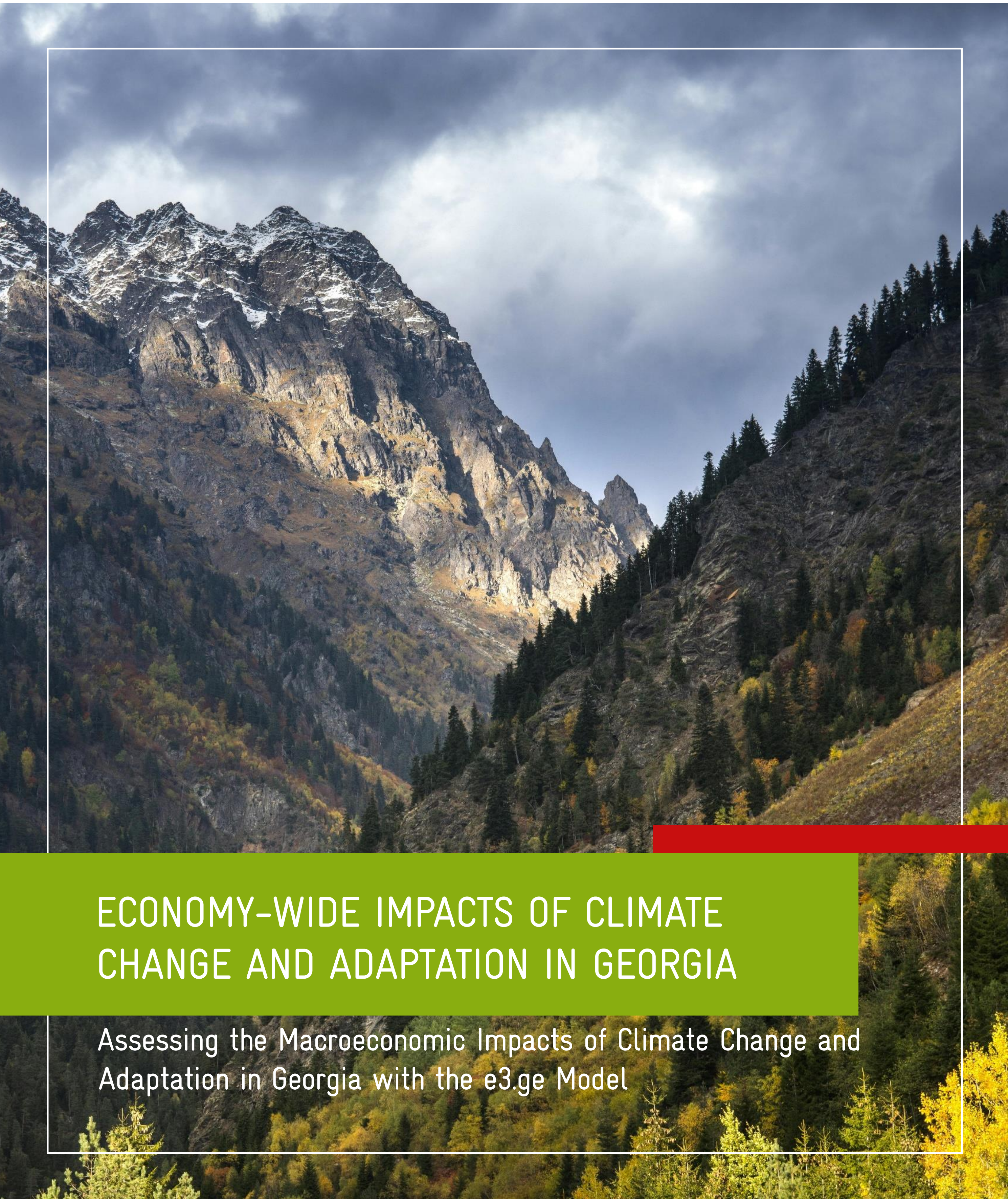

ECONOMY-WIDE IMPACTS OF CLIMATE CHANGE AND ADAPTATION IN GEORGIA

Assessing the Macroeconomic Impacts of Climate Change and Adaptation in Georgia with the e3.ge Model

Published by:

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Supported by:

Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection

INTERNATIONAL CLIMATE INITIATIVE

based on a decision of the German Bundestag

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

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This report was elaborated by the experts of the international consultancy Gesellschaft für Wirtschaftliche Strukturforschung | Institute of Economic Structures Research (GWS) within the global programme "Policy Advice for Climate Resilient Economic Development", implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) on behalf of the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV).

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

Germany 2025

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June 2025

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1. INTRODUCTION

Climate change poses a significant threat to the environment, the economy, and the society in Georgia. Georgia has already experienced increased extreme weather events such as droughts and heavy rainfall. These trends are expected to continue, impacting critical sectors of the Georgian economy.

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).

To support informed decision-making, 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 Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) as part of the GIZ CRED program (Policy Advice for Climate Resilient Economic Development), that aims to support macroeconomic modelling for evidence-based policy making.

The e3.ge model contains three interlinked model parts, the economy module, energy module and emissions module. The abbreviation *ge* denotes the respective country code for Georgia.

This report updates the country report that was prepared as part of the first project phase of CRED (Flaute et al. 2022). In terms of content, this primarily concerns the quantification of the damage caused by climate change and of the adaptation measures. Climate-related damage, especially in the form of heatwaves, droughts and floods, is now distinguished according to different SSPs (SSP1-2.6, SSP2-4.5 and SSP5-8.5) and is based on benchmark damage and assumptions regarding the probability of occurrence of damaging events. This process was supported by national and international experts, among others MoESD, Berlin Economics, EarthYield Advisories, TBSC Consulting, and Sustainable Development Center "Remissia".

Various cost-benefit analyses have been prepared by national consultants for the adaptation measures. They consider measures in the areas of agriculture and forestry, as well as infrastructure. In 2024, the existing E3 model for Georgia was also extended and updated in close coordination with MoESD.

The report is organized as follows: Chapter 2 briefly describes the e3 modelling approach and the technique of scenario analysis. Chapter 3 describes in a nutshell the assumptions and results of the reference scenario, which serve as a basis for the climate change and adaptation scenarios. Chapter 4 describes how climate change is incorporated into the model and what socio-economic effects it causes. The effects of adaptation measures are described in section 0. Chapter 6 points out the key messages and concludes.

2. MODELLING APPROACH

2.1. The e3.ge model

As part of GIZ's Climate-Resilient Economic Development (CRED) project, a so-called E3 model (Economy, Energy, Emissions) has been developed for Georgia that is described in detail in the national report (Flaute et al. 2022). E3.ge is a dynamic macroeconometric input-output model that can determine the socio-economic effects of climate change and adaptation to climate change. The following figure shows the main parts of the model and how they are connected. It is important to note that, in addition to macroeconomic variables such as GDP and employment, sectoral variables are also updated at the industry level. These include, among other things, various final demand components such as private consumption and investment, production values, employment and prices.

Figure 1 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 labour 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 centre 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 labour productivity) and adaptation measures (e. g., irrigations systems, windbreaks) are being added to the model and can trigger various economy-wide effects. More details about its application and transferability to other countries can be found in the model handbook (GIZ 2023b).

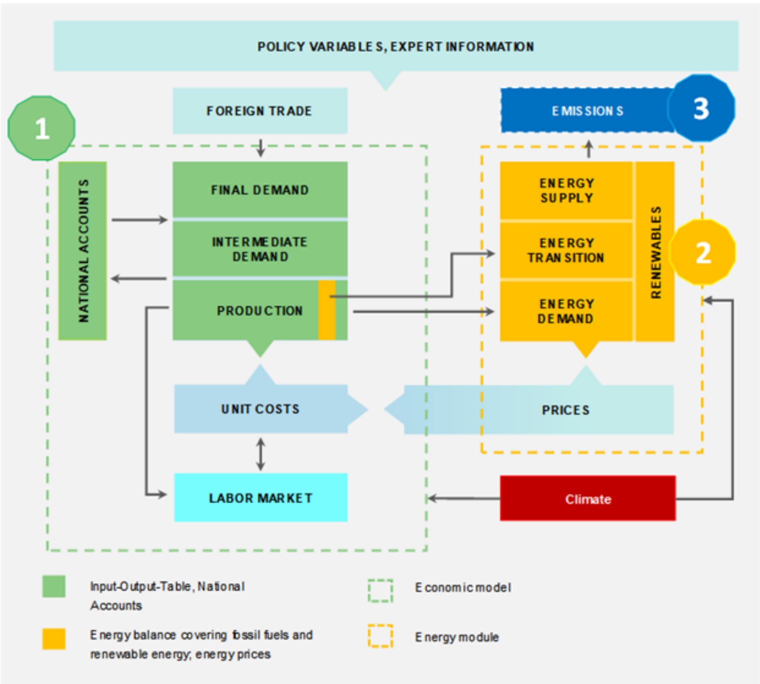

Figure 1: The e3.ge modelling approach

Source: Own figure based on GIZ, 2023a

2.2. Scenario analysis

Scenario analysis is a method for dealing with the different kind of uncertainties of the future. Scenario analysis helps to analyse 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 (Flaute al. 2022).

The e3.ge model is applied to simulate the economy-wide impacts of three climate scenarios (SSP1-2.6, SSP2-4.5 and SSP5-8.5) as well as the effects of respective climate change adaptation measures. Thus, climate scenarios consider the sectoral impacts of the main climate hazards impacting the Georgian economy the most which are not reflected in the REF scenario. Climate change adaptation scenarios build upon the climate scenarios and consider the sector-specific costs and benefits of adaptation measures as well. The scenario settings and required data for the scenarios have been jointly selected and collected with national, sectoral and climate experts.

The simulation of the climate scenarios and the adaptation scenarios with their respective scenario settings cause chain reactions in the e3.ge model resulting in an "alternative" future. To see the impacts of a climate change scenario, the results for relevant model variables such as employment, GDP or production are evaluated against the REF scenario (

Figure 2). To see the effects of an adaptation measure, this scenario must be compared to the respective climate change scenario which includes climate change impacts but no adaptation policies.

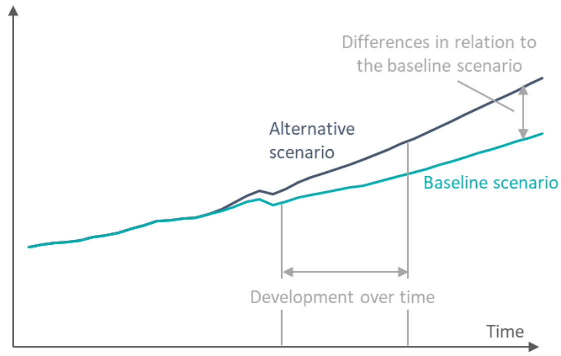

Figure 2: Scenario comparison

Source: Own representation by GWS.

With the help of the e3.ge model, not only direct, but also indirect and feedback effects of alternative scenarios can be evaluated which includes sectoral detail and an economy-wide analysis. The e3.ge model aims at helping model users to identify highly effective adaptation options with positive effects on the economy, employment, and the environment. This is only possible due to the modelled relationships between economic activity, energy, and the emissions as well as the implication of socio-economic relationships (so-called e3 modelling).

Table 1: Description of scenarios for climate change and adaptation

SCENARIO	DESCRIPTION
BUSINESS-AS-USUAL (BAU) OR BASELINE SCENARIO 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 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. 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, climate change scenarios including the effects of climate change have to be compared to a reference scenario (or business-as-usual scenario, BAU) which reflects the continuation of the economic development without climate change. In a further step, various scenarios are created that depict adaptation measures to climate change. Impacts of the adaptation scenario should be compared to climate change scenarios.

Chapter 4 and 0 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 analysed. Furthermore, different adaptation measures will be analysed on a sectoral level.

2.3. Implementing climate change and adaptation

The integration of climate change into economic models is a very demanding and challenging task. The approach is to focus on the relevant extreme weather events. Thereby different effects are integrated on a sectoral level, e.g. the effects of heat waves on agriculture. The interlinkages in the modelling framework are about to calculate the overall macroeconomic effects out of the respective sectoral changes. The approach for Georgia builds on the damage data concept for assessing economic impacts from climate change in e3 models.

As the e3.ge 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; see World Bank 2017), the modelling of future impacts of climate change on the national economy needs a link between future climate projections and sectoral economic damages.

Economic and climate models are operating on different temporal and spatial scales. While climate models often have a high spatial resolution (small grids) and a long-term horizon (up to 2100), the e3.ge model represents the Georgian economy at the national level and has a mid to long-term perspective (up to 2050). To implement climate change into the e3.model a scenario analysis linking future climate projections and sectoral economic damages is applied. The process follows a four-step approach (Figure 3):

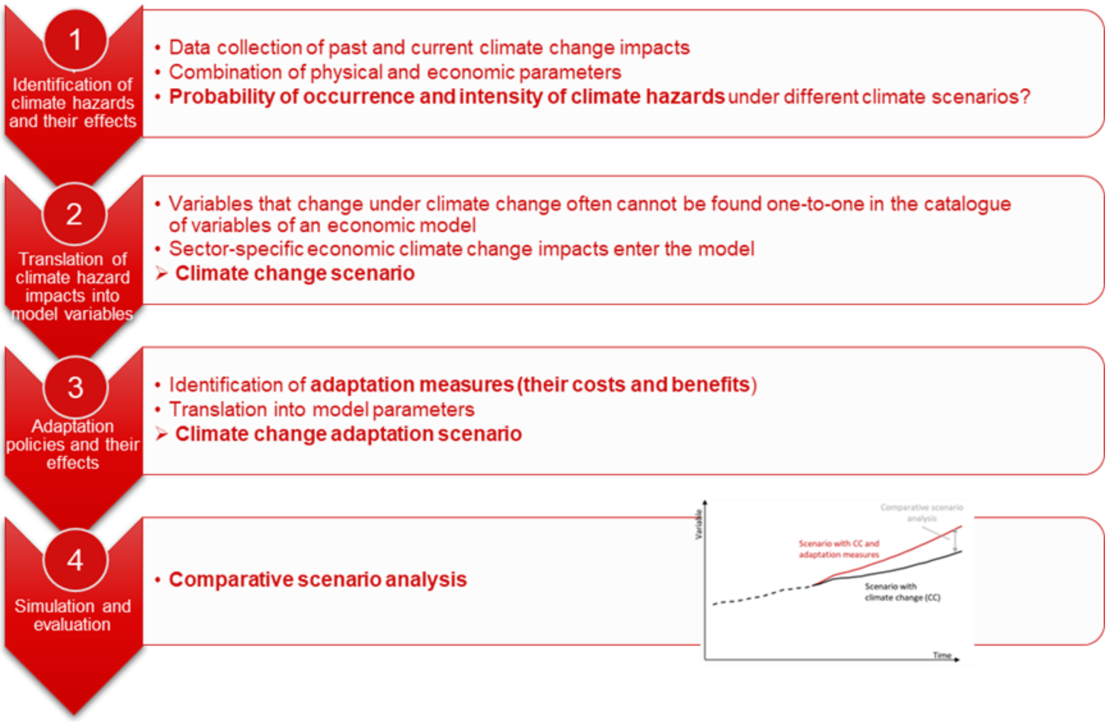

Figure 3: Integration of climate change and adaptation in an economic model; proceeding in four steps

Source: Adapted from Flaute et al. (2022)

(1) Identification of climate hazards and their effects: A scenario with climate change is created which explicitly implements climate change hazards and its effects. It was agreed to consider the climate hazards heatwaves, droughts and floods for Georgia.

The impact chain concept (Fritzsche et al. 2014) is used to identify qualitative descriptions of the economic effects of climate hazards (e. g. water scarcity affects agricultural output). In particular, sector-specific damage data from past climate events are used to quantify the direct climate change impacts. These were collected by local partners in Georgia from TBSC (detailed analysis of past extreme weather events; non-monetary and monetary damages), screening of scientific (national and international) literature, and databases (such as European Climate Damage and Adaptation Platforms PESETA, Climate-Adapt), media and expert surveys, and evidence from other countries (e.g. Germany). The damage / impact data differentiated for three intensity categories (low, medium and high) serve as a benchmark for estimating future climate hazard impacts.

The analysis of climate change and its impacts is based on the Shared Socioeconomic Pathways (SSPs) which represent different climate policy choices at global scale impacting GHG emissions. The CRED II project focuses on the SSP1-2.6, SSP2-4.5 and SSP5-8.5 scenarios, which range from low to high emission scenarios. SSP suffixes with higher values representing stronger climate warming effects. For the considered climate hazards the probabilities of occurrence for three intensity categories (low, medium, high) are provided for three SSP/RCP scenarios (SSP1-2.6, SSP2-4.5 and SSP5-8.5) on an annual basis by experts from EarthYield Advisories (GIZ 2025a). The climate projections for the period 2024-2050 are used for the economic modelling.

(2) Translation of climate hazard impacts into the model variables: 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 hazards by intensities and observed climate hazard impacts by intensity category results in a time series of expected future impacts for the respective climate hazards.

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) Adaptation policies and their effects: The third step comprises the identification of adaptation measures and their translation into the e3.ge model. Therefore, quantified sector-specific costs and benefits of adaptation measures are required to subsequently analyse the economy-wide impacts with e3.ge. The results of the CBAs then serve as an input for the e3.ge model. The costs of adaptation measures are usually implemented as investments and the benefits reduce the climate change impacts.

(4) Simulation and evaluation: Finally, a scenario-analysis (see chapter 2.1) is being performed to evaluate the economic effects of climate change and adaptation to climate change. Results are presented in chapter 4 and chapter 0.

3. 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 to provide a solid basis for the other scenarios. As described in the national report from 2022 developments observed in the past are used to project the development of the Georgian economy to the future (Flaute et al. 2022). For this report, the data base in the model ranges up to the year 2022. Sector data is historical data until 2021.

Figure 4 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. Between 2010 and 2022, the Georgian economy grew by an average of 4.7% per year. This already includes the significant slump caused by the coronavirus pandemic in 2020. Exports, which grew at an above-average rate, contributed to this. They also grew faster than imports, so that the foreign trade balance developed positively. Private consumption increase has also been above average. By contrast, investment and, in particular, government consumption growth rates have been below average. In the future, economic growth is expected to increase until 2030 due to the high economic growth in recent years, before growth rates stabilize at 4.4% on an annual average (see Table 2).

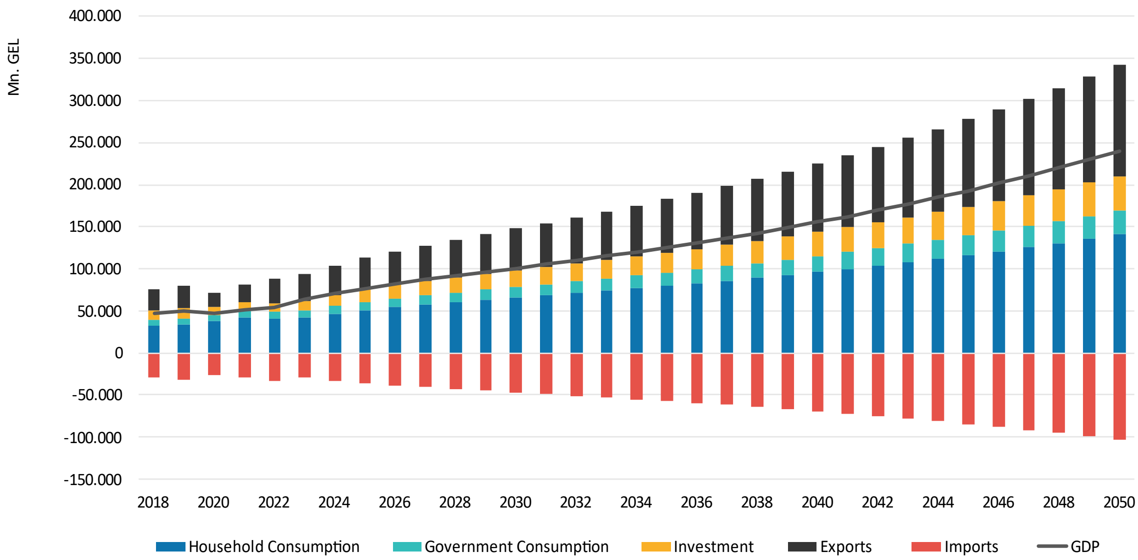

Figure 4: Reference scenario, projection of GDP and components, real values, in million GEL

Source: Own figure based on e3.ge results.

Table 2: GDP and components of final demand in constant prices – Average annual growth rates (AAGR)

	2010-2022	2023-2030	2031-2040	2041-2050
GDP	4,7%	6,7%	4,4%	4,4%
CONSUMPTION EXPENDITURES OF HOUSEHOLDS	5,2%	6,4%	3,9%	3,9%
CONSUMPTION EXPENDITURES OF THE GENERAL GOVERNMENT	2,0%	7,7%	4,0%	4,0%
GROSS FIXED CAPITAL FORMATION	4,0%	8,0%	3,8%	3,8%
EXPORTS OF GOODS AND SERVICES	6,7%	6,4%	5,0%	5,0%
IMPORTS OF GOODS AND SERVICES	5,4%	6,8%	4,0%	4,0%

Source: Own figure based on e3.ge results.

Sectoral production follows the macroeconomic development considering inter-industry relationships. For the projection period, no major structural changes or economic diversification of the economy are assumed. This means that the private services remain by far the most important sector, followed by manufacturing, public services, construction and agriculture. Figure 5 depicts the projections for real gross production by economic sectors.

Sectoral employment follows the sectoral economic activity considering the sector-specific labour productivity, real wages and partly population development. In agriculture, labour productivity is very low, whereas in manufacturing it is above average. Overall, in view of the population development, no further increase in total employment is expected (Figure 6).

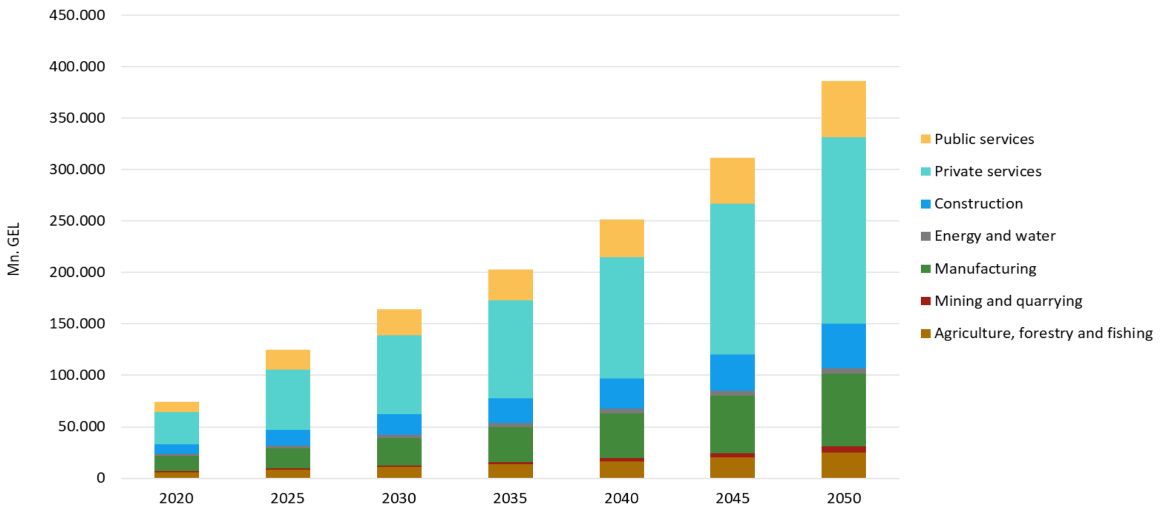

Figure 5: Reference scenario: Real gross production by economic sectors in Mn. GEL

Source: GWS based on e3.ge

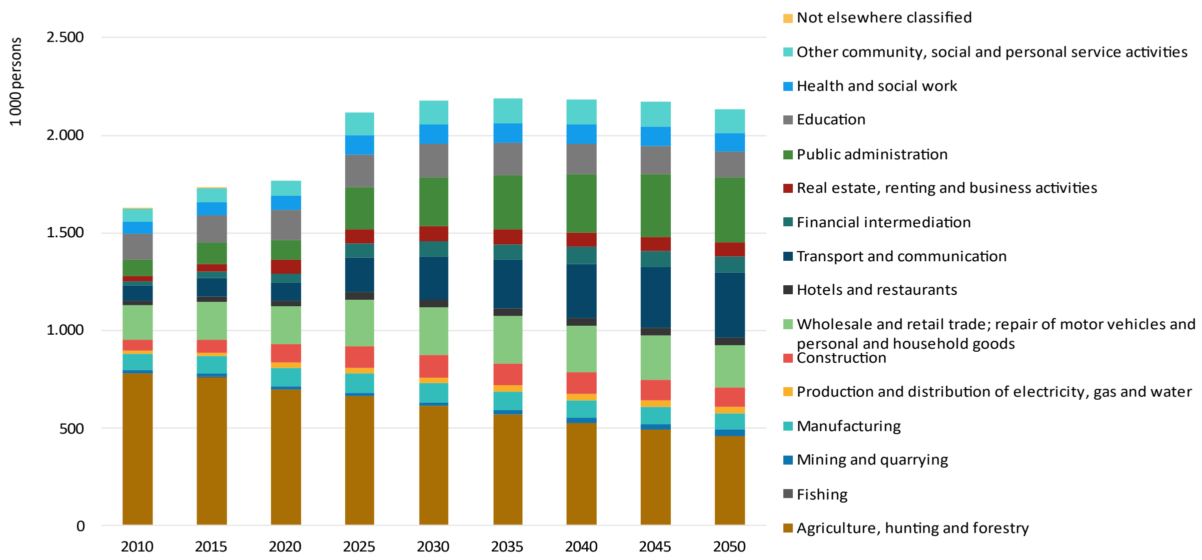

Figure 6: Reference scenario: Employed persons by economic activity in 1,000 persons

Source: GWS based on e3.ge, historical data until 2018 based on ILO

The proportion of women in employment is lower than that of men. Assuming that the proportions in the individual sectors remain unchanged, the number of male employees will continue to rise in the future, while the number of employed women will fall. This is not necessarily realistic in view of the expectation of a rising employment rate and better education of women in the future (Figure 7). Some gender-specific differences can be seen for some economic activities. Male employment dominates mining and quarrying (93% vs 7%), manufacturing (67% vs. 33%), production and distribution of electricity, gas and water (78% vs. 22%), construction (96% vs. 4%), transport and communication (84% vs. 16%) and public administration (68% vs. 32%). In contrary, female employment dominates financial intermediation (64% vs. 36%), education (81% vs. 19%), health and social work (81% vs. 19%), and other community, social and personal service activities (69% vs. 31%).

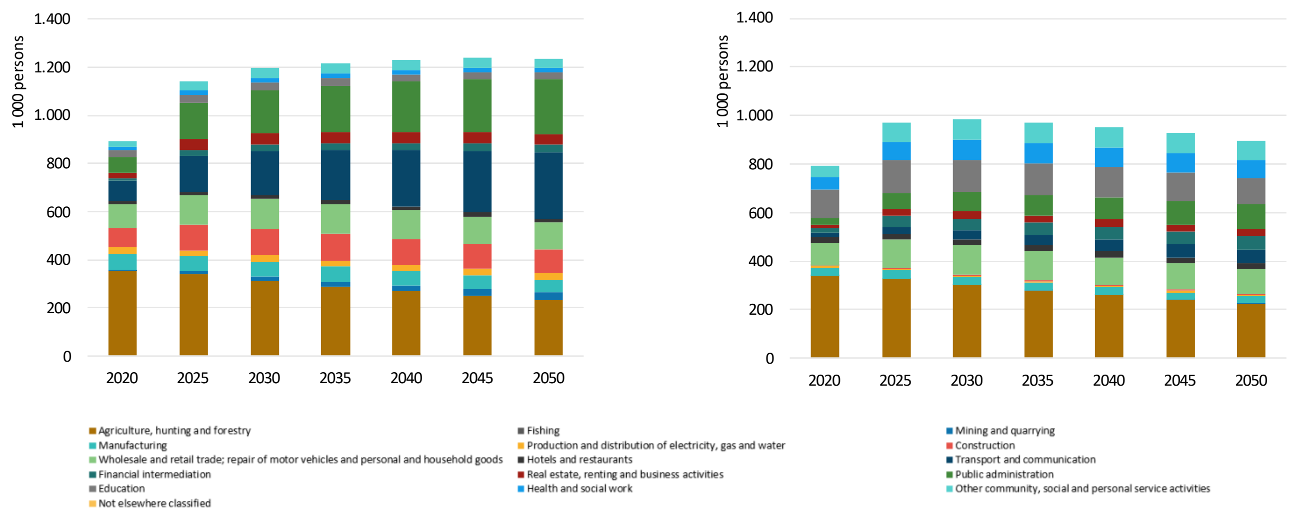

Figure 7: REF scenario: Employed persons by economic activity and gender in 1,000 persons (2020-2050), male (left figure), female (right figure)

Source: GWS based on e3.ge, shares of male/female based on ILO

4. ECONOMICS OF CLIMATE CHANGE

In this chapter, the economy-wide impacts of three climate change scenarios are described regarding their impacts on economic growth, production and employment.

As introduced in section **Error! Reference source n ot found.**, the future development of the main climate hazards under different climate change scenarios are required as well as the average sectoral benchmark impacts as observed in the past (section 2.3, step 1). The three SSP scenarios (SSP1-2.6, SSP2-4.5 and SSP5-8.5) were selected to represent a range of possible global temperature increases and the associated extent (frequency and intensity) of climate hazards in Georgia.

The desk research and exchanges with national climate experts during CRED I and II project revealed that floods, heatwaves and droughts are the most relevant climate hazards in Georgia impacting people and key economic sectors either directly or indirectly. These climate hazards are therefore examined below. Data is not available for all impacts of climate hazards, so the macroeconomic analysis of climate change refers to those that can currently be quantified.

In a second step, the identified biophysical and economic effects need to be translated into model parameters. The detailed analysis on future development of climate hazards by intensities and observed climate hazard impacts by intensity category for the three climate change scenarios results in a time series of expected future impacts for the respective climate hazards. These time series are then assigned to specific variables in the e3.ge model. To show the economy-wide impacts a scenario analysis is being performed, the results are shown in section 0.

4.1. Scenario Settings

This section gives an overview of the scenario assumptions for the three climate scenarios. Firstly, the future development of the main climate hazards under different climate change scenarios are described (SSP1-2.6, SSP2-4.5 and SSP5-8.5). Secondly, the assumptions and sources for benchmark damages for heatwaves, droughts and floods are presented.

According to EarthYield Advisories (GIZ 2025a), the most relevant climate hazards are floods, droughts and heatwaves. In the future, climate hazards will occur even more frequently and more severely. In general, less intense climate hazards (low, red line in Figure 8) are expected to happen more frequent than those with medium and those with high intensity (light and dark grey in Figure 8). The probability of occurrences for the climate hazards by intensity differs comparing the three SSP scenarios (Figure 8).

There is a tendency that the probability of occurrence of climate hazards is greater in Shared Socioeconomic Pathways (SSP) scenarios with higher warming potential due to higher emission pathways, e.g. SSP5-8.5 compared to SSP1-2.6 (GIZ 2025a). It is important to point out here that this trend is particularly evident for the period up to 2100 and that probabilities of occurrences increase significantly from 2050 onwards (see Figure 45, for better visibility the period up to 2050 is shaded in light grey).

As the economic e3.ge model has a time horizon up to 2050, only this time period is considered for modelling.

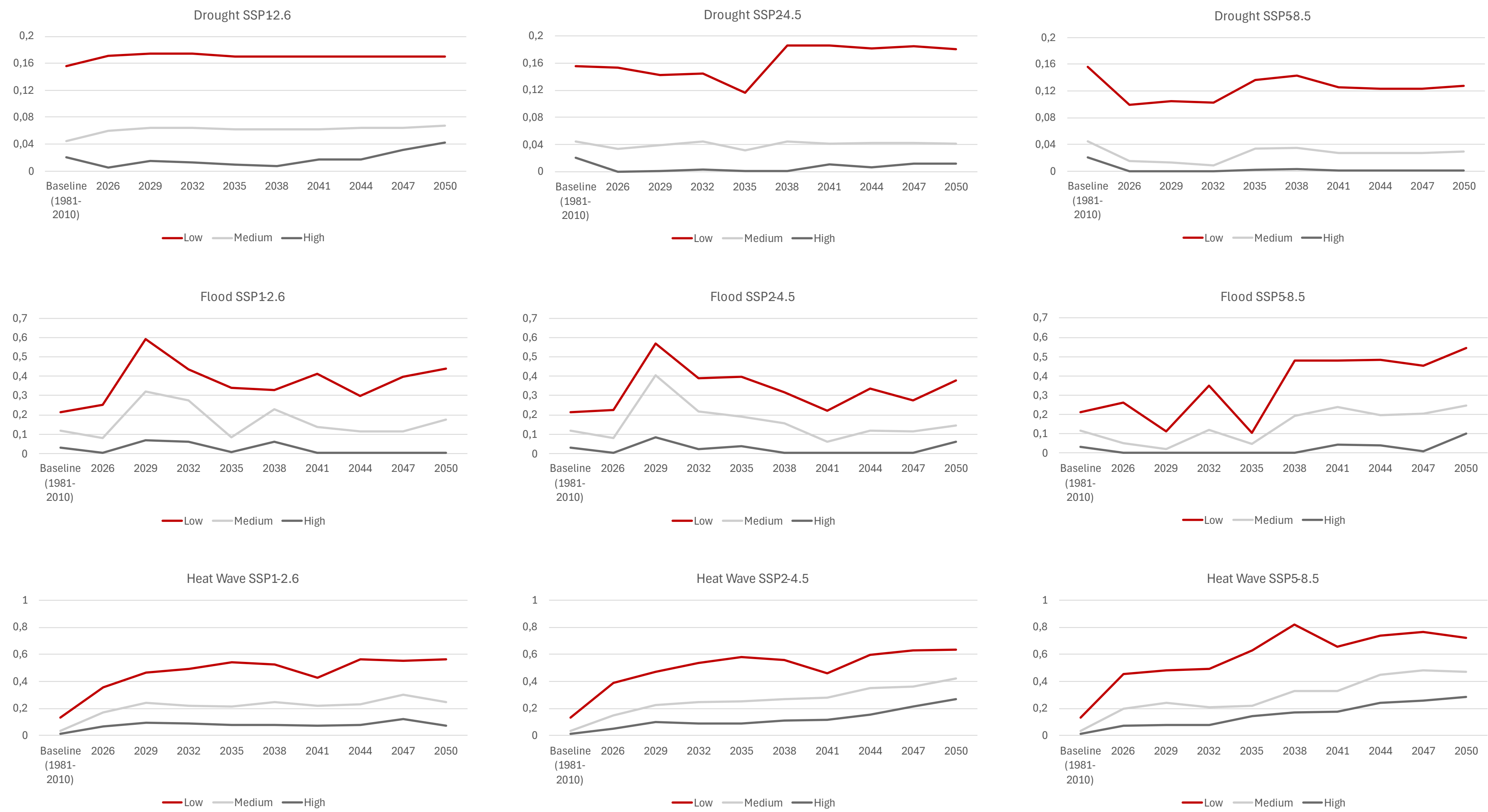

Figure 8: Probability of occurrence by intensity (low, medium, high) for droughts, heatwaves and floods under SSP1-2.6, SSP2-4.5 and SSP5-8.5 scenario until 2050

Source: Results provided by EarthYield Advisories (GIZ 2025a)

The following sections and tables describe the scenario assumptions and implementation of the considered extreme events heatwaves, droughts and floods. These were collected by local partners in Georgia from TBSC (detailed analysis of past extreme weather events; non-monetary and monetary damages), screening of scientific (national and international) literature, and databases (such as European Climate Damage and Adaptation Platforms PESETA, Climate-Adapt), media and expert surveys, and evidence from other countries (e.g. Germany). The damage / impact data differentiated for three intensity categories (low, medium and high) serve as a benchmark for estimating future climate hazard impacts.

Heatwaves affect several sectors. The agricultural sector faces crop losses due to the scarcity of rain and water. The risk for forest diseases is increasing. Irrigation canals and systems get damaged. The energy sector is affected by an increased energy demand for cooling, the food sector is facing a higher demand for beverages. Average labour productivity declines due to heat stress. Especially outdoor workers and physically hard-working workers are affected, for instance in the agricultural, manufacturing and construction sectors. The more physical intense the labour is in a sector, the higher is the average productivity loss. Heatwave also affect human health, so Georgia is confronted with increasing heat-related health expenditures.

Table 3 shows the benchmark damages / impacts of heatwaves for the intensity category high. It is assumed that the benchmark damage of intensity category low is 10% of intensity category high, and that the benchmark damage of the intensity category medium is in the middle. It is assumed that households do not have more income, so that the further household consumption is reduced by additional expenditure for energy demand, health care services, and demand for beverages.

Table 3: Heatwaves

IMPACT	BENCHMARK DAMAGE / IMPACT	SOURCE:
LOSSES IN HARVEST DUE TO SCARCITY OF RAIN AND WATER	-10 %	PESETA Project (Freyen et al. (2020), Hristov et al. (2020))
ADDITIONAL ENERGY DEMAND FOR COOLING	0.5-8.5 %	World Bank / ADB (2021)
HIGHER DEMAND FOR HEALTH CARE SERVICES	1.6 %	Own assumption based on Hübler (2008, 2014)
HIGHER DEMAND FOR BEVERAGES	5 – 7 %	Own assumption based on evidence from Germany
PRODUCTION LOSSES DUE TO LOWER LABOUR PRODUCTIVITY (ALL SECTORS; DIVIDED INTO LIGHT INDOOR, MODERATE INDOOR AND OUTDOOR ACTIVITIES)	-1.7% (RCP 2.6, 2050) -2.5% (RCP 4.5, 2050) -3.6% (RCP 8.5, 2050)	Climate Analytics (2025)
DAMAGES TO IRRIGATION CANALS AND SYSTEMS	1 m. GEL	Own assumption
LOSSES DUE TO FOREST DISEASES	121 m GEL	Remissia (2025b)

Source: own compilation, see also Flaute et al. (2022)

Droughts mainly affect the agricultural and forestry sector. The agricultural sector faces crop losses due to the scarcity of rain and water. Further, grapes get damaged which leads to quality losses and losses in harvest. The risk of forest fires increases. Irrigation canals and systems get damaged. The energy sector is affected by limited energy generation from hydropower.

Table 4 shows the benchmark damages / impacts of droughts for the intensity category high. It is assumed that the benchmark damage of intensity category low is 10% of intensity category high, and that the benchmark damage of the intensity category medium is in the middle.

Table 4: Droughts

IMPACT	BENCHMARK DAMAGE / IMPACT	SOURCE:
DAMAGES TO GRAPES	50 m. GEL	Own assumption based on evidence from France
LOSSES IN HARVEST DUE TO SCARCITY OF RAIN AND WATER	-10 %	PESETA Project (Freyen et al. (2020), Hristov et al. (2020))
DAMAGES TO IRRIGATION CANALS AND SYSTEMS	1 m. GEL	Own assumption
LIMITED ELECTRICITY SUPPLY FROM HYDRO POWER	-5,2 / -20 %	Own assumption based on van Vliet (2016)
LOSSES DUE TO FOREST FIRES	5,8 m. GEL	Remissia (2025b)

Source: own compilation, see also Flaute et al. (2022)

Floods might damage buildings, properties and transport, water and energy infrastructures. Due to interrupted supply chains production losses occur in affected sectors and impact also downstream sectors.

Table 5 shows the benchmark damages / impacts of floods for the intensity category high. It is assumed that the benchmark damage of intensity category low is 10% of intensity category high, and that the benchmark damage of the intensity category medium is in the middle.

Table 5: Floods

IMPACT	BENCHMARK DAMAGE / IMPACT	SOURCE:
BUILDINGS GET DAMAGED AND NEED TO BE RECONSTRUCTED	14,5 m. GEL	GFDRR et al. (2015)
INFRASTRUCTURE IS DAMAGED AND NEEDS TO BE RECONSTRUCTED	32 m. GEL	GFDRR et al. (2015)
WATER AND SANITATION SYSTEM GETS DAMAGED AND NEED TO BE RECONSTRUCTED	2,7 m. GEL	GFDRR et al. (2015)
HOUSEHOLD GOODS NEED TO BE REPLACED	1,6 m GEL	GFDRR et al. (2015)
CARS ARE FLOODED AND NEED TO BE REPLACED	1,2 m GEL	GFDRR et al. (2015)
ELECTRICITY SYSTEM, OIL AND GAS PIPELINES AND IRRIGATION SYSTEMS GET DAMAGED AND NEED TO BE RECONSTRUCTED	1 m. GEL each	Own assumption
PRODUCTION LOSSES DUE TO INTERRUPTED SUPPLY CHAINS AND FLOODED PRODUCTION SITES (SECTORS 3-18)	-1%	Own assumption
CROP LOSSES	-10%	PESETA Project (Freyen et al. (2020), Hristov et al. (2020))

Source: Own compilation, see also Flaute et al. (2022)

4.2. Results of scenario SSP5-8.5

A scenario analysis is being performed to show the economy-wide impacts of the climate change scenarios. The detailed analysis on future development of climate hazards by intensities and observed climate hazard impacts by intensity category for the three climate change scenarios results in a time series of expected future impacts for the respective climate hazards. These time series are then assigned to specific variables in the e3.ge model.

In this section the focus of the description is on SSP5-8.5, which is the most pessimistic scenario in terms of concentrations of GHG in the atmosphere and global temperature increase compared to the preindustrial level. The effects of the two other SSPs (SSP1-2.6 and SSP2-4.5) are briefly described in section 0.

The following results show aggregated GDP impacts of floods, droughts and heatwaves for Georgia. In scenario SSP5-8.5 climate damage increases continuously until 2050 and result in a GDP loss of 4.9% (resp. 11.8 mln GEL) compared to the reference without climate change in 2050 (Figure 9). Imports are increasing due to limited production capacity caused by damages, production losses due to interrupted supply chains and reduced labour productivity in many sectors. It is assumed that imports will replace (lost) domestic production in order to satisfy demand. Consumption expenditures of households and government and gross fixed capital formation will be negatively impacted.

Overall, total real production decreases by 27.2 mln GEL in 2050 compared to the reference. Particularly large negative effects occur in agriculture, manufacturing and private services, which account for the largest share of total value added (Figure 10). Agriculture is particularly affected from the crop losses during droughts, heatwaves and floods and the productivity losses during heatwaves. Many other sectors are impacted from reduced labour productivity during heatwaves and production interruptions. Energy production could benefit slightly from higher precipitation and the associated electricity generation from hydropower.

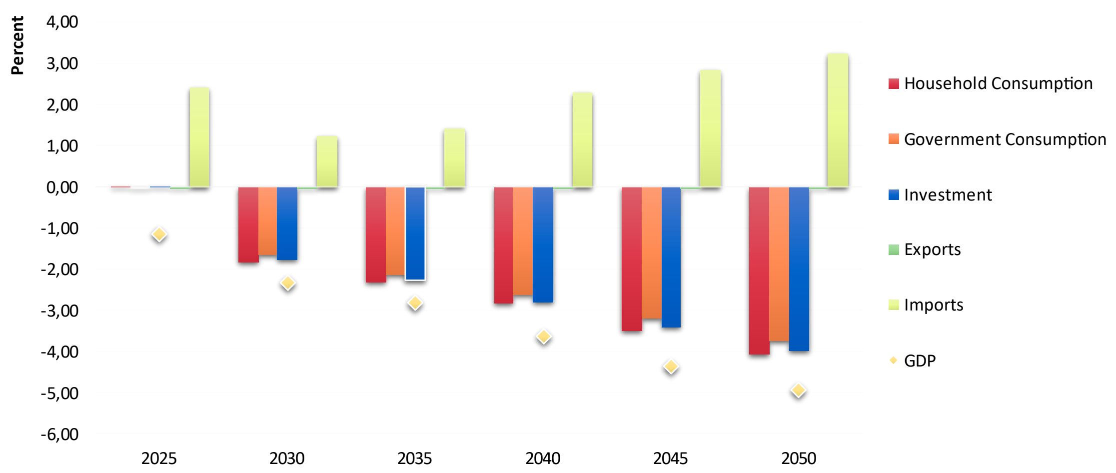

Figure 9: SSP5-8.5: Macroeconomic effects of climate change (compared to reference, in %)

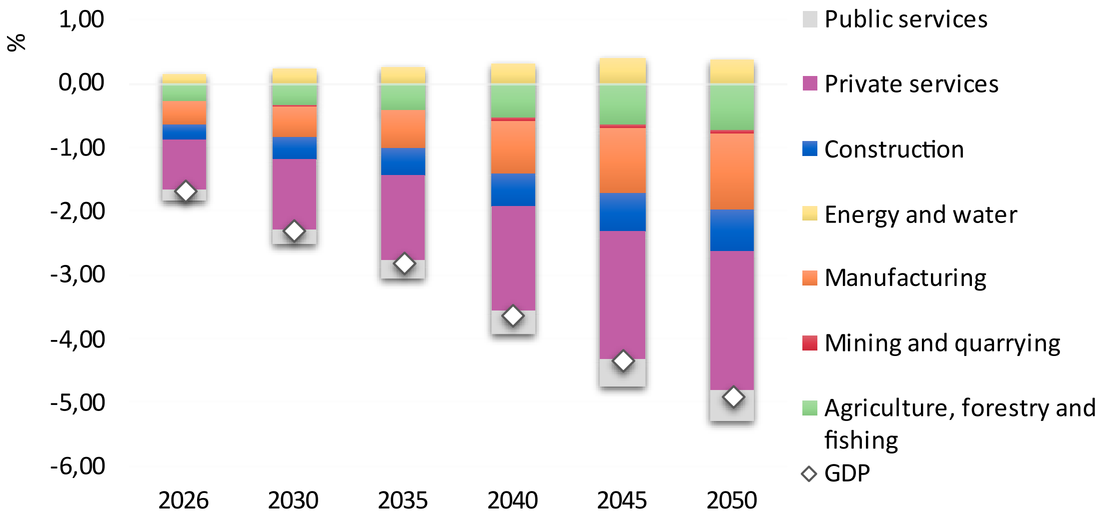

Figure 10: SSP5-8.5: Climate change effects on production (compared to reference, in %)

Source: GWS based on e3.ge

In 2050 total employment will be 4,700 persons (respectively 0,2 %) lower than in the reference without climate change (Figure 11). The sectoral effects are similar to those of production. The decline in employment particularly affects the agricultural, forestry and fishing sectors as well as the private services sector, while employment in energy and water is increasing.

Analysing the results differentiated by gender (Figure 12) shows that female workers are in total more affected than male workers, because male employment dominates in the energy and water sectors, which compensate for the decline in the other sectors. In 2050 total female employment will be 5,200 persons lower than in the reference, while mainly structural effects are identified for male employment.

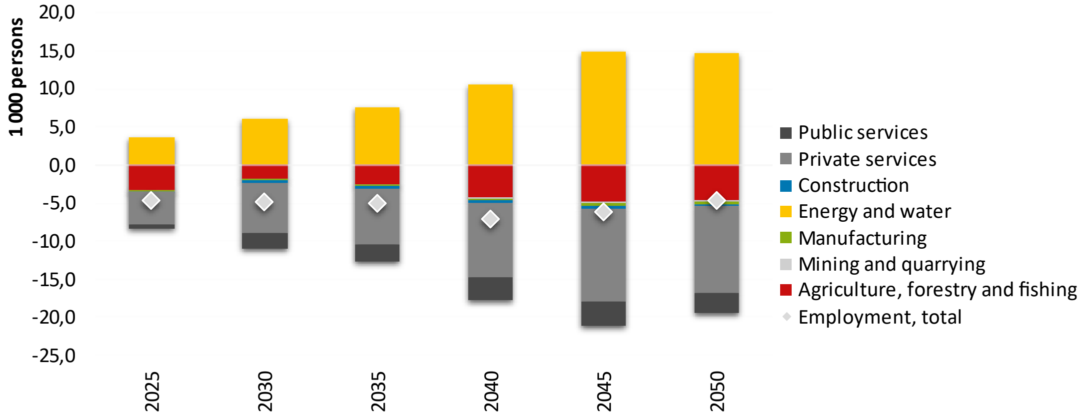

Figure 11: SSP5-8.5 scenario: employment by economic activities (compared to reference, in 1000 persons)

Source: GWS based on e3ge

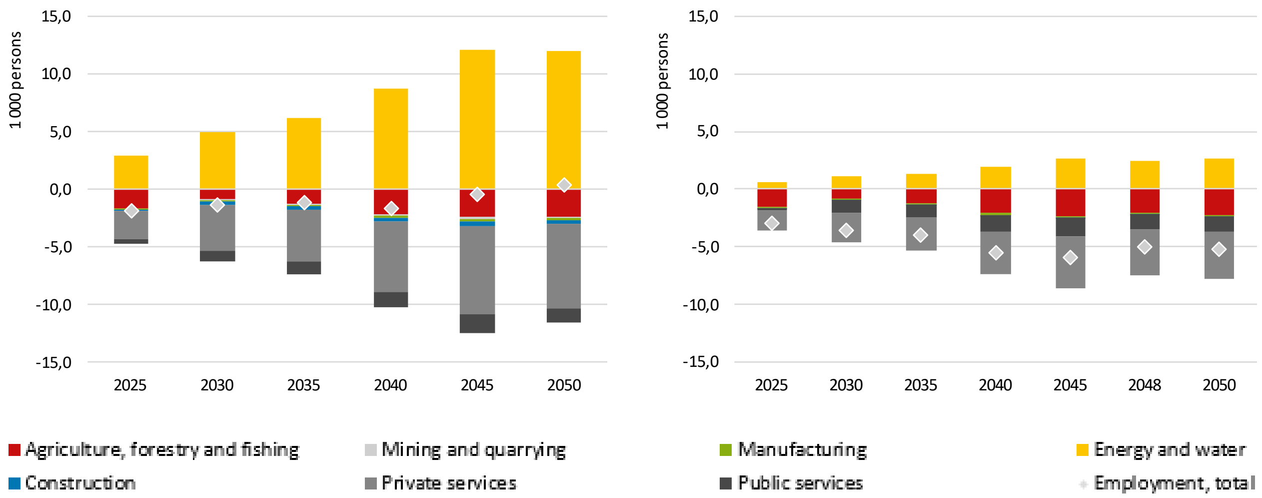

Figure 12: SSP5-8.5 scenario: employment by economic activities and gender in 1,000 persons (2025-2050), male (left figure), female (right figure)

Source: GWS based on e3ge

The following sections show briefly the macroeconomic effects of heatwaves, droughts and floods separately.

In scenario SSP5-8.5 climate damage of heatwaves increases continuously until 2050 and result in a GDP loss of 4.5 % compared to the reference without climate change. Particularly negative effects arise for household consumption and imports. The effects result mainly from changes in the structure of household consumption and production losses due to lower labour productivity. Particularly large negative effects occur in agriculture, manufacturing and private services, which account for the largest share of total value added.

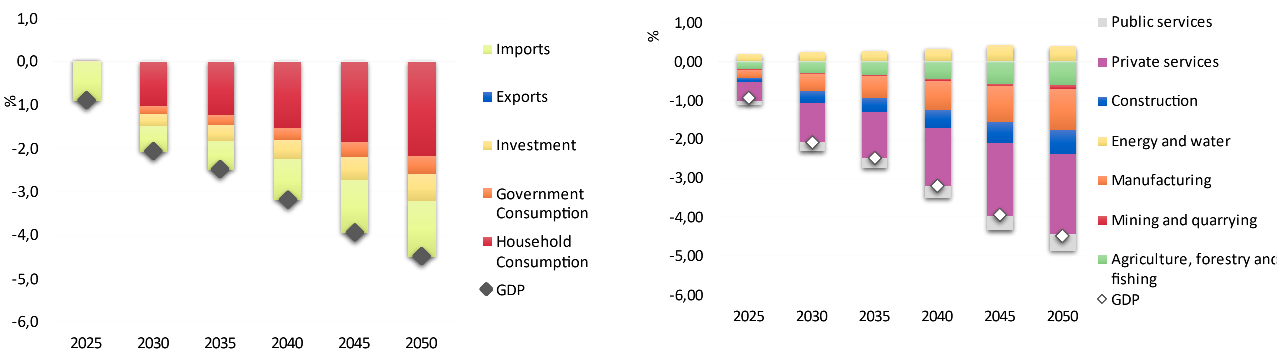

Figure 13: SSP5-8.5 Climate change effects of heatwaves on GDP and its components (left) and production (right), (2025-2050, compared to reference, in %)

Source: GWS based on e3ge

In scenario SSP5-8.5 climate damage of droughts are constant over time and result in a GDP loss of 0.2 % compared to the reference without climate change. The results are partly because the probability of occurrences for the three intensity categories of scenario SSP5-8.5 are also rather constant over time. While there are mainly negative effects on imports in the near future, there are mainly negative effects on household consumption in the following years. Particularly large negative effects occur in energy and water in the near future, due to the limited electricity supply from hydro power, and private services in the following years.

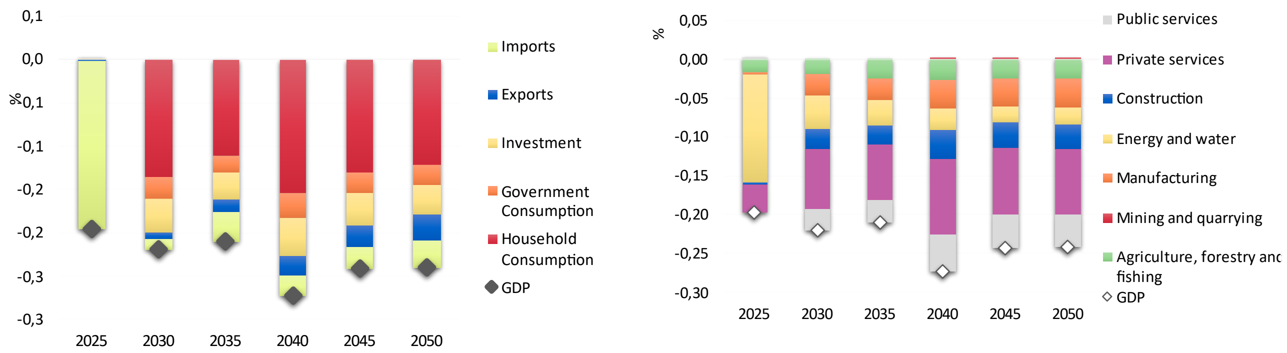

Figure 14: SSP5-8.5 Climate change effects of droughts on GDP and its components (left) and production (right), (2025-2050, compared to reference, in %)

Source: GWS based on e3ge

In scenario SSP5-8.5 climate damage of floods result in a GDP loss of around 0.1 % up to 2035 and around 0.2 % up to 2050 compared to the reference without climate change. The results are partly because the probability of occurrences for the three intensity categories of scenario SSP5-8.5 are also rather constant over time. While there are mainly negative effects on imports in the near future, there are mainly negative effects on household consumption in the following years. Particularly large negative effects occur in agriculture and private services.

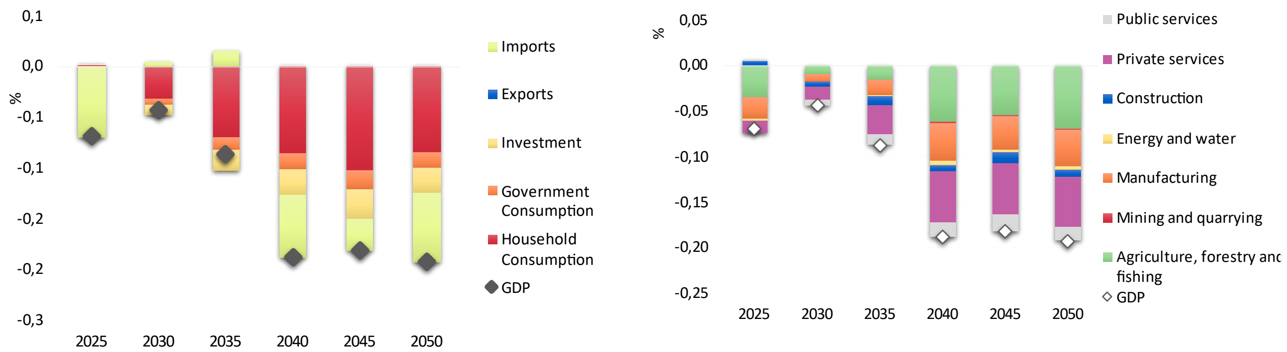

Figure 15: SSP5-8.5 Climate change effects of floods on GDP and its components (left) and production (right), (2025-2050, compared to reference, in %)

Source: GWS based on e3ge

4.3. Comparative presentation of results for SSP1-2.6 and SSP2-4.5

Scenario SSP1-2.6, which corresponds to comprehensive global climate protection, shows also negative impacts for GDP, consumption and investment compared to the reference, that largely stagnate from 2030 onwards. SSP2-4.5 lies in-between the two other scenarios. Its development is similar to SSP1-2.6 until 2040, then climate change damage increase. The results are within the range of the literature (IMF 2019, Waidelich et al. 2024).

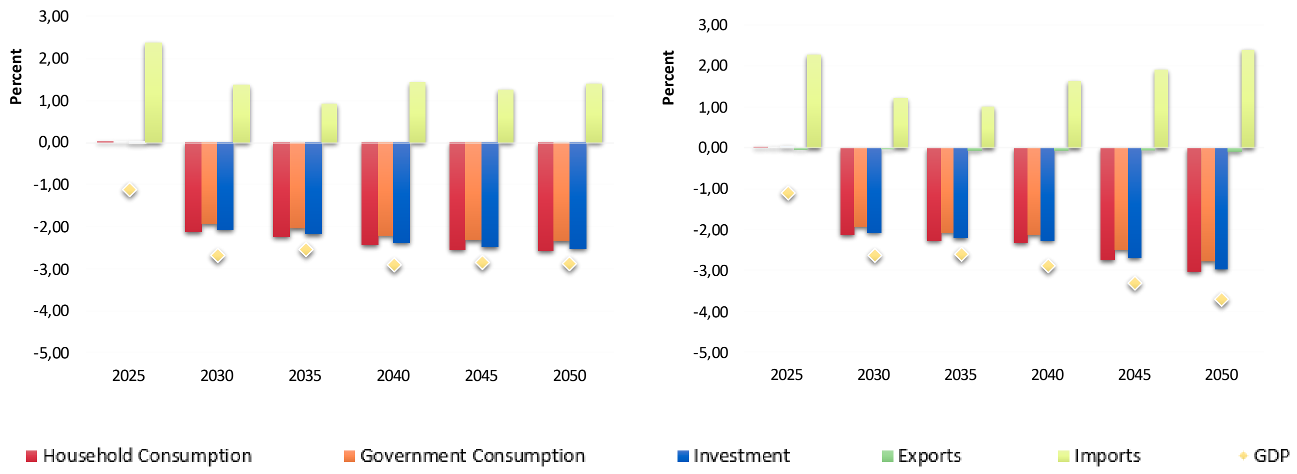

Figure 16: Macroeconomic effects of climate change (compared to reference, in %), SSP1-2.6 (left) & SSP2-4.5 (right)

Source: GWS based on e3ge

At the sectoral level, climate change leads to predominantly negative effects on production and employment, with services, manufacturing, construction, and agriculture being particularly affected. In contrast, electricity generation can even expect positive effects due to higher water availability. In the long term, however, these are likely to turn negative because less water will be available in the second half of the century.

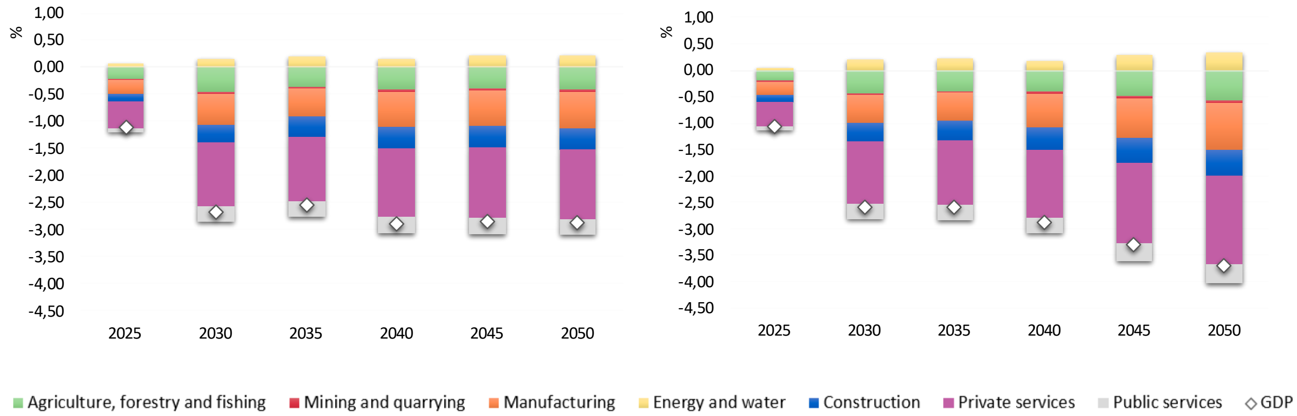

Figure 17: Climate change effects on production (compared to reference, in %), SSP1-2.6 (left) & SSP2-4.5 (right)

Source: GWS based on e3ge

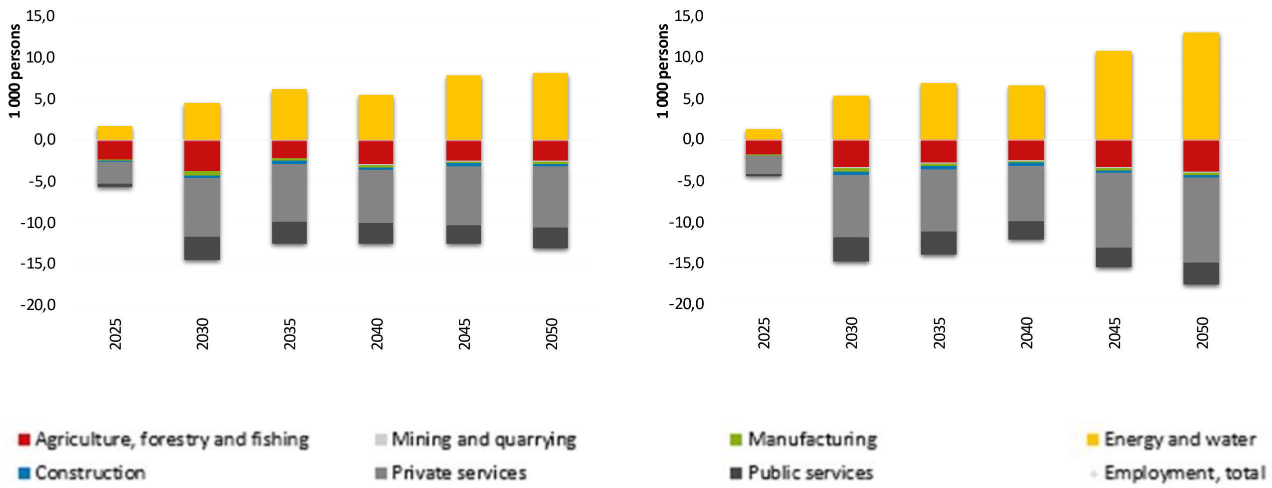

Figure 18: Employment by economic activities (compared to reference, in 1000 persons), SSP1-2.6 (left) & SSP2-4.5 (right)

Source: GWS based on e3ge

5. ECONOMICS OF ADAPTION TO CLIMATE CHANGE

5.1. Adaptation in agriculture: Enhanced windbreaks

The restoration of windbreaks has been recognized as a crucial step in the adaptation to the effects of climate change, in particular the decline in crop yields due to wind erosion and heavy winds. Basic considerations on implementation in the e3.ge model and first quantifications can be found in Flaute et al. (2022).

There are three fundamental differences compared to this publication: Firstly, the economic model has been updated in 2024. Secondly, the damage caused by extreme wind events is no longer assumed to occur every 5 years but is distributed over the entire simulation period. Thirdly, the cost-benefit analysis of Sustainable Development Center "Remissia" (2025a) was fundamentally revised regarding the rehabilitation of the windbreaks.

The starting point for the scenario calculations is the reference scenario. There are two scenarios implemented: the climate change scenario (reduced crop yield due to heavy wind and wind erosion) and the adaptation scenario (rehabilitation of windbreaks).

5.1.1. Scenario settings

Table 7: Investment Costs (2026 to 2028)

INVESTMENTS PER HECTAR	Cost (GEL/ha)
Clearing the territory from stones, shrubs, and remaining roots and stumps	3,000
Soil laboratory analysis	400
Soil primary tillage with deep ploughing and harrowing	1,200
Drip Irrigation System Installation Costs	5,000
Fencing the Area for Restoration/Planting new windbreakers	7,000
Ploughing and Subsequent Harrowing a 1-1.5m wide strips along the windbreaker for fire prevention	400
NUMBER OF INSTALLATIONS PER HA	Costs per installations
One Agrometeorological Station **will be installed per 100** ha of **protected lands**. Agrometeorological Stations measure (Wind Direction, Speed, Temperature, Humidity, Soil Moisture, etc.)	48,000
Camera for Monitoring of safety of plantations (Solar Panel and SIM supported), Installed on a High Pole. One camera is needed per hectare of wind breaker.	2,500
PLANTING OF WINDBREAKS (2500 trees will be planted per hectare of windbreaker)	Cost (GEL/ha)
Cost for 2500 saplings per ha and for whole hectares of windbreakers (3 GEL each)	7,500
Cost for preparation of planting process: identification of locations for planting, digging and preparation of wholes, pre-planting placement of seedlings in holes (preparing wholes and seedlings for planting) (1 GEL each)	2,500

Planting Seedlings (1 GEL each)	2,500
Purchase and Installation of Support Stakes for Seedlings (1 GEL each)	2,500
ADMINISTRATION COSTS	Cost (GEL/ha)
Preparation of Windbreak Restoration and Establishment Project/Plan	1,080
PUBLIC AWARENESS COSTS	Number of farmers
Conducting awareness raising activities on Windbreaks for 46 200 farmers (100 GEL each)	46,200

Source: Remissia (2025a)

Table 8: Operational Costs

COSTS BY LAND AGENCY/ MUNICIPALITY	Cost (GEL/ha)
Monitoring and Evaluation of windbreaks with 1 employee per 300 ha of windbreak strips with 18,000₾ annual gross salary.	60
WINDBREAK MAINTENANCE AND IRRIGATION – only done for the first 5 years	Cost (GEL/ha)
Pruning and Shaping (Routine, Sanitary and Reconstruction)	500
Removal dead saplings and replanting new ones	1,133
Pathological Studies and Monitoring	50
Pest and Disease Control	400
Weed Control	400
Annual Irrigation Water Fee (Melioration)	75
Seasonal Irrigation Operational Costs (Electricity)	500
Maintenance Costs for Irrigation System	500
PROTECTION FROM FIRE, OVERGRAZING, AND CUTTING. CLIMATE AND REMOTE OBSERVATION	Cost (GEL/ha)
For Fire Prevention: Ploughing a 1-1.5m Wide Strip Along the Windbreak and Subsequent Harrowing	400
Internet Subscription Fee for Camera	60
API annual fee for the weather station	20
Maintenance costs such as: cleaning, software update, replacement of batteries and infrared sensors.	50
Annual Subscription Fee for Satellite Monitoring System	15

Source: Remissia (2025a)

The aggregated values for the two regions analysed in the CBA, Shida Kartli and Kakheti, are shown in Table 9.

Table 9: Total investment and annual operational costs

COSTS	CATEGORY
INVESTMENT COSTS (TOTAL)	Preparation and planting (243.6 m GEL), agrometeorological stations and cameras (80.1 m GEL), public awareness and administrative costs (13.4 m GEL). Investment is distributed over 3 years (40%, 40%, 20%).
OPERATIONAL COSTS (ANNUALLY)	Maintenance and irrigation (27.4 m GEL, for the first 5 years), monitoring and evaluation (0.5 m GEL), protection and remote observation (3.7 m GEL)

Source: Own representation based on Remissia (2025a)

The CBA was carried out by Remissia for the two most vulnerable regions to high-speed winds, Shida Kartli and Kakheti. For both regions, a total of 7691.8 ha of windbreaks are to be restored and maintained. To upscale the analysis to the national level, it was assumed that category 1 regions (wind speeds above 9 m/s) will be restored, which corresponds to 11,914.14 ha. This results in total investment costs of 522 m GEL and annual operational costs of 48.9 m GEL for the first five years and 6.5 m GEL for the following years.

The costs associated with the investment in windbreaks are distributed as follows: 70% from the government, 20% from international organizations, and 10% from the private sector. It is assumed that new equipment such as meteorological stations and cameras are investment goods that are mainly imported from abroad. Expenditure on personnel and administration, on the other hand, is recorded as government consumption with a higher domestic share in the value chain.

The costs for maintenance and operation are distributed as follows: It is assumed that initially the government holds 90% of the windbreaks and the private sector 10%. Over time, the government's share would decrease while the private sector's involvement and ownership share would increase, it is assumed that 30% would be held by the state and 70% by the private sector by 2050. The costs are accounted for as private or public consumption and also distributed over time based on these shares.

In year 1 and 2, in both years 40% of the windbreaks are restored, in year 3 the remaining 20%. In line with the CBA, we therefore assume a rapid restoration of windbreaks. Windbreak maintenance and irrigation needs only be done for the first 5 years (2026-2032). Further operational costs incur annually (2026-2050).

The last two assumptions about the temporal allocation of investment expenditure and operational costs are then also reflected in the temporal course of the macroeconomic effects.

Table 10: Benefits of the rehabilitation of windbreaks

BENEFITS
Reduced loss of crop yields: 16%
Saving irrigation costs: 20
Increased value of land: 1%.

Source: Remissia (2025a)

The benefits of the planted windbreaks begin to pay off 5 years after rehabilitation. For the sake of simplicity, it is assumed that this effect does not further increase over time.11,914.14 ha of windbreaks protect 196,294 ha agricultural land.

The benefits of windbreaks differ depending on the crop type. In the first phase of CRED, the following benefits (increased crops yields from windbreaks p.a.) were determined for the individual crops on the basis of literature research and expert meetings:

Table 11: Increased crop yields from windbreaks by different crop types

• Maize: 18%	• Potato: 15%	• Vegetables: 15%
• Wheat: 15%	• Fodder crops: 20%	• Others: 15%
• Barley: 25%		

Source: see Flaute et al. (2022)

Barley and fodder crops are therefore more vulnerable to strong winds than other crops. Further benefits resulting from windbreaks, such as their potential for carbon storage and sequestration are currently not included in the modelling but could have an additional impact. Carbon storage could achieve a high value on an (international) carbon market in the future, depending on the price of CO_2; currently, the carbon price in the EU ETS is around 60 euros per ton of CO_2.

5.1.2. Results

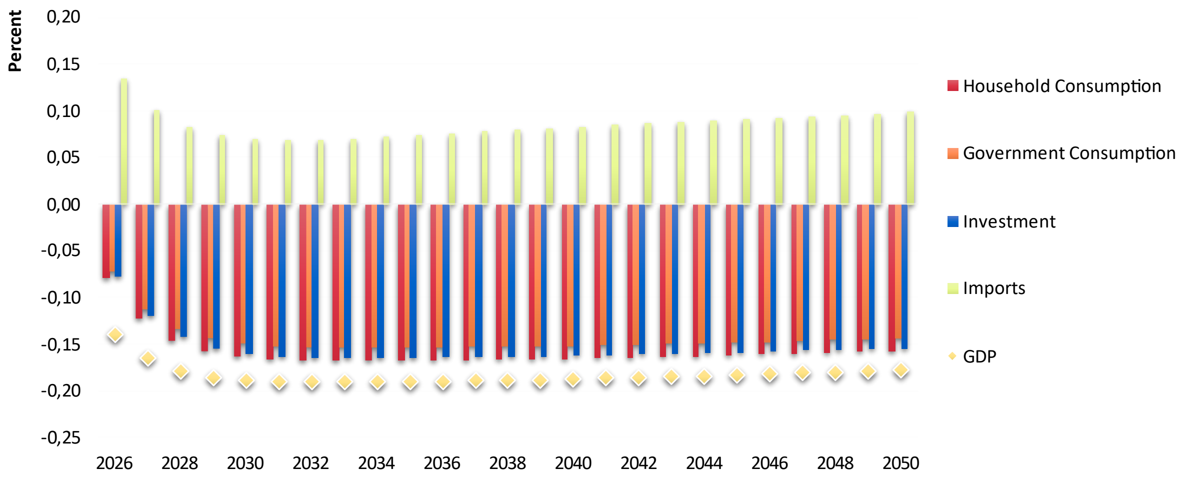

Figure 19: GDP Impacts of Climate Change Scenario (SSP 5-8.5) (Compared to Reference, in %)

Source: GWS based on e3ge

The macroeconomic effects of the climate change scenario (wind damages on crop yields, SSP 5-8.5) are shown as deviations from the reference scenario in percent in Figure 19 and in absolute terms in Figure 20. Climate change leads to crop losses due to heavy wind events and wind erosion. This will increase agricultural imports and decrease GDP. Consumption expenditures of households and government and gross fixed capital formation will be negatively impacted. In absolute terms GDP losses will go up to -427 m GEL in 2050 (resp. -0.18%). The highest percentage deviation is -0.19% in 2032.

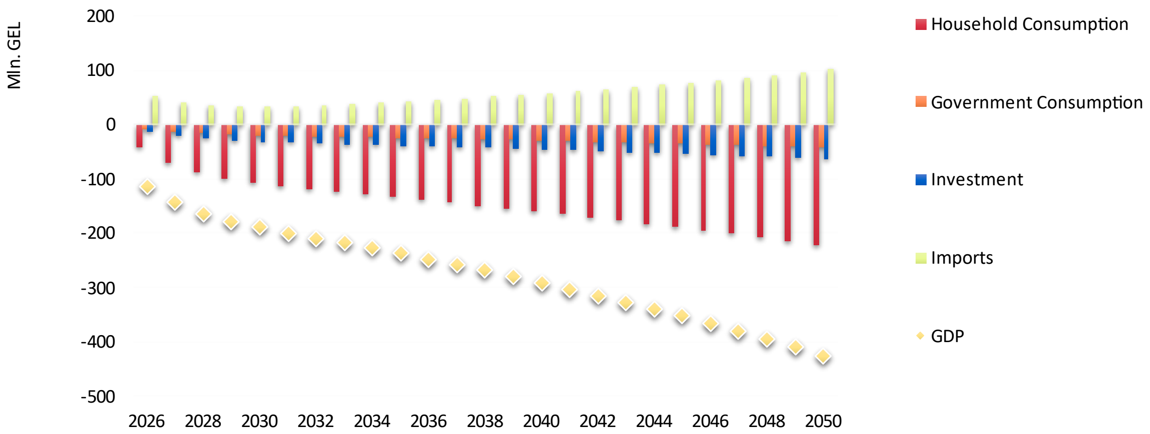

Figure 20: GDP Impacts of Climate Change Scenario (Compared to Reference, in m GEL)

Source: GWS based on e3ge

The macroeconomic effects of the adaptation scenario (investing in and operation and maintenance of natural windbreaks) are shown as relative deviations from the climate change scenario in percent in Figure 21 and as absolute deviations from the climate change scenario in m GEL in Figure 22.

The investments in windbreaks imply preparation of the soil and planting of seedlings, which is done by local workings providing agricultural services. Further, agrometeorological stations and cameras needed, leading to investment in computer products and services. Additionally, drip irrigation systems are installed, that are imported, which on the one hand require the local construction industry for installation and on the other hand water fees need to be paid. Public administration is also preparing a windbreak restoration and establishment plan and implementing accompanying awareness raising activities. Over time, monitoring and maintenance activities will be carried out, for which agricultural services, laboratory analysis, and computer services will be needed.

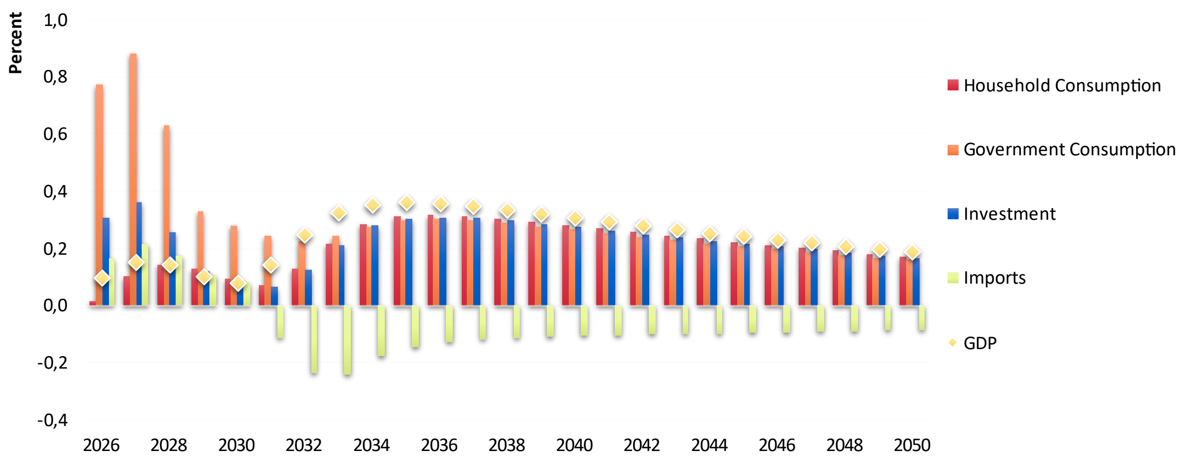

Figure 21: Adaptation Scenario: GDP Impacts of Rehabilitation of Windbreaks (Compared to Climate Change Scenario, in %)

Source: GWS based on e3ge

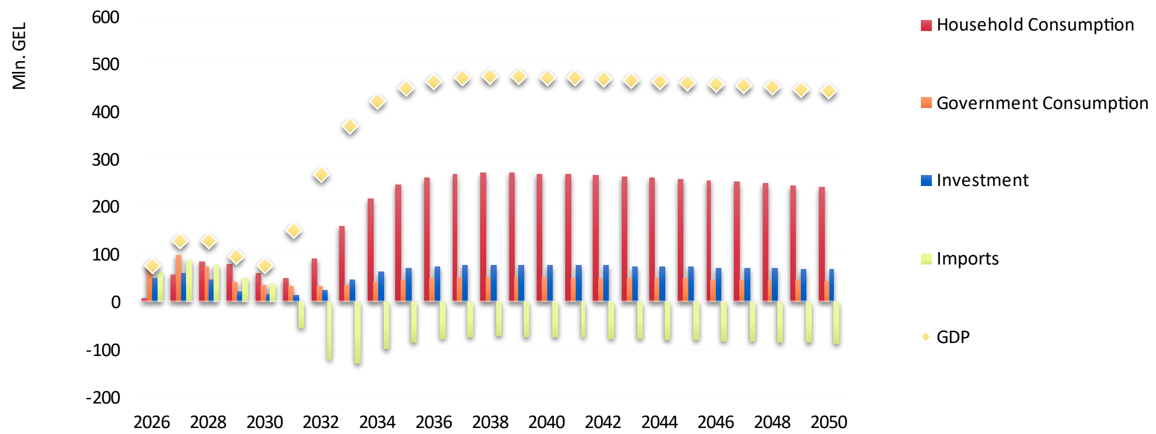

Figure 22: Adaptation Scenario: GDP Impacts of Rehabilitation of Windbreaks (Compared to Climate Change Scenario, in m GEL)

Source: GWS based on e3ge

The rehabilitation of windbreaks leads to an increase in consumption expenditures of households and government and gross fixed capital formation and have a positive effect on GDP. Windbreaks lead also to higher crop yields, what reduces imports and increases GDP. The highest percentage deviation in GDP is 0.36% in 2035. In absolute terms the highest GDP increase is 472 m GEL in 2039.

The GDP effects over time can be explained as follows: Over the course of the first 3 years show additionally assumed adaptation investments, mainly as government consumption, increase GDP. In the following years, higher operating costs are still incurred until the wind breaks have grown sufficiently, which is reflected in a slight increase in government spending in the years 2029 to 2032. Thereafter, the operating costs are significantly lower.

Crop yields will only begin to increase after 5 years, when it is assumed that the wind breaks have grown so high that they better protect the fields and crop yields increase again. Crop imports start to decrease in 2031 due to higher domestic production and GDP and its domestic components are correspondingly higher than in the climate change scenario. Then the higher crop yields are primarily responsible for the positive GDP effects.

The sectoral effects are similar for production and employment. Especially in agriculture and services, but also in the manufacturing and construction sectors, there is an increase compared to the reference, on the one hand due to the additional investments (see below for more detail) and on the other hand due to the avoided damages in agriculture.

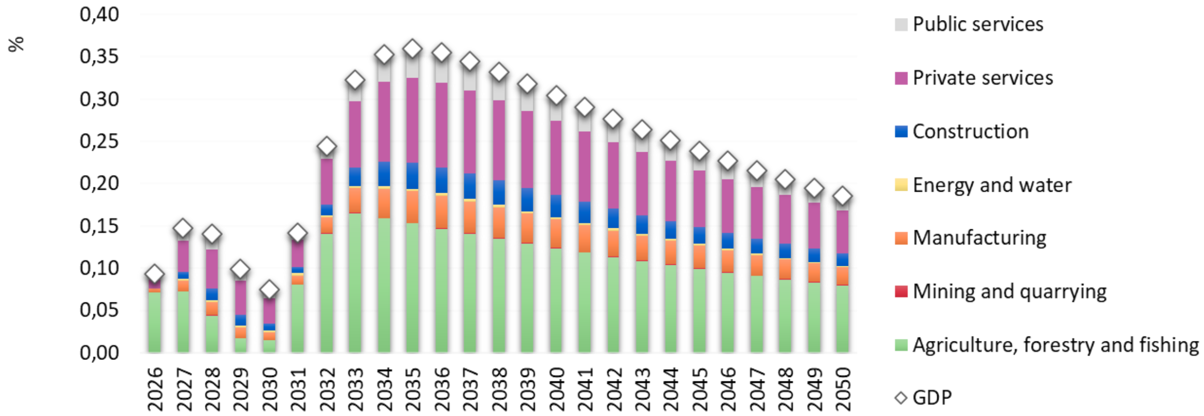

Figure 23: Effects on production of Rehabilitation of Windbreaks (Compared to Climate Change Scenario, scaled to GDP change in %)

Source: GWS based on e3ge

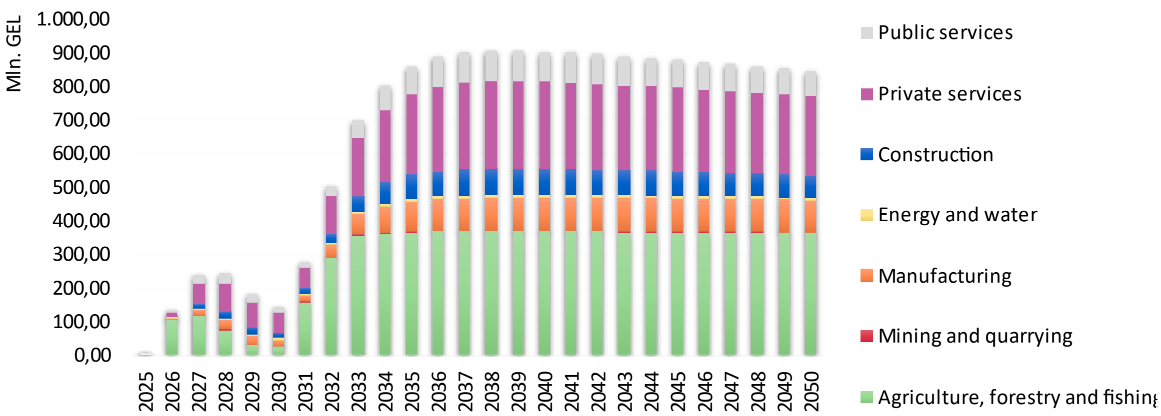

Figure 24: Effects on production of Rehabilitation of Windbreaks (Compared to Climate Change Scenario, in m GEL)

Source: GWS based on e3ge

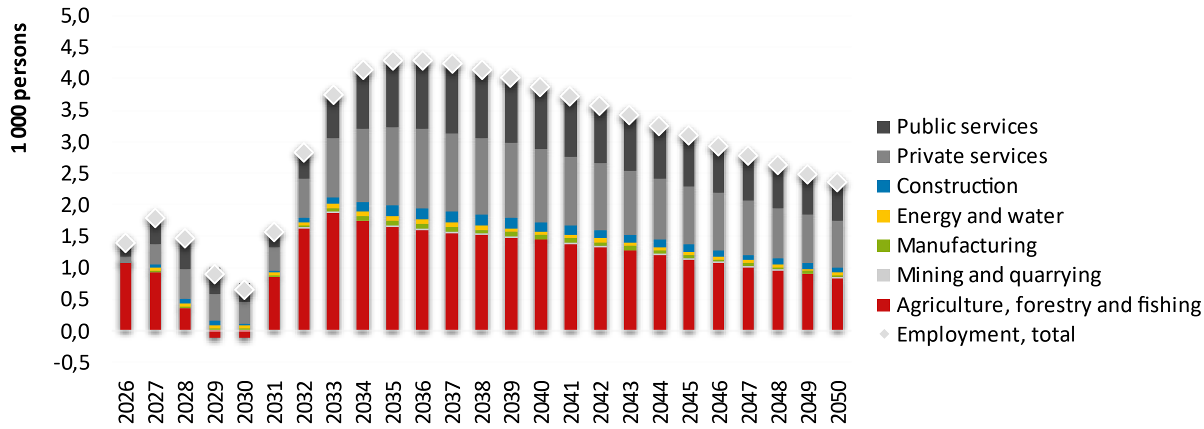

Figure 25: Employment Effects of Rehabilitation of Windbreaks (Compared to Climate Change Scenario)

Source: GWS based on e3ge

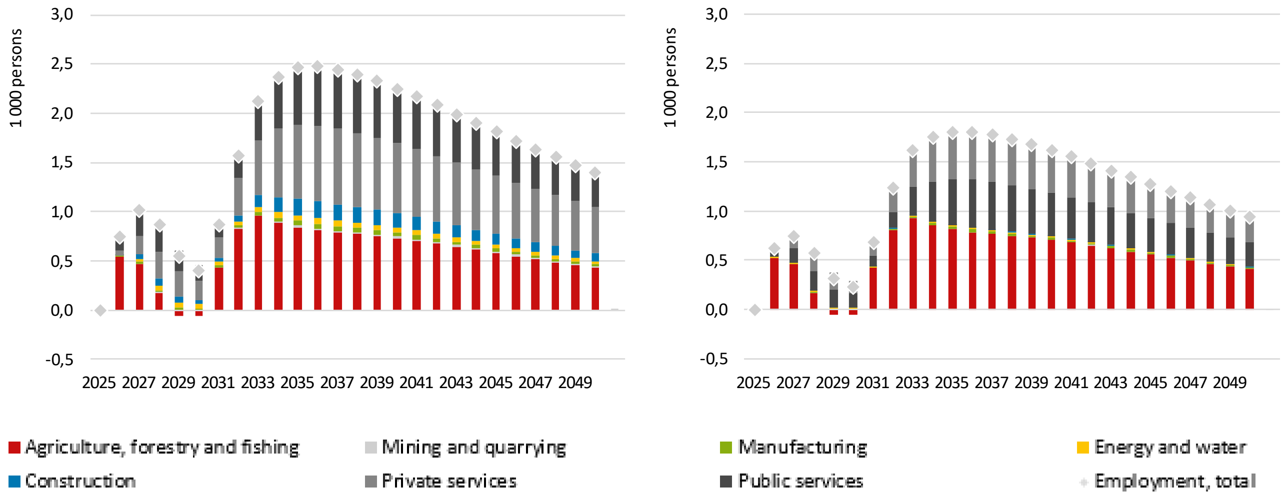

Figure 26: Rehabilitation of Windbreaks: Employed persons by economic activity and gender in 1,000 persons (2025-2050), male (left figure), female (right figure)

The implementation of the adaptation measure has also positive effects on employment, shown in Figure 7. The effects are shown as absolute deviations from the climate change scenario (in 1,000 persons). For example, up to 4,280 additional people can be employed in 2035. This corresponds to an increase of up to 0.2% in that year. 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 public administration and in the transportation sector. The additional employment decreases over time but remains clearly positive.

Positive macroeconomic effects result from two assumptions and the transmission channels based on them: Firstly, adjustment investments are additional. We assume that these investments are in addition to existing expenditure and do not crowd out other investments. This can be justified on the one hand by high benefit-cost ratios of the adaptation measures, i.e. they are at least partially financed by the positive macroeconomic impact via higher GDP and the associated government revenues. On the other hand, it can be assumed that at least some of the investments will be paid for from international sources of climate financing or economic cooperation in general. It can be assumed that at least some of the corresponding payments will be additional. If the adaptation investments are not additional in the sense described, there would be less of a positive macroeconomic effect, depending on what effect the crowded-out investments would have had. However, this can hardly be quantified without a more detailed analysis. Secondly, the adjustment measures have a positive effect on agricultural production, which is also reflected on the macroeconomic level.

5.2. Forestry: Adaptation against forest fires and forest diseases

Forests are severely affected by climate change due to additional forest fires and diseases. It should be noted that they also play an important role in climate protection because healthy forests can store carbon to a greater extent and therefore represent an important natural negative emissions option. This aspect is not considered below but could have an additional important impact on GDP especially if carbon prices are higher. To mitigate the climate change related risks of forest fires and forest diseases in Georgia, several adaptation measures have been proposed. The following two scenarios are implemented:

- Climate Change Scenario: Losses due to forest fires and forest diseases
- Adaptation Scenario: Implementation of adaptation measures such as a weather monitoring system, development of fire-protective roads, construction of water ponds against forest fires and a weather monitoring system, the establishment of a phytopathological and bio-laboratory, and capacity building initiatives against forest diseases. Rehabilitation of previously damaged areas is also part of the adaptation scenario.

The starting point for the scenario calculations is the reference scenario.

5.2.1. Scenario settings

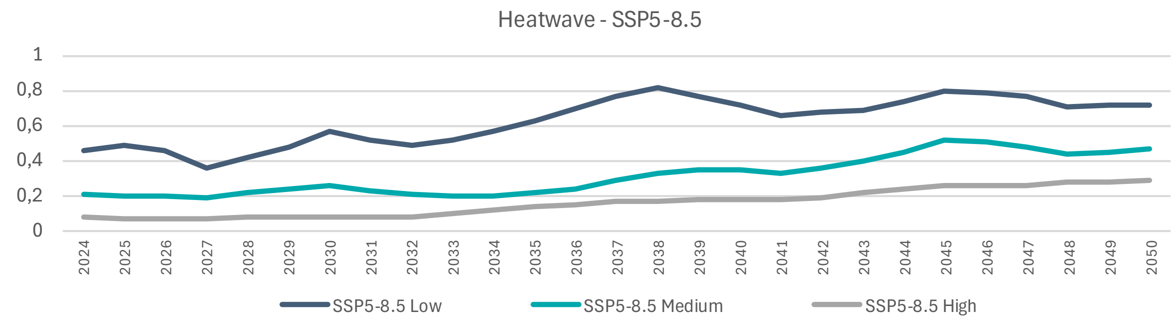

Figure 27: Probability of occurrences for heatwaves in SSP5-8.5

Source: GWS, based on data from EarthYield Advisories (GIZ 2025a)

The damage caused by forest diseases will be much higher than the damage caused by forest fires. In 2025, the ratio is 8:1, and in 2050 it will be as high as 17:1.

The adaptation scenario is based on two CBAs (for forest fires and forest diseases) carried out by Remissia and contains the following assumptions:

Table 12: Investment Costs: Forest Fires

INVESTMENT COSTS: ADAPTATION AGAINST FOREST FIRES	UNITS	COSTS PER UNIT (USD)	COST (USD)
SENSOR FOR MEASURING WEATHER /CLIMATIC PARAMETERS	7	35,000	245,000
COMPUTER	14	2,000	28,000
SOFTWARE FOR CALCULATION OF FIRE INDEX AND HEAT WAVE INDEX	14	5,000	70,000
DRONES	3	20,000	60,000
ARRANGEMENT OF FIRE PROTECTIVE ROADS 0.5 KM PER 100 HA	9,048	2,500	22,620,000
ROAD PAYMENT TECHNIQUE	3	170,000	510,000
ARRANGEMENT OF WATER SOURCE FOR FIRE	45	50,000	300,000
FIRE PROTECTIVE CLOTHING AND EQUIPMENT	25	300	7,500
FIRE CARS	3	360,000	1,080,000
REHABILITATION OF AREAS DAMAGED BEFORE 2025			15,475,000

Source: Remissia (2025b)

Table 13: Operational Costs: Forest Fires

OPERATIONAL COSTS: ADAPTATION AGAINST FOREST FIRES	UNITS	COSTS PER UNIT (USD)	COST (USD)
PERSONS SERVING THE MONITORING SYSTEM	14	12,000	168,000
PERSONS RESPONSIBLE FOR MONITORING OF FIRE PREVENTION PROTOCOLS.	6	12,000	72,000

Source: Remissia (2025b)

Table 14: Investment Costs: Forest Diseases

INVESTMENT COSTS: ADAPTATION AGAINST FOREST FIRES	UNITS	COSTS PER UNIT (USD)	COST (USD)
METEOROLOGICAL STATIONS FOR MONITORING OF HEAT WAVES AND OTHER CLIMATIC PARAMETERS/INDEXES	12	35,000	420,000
COMPUTERS FOR ANALYSING MEASURED/MONITORED CLIMATIC DATA	10	2,000	20,000
SOFTWARE FOR CALCULATION OF HEAT WAVE INDEX	10	5,000	50,000
ESTABLISHMENT OF PATHO-BIO LABORATORY	1	400,000	400,000
CAPACITY BUILDING	3	1,000,000	3,000,000
REHABILITATION OF AREAS DAMAGED BEFORE 2025, 89140 HA	89,140	5,000	445,700,000

Source: Remissia (2025b)

Table 15: Operational Costs: Forest Diseases

OPERATIONAL COSTS: ADAPTATION AGAINST FOREST FIRES	UNITS	COSTS PER UNIT (USD)	COST (USD)
FULL INTEGRATED PEST MANAGEMENT	81	30,000	2,431,200
FORESTERS' ANNUAL SALARY	10	8,400	84,000
PERSONS SERVING THE MONITORING SYSTEM	10	20,000	200,000

Source: Remissia (2025b)

The CBA for forest fires was conducted by Remissia for the three most vulnerable regions Samtskhe-Javakheti, Imereti, and Kakheti, covering a total area of 904,800 hectares, which equals 40% of total forest cover in Georgia. These three regions form the category 1 regions, which are particularly vulnerable to damages.

The aggregated values for forest fires for the three regions analysed in the CBA, Samtskhe-Javakheti, Imereti, and Kakheti, are shown in Table 16.

The CBA for forest diseases was conducted by Remissia for the three most vulnerable regions Adjara, Imereti and Samegrelo-Zemo Svaneti, covering a total area of 663,500 ha. In order to upscale the analysis to the national level, it was assumed that category 1 regions, covering an area of 1,352,700 ha, will be adapted.

The aggregated values for forest diseases for the three regions analysed in the CBA, Adjara, Imereti and Samegrelo-Zemo Svaneti, are shown in Table 17.

Table 16: Total investment and annual operational costs

COSTS	CATEGORY
INVESTMENT COSTS (TOTAL)	Sensors and computer technology, software and drones (2.6 m GEL), construction of roads and water ponds (71.1 m GEL), fire protective equipment (0.02 m GEL), rehabilitation (44.3 m GEL). Investment is distributed over 3 years (40%, 40%, 20%).
OPERATIONAL COSTS (ANNUALLY)	labour costs (0.7 m GEL)

Source: Own representation based on Remissia (2025b)

Table 17: Total investment and annual operational costs

COSTS	CATEGORY
INVESTMENT COSTS (TOTAL)	Sensors and computer technology, software (1.4 m GEL), laboratory (1.1 m GEL), capacity building (8.6 m GEL), rehabilitation (1274.7 m GEL). Investment is distributed over 3 years (40%, 40%, 20%).
OPERATIONAL COSTS (ANNUALLY)	Labour costs (7.8 m GEL).

Source: Own representation based on Remissia (2025b)

The costs associated with the investments are 100% financed by government. Investment costs are distributed over the respective years as follows: 40% in year 1; 40% in year 2; 20% in year 3. Operational costs are incurred annually from year 2 onwards (2026-2050).

BENEFITS:
Reduced losses due to adaptation against forest fires: 70%
Reduced losses due to adaptation against forest diseases: 70%
The benefits begin to pay off from year 4 onwards (2028-2050)

Source: Remissia (2025b)

Since the losses due to forest diseases are much higher than the losses due to forest fires, the majority of the absolute loss reduction occurs with the diseases.

5.2.2. Results

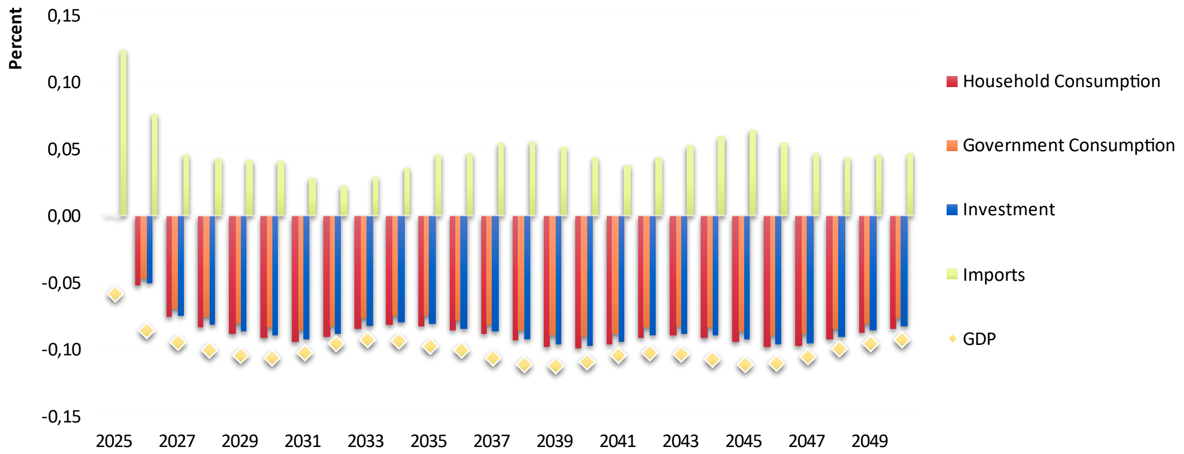

Figure 28: GDP Impacts of Climate Change Scenario (SSP5-8.5) (Compared to Reference, in %)

Source: GWS based on e3ge

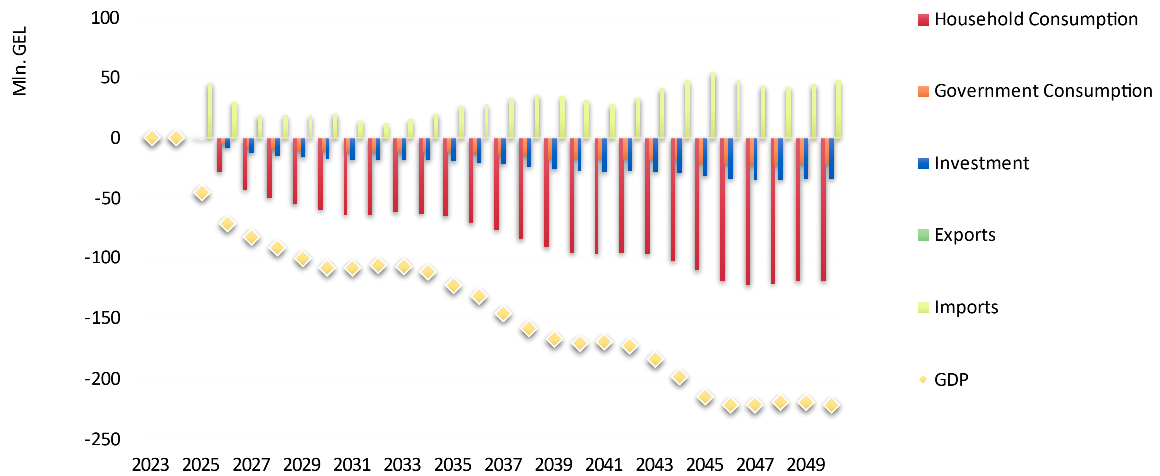

Figure 29: GDP Impacts of Climate Change Scenario (SSP5-8.5) (Compared to Reference, in m GEL)

Source: GWS based on e3ge

The macroeconomic effects of the adaptation measures against forest fires and diseases are shown as relative deviations from the climate change scenario in percent in Figure 30 (and Figure 31 only for the years 2030-2050 to visualize these years more clearly) and as absolute deviations from the climate change scenario in m GEL in Figure 32.

The investments in adaptation contain the installation of monitoring and early warning systems including sensors, computers, software, laboratories and drones leading to investment in computer products and services and scientific services. Further, the construction of roads and water ponds requiring the local construction industry. Capacity building is implemented. Additionally, afforestation of previously damaged areas is conducted by local workers providing agricultural services.

Implementing the mentioned adaptation measures will lead to an increase in consumption expenditures of households and government and gross fixed capital formation and will have a positive effect on GDP. Lower damages reduce imports and increase GDP. The highest deviation in GDP is -1.4% (resp. 1142 m GEL) in 2026 (Figure 30, Figure 32). The GDP effects over time can be explained as follows: Over the course of the first 3 years additionally assumed adaptation investments increase GDP. From the second year, higher operating costs will be needed, mainly in the form of government consumption.

The reduced forest damage after 4 to 6 years plays only a minor role at the macroeconomic level. This has to do with the limited value added of forestry. Forests grow over the long term and wood can continue to be removed from the stock. Above all, the forest also acts as a basis for nature-based services in the long term, which have not been quantified, and could also be used as a carbon sink, which is not taken into account in the adaptation scenario.

It is noticeable that, according to the CBA, investments in the first few years are also very high in macroeconomic terms, which also has a strong effect on GDP. Stretching the investments over the observation period would lead to a more even picture, but of course many losses would be reduced later.

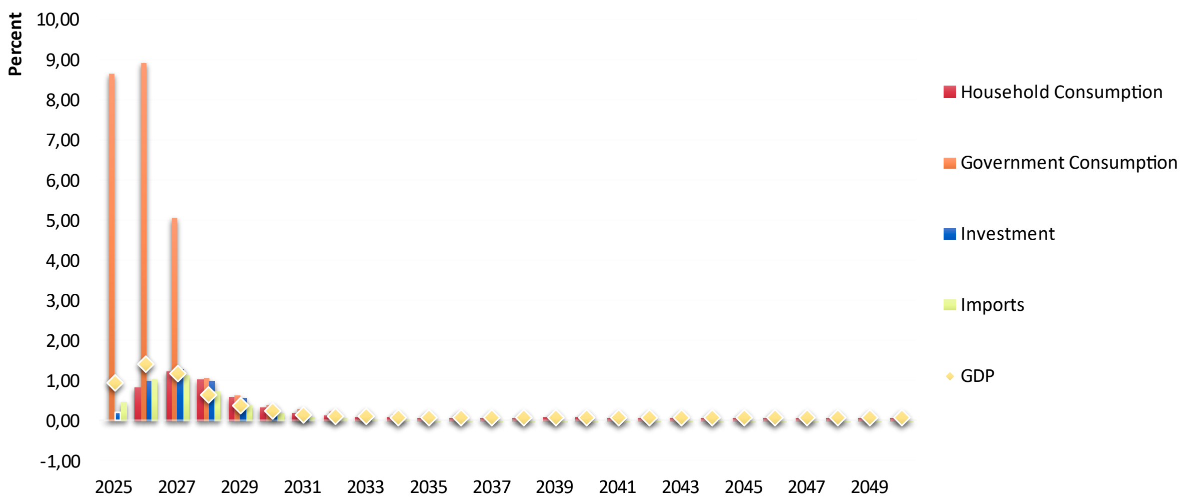

Figure 30: GDP impacts of Adaptation to Forest Fires and Diseases (compared to CC Scenario, in %)

Source: GWS based on e3ge

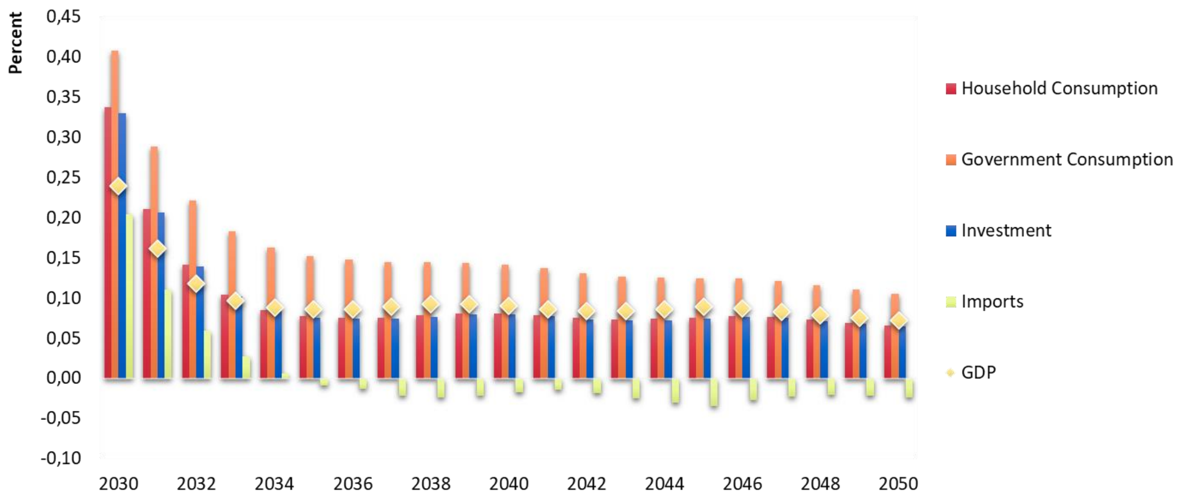

Figure 31: GDP impacts of Adaptation to Forest Fires and Diseases (compared to CC Scenario, in %, 2030-2050)

Source: GWS based on e3ge

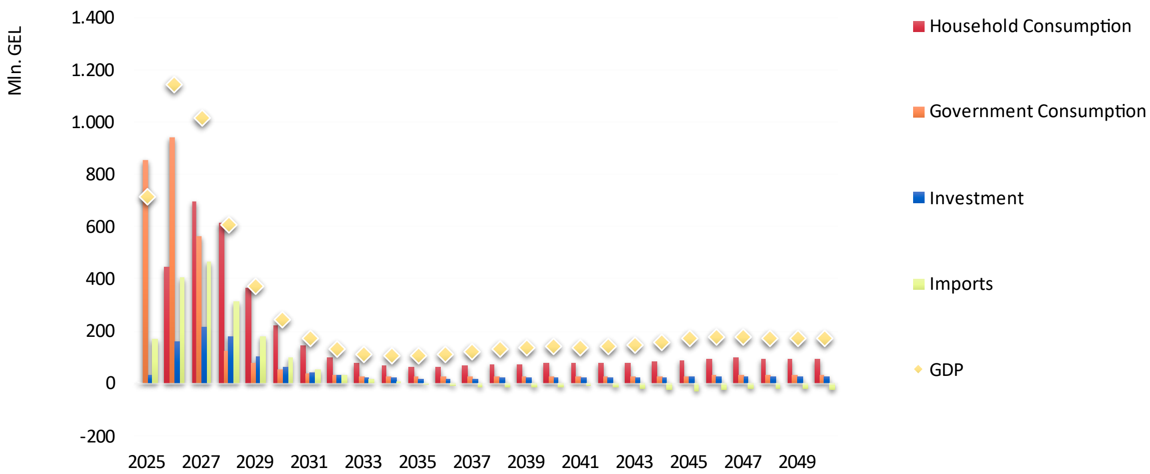

Figure 32: GDP impacts of Adaptation to Forest Fires and Diseases (compared to CC Scenario, in m GEL)

Source: GWS based on e3ge

The sectoral effects are similar for production (Figure 33 and Figure 34) and employment (Figure 35). Especially in agriculture, forestry and fishing and in services, but also in the manufacturing and construction sectors, there is an increase compared to the reference, on the one hand due to the additional investments (see below for more detail) and on the other hand due to the avoided damages.

For production, the effects are shown as relative deviations from the climate change scenario in % and as absolute deviations from the climate change scenario in m GEL. The highest deviation is 1122 m GEL (resp. 1.4%) in 2026.

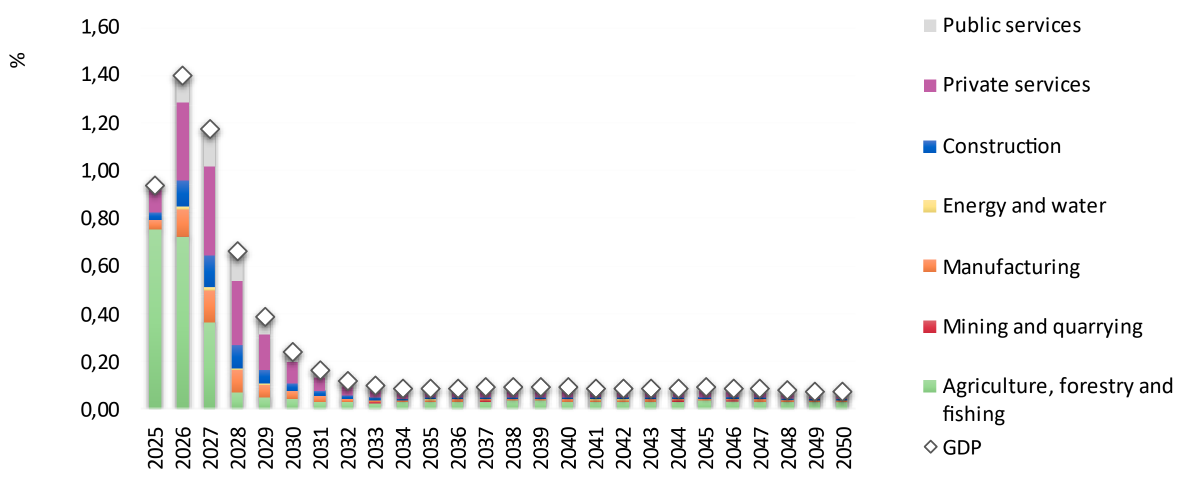

Figure 33: Effects on production of Adaptation to Forest Fires and Diseases (Compared to Climate Change Scenario, in %)

Source: GWS based on e3ge

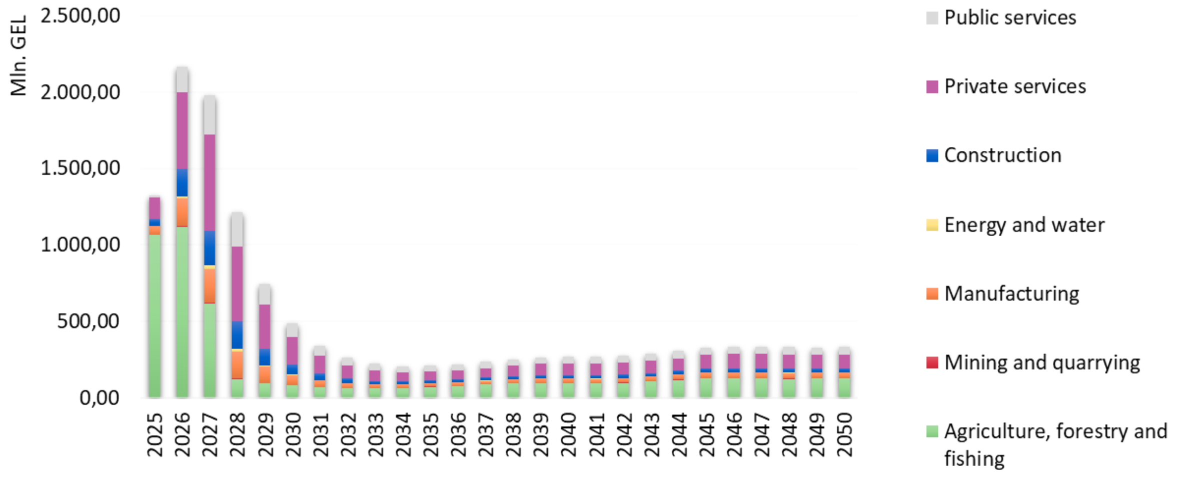

Figure 34: Effects on production of Forest Fires and Diseases (Compared to Climate Change Scenario, in m GEL)

Source: GWS based on e3ge

The employment effects result on the one hand from the additional investments in adaptation measures at the beginning of the period and from the continuous operating costs. On the other hand, employment is also created by the reduced climate damage in the sectors that benefit from adaptation, which enables higher production and the associated employment. Finally, other sectors also benefit from the overall higher economic output, which is particularly evident in absolute terms in the service sector.

The effects on employment are shown as absolute deviations from the climate change scenario (in 1,000 persons) in Figure 35. For example, up to 14,880 additional people can be employed in 2026. This corresponds to an increase of up to 0.7% in that year. This additional employment initially takes place mainly in the agricultural and forestry sector due to the rehabilitation of forests.

The various adaptation measures also lead to additional production in the investment phase in public and private services and in the construction industry. Accordingly, additional jobs are also created in these sectors. The additional employment decreases over time because adaptation investments are phased out and wages rise with higher employment, which increases labour intensity. In 2040, for example, 1,340 additional people can be employed (increase of 0.06%).

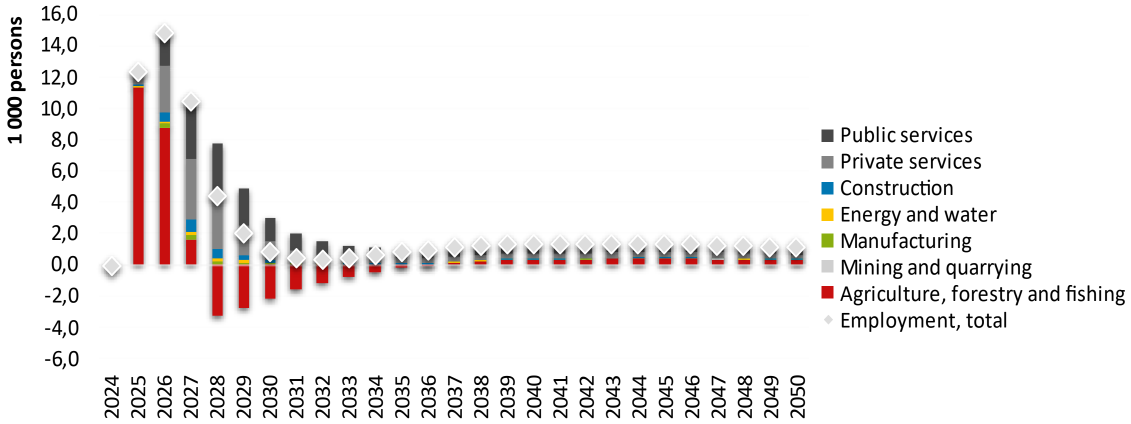

Figure 35: Employment Effects of Adaptation to Forest Fires and Diseases (compared to Climate Change Scenario)

Source: GWS based on e3ge

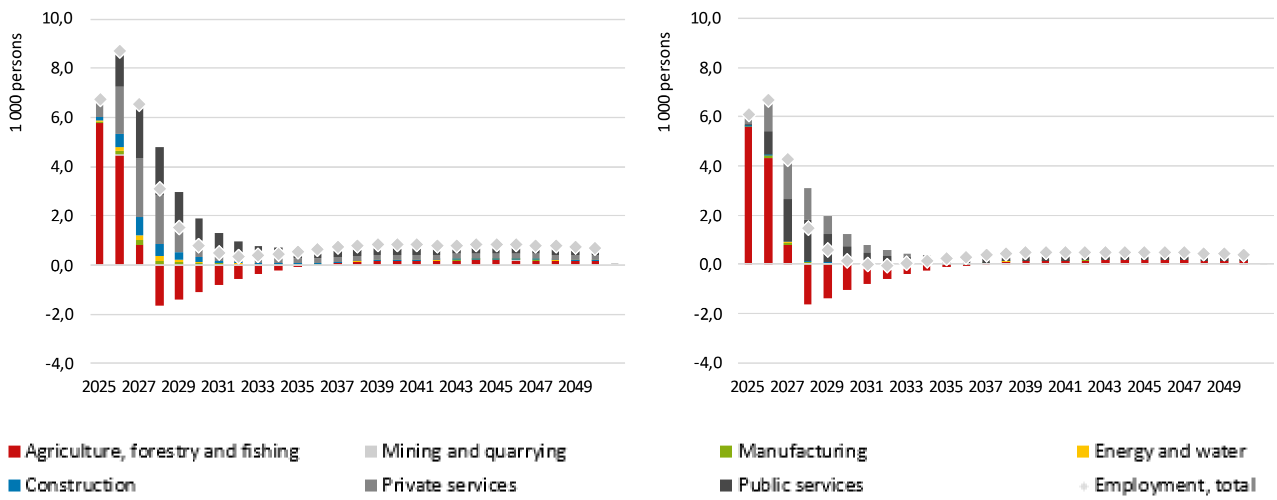

Figure 36: Adaptation to Forest Fires and Diseases: Employed persons by economic activity and gender in 1,000 persons (2025-2050), male (left figure), female (right figure)

Source: GWS based on e3ge

Positive macroeconomic effects result from two assumptions and the transmission channels based on them: Firstly, investment and operating costs in adaptation are assumed to be additional. and do not crowd out other investments. This can be justified on the one hand by high benefit-cost ratios of the adaptation measures, i.e. they are at least partially financed by the positive macroeconomic impact via higher GDP and the associated government revenues. On the other hand, it can be assumed that at least some of the investments will be financed by international sources of climate financing or economic cooperation in general. At least some of the corresponding payments will be additional. If adaptation investments are not additional in the sense described, there would be less positive macroeconomic effects, depending on the impact of crowded-out investments. However, this can hardly be quantified without a more detailed analysis. Secondly, the adjustment measures have a positive effect on forestry production, which is reflected on the macroeconomic level to a limited extent.

5.3. Flood protection

In the context of climate change, an increase in flood events in Georgia is expected. With various flood protection measures, the negative effects could be mitigated in the coming decades. To mitigate the climate change related risks of floods in Georgia, several adaptation measures have been proposed. The following two scenarios are implemented:

- Climate Change Scenario: Losses due to floods (buildings, infrastructure, agriculture, …)
- Adaptation Scenario: Implementation of adaptation measures such as flood risk zoning, introduction of flood resistance building code, Early Warning Systems, insurance schemes for buildings and agriculture, and flood proofing of infrastructure

5.3.1. Scenario settings

Table 18: Investment Costs: Rioni

INVESTMENT COSTS:	UNITS	COSTS PER UNIT (USD)	COST (USD)
FLOOD RISKS ZONING			
Flood risks Zoning	1	670,000	670,000
Development of policy framework and guidelines for land use planning in Georgia	1	80,000	80,000
FLOOD RESISTANCE BUILDING CODE (NATIONWIDE)			
Development and implementation of climate change risks-based building construction code for flood proof buildings construction in high flood risks areas.	1	30,000,000	30,000,000
EARLY WARNING SYSTEM			
Weather parameters measuring meteostation	26	30,000	780,000
weather parameters measuring meteo posts	26	15,000	390,000
Hydrological posts for measuring river runoff parameters (speed and depth)	32	20,000	640,000

INVESTMENT COSTS:	UNITS	COSTS PER UNIT (USD)	COST (USD)
Timely dissemination of EW information Systems established at the national and subnational levelled by the NEA	1	10,000,000	10,000,000
Capacity building of system staff and technical support	415	5,000	2,075,000
INSURANCES			
Insurance schemes implementation costs	1	10,000,000	10,000,000
FLOOD PROOF INFRASTRUCTURE			
Approximate costs of flood mitigation to be cost beneficial (for residual risks)	15	2,868,000	43,020,000

Source: Remissia (2025c)

Table 19: Operational Costs: Rioni

OPERATIONAL COSTS:	COST (USD)
OPERATION COSTS 1 (NEA + INSURANCE COMPANY)	7,476,000
OPERATIONAL COSTS 2 FOR AGRICULTURE INSURANCE	827,040.5
OPERATIONAL COSTS 3 FOR PROPERTY BUILDING INSURANCE	3,301,013

Source: Remissia (2025c)

Table 20: Investment Costs: Mtkvari

INVESTMENT COSTS:	UNITS	COSTS PER UNIT (USD)	COST (USD)
FLOOD RISKS ZONING			
Flood risks Zoning	3.5	670,000	2,345,000
Development of policy framework and guidelines for land use planning in Georgia	1	80,000	80,000
EARLY WARNING SYSTEM			
Weather parameters measuring meteostation	91	30,000	2,730, 000
weather parameters measuring meteo posts	91	15,000	1,365,000
Hydrological posts for measuring river runoff parameters (speed and depth)	112	20,000	2,240,000
Timely dissemination of EW information Systems established at the national and subnational levelled by the NEA	1	10,000,000	10,000,000
Capacity building of system staff and technical support	415	5,000	2,075,000
INSURANCES			
Insurance schemes implementation costs	1	10,000,000	10,000,000
FLOOD PROOF INFRASTRUCTURE			
Approximate costs of flood mitigation to be cost beneficial (for residual risks)	15	2,868,000	43,020,000

Source: Remissia (2025c)

Table 21: Operational Costs: Mtkvari

OPERATIONAL COSTS	COSTS (USD)
OPERATION COSTS 1 (NEA + INSURANCE COMPANY)	22,428,000
OPERATIONAL COSTS 2 FOR AGRICULTURE INSURANCE	3,968,052
OPERATIONAL COSTS 3 FOR PROPERTY BUILDING INSURANCE	7,393,887

Source: Remissia (2025c)

Table 22: Total investment and annual operational costs

COSTS	CATEGORY
INVESTMENT COSTS (TOTAL)	Flood risk zoning (9.1 m GEL), introducing flood resistance building code (85.8 m GEL), Early Warning Systems (92.4 m GEL), insurance schemes for buildings and agriculture (57.2 m GEL), and flood proofing of infrastructure (246.1 m GEL). Investment is distributed over 4 years (30%, 30%, 30%, 10%)
OPERATIONAL COSTS (ANNUALLY)	Insurance premiums (128.9 m GEL)

Source: Own representation based on Remissia (2025c)

The assumptions regarding the temporal allocation and financing of the adaptation measures are important for the temporal course of the economic effects. Most of the measures are implemented in the first few years and quickly lead to benefits.

- The costs associated with the investments are born 100% by government.
- Investment costs are distributed over the respective years as follows: 30% in year 1; 30% in year 2; 30% in year 3; 10% in year 4.
- Operational costs are incurred annually from year 2 onwards.

Benefits:

- Reduced losses agriculture: 50%
- Reduced losses buildings/properties: 70%
- The benefits begin to pay off from year 2 onwards

Source: Remissia (2025c)

5.3.2. Results

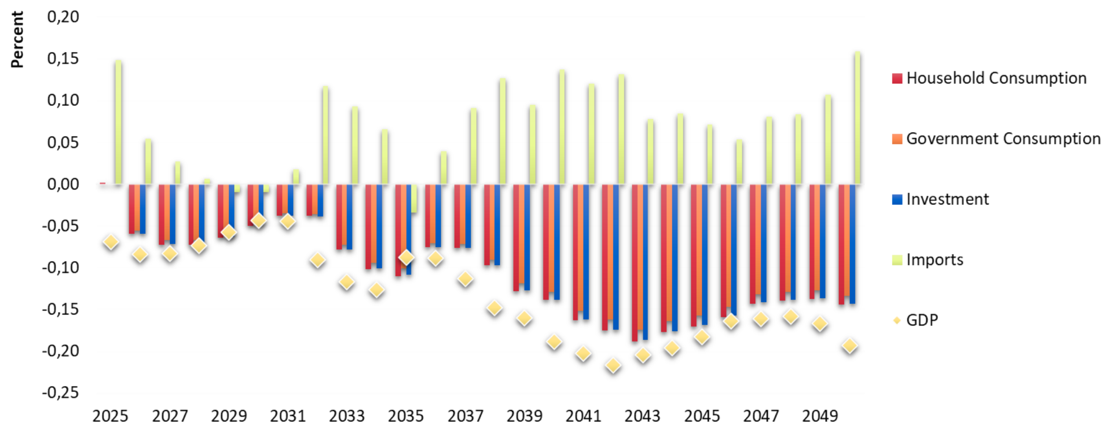

Figure 37: GDP Impacts of Climate Change Scenario (SSP5-8.5) (Compared to Reference, in %)

Source: GWS based on e3ge

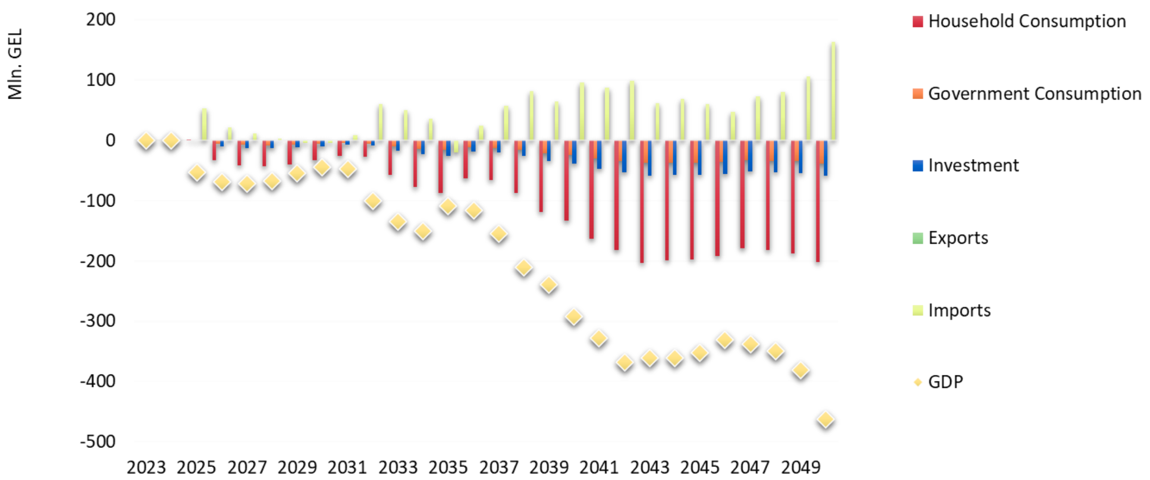

Figure 38: GDP Impacts of Climate Change Scenario (SSP5-8.5) (Compared to Reference, in m GEL)

Source: GWS based on e3ge

The macroeconomic effects of the adaptation scenario are shown as relative deviations from the climate change scenario in percent in Figure 39 and as absolute deviations from the climate change scenario in m GEL in Figure 40.

The investments in adaptation contain flood risk zoning, the development of a policy framework and guidelines for land-use planning, and the introduction of a flood resistance building code in high flood risks areas. Further, the installation of early warning systems including meteorological stations, meteorological posts and hydrological posts, leading to investment in computer products and services, accompanied by capacity building. Additionally, insurance schemes are implemented and fore the demonstration of the benefits insurance premiums are mainly covered by the government. Moreover, flood proof infrastructure is built by the local construction industry.

Implementing the mentioned adaptation measures will lead to an increase in consumption expenditures of households and government and gross fixed capital formation and have a positive effect on GDP. Less losses reduce imports and increase GDP. The highest percentage deviation in GDP is 0.3% in 2027, in absolute terms GDP increases up to 330 m GEL in 2050.

The GDP effects over time can be explained as follows: During the first 4 years, additional assumed adaptation investments, mainly as investment, increase GDP. Investments in early warning systems and flood proof infrastructure account for the majority of investments. In the following years annual operating costs for insurances are incurred, reflected in an increase in government consumption. In addition, the benefits of adaptation measures quickly result from reduced damages, so GDP and its components are higher compared to the climate change scenario.

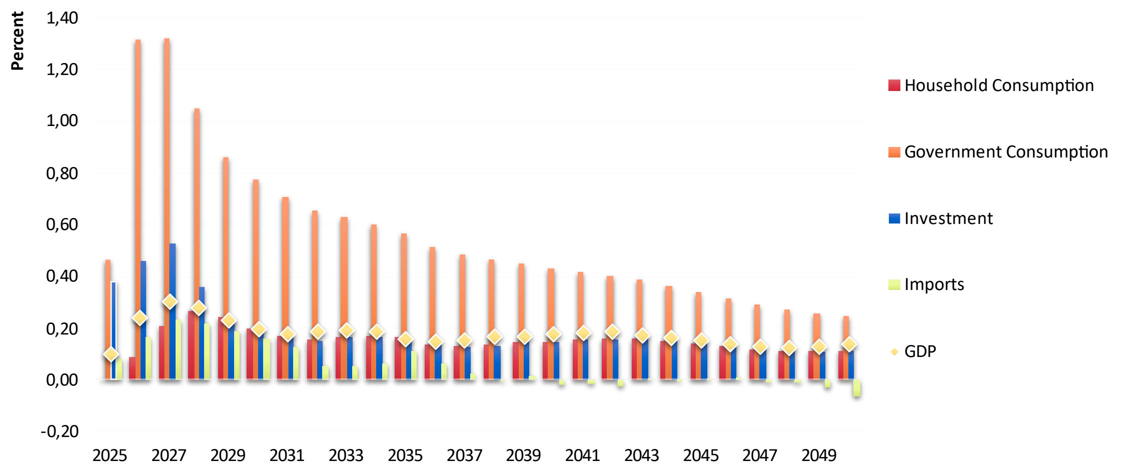

Figure 39: Adaptation Scenario: GDP Impacts of Flood protection (compared to Climate Change Scenario, in %)

Source: GWS based on e3ge

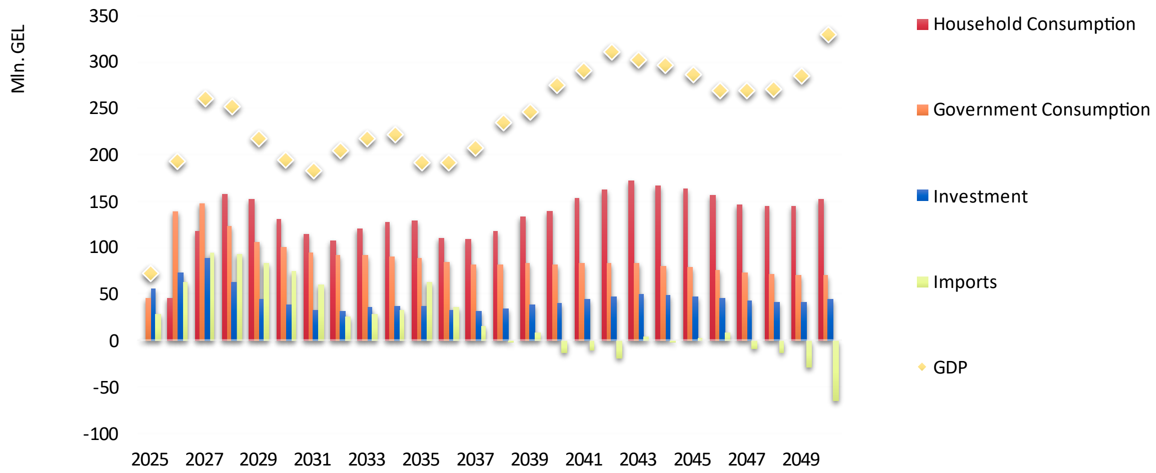

Figure 40: Adaptation Scenario: GDP Impacts of Flood protection (compared to Climate Change Scenario, in m GEL)

Source: GWS based on e3ge

The sectoral effects are similar for production (Figure 41 and Figure 42) and employment (Figure 43 and Figure 44). Especially in construction and manufacturing in the first years and in services over the whole period, there is an increase compared to the reference, mainly due to the additional investments and operational costs (see below for more detail).

For production the effects are shown as relative deviations from the climate change scenario in % (Figure 41) and as absolute deviations from the climate change scenario in m GEL (Figure 42). The highest percentage deviation is 0.3% in 2027, the highest deviation in absolute terms is 634.8 m GEL in 2050.

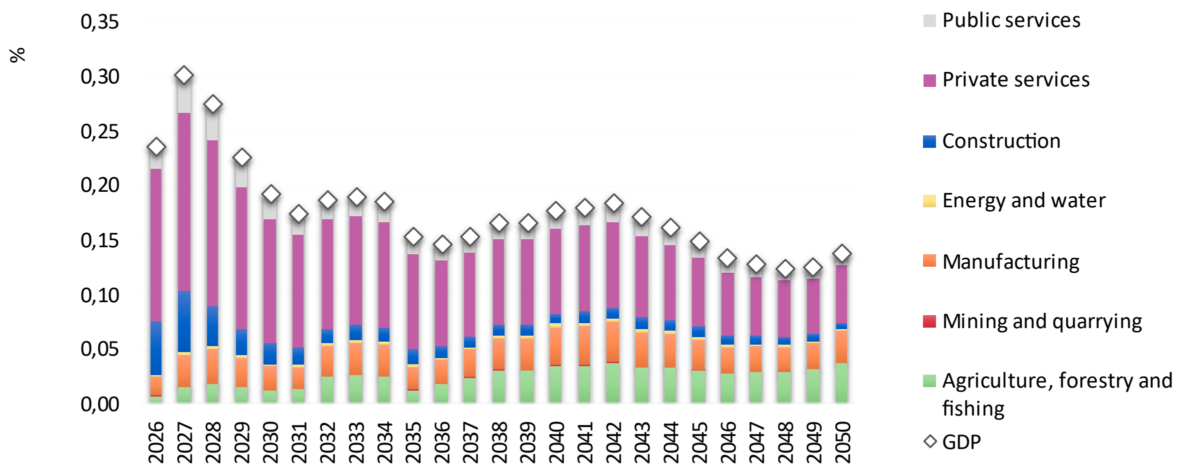

Figure 41: Effects on production of flood protection (Compared to Climate Change Scenario, scaled to GDP change in %)

Source: GWS based on e3ge

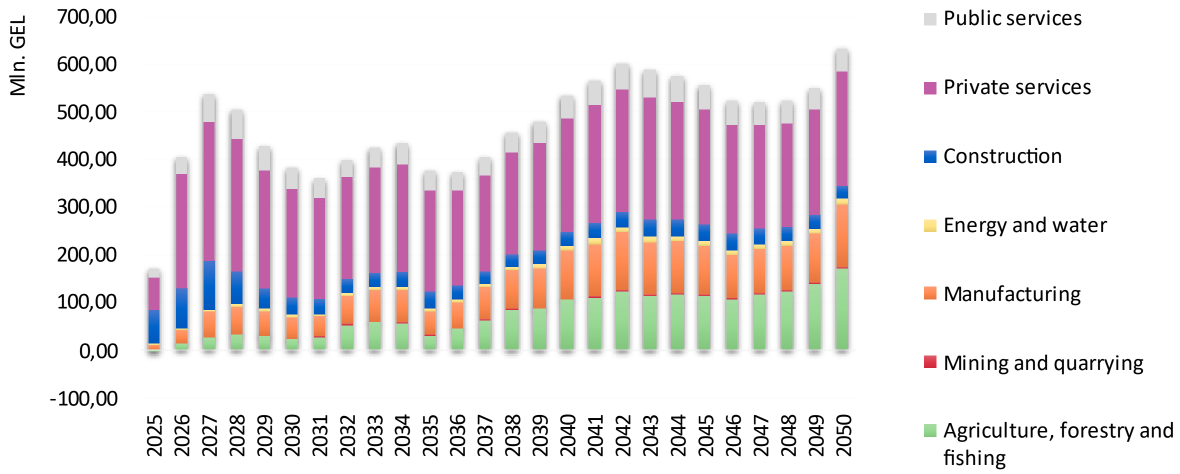

Figure 42: Effects on production of flood protection (Compared to Climate Change Scenario, in m GEL)

Source: GWS based on e3ge

The implementation of the adaptation measure has also positive effects on employment. The effects are shown as absolute deviations from the climate change scenario (in 1,000 persons). For example, up to 3,660 additional people can be employed in 2027. This corresponds to an increase of up to 0.2% in that year. This additional employment takes place mainly in the private services sector. The additional employment decreases over time but remains positive.

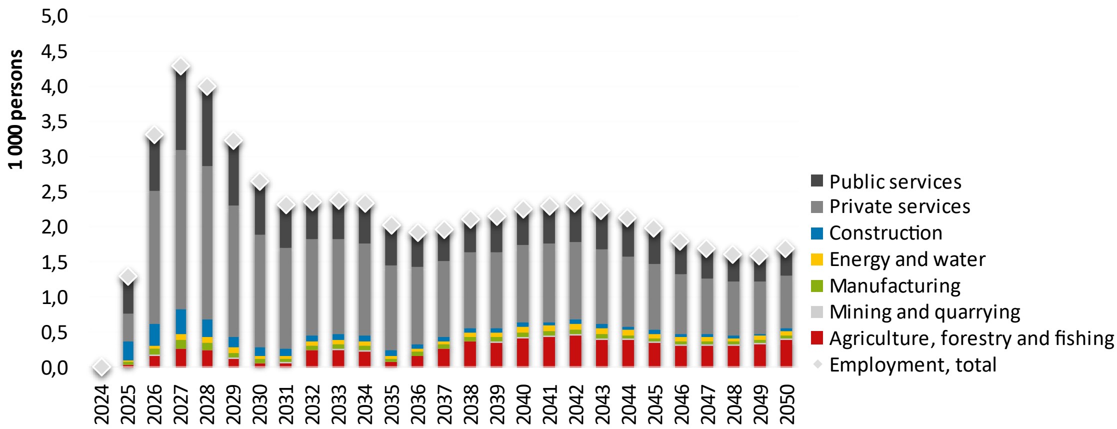

Figure 43: Employment Effects of Flood protection (compared to Climate Change Scenario)

Source: GWS based on e3ge

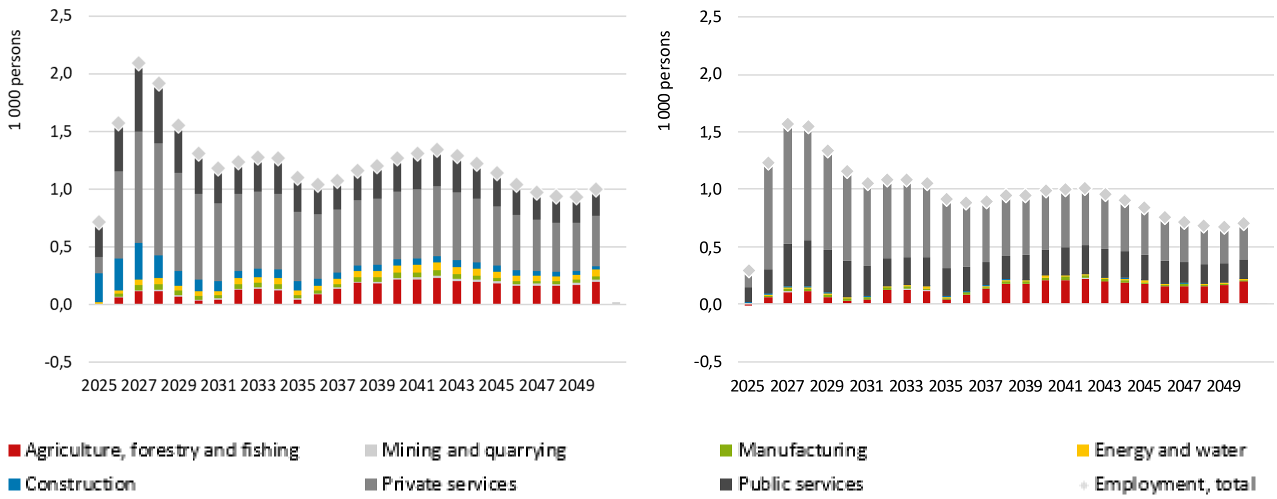

Figure 44: Flood protection: Employed persons by economic activity and gender in 1,000 persons (2025-2050), male (left figure), female (right figure)

Source: GWS based on e3ge

Positive macroeconomic effects result from two assumptions and the transmission channels based on them: Firstly, investments in adaptation are additional. We assume that these investments are in addition to existing expenditure and do not crowd out other investments. This can be justified on the one hand by high benefit-cost ratios of the adaptation measures, i.e. they are at least partially financed by the positive macroeconomic impact via higher GDP and the associated government revenues. On the other hand, it can be assumed that at least some of the investments will be paid for from international sources of climate financing or economic cooperation in general. It can be assumed that at least some of the corresponding payments will be additional. If the adaptation investments are not additional in the sense described, there would be less of a positive macroeconomic effect, depending on what effect the crowded-out investments would have had. However, this can hardly be quantified without a more detailed analysis. Secondly, the adaptation measures have a positive effect on agricultural production and reduce power transmission failures significantly, which is also reflected on the macroeconomic level.

6. CONCLUSION

The e3.ge model has proven itself as a tool for analysing the macroeconomic and sectoral effects of climate change and targeted adaptation measures. To this end, various scenarios are developed, building on a reference scenario, which quantify the individual elements of climate change and adaptation measures individually and collectively.

Climate change has negative economic effects for Georgia. Georgia is threatened by the greatest damages from climate change due to heatwaves, droughts and floods. However, further effects such as wind erosion also endanger economic development. The quantification of climate change is based on the work of national and international consultants. Unlike in the first national report (2022), probabilities of occurrence have been determined for the damage, which are multiplied by benchmark damages.

Adaptation measures can reduce the damage caused by climate change. Compared to scenarios with only climate change, the macroeconomic effect is positive. The adaptation measures are based on detailed cost-benefit analyses carried out by national forestry and flood protection consultants. They often show high benefit-cost ratios, i.e. the adaptation measures are very profitable. The positive macroeconomic effects of the adaptation measures are based on two effects. On the one hand, the damage reduction according to the CBA. On the other hand, it is based on the assumption of additionality of the adaptation investments. This is based on the expectation that foreign donors will finance part of the adaptation and that the high benefit-cost ratio will enable partial self-financing.

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Appendix

Figure 45: Probability of occurrence by intensity (low, medium, high) for droughts, heatwaves and floods under SSP1-2.6, SSP2-4.5 and SSP5-8.5 scenario until 2100

Source: Results provided by EarthYield Advisories GIZ (2025a)