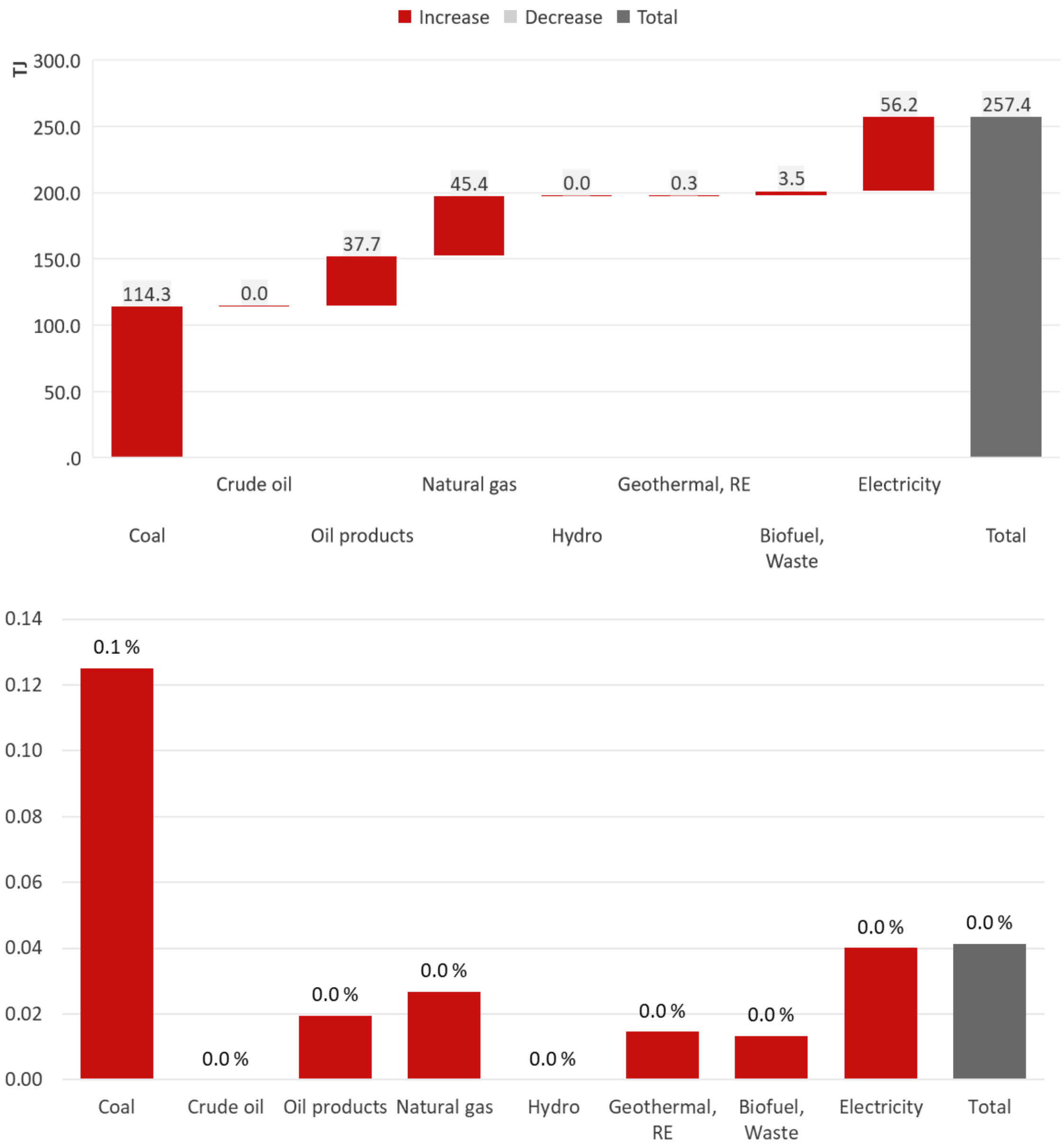


Figure 80: Effects of the "Roads and Bridges" scenario on final energy consumption, 2040, deviations from the "CC" scenario in TJ (top figure) and percent (bottom figure)

Source: own figure based on e3.ge results.

The effects on final energy consumption are small, increased by 250 TJ in 2040. Since the additional economic activity is smaller in the other years (see Figure 77), the effects on final energy consumption are also smaller in the respective years. The impact on CO_2 emissions follows the use of fossil fuels in the respective sectors as shown in Figure 81.

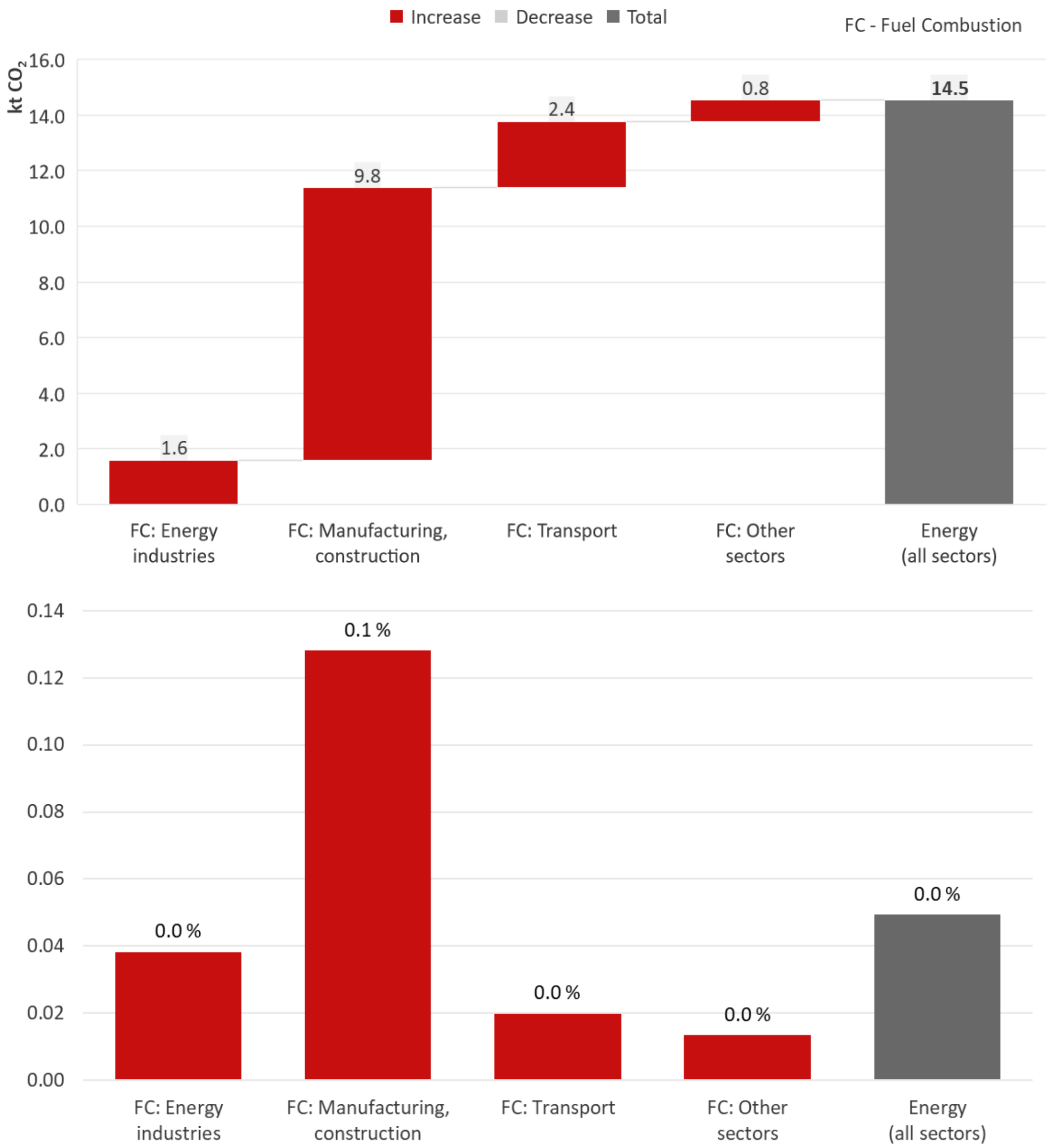


Figure 81: Effects of the "Roads and Bridges" scenario on CO_2 emissions, 2040, deviations from the "CC" scenario in kt CO_2 (top figure) and percent (bottom figure)

Source: own figure based on e3.ge results.

6.2.2.5 Key messages

The consequences of climate change in Georgia are already noticeable and will become more frequent and more severe. Both, tourism and infrastructure, are vulnerable to climate change. Since tourism is one of the priority sectors of the national economy and one of the fastest-growing industries in Georgia, more needs to be done to adapt to climate change. Several options exist for adapting to climate change that are relevant for both infrastructure and tourism. The adaptation measures can reduce the costs and risks induced by climate change and provide benefits not only to the tourism sector but to the whole economy.

Coastline protection and the construction of climate resilient roads and bridges are two possible adaptation measures that may have an impact on tourism flows and may reduce the expected damages from heavy precipitation

Both adaptation measures analyzed with the e3.ge model show that investments in adaptation provide co-benefits: not only can the damages in years with climate change effects be reduced, but also the flow of tourists in every year could be increased and several industries benefit compared to a scenario with no adaptation. The domestic economy gets positive impacts resulting from an increased domestic production, which in turn calls for additional jobs. Other adaptation measures may add up to this and can further enhance these positive effects.

The results raise the awareness and illustrate how the economy in Georgia is developing under the effects of climate change and what the economic benefits of adaptation to climate change are. As with adaptation to agriculture, the prospects for (partial) funding of the measures are good. In this case, the macroeconomic effects of the measures would be even better.

7 INTEGRATING THE MODEL RESULTS IN THE POLICY PROCESS

7.1 ENTRY POINTS FOR MACROECONOMIC MODELLING RESULTS IN POLICY PROCESSES

There are various efforts in Georgia to include the issue of climate change and also adaptation to climate change on the current political agenda as well as in sectoral policy strategies and plans. The strategies and plans mentioned above (Georgian Agriculture Development Strategy (2015-2020) (see MoA 2015), National Adaptation Plan of Georgia's agriculture sector to Climate Change (AgriNAP), Irrigation strategy in Georgia, The Georgian Tourism Strategy 2025) serve as examples. These strategies directly address climate change impacts, the reduction of risks of hazards and sector development risks to reduce negative impacts on the economic and social welfare.

Georgia recently updated its Nationally Determined Contributions (NDCs) and expanded the pledge to reduce its total greenhouse gas (GHG) emissions. The assessment of specific impacts of climate change on coastal zones, mountain ecosystems, forests and water resources are on the future agenda as well as the introduction of relevant adaptation measures. Furthermore, the assessment of the economic, social and health impacts of climate change and the introduction of relevant adaptation measures are mentioned as key components of Georgia's new climate pledge.[10]

Deriving suitable adaptation strategies is a multi-discipline, multi-level endeavor which requires a systemic approach (see Figure 50). Possible adaptation options need to be aligned to current and future economic developments. The CRED approach supports macroeconomic modelling to assess and plan climate-resilient economic development. Adaptation options that have been identified for a respective economic sector are examined with respect to their impacts on the whole economy and environment before implementation to detect possible synergies but also adverse side-effects. Thus, modelling results will help to understand which planned sector-specific adaptation measures (or a combination thereof) are better suited in terms of e. g. GDP, sector-specific production and employment as well as CO_2 emissions.

The following Figure 82 (and also Figure 50) shows how macroeconomic modelling can enter the policy process. The key role of the e3.ge model application is the macroeconomic and sectoral assessment of climate change and adaptation options. These quantifications inform the selection of measures for adaptation and sectoral planning. It supports thus mainstreaming and finally implementation of adaptation into development strategies and financial decisions. More general, the approach provides a framework for monitoring and evaluating adaptation measures.

Basically, the policy processes can be divided into three parts:

(1) The phase of preparation is about formulating the key policy questions. These can relate to climatic impacts as well as to possibilities for adaptation. The consultation of key experts and policy makers is important to obtain high-level political support for the intended economic evaluation of adaptation options.

(2) In the phase of modelling and evaluation, the e3.ge model can be used for scenario analysis of possible adaptation options. In a first step, the economy-wide effects of the identified climate risks and hazards can be evaluated. Finally, different scenarios for adaptation can be calculated and

[10] https://www.ge.undp.org/content/georgia/en/home/presscenter/pressreleases/2021/georgia-ndcs.html

compared. Various indicators are calculated, which can then be used to evaluate the adaptation options. If a model is not yet available, it must first be developed.

(3) In the phase of implementation, the model results create the basis for the selection of adaptation measures in the NAP process or in sectoral planning. The information can be used to underpin budgeting decisions and to explore possible funding options. Furthermore, a process of and framework of monitoring and evaluation needs to be initiated.

The modeling process in step 4 should not be regarded as a completely isolated step in this process. In fact, the preparation of the modelling activities also contributes to the steps 1 to 3 as it can provide useful information to the overall preparation of the process. Furthermore, the results of the modelling process are key for the phase of implementation in the steps 5 to 7. Thus, there are several interlinkages between the modeling activities and the other steps throughout the whole process.

Although the financial and economic impacts are relevant for policymakers to prioritize adaptation measures, other criteria must be considered as well such as health aspects and ecosystem services (biodiversity, regulation of the water balance) to get a more comprehensive evaluation of a measure, and to formulate an appropriate adaptation strategy. The economic effects should only be one possible basis for decisions on the selection of adaptation measures in Georgia.

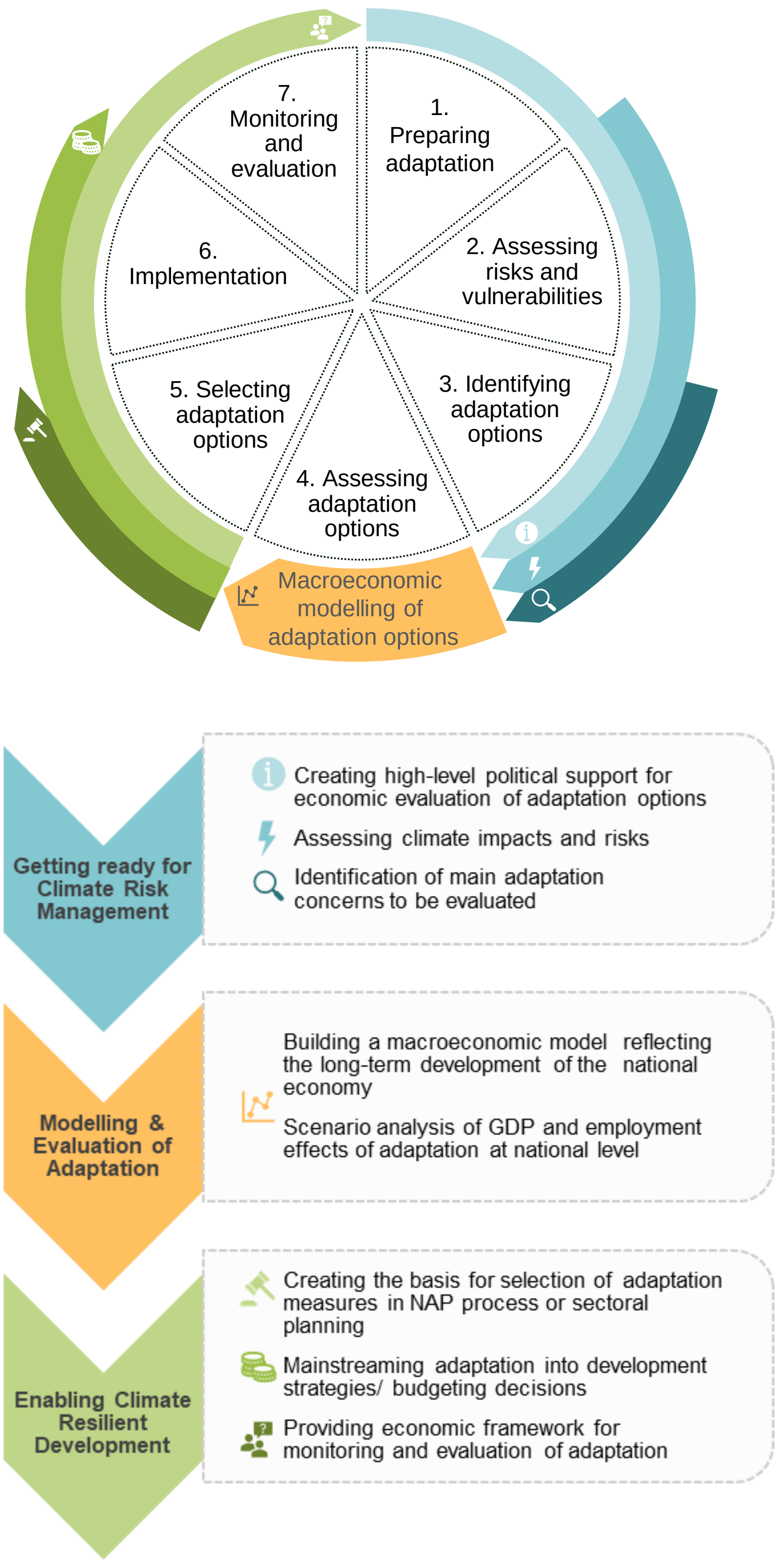


Figure 82: Integration of macroeconomic modelling in policy processes

Source: Figure based on Climate-ADAPT (n.d.).

7.2 THE BENEFITS OF MODEL APPLICATION

Climate change causes risks and adaptation pressures that need to be systematically considered in development strategies and, as far as possible, compensated by adaptation in order to ensure sustainable development in the long term.

Raising the awareness and strengthening the knowledge base for climate change impacts

The use of the e3.ge model contributes first of all to strengthening the knowledge base for climate change impacts and adaptation options in Georgia itself. Scientific knowledge is condensed in the form of key outcomes of climate scenarios and physical effects in different sectors of the national economy. Impacts on individual economic sectors such as agriculture and tourism are determined on this basis in sector models, which show specific details on the sector structure, its spatial resolution, damage potentials and possibilities for action for adaptation. Information on the effects at the micro level and in the respective spatial context is very important. Cost-benefit analyses of individual actions and measures at the market level form the central basis for understanding and quantifying the direct effects on various actors. The financing requirement is a key factor in this context. Corresponding models and studies inform the macroeconomic modeling in e3.ge. The effects in the sectors are to be quantified on the one hand in their monetary magnitude and on the other hand in their effect on the structure of the goods used and the sectors involved. Putting climate change and adaptation on the political agenda by the use of the macroeconomic modeling automatically raises the awareness to this topic. The results of the modeling provide a quantification of the effects.

Quantification of economy-wide impacts of climate change and adaptation

The use of the model e3.ge allows for the quantification of economy-wide and environmental impacts of climate change as well as of sector-specific adaptation options based on the information mentioned previously. Both individual adaptation measures and combinations of adaptation measures can be calculated.

Reduction of uncertainty about the effects of climate change on the economy

The use of the model e3.ge in combination with scenario analysis helps to deal with the inherent uncertainty of climate change and the future in general. In scenarios, different assumptions on the frequency, intensity and occurrence of climate hazards can be examined. Various adaptation options can be analyzed with respect to their impacts on the 3E's.

Highlighting the sectoral interlinkages in the economy

On this basis, the model e3.ge maps not only the direct effects but also indirect and induced effects of climate change and adaptation measures in the consistent framework of national accounts and input-output tables. Thus, by applying the model, it is possible to illustrate the sectoral interlinkages in the economy and, in particular, to show how the effects of climate change on just one sector (e.g. agriculture) are transmitted in the entire economic structure via intermediate inputs. This also contributes the point of raising awareness. Thus, the use of the e3.ge model allows "smarter adaptation: improving knowledge and managing uncertainty", as described by the World Bank (2020a).

Increased effectiveness of adaptation strategies by choosing the right adaptation measures

By comparing different scenarios and analyzing relevant model indicators, adaptation options that are highly effective and have positive effects on the economy, employment and environment can be identified (win-win options).

Possibilities of extension and other scenarios

Which additional questions can be answered with the model? The answer to this question can be based on the one hand on the knowledge about climate change and on the other hand on the possibilities for adaptation. In particular, extreme weather events such as heatwaves, drought, floods and landslides affect Georgia (WBG and ADB 2021). In addition, there are also more gradual changes due to an increase in hot days with temperatures above 30 degrees, when labor productivity drops significantly, especially in outdoor work such as agriculture and construction (ILO 2019). ADB provides detailed information about an increase in future heat stress especially in Tbilisi. Corresponding simulations could be well performed with the model e3.ge. In this context, the ADB also points out that the power consumption could increase in the order of 0.5 - 0.8% per year as a result of the temperature changes due to higher cooling requirements. In return, the heating energy demand in winter is likely to decrease. Changes in precipitation amounts and frequencies are also likely to be important for Georgia's energy supply. Due to the high share of hydropower in electricity generation, prolonged droughts are likely to lead to reduced electricity generation. Electricity demand would then have to be increasingly covered by imports, which would have a negative impact on the macroeconomy. An alternative, which would ultimately also be an adaptation to climate change, would be the expansion of other renewable energies such as PV and wind, which have a much greater labor requirement than large-scale power plants anyway. According to experiences in other countries, a corresponding scenario with increased expansion of renewable energies should lead to positive employment effects in Georgia.

In the impact assessment for the new EU adaptation strategy (EU COM 2021) deepening of existing actions of the adaptation strategy from 2013 and novel actions have been checked for modelling opportunities. “Mainstreaming nature-based adaptation, including coastal protection and green infrastructure” could increase construction activities and reduce related damages. The same can be expected from “Climate proofing of infrastructure and beyond”. “The establishment of an EU observatory for climate change and health” has been supposed to reduce spending of the health system and increase labor productivity. These examples show that it is in principle possible to quantify adaptation measures. At the EU level, the problem is that the effects depend very much on regional and country-specific conditions, so that the modeling for the EU as a whole must remain somewhat abstract and exemplary.

Possibilities of cooperation with other projects

For Georgia, the use of results of detailed studies (such as Sparkassenstiftung, World Bank) offers the possibility to model more specifically concrete adaptation measures.

Making financing options visible

An important advantage of using models is the quantification of the economic impacts of adaptation measures as well as the financial resources needed to implement adaptation measures. Thus, model use contributes to making financing opportunities visible to international partner organizations and investors. In view of the diverse activities of, for example, the World Bank, the Asian Development Bank, Sparkassenstiftung, GIZ and other organizations, close cooperation and the linking of the information generated is a key aspect.

7.3 INSTITUTIONALIZATION AND OUTLOOK

The e3.ge model combines macroeconomic variables with sectoral structural information. It is linked to energy consumption information of the energy balance and related CO_2 emissions. And last but not least, it can be used to map the effects of climate change and adaptation measures.

Thus, the model offers a variety of starting points for modeling corresponding structural changes. How do changes in the economic structure, the energy mix, changes in world trade and technological change affect the climate? What opportunities do policy measures offer in this context? And how can policy processes such as the planning of Nationally Determined Contributions (NDCs) or the establishment of a National Adaptation Plan (NAP) be designed to best support other development lines?

With regard to the requirements for mapping climate change and in particular adaptation to climate change, the EU Adaptation strategy (European Commission 2021c) provides a good basis. The goal is smart adaptation that helps to deal with uncertainty about future change based on better knowledge. Adaptation must be more systemic to support policy at all levels and in all sectors. Adaptation must be faster in the future in terms of dissemination of adaptation measures, reduction of climate risks, and climate protection. Last but not least, support for international action needs to be significantly accelerated and increased. Here is one of the exciting point for application of the e3.ge model. It can be the crystallization point where the increased efforts also of international institutions and donors are linked to national needs and processes. Ideally, the impacts of adaptation measures are identified and quantified in the e3.ge model and shared and discussed afterwards with international institutions. On this basis, financial resources can then be made available very quickly for implementation.

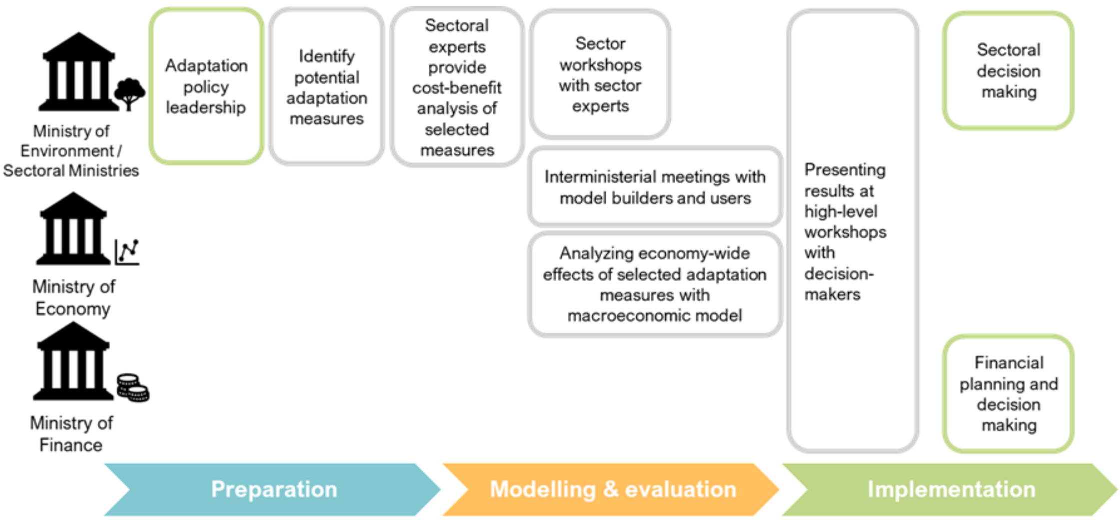


Figure 83: Actor involvement in adaptation policy processes

Source: GIZ

Figure 83 visualizes the interdependencies between the different authorities which require established communication channels, coordination mechanism and responsibilities. By clearly structuring these processes, duplication of work can be avoided.

While the ministry of environment seeks a role in creating possible adaptation strategies for ecological reasons, the ministry of economy may be particularly interested in the economic impacts, while the ministry of finance has to address the issues of financing. All policy makers involved in this process should therefore act in close coordination with each other and need to know about the pay-off of their contribution. In close coordination of the processes, the use of the model can thus be easily enabled and the results of the modeling can provide an important contribution to the decision-making process. The following are possible ways to work on the processes together:

- Joint meetings with other experts to discuss adaptation options from different points of view. This is primarily to gather knowledge that can then be used for model-based scenario analysis. The scope of the contribution is limited.
- Capacity building on model application, i.e. scenario analysis. This is much more time consuming and usually limited to selected modeling experts. It is a necessary prerequisite for independent future use and ownership of the model.
- Distribution of information, e. g. in form of policy briefs which can be widely disseminated.
- Access to the model and/or model results. While the access to the model e3.ge might be restricted by the model owner (Ministry of Economy and Sustainable Development) , model results can be widely disseminated.

Another important aspect – partly related to contributions – is the clarification of responsibilities and rights. Once vulnerabilities and adaptation options have been identified, the corresponding sector experts need to provide cost-benefit analyses (CBA) which give detailed sector-specific information about adaptation actions and measures. If country-specific information is scarce or not available at all, international studies may serve as initial benchmarks. Discussions with country experts help to verify if these benchmarks are applicable for Georgia as well.

The institutionalization of the macroeconomic model presupposes its application. For this, it is important that there is a group of people who are familiar with the technical aspects and the handling of such a model tool. These people serve as experts, who have been trained in building and using the model through training sessions, coaching sessions and exercises and who are constantly expanding their knowledge through regular use of the model. This group of experts can then also take on the role of trainers in the country and thus train further experts. Thus, the model can be developed further through dialogues and joint development work in this expert group. They can ensure that the database is updated at regular intervals, so that the model itself is always up to date and takes into account the latest economic developments. Another essential prerequisite is the concrete formulation of possible fields of application and key policy questions to answer. Are there any political challenges and decision-making processes that require further economic arguments for the discussion process in order to reach a decision? If there are such policy questions, the application of the model needs to be prepared and carried out in close cooperation with the respective policy makers (see Figure 83). In close exchange with these experts, the individual steps of the scenario calculation have to be taken. Data and information should be provided by (sector) experts. Apart from the use for the model, it is recommended to establish a systematic collection of damages and effects due to climate change related events. The data from such a database can be used for a variety of purposes (e. g. for macroeconomic modelling) and raise the awareness to the topic. In the context of an application for climate policy questions or for the analysis of sector-specific adaptation measures, this can be data on damages as well as the costs and benefits of the respective adaptation measures. These data form the input for the model, which will finally calculate the economy-wide macroeconomic effects of the respective adaptation measures.

8 KEY MESSAGES AND CONCLUSIONS

The consequences of climate change are already noticeable today and will become more frequent and more severe. The effects of climate change are striking an economy in Georgia that has undergone a major transformation since the fall of the Soviet Union, growing in double digits due to several economic and democratic reforms. Thus, to ensure a sustainable development in the long term, the risk of climate change should be taken into account for future projections and adaptation to climate change needs to be systematically considered in development strategies. Quantitative economic models in combination with scenario analysis are powerful tools to effectively support policy makers in the assessment and evaluation of different climate change adaptation options.

The e3.ge model which uses the Excel-based DIOM-X framework in conjunction with intensive capacity building reduce the typical technical hurdles of model building and application. Due to the “white box” approach in the modelling activities, all aspects of the model (data, model code and equations, results) are fully accessible and customizable by the model users. However, the capacity building process also increased the awareness for possible model applications and limitations. Possible entry points for modelling results in policy processes are discussed in order to institutionalize the model and underpin policy strategies with macroeconomic information and data.

The successful integration of the e3.ge model into strategic planning processes is linked to various preconditions. For a data-driven model such as e3.ge, the quality of results greatly depends on the quality and timely availability of the underlying historic data. Frictions can only be avoided if data sources and responsibilities are identified at the beginning of the project. Transparency in the process of generating the dataset is also crucial to increase confidence in the model results

Each model represents a simplified view of the underlying economy. The increase in the level of detail inevitably also increases the model complexity. The chosen modelling approach in the e3.ge model takes into account the basic interrelationships of the economy in order to answer the relevant questions concerning climate change and adaptation. Once the model users are familiar with the usage of the model, the model can even be adopted to evolving requirements and future policy questions.

The quantitative results derived from the modeling of adaptation measures in the e3.ge model in this report support the selection of adaptation measures for policy making processes, as they provide additional macroeconomic information for possible adaptation measures. Adaptation measures, on the one hand, reduce the damage caused by the extreme weather event or gradual rise in temperature and thus reduce the funds that would have been needed to repair the damage caused in the absence of adaptation. On the other hand, they require regular investments that also contribute to a sustainable improvement in climate resilience and develop ecological benefits in addition to the classic economic growth contributions (Lehr et al. 2020).

Two adaptation measures each for agriculture and tourism were implemented in the e3.ge model and the macroeconomic effects were analyzed. The two adaptation measures under consideration for agriculture, irrigation systems and windbreaks, were already used in Soviet times to increase productivity in agriculture. Both adaptation measures show that investments in adaptation provide co-benefits: not only can the damages in years with climate change effects in the agricultural sector be reduced, but even with regard to the effects of climate change also the crop yields in every year can be increased and the up- and downstream industries benefit. Likewise, the investment in coastline protection and climate resilient roads and bridges have a positive impact on the economy and reduce the damages in years with climate change.

The upgrading of infrastructure plays a prominent role when talking about adaptation. The economic effects are positive, as investments in climate-resilient railways, roads, buildings and water infrastructure make a positive contribution to GDP and employment. Investment in climate resilient infrastructure also helps to reduce the investment gap and enables the transformation of the economy towards a low-carbon, green economy.

The results of the scenario analysis with the e3.ge model provide an economic evaluation of different adaptation measures. However, since the future is uncertain with respect to climate change and the economy, the results are subject to uncertainties themselves and should be considered as an information that can serve as a starting point for the development of an adaptation strategy. They should raise the awareness and illustrate how the economy in Georgia is developing under the effects of climate change and what the economic benefits of adaptation to climate change are.

Financing of adaptation measures through international funds was not assumed. Given the promises of the industrialized countries to support climate protection measures such as adaptation measures with USD 100 billion per year in the future, the prospects for (partial) funding of the measures are good. In this case, the macroeconomic effects of the measures would be even better.

Although the financial and economic impacts are relevant for policymakers to prioritize adaptation measures, other criteria must be considered as well such as health aspects and ecosystem services (biodiversity, regulation of the water balance) to get a more comprehensive evaluation of a measure, and to formulate an appropriate adaptation strategy. The economic effects should only be one possible basis for decisions on the selection of adaptation measures in Georgia.

The CRED approach and process with its three main pillars – model development, capacity building and policy support regarding adaptation planning – is on the one hand challenging with respect to coordination and planning as well as time-consuming for all partners involved. On the other hand the approach is very successful in terms of collaboration 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, and providing better policy strategies and instruments for the future.

REFERENCES

Anthoff, D., Rose, S., Tol, R. S. J. & Waldhoff, S. (2011): Regional and Sectoral Estimates of the Social Cost of Carbon: An Application of FUND. ESRI Working Paper, (375). Retrieved from https://www.esri.ie/system/files/media/file-uploads/2015-07/WP375.pdf

Barrios, S. & Ibañez, J.N. (2013): Tourism demand, climatic conditions and transport costs: an integrated analysis for EU regions. Report for the PESETA II study on the impact of climate change in Europe. JRC Scientific and Policy Reports 25937 EN.

Bockarjova, M., Steenge A.E. & van der Veen A. (2004): On direct estimation of initial damage in the case of a major catastrophe: derivation of the "basic equation." In: Disaster Prevention and Management 13, no. 4, S. 330–336.

Bosello, F. & Parrado, R. (2020): Macro-economic assessment of climate change impacts: methods and findings, EKONOMIAZ. Revista vasca de Economía, 97, issue 01, p. 45-61.

Brasseur, G., Jacob, D. & Schuck-Zöller, S. (2017): Klimawandel in Deutschland. Entwicklung, Folgen, Risiken und Perspektiven. Springer Spektrum, 2017.

Ciscar, J.-C., Szabó, L., van Regenmorter, D. & Soria, A. (2012): The integration of PESETA sectoral economic impacts into the GEM-E3 Europe model: methodology and results. Climate Change 112, 127-142.

Ciscar J.-C., Feyen L., Soria A., Lavalle C., Raes F., Perry M., Nemry F., Demirel H., Rozsai M., Dosio A., Donatelli M., Srivastava A., Fumagalli D., Niemeyer S., Shrestha S., Ciaian P., Himics M., Van Doorslaer B., Barrios S., Ibáñez N., Forzieri G., Rojas R., Bianchi A., Dowling P., Camia A., Libertà G., San Miguel J., de Rigo D., Caudullo G., Barredo J.I., Paci D., Pycroft J., Saveyn B., Van Regemorter D., Revesz T., Vandyck T., Vrontisi Z., Baranzelli C., Vandecasteele I., Batista e Silva F. & Ibarreta D. (2014): Climate Impacts in Europe. The JRC PESETA II Project. JRC Scientific and Policy Reports, EUR 26586EN.

Climate-ADAPT (n.d.): Adaptation Support Tool. https://climate-adapt.eea.europa.eu/#t-adapt (last accessed May 13, 2022).

COACCH (2021): The Economic Cost of Climate Change in Europe: Synthesis Report on Interim Results. Policy brief by the COACCH project. Editors: Paul Watkiss, Jenny Troeltzsch, Katriona McGlade, Michelle Watkiss. Published July 2021.

Cochrane, H. (2004): Economic loss: myth and measurement. In: Disaster Prevention and Management 13, no. 4: S. 290–296.

CZ-NAP (2020): National Action Plan for Adapting to Climate Change Impacts in the Black Sea Coastal Zone. Tbilisi, 2020.

EEA (2017): Climate change, impacts and vulnerability in Europe 2016 – An indicator-based report. EEA Report No 1/2017, Publications Office of the European Union, Luxembourg.

Eisenack, K. (2009): Autonomous Adaptation to Climate Change is Inefficient, 17th Annual Conference of the European Association of Environmental and Resource Economists, Amsterdam.

European Commission (2020): Study on Adaptation Modelling. Comprehensive Desk Review: Concise Summary. CLIMA/A.3/ETU/2018/0010 4th December 2020. https://www.adaptecca.es/sites/default/files/documentos/study_on_adaptation_modelling._concise_summary.pdf (last accessed October 4, 2020)

European Commission (2021a): Commission Staff Working Document Impact Assessment Report, SWD/2021/25 final, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=SWD:2021:25:FIN.

European Commission (2021b): Joint Staff Working Document Association Implementation Report on Georgia, SWD/2021/18 final. Brussels: High Representative of the Union for Foreign Affairs and Security Policy.

European Commission (2021c): Forging a climate-resilient Europe - the new EU Strategy on Adaptation to Climate Change, COM/2021/82 final.

Feyen L., Ciscar J.C., Gosling S., Ibarreta D. & Soria A. (editors) (2020). Climate change impacts and adaptation in Europe. JRC PESETA IV final report. EUR 30180EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-76-18123-1, doi:10.2760/171121, JRC119178.

GEOSTAT (2020): Statistical Yearbook of Georgia 2020. Tbilisi: National Statistics Office of Georgia. https://www.geostat.ge/media/35685/Yearbook_2020.pdf

GEOSTAT (2021a): National Accounts of Georgia 2019. Tbilisi: National Accounts Department of National Statistics Office of Georgia. https://www.geostat.ge/media/36173/%E1%83%99%E1%83%A0%E1%83%94%E1%83%91%E1%83%A3%E1%83%9A%E1%83%98-2019_-29.01.2021.pdf

GEOSTAT (2021b): National Statistics Office of Georgia. https://www.geostat.ge/en

Gesellschaft für Wirtschaftliche Strukturforschung (GWS) (2022). Modell PANTHA RHEI. https://gws-os.com/fileadmin/Redaktion/Files/Modelle/Energie-und-Klima/modell-panta-rhei-en.png (last accessed March 2, 2022).

GFDRR, Government of Georgia, UN Development Programme & The World Bank (2015): Tbilisi Disaster Needs Assessment 2015. Tbilisi, 2015.

GNTA (2018): Georgian Tourism in Figures 2018. Structure & industry data. Georgian National Tourism Administration. Tbilisi, 2018

GNTA (2020): Georgian Tourism in Figures 2019. Structure & industry data. Ministry of Economy and Sustainable Development of Georgia and Georgian National Tourism Administration. Tbilisi, 2020.

Haimes, Y.Y. & Jiang, P. (2001): Leontief-Based Model of Risk in Complex Interconnected Infrastructures. In: Journal of Infrastructure Systems 7, no. 1: 1–12.

Hallegatte, S., Ranger, N., Mestre, O., Dumas, P., Corfee-Morlot, J., Herweijer, C. & Muir Wood, R. (2011): Assessing climate change impacts, sea level rise and storm surge risk in port cities: a case study on Copenhagen. In: Climatic Change 104, no. 1: S. 113–137

Hübler, M. (2014). Sozio-ökonomische Bewertung von Gesundheitseffekten des Klimawandels in Deutschland. In: Lozán, J. L., Grassl, H., Karbe, L., G. Jendritzky (ed.). Warnsignal Klima: Gefahren für Pflanzen, Tiere und Menschen. 2. Auflage. Electronic publication. Chapter 4.13. https://www.klima-warnsignale.uni-hamburg.de/wp-content/uploads/pdf/de/gesundheitsrisiken/warnsignal_klima-gesundheitsrisiken-kapitel-4_13.pdf (last accessed October 4, 2020).

Hwang, I.C., Tol, R. S.J. & Hofkes, M. W. (2016): Fat-tailed risk about climate change and climate policy, in: Energy Policy, Volume 89, 25–35.

IBiS (2019): Approach for “Rehabilitation of Windbreaks in East Georgia”. Integrated Biodiversity Management, South Caucasus. 2019.

ILO (2019): Working on a warmer planet. The impact of heat stress on labour productivity and decent work. International Labour Organization. Geneva, 2019.

IPCC (2018): Annex I: Glossary [Matthews, J.B.R. (ed.)]. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)].

Kahn, M. E.; Mohaddes, K.; Ng, R. C. C.; Pesaran, M. H.; Raissi, M. & Yang J.-C. (2019): Long-Term Macroeconomic Effects of Climate Change: A Cross-Country Analysis. IMF Working paper WP/19/215. International Monetary Fund, 2019.

Kakulia, M. & Kapanadze, N. (2020): Impact of Anti-Pandemic Restrictions and Government Anti-Crisis Measures on Employment, Incomes and the Poverty Level in Georgia. Tbilisi, 2020.

Lehr, U., Flaute, M., Ahmann, L., Nieters, A., Hirschfeld, J., Welling, M., Wolff, C., Gall, A., Kersting, J., Mahlbacher, M. & von Möllendorff, C. (2020): Vertiefte ökonomische Analyse einzelner Politikinstrumente und Maßnahmen zur Anpassung an den Klimawandel. UBA, Reihe Climate Change, 2020.

Máñez Costa, M., Rechid, D., Bieritz, L., Lutz, C., Nieters, A., Stöver, B., Jahn, M., Rische, M.-C., Schulze, S., Yadegar, E., Hirschfeld, J., Schröder, A., Hirte, G., Langer, S. & Tscharaktschiew, S. (2016): Synthesis of existing regional and sectoral economic modelling and its possible integration with regional earth system models in the context of climate modelling. Report 27. Climate Service Center, Hamburg.

MEPA (2017): Climate Change National Adaptation Plan for Georgia’s Agriculture Sector. Ministry of Environment and Natural Resources Protection of Georgia. Tbilisi, 2017.

Miller, R. E. & Blair , P. D. (2009): Input-Output Analysis – Foundations and Extensions. 2nd edition. Cambridge University Press.

MoA (2015): Strategy for agricultural development in Georgia 2015-2020. Tbilisi, 2015.

MoA (2017): Irrigation Strategy for Georgia 2017-2025. Ministry of Agriculture. Tbilisi, 2017.

MoE (2015): Georgia's Third National Communication to the UNFCCC. Ministry of Environment and Natural Resources Protection of Georgia. Tbilisi, 2015.

MoESD (2019): Georgia in International Ratings 2012 – 2019. Ministry of Economy and Sustainable Development of Georgia. Tbilisi, 2019.

Moore, L.: Economics of Windbreaks. USDA-NRCS, n.d.

Navarro, J. S. & Jorda Sanchez, G. (2021): Report on the climate hazards analysis for Georgia in the frame of the CRED project. Forthcoming.

Nordhaus, W. D. (1992): The "Dice" Model: Background and Structure Of a Dynamic Integrated Climate-Economy Model of the Economics of Global Warming. Cowles Foundation for Research in Economics at Yale University, Discussion Paper Nr. 1009, 1992.

Nordhaus, W. D. (2017): Evolution of Assessments of the Economics of Global Warming: Changes in the DICE model, 1992–2017. Climatic Change, 148, 4, Pp. 623-640.

OECD (2018): Climate-resilient Infrastructure. Policy perspectives. OECD Environment Policy Paper No. 14. Paris, 2018.

OECD (2021): Sustainable Infrastructure for Low-carbon Development in the EU Eastern Partnership: Hotspot Analysis and Needs Assessment. Paris, 2020.

Official Journal of the European Union (2014): Association Agreement between the European Union and the European Atomic Energy Community and their Member States, of the one part, and Georgia, of the other part, O.J. 2014 L 261/4.

Okuyama, Y., Hewings, G.J.D. & Michael Sonis (2004): Measuring Economic Impacts of Disasters: Interregional Input-Output Analysis Using Sequential Interindustry Model. In: Modeling Spatial and Economic Impacts of Disasters, ed by. Yasuhide Okuyama and Stephanie E. Chang, S. 77–101. Springer.

Ricke, K., Drouet, L., Caldeira, K. & Tavoni, M. (2018): Country-level social cost of carbon, in Nature Climate Change, Vol. 8, 2018, 895–900.

Schinko, T., Drouet, L., Vrontisi, Z., Hof, A., Hinkel, J., Mochizuki, J., Bosetti, V., Fragkiadakis, K., van Vuuren, D. & Lincke, D. (2020): Economy-wide effects of coastal flooding due to sea level rise: a multi-model simultaneous treatment of mitigation, adaptation, and residual impacts. Environ. Res. Commun. **2** (2020) 015002.

Smith, M. M., Bentrup, G., Kellerman, T., MacFarland, K., Straight, R. & Ameyaw, L. (2021): Windbreaks in the United States: A systematic review of producer-reported benefits, challenges, management activities and drivers of adoption. Agricultural systems 187 (2021) 103032.

Steininger, K.W., König, M., Bednar-Friedl, B., Kranzl, L., Loibl, W. & Prettenthaler, F. (Eds.) (2015): Economic Evaluation of Climate Change Impacts – Development of a Cross-Sectoral Framework and Results for Austria. 2015, Springer.v. Möllendorff, C., Hirschfeld, J. (2017): Datenbank Policy Mix – Erläuterungsbericht. Erstellt im Rahmen des UBA-Projektes „Vertiefte ökonomische Analyse einzelner Politikinstrumente und Maßnahmen zur Anpassung an den Klimawandel" (UFOPLAN 3716 48 100 0).

Sue Wing, I. (2004): Computable General Equilibrium Models and Their Use in Economy-Wide Policy Analysis: Everything You Ever Wanted to Know (But Were Afraid to Ask). http://www.rri.wvu.edu/CGECourse/Sue%20Wing.pdf.

TBC Capital (2019): Tourism industry overview: The next destination. Tbilisi, 2019.

TBC Capital (2020): COVID-19 Impact on Georgian economy. Tbilisi, 2020.

UNDP (2014): Disaster Risk Reduction Capacity Assessment Report. United Nations Development Programme, 2014. Link: http://www.ge.undp.org/content/dam/georgia/docs/publications/GE_UNDP_Disaster_Risk_Reduction_Capacity_Assesment_Report_2014_Eng.pdf.

UNDP (2020): Human Development Reports. http://hdr.undp.org/en/countries/profiles/GEO

United Nations Framework Convention on Climate Change (UNFCC) (2013): Glossary of climate change acronyms. https://unfccc.int/process-and-meetings/the-convention/glossary-of-climate-change-acronyms-and-terms#a (03.09.2021)

USAID (2016): The Georgian Road Map on Climate Change Adaptation. Tbilisi: Color Ltd.

USAID (2017): Climate Risk in Georgia: Country Profile. https://www.climatelinks.org/resources/climate-risk-profile-georgia

United Nations (2018): Handbook on Supply, Use and Input-Output Tables with Extensions and Applications. Department of Economic and Social Affairs, Statistics Division, New York.

Weitzman, M. L. (1998): Why the Far-Distant Future Should Be Discounted at Its Lowest Possible Rate. Journal of Environmental Economics and Management 36, 201-208 (1998).

Weitzman, M. L. (2011): Why the Far-Distant Future Should Be Discounted at Its Lowest Possible Rate, in Journal of Environmental Economics and Management 36, 201–208 (1998), Article No. EE981052.

WBG & ADB (2021): Climate Risk Country Profile: Georgia. The World Bank Group and the Asian Development Bank.

World Bank (2017): Disaster Risk Finance Country Note: Georgia. World Bank Group, 2017.

World Bank (2018): Georgia - Systematic Country Diagnostic: From Reformer to Performer. Washington, D.C.: World Bank Group. http://documents.worldbank.org/curated/en/496731525097717444/Georgia-Systematic-Country-Diagnostic-from-reformer-to-performer

World Bank (2019): Georgia: Beyond Arrivals – Emerging Opportunities for Georgian Firms in Tourism Value Chains, Washington, DC: World Bank. http://documents1.worldbank.org/curated/en/264181575569238865/pdf/Georgia-Beyond-Arrivals-Emerging-Opportunities-for-Georgian-Firms-in-Tourism-Value-Chains.pdf

World Bank (2020): Georgia: Towards Green and Resilient Growth. World Bank, Washington, DC.

World Bank (2020a): Adaptation Principles: A Guide for Designing Strategies for Climate Change Adaptation and Resilience. World Bank, Washington, DC.

World Bank (2020b): Impacts of Climate Change on Georgia's Coastal Zone – Vulnerability Assessment and Adaptation Options. The World Bank, Washington, 2020.

World Bank (2020c): Doing Business 2020. https://www.doingbusiness.org/en/reports/global-reports/doing-business-2020

World Bank (2021): Data https://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG?locations=GE