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Appendix 11: Macroeconomic Implications of Climate Change – Analysis

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Abbreviations and Acronyms

AD-DICE	Adaptation in Dynamic Integrate Climate-Economy
AEZ	Agro-Ecological Zone
BaU	Business as Usual
CGE	Computable General Equilibrium
ENV-Linkage	Environment Directorate's Linkage
EU	European Union
FAO	Food and Agriculture Organization
FX	Foreign Exchange
GDP	Gross Domestic Product
GTAP	Global Trade Analysis Project
ICOR	Incremental Capital Output Ratio
IIASA	International Institute for Applied Systems Analysis
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
LGP	Length of Growing Period
MoEW	Ministry of Environment and Water
OECD	Organisation for Economic Cooperation and Development
RB	River Basin
RCP	Representative Concentration Pathway
SAM	Social Accounting Matrix
SLR	Sea Level Rise
ToT	Terms of Trade
WBGT	Wet Bulb Global Temperature

1. Introduction

1. The objective of the present analysis is to assess the cascading effects from climate change on the Bulgarian economy and inform decision makers on investment needs for climate change adaptation, based on an integrated analysis coupling socioeconomic and physical climate models.

2. This analysis evaluates the social and economic implications of climate change impacts and adaptation actions in Bulgaria and highlights the costs of inaction and the benefits of climate action within an economy-wide framework. The analysis estimates overall economic activity (that is, gross domestic product [GDP]), economic welfare, sectoral output, and employment levels, all with and without climate adaptation to provide elements in answer to the following questions: what are the most vulnerable sectors to climate change, how effective is adaptation to its most significant impacts, and what are the broader socioeconomic benefits from climate change adaptation? This study is thus complementary to other analytical work undertaken under the present Advisory Services aiming at strengthening policy-making and strategic planning on climate change adaptation, including providing input to the first National Adaptation Strategy and Action Plan for Bulgaria. The scope of this macro-economic analysis is to inform high-level policy dialogue, on the rationale to adapt (comparing the costs of action with the costs of inaction), and on overall funding needs and potential financing mechanisms. It is complemented by additional work to inform actions at sectoral level that will also feed into the National Adaptation Strategy and Action Plan, including understanding of climate vulnerability and prioritization of adaptation measures, based on expert judgement and cost-benefit analysis.

3. For this analysis, an economy-wide framework, the so-called Computable General Equilibrium (CGE) model, was developed for Bulgaria and complemented with scenarios of climate change impacts on land, forest, and water resources. CGEs are a class of economic models that use actual economic data to estimate how an economy might react to changes in policy, technology, or other external factors linked to economic or noneconomic factors (for example, fiscal policy reforms or climate change-induced shocks). The Bulgaria CGE model was developed using the Global Trade Analysis Project (GTAP) modelling framework and database (Hertel 1997), which currently represents the global economy (140 countries) in 2011. The standard GTAP model and database have been widely used by the World Bank,[1] the Organisation for Economic Cooperation and Development (OECD), the European Union (EU), and universities and research institutes globally, for policy analysis across a wide range of topics, including green growth, climate change, and environmental sustainability.

4. In this analysis, the GTAP standard model and database were tailored to the Bulgarian context by developing a water and land use module to allow estimating the impact of climate change at a more granular level, both from a sectoral point of view (that is, with a finer description of agricultural activities and how vulnerable they are to climate change) and from a geographic point of view (that is, with the consideration of Bulgaria's four river basins). This is the first attempt to build an integrated assessment model on climate adaptation for Bulgaria,

[1] World Bank 2012, 2016a, 2016b.

by coupling a macro-economic model with environmental modules. There is a particular focus on agriculture as one of the most vulnerable sectors to climate change. The CGE model can analyze well the link between natural assets such as land and water, that are vulnerable to climate change, and primary production factors for agriculture. Based on policy interest and available micro-economic and technical information at sectoral level, the model could be further enhanced to similarly improve the representation of climate vulnerability and adaptation potential in other sectors or to analyze mitigation issues. Those are potential directions for further research.

5. Following this Introduction, ***Section 2*** lays out the analytical framework and various steps in the development of the Bulgaria CGE model, ***Section 3*** describes the working hypotheses on the economic and climatic conditions to 2050 for a reference scenario (baseline), and ***Section 4*** develops two sets of adaptation policies and estimates their net socioeconomic benefits on top of the economic growth benefits described in the reference scenario.

2. Bulgaria CGE: An Analytical Overview

6. As economy-wide frameworks, CGE models have a flexible mathematical structure that can accommodate economic, biophysical (natural resources: forest, land, and water), and climate-related components, making them well-suited tools to analyze scenarios of the potential impacts of climate change on economic growth and the rationale/cost-effectiveness of adaptation strategies. In addition to domestic market conditions and global market volatility, the Bulgaria CGE model developed for this analysis thus considers the impacts of climate change on productivity (that is, change in crop yield), infrastructure (that is, damage to buildings and roads), natural capital (that is, change in water availability), or populations (that is, increased mortality and lower labor productivity).

Table 1. Climate-related vulnerabilities by sector and their representation in the CGE model

Sector	Climate Change Vulnerability	Modelled / Not Modelled
Agriculture	Changes in crop yields	Modelled
	Livestock mortality and morbidity from heat and cold exposure	Not modelled - insufficient evidence/data
	Changes in pasture and rangeland productivity	Not modelled - insufficient evidence/data
	Changes in aquaculture productivity and fisheries catches	Not modelled - insufficient evidence/data
Costal zones (natural assets and built environment)	Loss of land and capital from sea level rise (SLR)	Modelled
	Marine biodiversity	Not modelled - not in the model specification
Weather hazards	Mortality, land and capital damages from floods	Not modelled - insufficient information on future flood risk
Human health	Mortality from heat exposure	Modelled
	Morbidity from heat and cold exposure	Not modelled - insufficient evidence/data
	Mortality and morbidity from infectious diseases and cardiovascular and respiratory disease	Not modelled - insufficient evidence/data
Energy demand	Changes in energy demand for cooling and heating	Modelled
Tourism	Changes in visitor flows and tourism services	Modelled
Ecosystem services and biodiversity	Loss of ecosystems and biodiversity	Not modelled - insufficient evidence/data
Forests	Changes in forest plantation yields	Not modelled - insufficient evidence/data
Water resources	Changes in water availability for hydropower generation and cooling of thermal power plants	Modelled - no prediction of acute scarcity is reported until 2050
	Changes in availability of drinking water to end users	Modelled - no prediction of acute scarcity is reported until 2050

7. Climate-related vulnerabilities that are likely to affect Bulgaria's economic sectors and their representation in the CGE model are displayed in ***Table 1***. The table covers the sectors considered in these advisory services on a National Climate Change Adaptation Strategy and Action Plan. Not all the channels through which climate change will affect natural resources, human settlements, and economic activities can be captured in the model for lack of sufficient data. This is for instance the case for nonmarket impacts (that is, how climate change will affect ecosystems and their services). Despite this partial coverage, the model represents climate change impacts in the sectors considered the most vulnerable to climate change as per the 2014 Risk and Vulnerability Analysis and Assessment of the Bulgarian Economic Sectors to Climate Change (MoEW 2014): Water (modelled off-line), Agriculture (modelled through damage functions), and Tourism (modelled through damage functions).

8. The structure of CGE models enables estimating the 'direct' and 'indirect' impacts of climate change on sectors. The 'direct' effect refers to a change in the availability or price of the factors of production or in total factor productivity in a given sector due to climate change (for example, how climate change affects crop yields). The 'indirect' effect refers to a change in a given sector's productive activity due to a variation in the demand for its outputs because of the impacts of climate on the demanding sectors (for example, how energy demand might be lower because of reduced economic activities in other sectors directly hit by climate change). CGE models are developed on the basis of input-output matrices that keep track of the abovementioned inter-sectoral links, which makes them well-suited models for a comprehensive assessment of the climate change impacts.

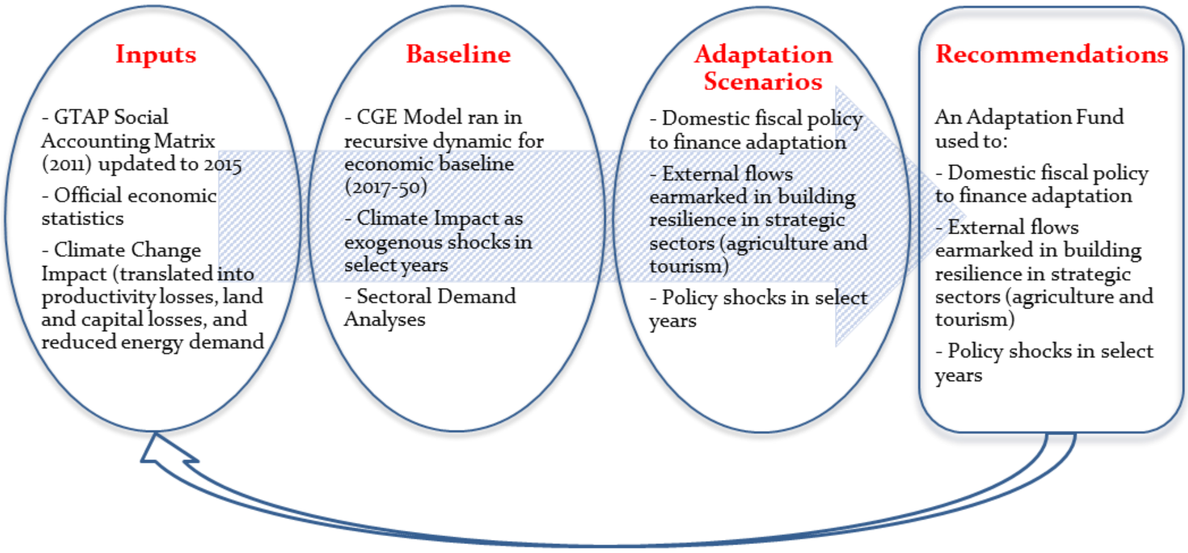
9. In this analysis, the CGE model is first used to develop the economic baseline (which does not account for climate change and its impacts). Second, the baseline scenario is expanded to include climate change impacts as productivity loss in land and water use related to slow onset and to rapid onset extreme events (floods and extreme temperatures). Rather than simulating the impact of individual disaster events, the information on slow onset and rapid onset events was introduced into the analysis through damage functions from the literature. Finally, adaptation scenarios are developed to analyze cost and effectiveness of actions to reduce the vulnerability of the economy and increase its resilience to climate change (see ***Figure 1***).

10. The simulation results include (changes in the) Bulgarian GDP growth, fiscal and external balances, sectoral value added, and employment, therefore providing information on the economic and environmental sustainability of the projected growth trends. The simulations estimate the ripple effect on the overall economy from specific projected climate change impacts, such as drop in crop yields, heat extremes, and more frequent floods as projected within the damage functions for Bulgaria, and the net socioeconomic benefits (for example, growth, trade, and poverty) of adaptation measures to these risks. The analysis also looks at the incidence of climate change on poverty at the aggregate level, based on the projected impact on prices for consumer goods (inflation), firms' demand for labor, and wages (see ***Section 3***).

11. Damage functions are introduced in the CGE model to represent how the physical impacts of climate change influence the economic activity. Damage functions are one or more relationships between climate variables (typically, average temperature, but sometimes also

humidity or heating degree days) and economic variables (potential income, productivity, resource endowments, and so on). These functions are calibrated for Bulgaria against the findings from the most recent literature (see ***Section 2.5***).

Figure 1. Structure of the CGE analysis



12. The model was first developed in a static version to represent the economic conditions in Bulgaria in 2011. It was then updated to reflect the current economic conditions in Bulgaria in 2015 and used as a basis for the dynamic model. In the static version of the model, investment is fixed (based on actual, observed investment) and its level is found in the model database. As a result, there is no capital accumulation in the pure static model: all goods/services produced in each year are consumed the same year (including to acquire investment goods) and there are no financial resources saved for the next time period. However, capital accumulation takes place in the recursive dynamic approach. In 2011–2015, the capital accumulation followed the observed trends, based on official statistics. For the development of the economic baseline to 2050, the static model was run 35 consecutive times to reach a cumulative capital accumulation over 2015–2050 in line with the macroeconomic forecasts by the International Monetary Fund (IMF) or OECD (2015).

13. Damages from climate change have been modelled through damage functions, as reductions in productivity in specific sectors, occurring in the year 2050, based on OECD (2015). This is a standard approach, which captures tangible reductions to productive capacity, arising from climate change effects such as reduction in yield, less healthy/reduced workforce, and damages to land/capital/natural resources.

14. Policy and investment interventions for climate change adaptation are analyzed as exogenous shocks to the model's economic baseline to 2050. These interventions result in changes in the allocative efficiency of the available resources (labor, capital, and natural resources) that lead to welfare gains or losses, which are also estimated by the model.

15. It is equally important to highlight that, given the static structure of the model, the cost of adaptation to climate change is also estimated within a static framework, where consumers and firms (and the government) do not have full information about future climate change

impacts, without any possibility to adapt endogenously to maintain their economic welfare in the years to come. The adaptation interventions are therefore modelled as exogenous interventions (shocks to the baseline parameters of the model structure in 2050), such as fiscal revenue collection to finance public and private investments for adaptation. In the absence of endogenous adaptation options for consumers and producers in this static model framework, the financial needs for adaptation could have thus been overestimated. Therefore, in the development of the dynamic baseline, the model was forced to replicate a growth trend for Bulgaria from a dynamic modelling analysis by the OECD (2015). In this manner, behavioral changes for consumers and firms by changing their consumption and production activities in anticipation of the climate change impacts were imposed to the Bulgaria CGE model. The Bulgarian consumer is therefore not myopic in its consumption behavior.

2.1. Description of the economic model structure

16. To capture the complex links between physical and socioeconomic variables, the standard GTAP model for Bulgaria was expanded into an integrated analytical platform by adding land, forest, and water resources and their uses at sub regional level (that is, Agro-Ecological Zones [AEZs] and River Basins [RBs]). Such a spatial analysis for Bulgaria's economy at the RB and AEZ levels was developed for the first time. This advances the modelling literature on Bulgaria, and it required multiple steps as described below.

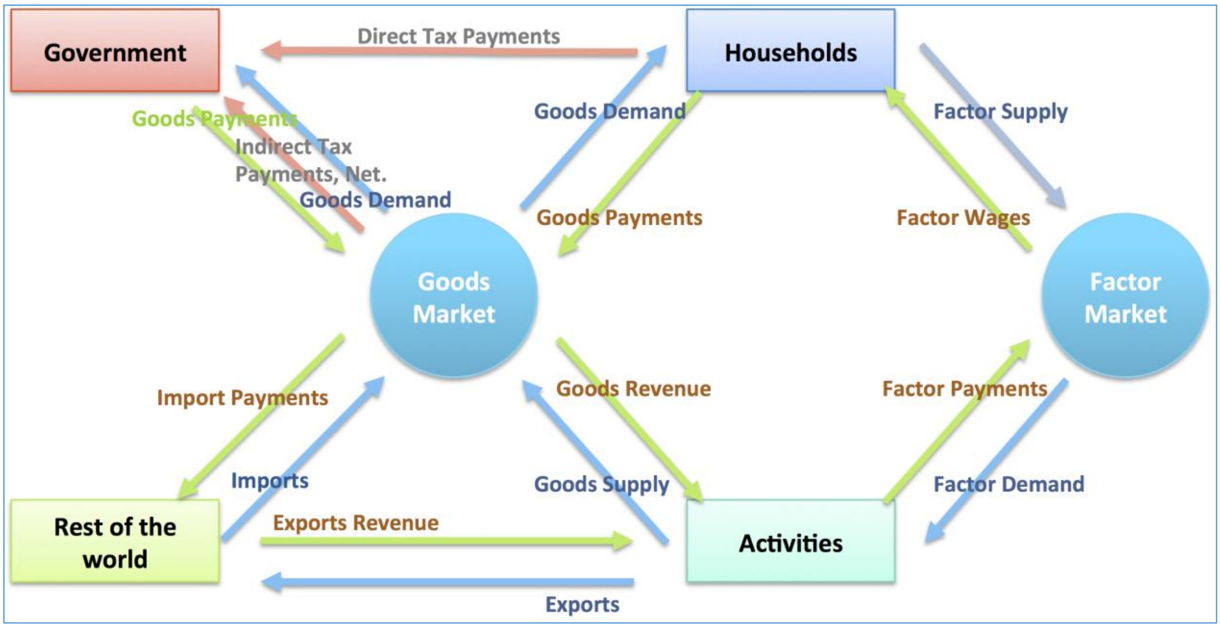
17. The underlying mathematical structure is the GTAP-AEZ model that was developed by Lee et al. (2005). For this analysis, the structure of the model by Lee et al. (2005) was populated with latest statistics on the Bulgarian economy and a Social Accounting Matrix (SAM) that was generated for Bulgaria by the project team. Data from the Bulgarian National Statistics Institute, EUROSTAT, Food and Agriculture Organization (FAO), the World Bank, United Nations, and IMF were used to complement and fine-tune the GTAP data. In other words, GTAP is the main data source, but because this is a general-purpose dataset with a base year of 2011 it requires both updating of, and enhancement to, data quality in sectors such as agriculture.

18. The Bulgarian economy is represented by 57 sectors at the national level among which agriculture, one of the sectors most vulnerable to climate change, is modelled in more detail at the AEZ level: eight crops for each one of the seven AEZs per Bulgarian classification (combined with the information on a five AEZ scale from the GTAP-FAO-IIASA[2] database). However, for the ease of presentation, the model results are provided in the report in an aggregate manner for the national economy: 5 AEZs and 4 RBs and the 57 sectors were grouped into 13 clusters.

19. The CGE model represents households, government, producers, major trade partners and their interactions. The model describes the flow of goods from production activities to households and the flow of production factors from households to activities, as well as the payments in exchange of these goods and the use of factors as shown in ***Figure 2***.

[2] International Institute for Applied Systems Analysis.

Figure 2. Schematic representation of the economic flows in the Bulgaria CGE model



20. Each sector has a different production function and maximizes profits subject to a production function that combines primary factors (including labor, capital, land, and natural resources such as water, minerals, fish, and forests) and intermediate inputs to produce a good. Firms pay wages/rental rates to the households in return for the use of land, labor, capital, and natural resources. Firms sell intermediate inputs to other firms and final goods to the private households and the government. Firms also export commodities and import intermediate inputs from trade partners. These goods are assumed to be differentiated by country of origin and the model can thus track bilateral trade flows between Bulgaria and its trade partners among the 120+ countries/country aggregates.

21. Households receive income by providing factors of production (land, capital, and labor) to the producers. Their consumption basket represents a variety of goods and services that are either locally produced or imported. They pay taxes to the government in return for public services such as defense, health, and education. The CGE model comprises a representative household, whose disposable income is split between consumption and savings.

22. Production and consumption activities generate taxes for the government budget. Tax revenues increase or decrease as a share of these economic activities. Public accounts comprise government and household savings. These funds are allocated following a public utility function. The analysis of potential adaptation financing mechanisms in ***Section 4*** considers, among other alternatives, a hypothetical 2 percent tax on final consumption on all commodities, to mobilize additional resources for adaptation. The economy-wide links would therefore lead to expansion or contraction in the sectors producing the goods affected by the aforementioned changes in the tax regime.

23. Climate change impacts on productivity (for example, change in crop yield), infrastructure (for example, damage to buildings and roads), natural capital (for example, change in water availability), or populations (for example, increased health risks and lower

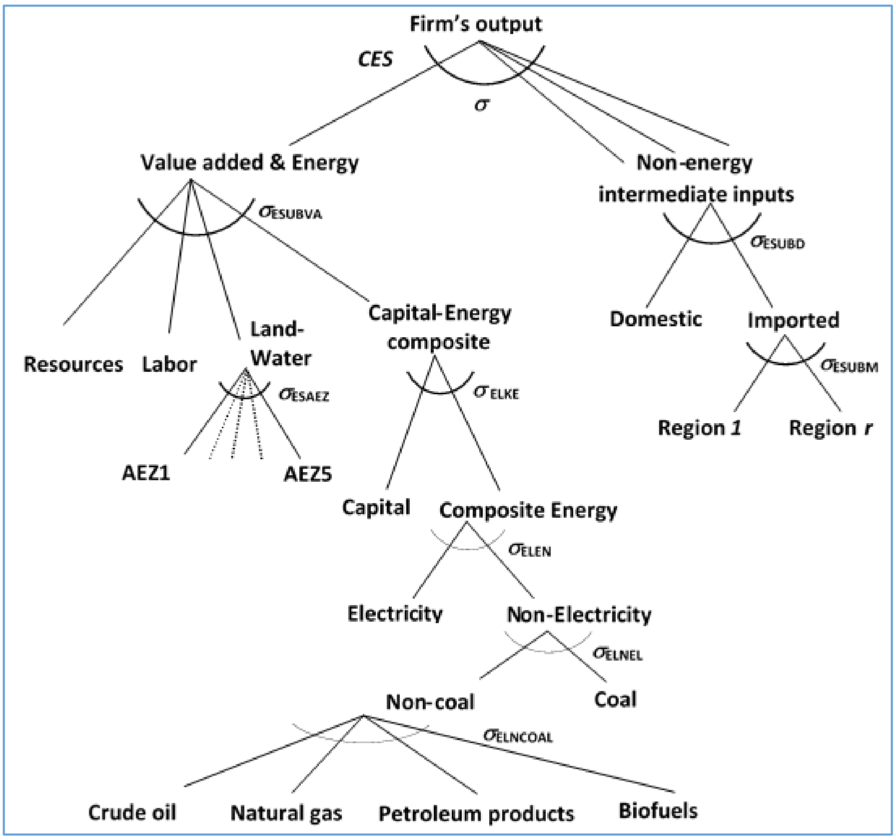
productivity) are integrated into the model by way of so-called damage functions, described in ***Section 2.5***.

24. The production and consumption modules of the CGE model, as well as the modeling of the agriculture sector, are described in more detail in the next sections.

2.2. Production functions and derived demands for inputs

25. The endowment in factors of production (land, capital, and labor) is fixed at the national level for each year and demand for these factors is endogenously determined by market mechanisms. Policy changes such as fiscal policies to fund adaptation measures result in changes in the allocative efficiency of these resources that lead to welfare gains or losses for the overall economy (which can be estimated using the model).

Figure 3. Production structure in the CGE

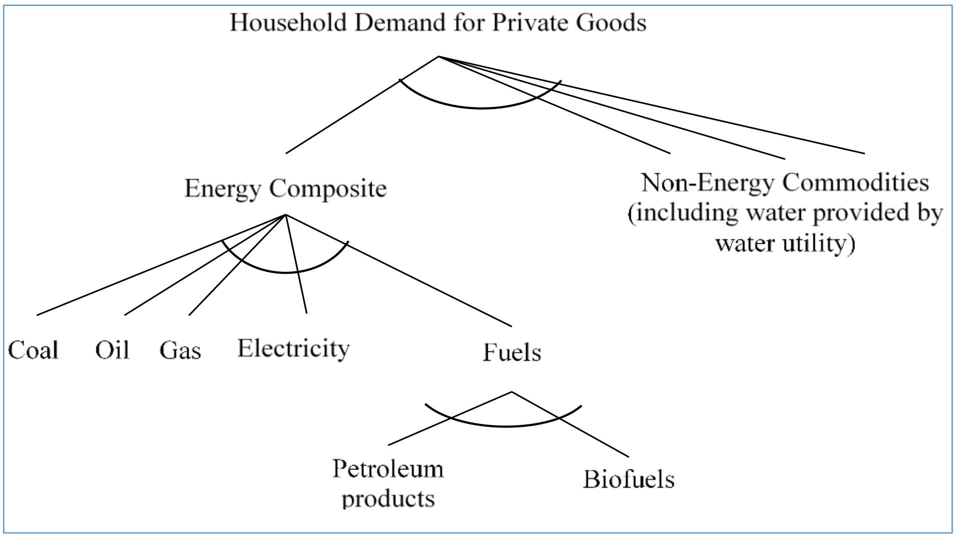


26. ***Figure 3*** displays the nested production function for Bulgaria. At the top level, the firms' production is based on two components: the value added (capital and labor) and energy bundle, and non-energy intermediate goods. These two components are partially substitutable. The second nest is about firms' demand in terms of factors of production and various types of energy. For each intermediate input, the model assumes an Armington elasticity (allowing for a partial substitution between domestically produced and imported commodities).

2.3. Household demand for final goods and services

27. The structure of household demand in the Bulgaria CGE model is presented in ***Figure 4***. In this demand structure, the representative household uses a mix of substitutable energy products. Hence, in response to changes in the relative prices of energy products, the demand from the representative household can switch from expensive energy sources to cheaper alternatives. Among energy commodities, electricity demand (the largest component of the final energy demand) is the most important indicator to track due to expected seasonal shifts in residential and commercial use under changing climate. Due to overall warming up of the temperature in Bulgaria, increased use of air conditioning and a decreased need for heating is expected. These two effects combined with the overall energy efficiency improvement in industrial use are expected to lead a decrease in the overall energy demand. The partial equilibrium models would overestimate these effects that occur simultaneously in the economy. The overall impact can be more accurately estimated in an economy-wide model such as the Bulgaria CGE model because the model allows for substitution of electricity between its alternative uses as well as among multiple industrial sectors and other economic agents (that is, households and the Government).

Figure 4. Household demand for goods and services in the Bulgaria CGE model



2.4. Modeling of the agriculture sector

28. Agriculture is among the sectors most vulnerable to climate change in Bulgaria and this study contributes to the existing literature by developing a spatially disaggregated analytical framework that allows examining the interactions between climate change, crop yield, and agricultural activities for Bulgaria. Many publications have studied the impacts of climate change on crop yields and food security (for example, Lobell et al. 2008; Nelson et al. 2010). These studies demonstrate how changes in climate variables affect food security across the world. However, they do not provide a clear picture on the interactions between climatic change, crop yield, and water availability. More recent papers (for example, Marshal et al. 2014; Willis et al. 2014) considered these interactions and showed that while climate change can induce incentives for irrigation, water scarcity may limit the extent that irrigation adoption

can be implemented. While these papers and earlier work in this area provide valuable economic and biophysical analyses of the impacts of climate change for crop production and food security, they ignore the interplay between climate change and international trade. Some papers have examined the interaction between trade and climate change. For example, Reilly et al. (2002) have shown that trade can improve food security in regions where crop production will be negatively affected by climate change factors. This study and its successors (for example, Baldos and Hertel 2015) usually ignore water scarcity induced by climate change and or economic factors. Liu et al. (2013) have shown that trade can mitigate the consequences of future irrigation shortfalls in regions where water scarcity threatens food security as well. However, this study ignores the impacts of climate change on crop yield in the presence of water scarcity. The Bulgaria CGE analysis incorporates all the above-mentioned elements and provides ex ante analysis of adaptation actions.

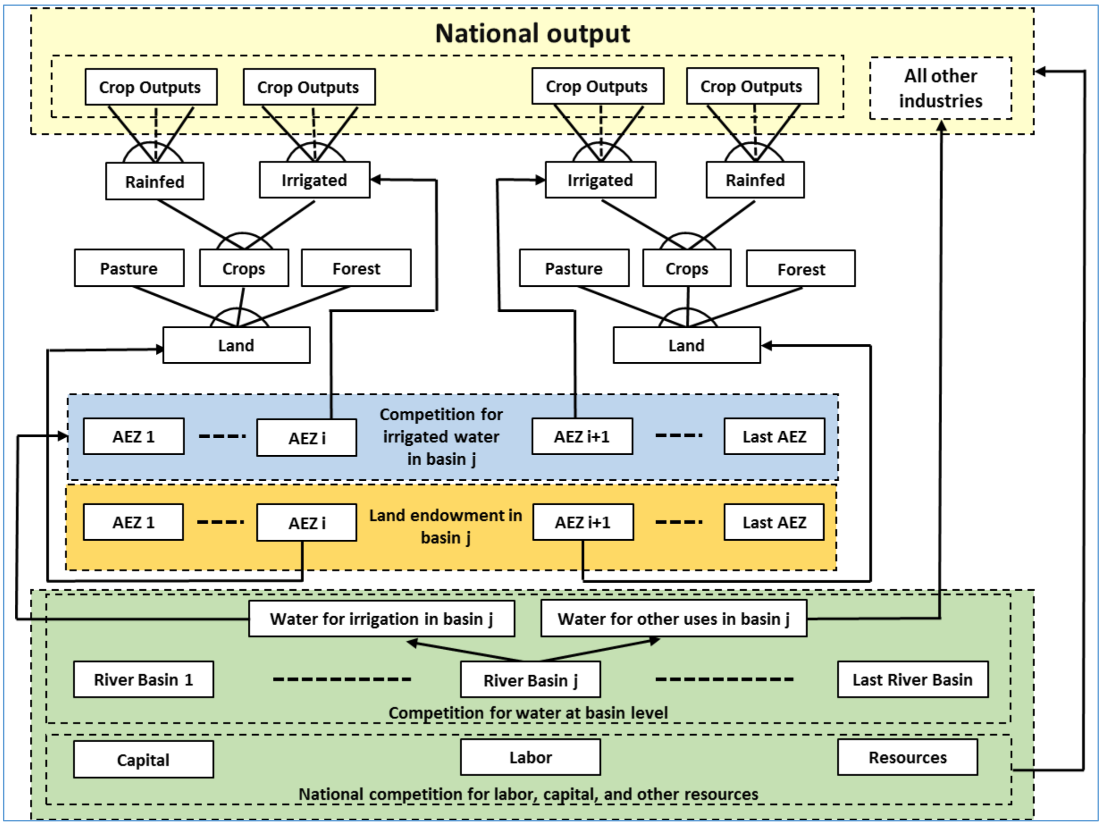
29. As the most sensitive sector to climate change, the highest granularity was adopted in the analysis of the agriculture. This level of spatial details allows the capture of climate change impact on land productivity for various RBs, which is the main originality of the Bulgaria CGE model. The analysis is also developed at an RB level to allow capturing climate impact on water resources. This hybrid method combined with a multi-sectoral economic model where land and water are the most important resources used in agricultural production allows analyzing climate impact in detail as explained below.

30. As mentioned earlier, the Bulgaria CGE model, as an advanced version of the standard GTAP model, traces demands for, and supplies of, a wide range of commodities starting with crops and electricity at the national and subnational (AEZ and RB) levels.

31. The model also considers resource constraints and models' allocation of limited resources including labor, capital, natural resources such as water, forests, and land, among their alternative uses. It divides crop producers into rainfed and irrigated. It traces water and land resources endowments and their demands at the spatial resolution of four RBs and five AEZs for Bulgaria. In this model, water can move across its alternative uses within an RB with limited movement across AEZs (see ***Figure 5***).

32. ***Figure 6*** displays the land demand for farming. Besides capital and intermediate inputs, farming activities require various types of land suitable for crop production. As shown in ***Figure 7*** main land use types in Bulgaria are croplands, followed by forests. ***Figure 8*** shows the AEZs based on Bulgarian sources. The model was developed using the global classification of AEZs as in Lee et al. (2005). It is important to highlight that the definition of GTAP for AEZs differs from national sources for Bulgaria. This analysis was developed for five AEZs for Bulgaria based on the GTAP database while national maps cover seven AEZs. Within the CGE model, each AEZ is rated based on its land productivity. The higher the land productivity, the higher the crop yield, thus the profit margin from this farming activity.

Figure 5. Detailed representation - land and water modules



33. Based on the literature, climate change is likely to affect either land or crop productivity negatively. A negative push on crop supply is expected to lead to higher crop prices. In the meantime, climate events such as floods may cause direct damage to the farmers. Both cases are examined in the baseline, including climate impact simulations.

Figure 6. Land demand in the Bulgaria CGE model

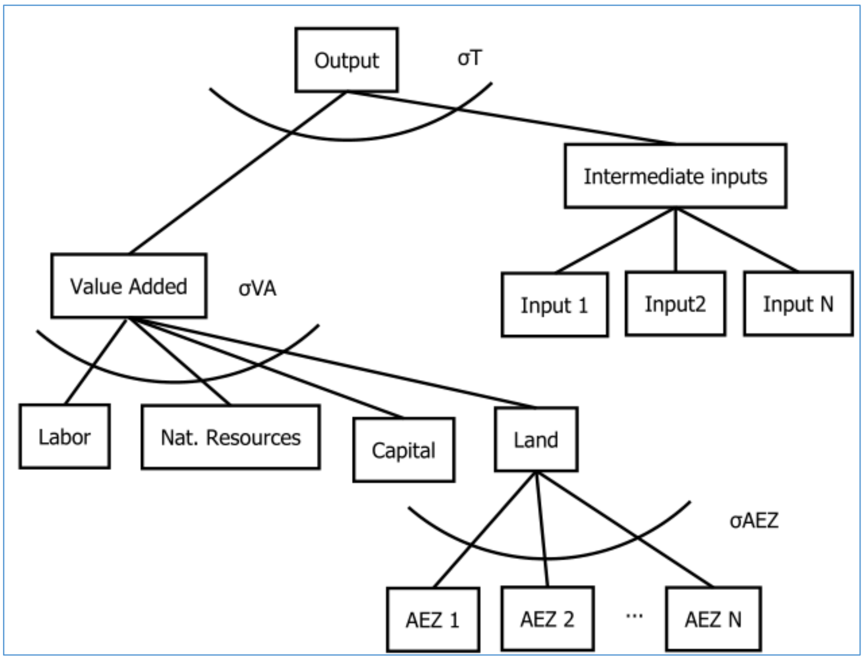
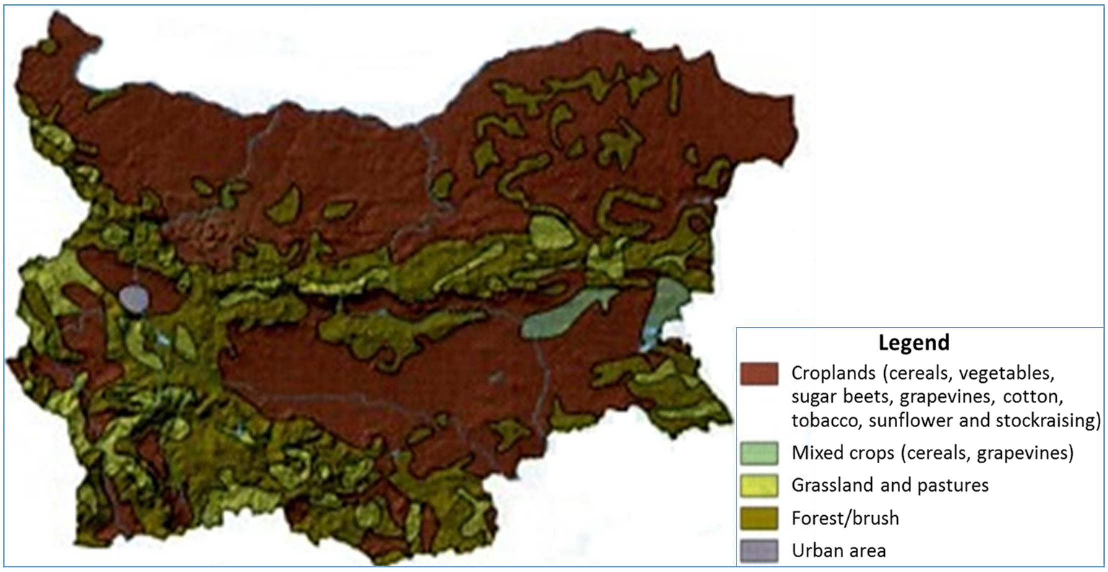
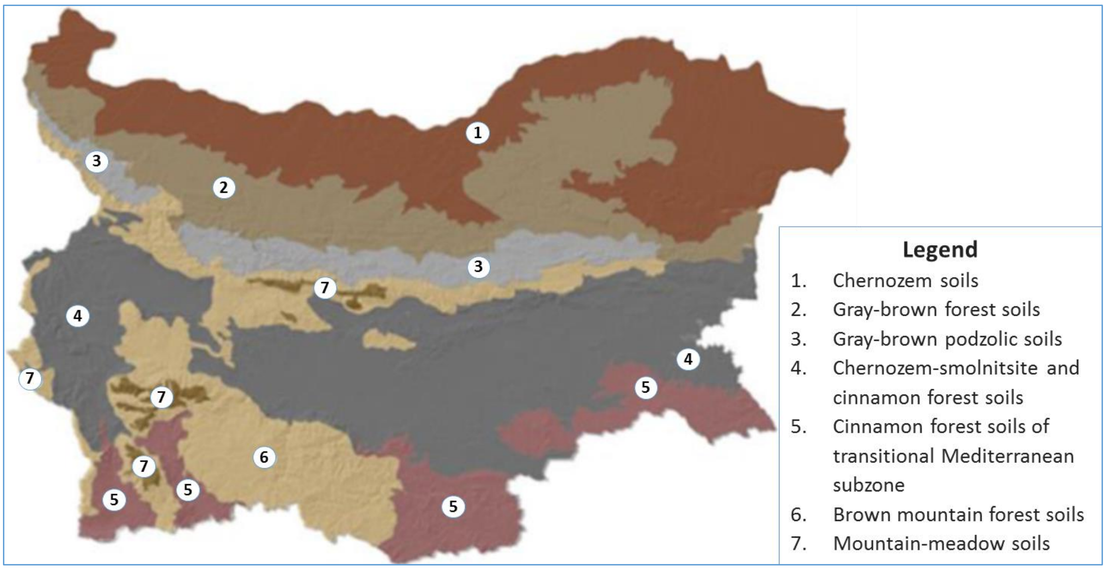


Figure 7. Types of agriculture and livestock production



Source: Kolev 2016.

Figure 8. AEZs in Bulgaria



Source: Kolev 2016.

Table 2. AEZ disaggregation used in this CGE analysis

LGP in days	Moisture regime	Climate zone	GTAPP class
0–59	Arid	Tropical	AEZ1
		Temperate	AEZ7
		Boreal	AEZ13
60–119	Dry semiarid	Tropical	AEZ2
		Temperate	AEZ8
		Boreal	AEZ14
120–179	Moist semiarid	Tropical	AEZ3
		Temperate	AEZ9
		Boreal	AEZ15

LGP in days	Moisture regime	Climate zone	GTAPP class
180–239	Sub humid	Tropical	AEZ4
		Temperate	AEZ10
		Boreal	AEZ16
240–299	Humid	Tropical	AEZ5
		Temperate	AEZ11
		Boreal	AEZ17
>300 days	Humid; year-round growing season	Tropical	AEZ6
		Temperate	AEZ12
		Boreal	AEZ18

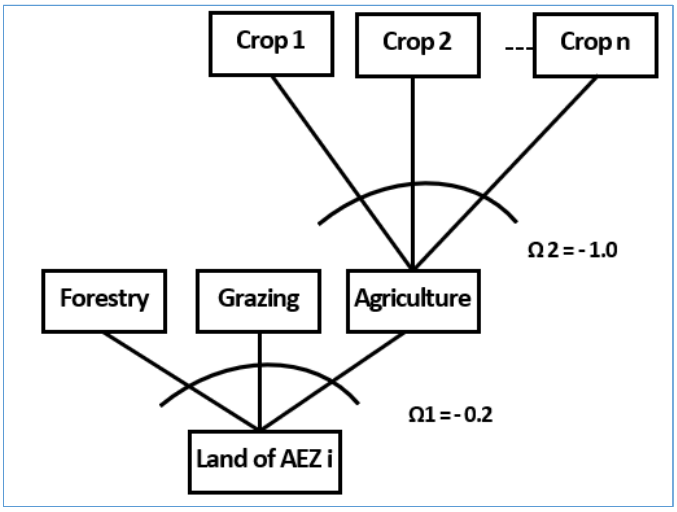
Note: LGP = Length of Growing Period.

Source: GTAP.

34. ***Figure 6*** displays the model structure for various land use. ***Table 2*** maps AEZs in Bulgaria based on the GTAP-FAO-IIASA classification for global AEZs. AEZ9 (temperate-moist-semiarid) covers most of the country while AEZ10 represents mostly the Western regions (***Figure 11***).

35. Besides, land productivity which is captured through the AEZ approach, analysis of the climate impact on agriculture in the country necessitates a good understanding of the country's seasonal and long-term climate patterns. The expected variations in duration of the growing season are introduced in the model as total productivity loss in the agriculture sector based on the estimates from Roson and Sartori (2016).

Figure 9. Land supply in the Bulgaria CGE model

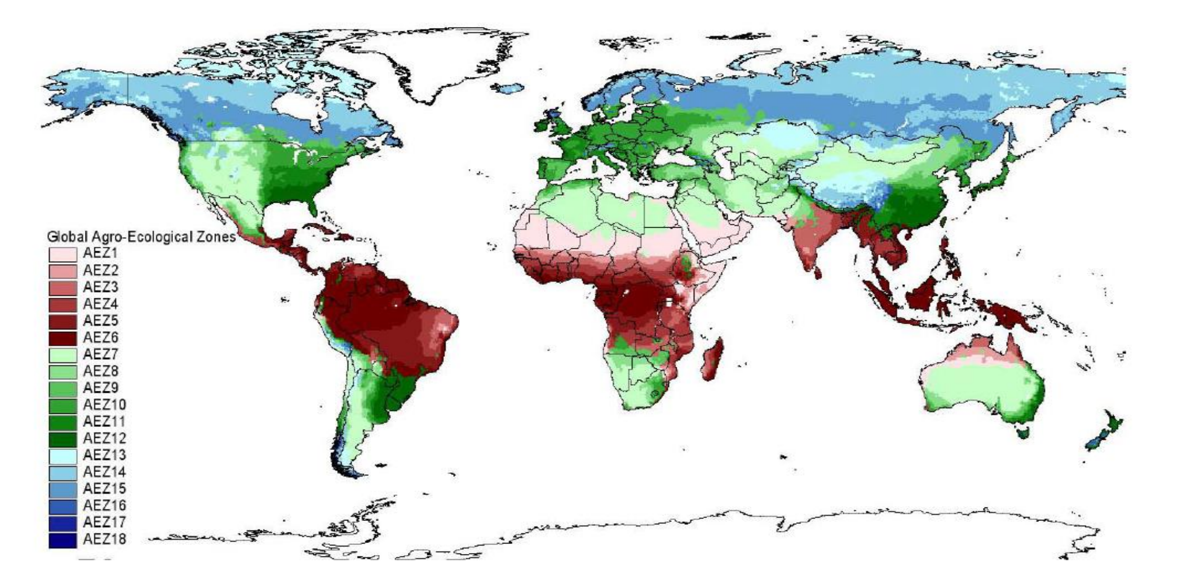


36. The competition for land use in agriculture takes place between the five AEZs (see ***Figure 9***) while competition for labor and capital takes place at the national level. Beyond land, the agriculture sector demands labor, capital, and natural resources such as water, minerals, fish, and forest. Land that is not used in agriculture is assumed to be used for livestock or covered by forests. Use of each factor of production is determined in a specific way: labor and capital are imperfect substitutes and mobile between sectors while land is used only for crop production, forestry, or livestock.

2.4.1. Land database construction

37. The GTAP 9 Land Use and Land Cover Data Base builds on global land cover and land use databases, as well as global forestry data. In keeping with the multiyear release of version 9, the land cover and land use database is updated to represent 2011 as shown in ***Figure 10***. This global dataset was tailored to include multiple sources of land and water use at the RB and AEZ levels for Bulgaria using the most detailed and complete databases.

Figure 10. Global AEZs



Source: Lee et al. (2005)

38. Procedures followed in updating the land cover data were the following:

(a) **Aggregation and normalization of agriculture and built-up land cover.** Within each 0.5 × 0.5 degree grid cell, the percentage of land cover for croplands, pasturelands, and built-up lands were added. Grid cells wherein the combined agriculture and built-up land cover exceeded 100 percent were normalized to ensure that the sum of land cover for these cells does not exceed 100 percent.

(b) **Derivation of the 'residual' land cover and its allocation to other land cover types.** The 'residual' land cover was calculated by deducting the normalized land cover of agricultural and built-up lands from grid cells with uniform value of 100 percent. The 'residual' land cover was then allocated to grasslands, forests, shrub lands, and other lands using the Global Maps of Potential Vegetation.

(c) **Conversion of the fractional land cover data into actual area of land cover.** To derive the grid-cell-level areas for the different land cover types, a global map of the surface area of the earth was used.

(d) **Aggregation of land cover areas by AEZ and by country.** The grid-cell-level areas for different land cover types were aggregated by overlaying the land cover maps with a map of global AEZs and countries.

(e) **Calculation of accessible forest area by AEZ and by country.** To derive the accessible forest area by AEZ and by country, the aggregated forest area data were weighted by the share of accessible forests in total forest area by AEZ and by country. These shares were taken from the GTAP 6 land cover database.

2.4.2. Water database construction

39. The process of incorporating water in the Bulgaria model as a factor of production starts with the underlying GTAP-AEZ database that identifies land located in various agroecological areas and its uses (sectors). It helps remember that when splitting the GTAP sectoral land rents into AEZs, land rent is tied to the harvested area, instead of the physically cultivated area. In other words, in the GTAP economic accounts for each country, land rents are generated from the activity on a given parcel of land during the calendar year. Therefore, the value of the land in production over the course of the entire year is what is important. The GTAP sectoral land rents are first split into 18 AEZs[3] according to the AEZ-specific production shares as derived from multiple sources.

40. The above method is used in conjunction with the following formula to split the GTAP sectoral land rents into 18 AEZs and then add water as factor of production.

$$R_{cs} = R_c \left[\sum_{i \in c} P_i Y_{ia} H_{ia} / \sum_{a \in AEZ} \sum_{i \in c} P_i Y_{ia} H_{ia} \right] * SH_{ws} * SH_{rb}$$

Where:

R_{cs} is the land rent accrued to GTAP sector *c* in AEZ *a*;

R_c is the total land rent of GTAP crop sector *c*, (no AEZ distinction here, VFM - Value of Firm Purchases at Market prices - header in GTAP);

P_i is the per ton price of FAO crop *i* (invariant to AEZs);

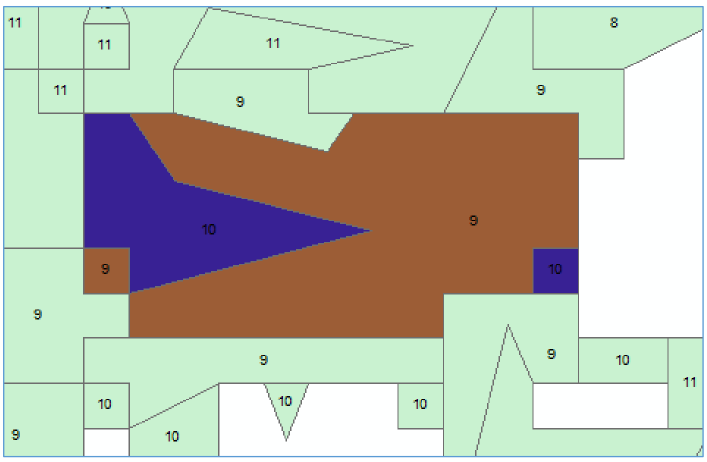
Y_{ia} is the yield (ton per 1,000 ha) of FAO crop *i* in AEZ *a*;

H_{ia} is the harvested area of FAO crop *i* in AEZ *a*;

SH_{ws} is the share of water type (*t* = groundwater or surface water, *b* = RBs) in total basin water supply; and

SH_{rb} is the water consumption share of sectors by RB.

Figure 11. Bulgaria AEZs based on global AEZ classification



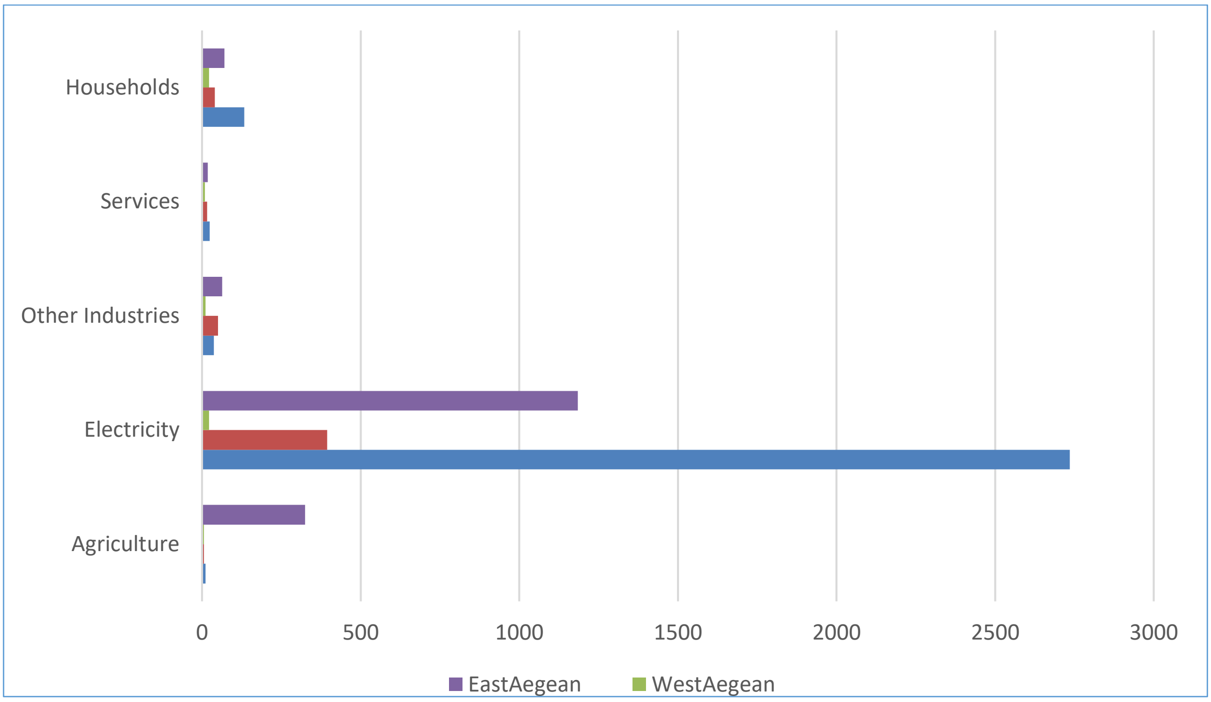
Sources: GTAP, FAO, and IIASA 2017.

Note: Brown and blue color areas represent Bulgaria. While Bulgarian sources define seven AEZs, GTAP-FAO-IIASA classification displays the Bulgarian territory in five global AEZs.

[3] 18 AEZs exist in the standard GTAP-AEZ data for different countries in the world. In effect, entries for these 18 AEZs have zeroes for all but 2 AEZs in Bulgaria. For sake of completeness of the data (because 'rest of the world' is considered in the model), all 18 AEZs have to be included

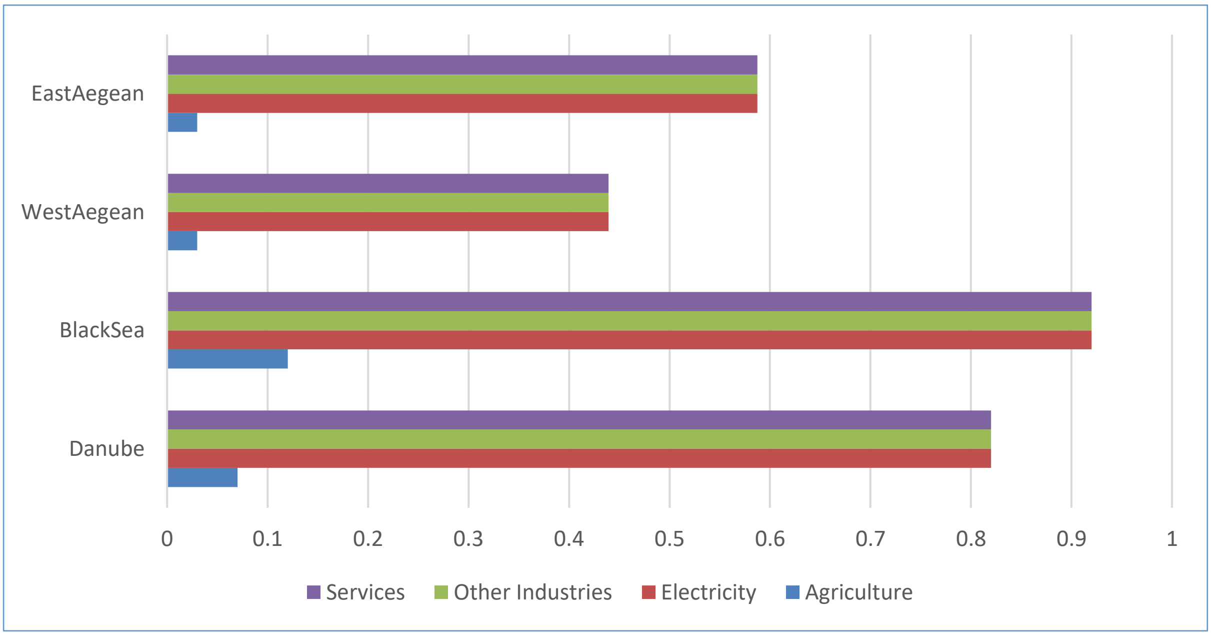
41. ***Figure 12*** shows the volume of water use by RB and sector for Bulgaria in 2011. Physical water consumption data were combined with data from ***Figure 13*** that shows the average water tariff across basins to generate the value of water use by sector and RB that is needed to generate the $SH_{rb}(c, b)$ share value used in the above equation. The $SH_{ws}(t, b)$ value was generated using the distribution of freshwater sources across the four RBs in Bulgaria.

Figure 12. Water use (million m³) by sector and RB, 2011



Source: Ministry of Agriculture, Foods and Forestry.

Figure 13. Average water tariff by sector and RB, 2011 (US$)



Source: Ministry of Agriculture, Foods and Forestry.

42. As can be seen in these figures, demand for water mainly comes from the Danube region for electricity generation. In the meantime, water tariffs for all industrial sectors are the same except for agriculture that benefits from the lowest tariffs. The Black Sea region pays the highest tariffs for water while the West Aegean region benefits from the lowest tariffs.

43. As an illustration, ***Table 3*** shows Bulgaria's total value-added creation, including for land rents (header 'VFM' - Value of Firm Purchases at Market prices - from the GTAP database) by crop (irrigated and rainfed), by RB, and by AEZ. The data show that most of the economic value is generated by Bulgaria's irrigated crops in the Danube RB in AEZ9 and AEZ10. This is in line with expectations because these two regions are known for their temperate climate that allows longer growing periods. In the data and model, water endowment, which is based on all managed water in the RBs, has an equilibrium, that is, supply and demand is equal; consumption of water from different RBs by different industries equals the total availability of water in each RB. Such a balance exists both in the reference year as well as in the baseline and climate scenarios with or without adaptation in future. This does not imply that future water scarcity and increased drought risk is not a concern with ongoing climate change, especially on the longer-term (that is, at the end of the century, well beyond the horizon of this analysis). On short-term (or the next 30 years), main risks linked to water resources relate primarily to flooding. Over this timeframe, groundwater availability is not expected to change significantly and with population decline and moderate economic growth, water availability is not likely to become a concern for those regions that use groundwater. Only the Black Sea region appears to be most vulnerable to water scarcity risk (on a seasonal basis), given its higher reliance on surface water and higher tourism activities. This points admittedly to the limits of the granularity of the analysis and could be a direction for further development: there might be seasonal shortages, but they cannot be captured in a model with a yearly time step and that degree of disaggregation.

Table 3. Bulgaria crop sector rents (US$, millions)

	pdr	wht	gro	v_f	osd	c_b	pfb	ocr
S_DB_AEZ8	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.05
G_DB_AEZ8	0.03	0.10	0.08	1.40	0.18	0.00	0.08	1.99
S_BS_AEZ8	0.00	0.00	0.00	0.05	0.01	0.00	0.00	0.08
G_BS_AEZ8	0.01	0.02	0.01	0.22	0.03	0.00	0.01	0.31
G_WA_AEZ8	0.01	0.03	0.03	0.44	0.06	0.00	0.03	0.63
S_DB_AEZ9	0.06	2.98	1.22	1.93	3.70	0.00	0.09	3.32
G_DB_AEZ9	2.26	112.16	45.85	72.59	139.05	0.00	3.32	124.78
S_BS_AEZ9	0.09	4.38	1.79	2.83	5.43	0.00	0.13	4.87
G_BS_AEZ9	0.36	17.70	7.24	11.46	21.94	0.00	0.52	19.69
S_EA_AEZ9	0.01	0.31	0.13	0.20	0.38	0.00	0.01	0.34
G_EA_AEZ9	0.02	1.05	0.43	0.68	1.30	0.00	0.03	1.17
S_WA_AEZ9	0.05	2.50	1.02	1.62	3.10	0.00	0.07	2.79
G_WA_AEZ9	0.72	35.61	14.56	23.04	44.14	0.00	1.05	39.61
S_DB_AEZ10	0.02	0.21	0.07	0.17	0.22	0.00	0.00	0.24
G_DB_AEZ10	0.57	7.97	2.81	6.51	8.42	0.00	0.10	9.21
S_BS_AEZ10	0.02	0.31	0.11	0.25	0.33	0.00	0.00	0.36

	pdr	wht	gro	v_f	osd	c_b	pfb	ocr
G_BS_AEZ10	0.09	1.26	0.44	1.03	1.33	0.00	0.02	1.45
S_EA_AEZ10	0.00	0.02	0.01	0.02	0.02	0.00	0.00	0.03
G_EA_AEZ10	0.01	0.07	0.03	0.06	0.08	0.00	0.00	0.09
S_WA_AEZ10	0.01	0.18	0.06	0.15	0.19	0.00	0.00	0.21
G_WA_AEZ10	0.18	2.53	0.89	2.07	2.67	0.00	0.03	2.92
G_DB_AEZ14	0.00	0.05	0.02	0.12	0.05	0.00	0.00	0.42
S_BS_AEZ15	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01
G_BS_AEZ15	0.00	0.03	0.01	0.02	0.02	0.00	0.00	0.03
G_WA_AEZ15	0.00	0.05	0.01	0.04	0.04	0.00	0.00	0.05
UnSkLab	2.74	153.32	47.77	108.56	187.98	0.04	1.15	128.36
SkLab	0.47	25.30	7.93	18.53	31.01	0.01	0.51	22.49
Capital	0.93	48.52	17.51	33.48	58.84	0.05	1.27	54.88
NatRes	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Note: Water type classification: S = surface water, G = groundwater; RB classification: DB = Danube, BS = Black Sea, WA = West Aegean, EA = East Aegean

Source: GTAP data processing using data from Ministry of Agriculture, Foods and Forestry.

2.5. Damage functions

44. Climate change affects economic activities through changes in observable physical parameters (temperature, rainfall, SLR, and so on) that are translated into shocks on economic variables in the economic model. The mathematical relations that capture these shocks are called 'damage' functions.

Estimating damage functions

45. Damage functions help translate physical impacts of climate change into economic variables of interest that can be used, for example, in a CGE framework. Seen this way, damage functions represent relationships between climate variables, such as temperature and precipitation, and economic variables, such as productivity, for example. What follows is the specification of some of the functional forms used for the Bulgaria CGE model. These equations are not part of the standard GTAP Bulgaria CGE model and are derived from these results as applied originally by Roson and Sartori (2016). The specific values that were finally fed into the CGE model can be found in ***Table 4***.

1) SLR function

$$SLR = [(\alpha + \beta\Delta t - V)(Y - 2000)]$$

where:

SLR is Sea Level Rise in meters;

Δt is the change in temperature relative to the baseline (1985–2005[4]);

Y is the year period (2050, for example);

V is vertical land movement;

α, β are parameters to be econometrically estimated from a panel data by Roson and Sartori (2016), who find α=0.00095 and β=0.00342.

[4] The specific year value differs by country. Roson and Sartori (2016) provide an estimate of these functions for 140 countries. Some countries have data for 1985 and some have it for 2005, hence the range.

46. Using this relation, the authors then estimated a derivative variable from SLR as a percentage change between land available for use in 2050 with respect to 2005. It gives a loss of land resulting from SLR of about 0.2 percent by 2050 for Central and Eastern Europe.

2) Impact on crop yields

$$DY = 115.992DT - 9.936DT^2 + 0.475DP + 7.9DK/K$$

where:

DY is change in output per hectare;

DT is change in temperature (°C);

DP is change in precipitation (mm);

DK is change in atmospheric carbon dioxide concentration (ppm).

47. This initial equation is then transformed so as to link changes in yield to variation in average temperature only and the authors compute DY/Y to get per cent changes in output per hectare. Such yield losses range between 1 and 11 percent for temperate regions, for different crops (as shown in ***Table 4***).

3) Heat stress and labor productivity

$$RH = 67.11 - 0.84T - 0.23P - 0.0005P^2$$

where:

RH is the average relative humidity (%);

T is the average air temperature (°C);

P is the monthly average precipitation (mm).

48. From *RH*, the average absolute humidity *E* is computed, from which the Wet Bulb Global Temperature (WBGT) is then computed, to define the percentage of a typical working hour that a person can work assuming the remaining time is rest. Losses in labor productivity due to RH adjustments coming from climate change vary between 2.5 and 17.5 percent.

$$E = (RH/100) \times 6.105 \times \exp(17.27\,T/(237.7 + T))$$
$$WBGT = 0.567\ T + 3.94 + 0.393E$$

4) Tourism

$$A = K_A \times \exp(0.22T - 0.00791T^2)$$
$$D = K_D \times \exp(-0.18T - 0.0.00438T^2\ )$$

where:

A is for arrivals;

D is for departures;

T is the average temperature (°C);

K_A and K_D are country-specific constants that are designed to account for all other factors that are different from temperature.

5) Energy

49. Climate change is likely to impact the energy sector through several channels, such as reduced efficiency of nuclear and thermal power plants (since higher air and water temperatures affect the efficiency of their cooling systems), uncertainty for hydropower generation (given river flows might be impacted by climate change), damages to infrastructure, including

transmission and distribution networks (with more frequent and intense weather hazards), or a shift in energy demand (from winter to summer). However, it should also be noted that a conclusion of the Risk and Vulnerability Analysis and Assessment of the Bulgarian Economic Sectors to Climate Change (MoEW 2014) is that the energy sector is 'extremely resilient' to expected impacts in the period until 2035. As a result, the present analysis focuses primarily on the impact of climate change on energy demand, an 'indirect' impact of climate change.

50. The relationship between (changes in) temperature and (changes in) energy consumption is rather complex and depends on the season, the source of energy, and the climatic conditions of the country. For instance, an increase in winter temperatures would cause a decrease in energy used for heating purposes, whereas an increase in summer temperatures is likely to cause an increase of energy consumed for cooling purposes. Analyses of climate change scenarios for Bulgaria indicate that the decrease in heating degree days is larger than the increase in cooling degree days, at least till the 2050's.[5] In other words, climate change will translate overall in a reduced energy demand. The impact of temperature change on energy demand is modeled following the specifications in Roson and Sartori (2016), based on seasonal long run temperature elasticities of energy demand, differentiated by energy source and climate region. Overall for Bulgaria, energy demand falls by about 1.9 percent in the optimistic scenario with 2 degrees temperature rise, and by about 10.7 percent in the pessimistic case with 4 degrees temperature rise.

51. Simulations described above are performed by identifying the relevant economic variables and imposing 'shocks' (exogenous changes) to these variables, such as the following:

- Land losses to SLR have been modelled as percent decreases in the stock of productive land and capital in Bulgaria. Both modifications concern variables, land and capital stocks, which are exogenous to the model and therefore they are straightforwardly implemented. As the information on capital losses is not available, it was assumed they are equivalent to land use losses;
- Changes in regional households' demand for oil, gas, and electricity are modelled as changes in the overall demand shifters of the respective industries;
- Changes in tourists' expenditure are modelled as changes in households' demand addressing the 'market services sector', which includes recreational services;
- Effects on agriculture are simulated through changes in crop productivity.

52. To analyze the macro-economic impacts of climate change and the benefits from adaptation, two climate change scenarios have been chosen, contrasting a climate sensitive-scenario (a 2°C warmer world) and a carbon intensive-scenario (a 4°C warmer world). Given currently published analyses for Europe, there is special value in considering a 4°C warmer world scenario (since available studies focus mostly on a 2°C warmer world, as explained in ***Section 3.2***). The climate-sensitive scenario corresponds to the Representative Concentration Pathway 4.5 (RCP 4.5),[6] which represents a future in which some collective action is taken to limit greenhouse gas emissions and global annual average temperature increases by 2.4 °C

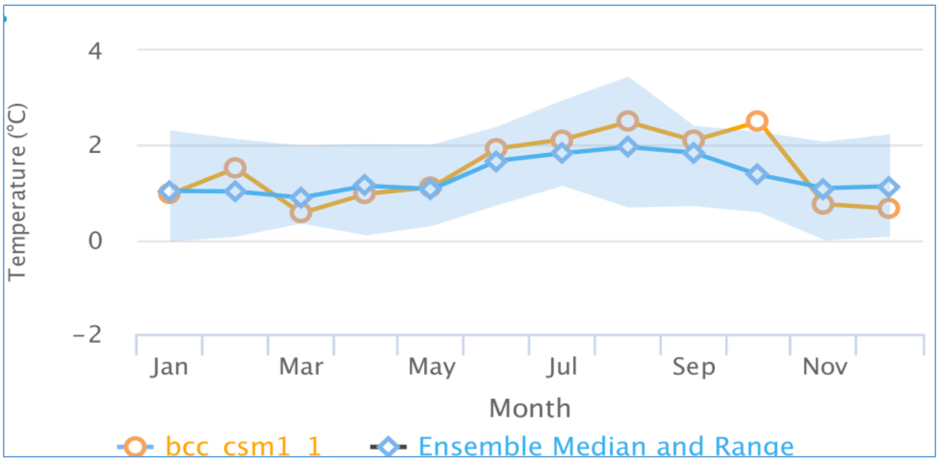
[5] World Bank Climate Change Knowledge Portal.

[6] Representative Concentration Pathways (RCPs) are four greenhouse gas concentration (not emissions) trajectories adopted by the Intergovernmental Panel on Climate Change (IPCC) for its fifth Assessment Report (AR5) in 2014.

(range of 1.7 to 3.2 °C) by 2100 relative to pre-industrial levels. The carbon-intensive scenario corresponds to RCP 8.5, which represents a future in which no actions are taken to reduce emissions and global annual average temperature increases by 4.3 °C (range of 3.2 to 5.4 °C) by 2100 relative to pre-industrial levels.

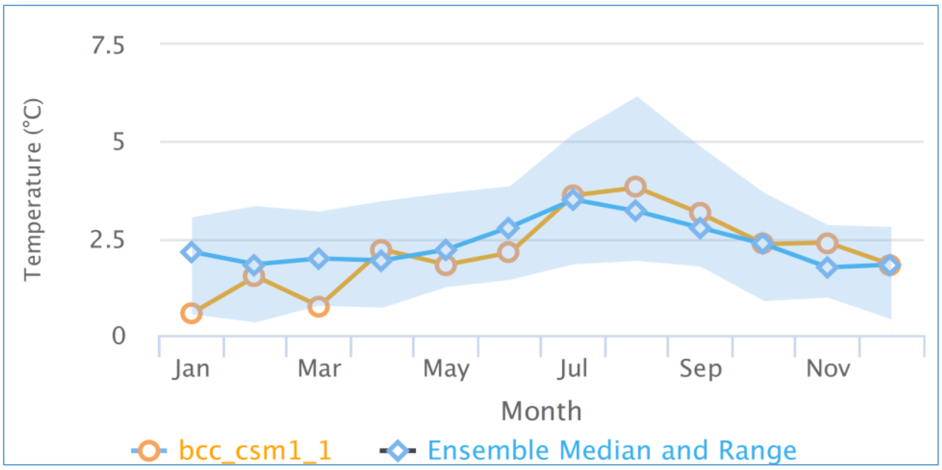
53. ***Figures 14 and 15*** show expected changes in monthly temperatures for Bulgaria, in 4°C warmer world (RCP 8.5). Under RCP 8.5, global mean temperature increases on average by about 2°C by mid-century and 4°C by the turn of the century while warming is more intense over Bulgaria: around 2.4°C by mid-century and 4.8°C by the turn of the century. For a few climate models, mean temperature change over Bulgaria gets close to 4°C as soon as 2050. The damage functions from Roson and Sartori (2016) are calibrated against anticipated global average temperature rise. This assumption is broadly consistent while slightly underestimating warming over Bulgaria at the same time.

Figure 14. Projected change in monthly temperature in Bulgaria in 2020–2039 (RCP 8.5)



Source: World Bank Climate Change Knowledge Portal.

Figure 15. Projected change in monthly temperature in Bulgaria in 2040–2059 (RCP 8.5)



Source: World Bank Climate Change Knowledge Portal.

54. These expected monthly temperature increases are translated into productivity changes in economic variables for 2°C (optimistic) and 4°C (pessimistic) temperature change scenarios using the shocks developed by Roson and Sartori (2016).

Table 4. Productivity changes in economic variables for 2°C (optimistic) and 4°C (pessimistic) temperature change scenarios using the shocks developed by Roson and Sartori 2016

Shocks/Scenario name	2°C temperature increase		4°C temperature increase	
	(a) Optimistic	(b) Pessimistic	(a) Optimistic	(b) Pessimistic
Productivity shocks (with respect to the baseline scenario)				
Rice	−1.53	−4.59	−3.53	−10.59
Wheat	−3.065	−9.195	−3.19	−9.57
Other grains	−1.345	−4.035	−3.345	−10.035
Energy demand shocks				
Electricity	−0.05	−0.15	−0.09	−0.27
Gas	−0.05	−0.15	−0.08	−0.24
Petroleum products	−5.15	−15.45	−9.93	−29.79
SLR shocks				
Land	−0.0002	−0.0006	−0.00037	−0.00111
Capital	−0.0002	−0.0006	−0.00037	−0.00111
Tourism shocks				
Demand for hotel and tourism services	0.178	0.534	0.356	1.068

55. This analytical framework developed for Bulgaria integrated a socioeconomic approach with the state-of-art climate and land/water use models. However, the extent of the analysis is still limited by the frontiers of climate science. The projections about direct or indirect impacts of climate change on a broad range of economic activities are still incomplete. For example, the current analysis does not consider the nonmarket impacts of climate change such as changes in species distributions, reductions in biodiversity, or losses of ecosystem goods and services. Regarding agriculture and energy, climate impact assessments are relatively advanced. These are the economic sectors that were the focus on developing the adaptation scenarios for Bulgaria.

56. While integrating socioeconomic and physical models, it is, therefore, primordial to address the underlying uncertainties in the climate impact assessments. To overcome the risk of cumulating uncertainties at different estimation levels, the study developed the macroeconomic analysis based on two climate scenarios: optimistic and pessimistic outlooks. Each scenario incorporates different assumptions about the magnitude of climate change by 2050 and about the direction and extent of likely impacts in the market sectors analyzed. In scenario development, the optimistic and pessimistic climate outlooks were tested for high and low vulnerability assumptions for each sector (in terms of its sensitivity to climate change and its ability to adapt).

Box 1. Limitations of the CGE approach

Despite the increase in the use of applied general equilibrium modelling for climate policy analysis over the last few years, the methodology is not without limitations. The main problem stems from the endemic difficulty of combining theory and reality. Applied general equilibrium models need an empirical basis for their calculation. A list of main modelling problems follows.

- **The model structure.** Choosing the model's functional forms, elasticity type, tax treatment, and so on, is the first obstacle the researchers face when modelling a specific economy. As an example, the GTAP model used here applies the same functional forms across households in different regions of the world. How realistic this happens to be for policy work is always debatable.
- **Data and parameter values.** CGE models rely on SAM to approximate the workings of an economy. However, the construction of a SAM is by no means a simple exercise. Adding to this complexity is combining SAMs from a wide range of countries to develop a global SAM and a global CGE model which further amplifies the problem. In addition, the different functional forms defined in the model require estimation of parameters. It is not possible to econometrically estimate all these functional parameters and some sort of approximation or expert estimate must be made. This further drives a wedge between reality and the model mentioned above.
- **Model verification and validation.** Another important problem associated with this methodology is the lack of statistical tests to confirm the validity of the model specifications. Most general equilibrium models are calibrated from a database for a specific year. For this reason, except for simple tests to analyze the sensitivity of certain parameters included in the model, econometric procedures cannot be used to test the model's validity.
- **Feedback mechanisms and vulnerability.** The impacts of climate change on the society and economy depend largely on the interplay with the new climate as well as on the vulnerability to extreme weather events. The degree of vulnerability is determined by factors such as technical and financial capability, demographic, socioeconomic, and behavioral constraints, and organization of the society. As these factors vary over time, vulnerability should vary as well (Tol and Fankhauser 1998). The model and approach used in this analysis does not explicitly take changing vulnerability into account. Also, because the GTAP model used here is somewhat aggregate in nature (sector and sub regions, time step), there is only limited room for feedback loops and adjustment mechanisms. Agriculture is among the sectors most vulnerable to climate change in Bulgaria and the model is reasonably well equipped to analyze the link between natural assets such as land and water that are vulnerable to climate change, and primary production factors in agriculture. Based on policy interest and available micro-economic and technical information at sectoral level, the model could be further enhanced to similarly improve the representation of climate vulnerability and adaptation potential in other sectors or to analyze mitigation issues. Those are potential directions for further research.
- **To overcome these limitations of the Bulgaria CGE,** climate parameters were borrowed from a global dynamic CGE model developed by Roson and Sartori (2016), with a sensitivity analysis (high and low vulnerability), for two climate change scenarios.

3. Model Baseline: Growth toward 2050

57. The CGE model simulations refer, first, to the development of an economic baseline that does not account for climate change and its impacts. Second, the economic projections in the baseline are adjusted for the estimated impacts of climate change. For Bulgaria, the model simulations indicate that climate change could result in a much slower economic growth, with the growth rate in 2050 lower by about 1 to 4 percent per year.[7] Third, an additional scenario is developed to illustrate potential net gains from climate change adaptation (discussed in ***Section 4***).

3.1. Baseline without climate change

58. The economic baseline to 2050 is the growth path that Bulgaria is likely to follow. It is developed based on the observed economic trends for the country over 2011–2015 and demographic projections (developed by the United Nations) that assume a constant fertility rate and constant migration trends over 2011–2015. These statistics and IMF projections to 2022 used in baseline development are presented in ***Table 5***.

59. The economic drivers, meaning demographic trends, investment, international trade over 2015–2022 as published by the IMF, are shown in ***Table 5***. Based on the past official statistics on these parameters, it was assumed that investment would represent around 23 percent of GDP for the next years and that the Bulgarian economy would grow 1.3 times by 2050, an annual average growth rate of around 1.7 percent per year. Improvement in investment productivity is one of the main drivers of growth.

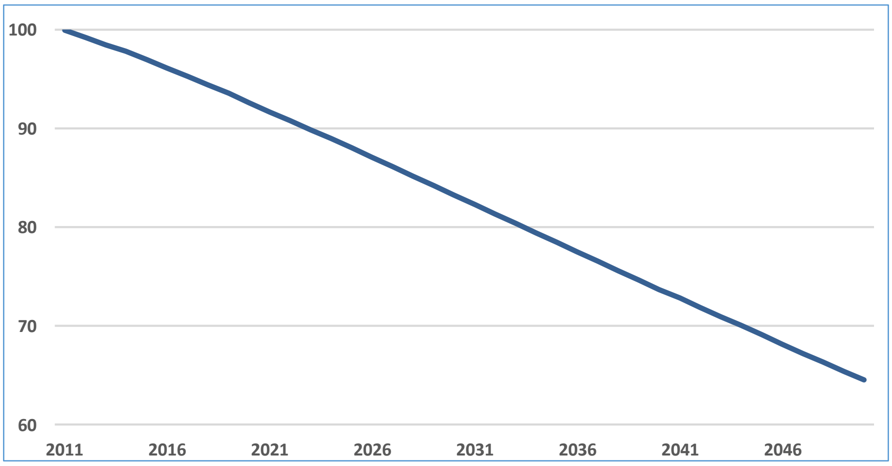
Table 5. Statistics used in the development of the baseline scenario

Bulgaria	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
GDP, constant prices (national currency)	76.203	76.227	76.884	77.906	80.724	83.503	85.924	88.244	90.45	92.712	95.029	97.405
GDP, constant prices (percentage change)	1.915	0.031	0.862	1.329	3.617	3.443	2.9	2.7	2.5	2.5	2.5	2.5
Total investment (percentage of GDP)	21.47	21.942	21.34	21.436	21.19	20.307	20.83	20.98	21.443	22.227	23.1	23.986
Current account balance (percentage of GDP)	0.33	−0.853	1.276	0.082	−0.134	4.198	2.258	2.034	1.731	0.946	0.105	−0.825
Population, total (number of people × 1,000)		7,395.6	7,348.3	7,305.9	7,265.1	7,223.9	7,178.0					

Source: IMF.

[7] OECD (2015) projects 1.7 annual growth in 2040–2050.

Figure 16. Population projections for Bulgaria (total population, constant fertility and migration rate)

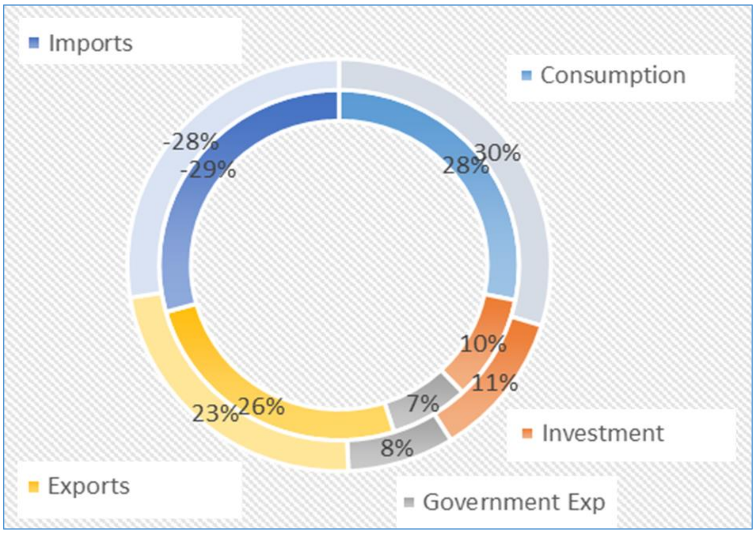


Note: Index 2011 (start year) = 100.

Source: UN Statistics.

60. As shown in ***Figure 16***, population is expected to decrease by 36 percent (from 7.39 million to 4.73 million) between 2011 and 2050. Decreasing population affects two parameters in the CGE model: decreasing demand for goods and services (that leads to decreased firm supply) and shrinking labor supply. Decreasing domestic demand can be compensated by exports with a boost in competitiveness. Decrease in labor supply may lead to higher wages due to unavailability of labor, hence increased production cost, and generate an adverse effect on competitiveness depending on the production and trade elasticities. Thus, labor-intensive sectors are likely to decline while less labor-intensive ones would expand in Bulgaria in the next decades. Among the sectors in Bulgaria, the agricultural sector is highly labor intensive: labor forms 46 to71 percent of the total factor input costs. Manufacturing sectors are highly capital intensive, with capital forming 50 to 75 percent of the total factor input costs. Services sectors are slightly more heterogenous, with labor cost shares varying between 40 percent and 70 percent; nevertheless, they are more labor intensive than manufacturing sectors.

Figure 17. GDP composition in 2011 (inner circle) and 2050 (outer circle), without climate change



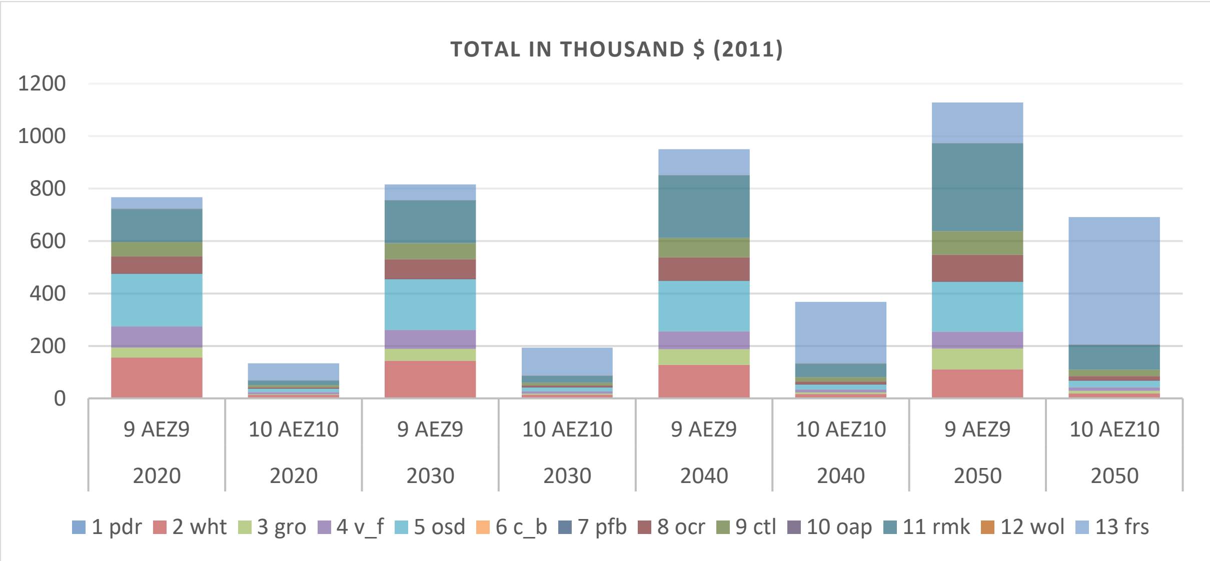
Source: Bulgaria CGE model results.

61. Based on the model projections toward 2050, investment and government expenses will grow at a moderate rate while consumption and imports are likely to grow faster than the rest of the macroeconomic accounts (***Figure 17***). In the end, growth is mostly consumption driven. Overall, the trade deficit is likely to persist till 2050. While the share of agriculture in trade is likely to stay constant, net exports of manufactured products (mainly machine and equipment) are likely to increase.

62. Sectoral value creation is expected to vary by sub region even without considering climate change. The largest changes are observed in the agriculture sector. As shown in ***Figure 18***, among the three temperate climate AEZs, agricultural production in AEZ9 (Western region), the most humid region, is likely to grow faster than in AEZ10 (Eastern region). The highest value creation is expected from raw milk in AEZ9 (Western region) and forest/forest products in AEZ10 (Eastern region). (See ***Table 1.1*** in Annex for definition of crops in GTAP).

63. It is important to underscore that the economic baseline does not integrate existing or planned sectoral strategies or reforms; it simply translates the growth potential based on the demand and supply projections for various sectors and AEZs. Demand for products comes from households, the government, industry, and trade partners while supply of goods relies on domestic production and imports. The market mechanisms lead to increasing prices if demand exceeds supply and vice versa.

Figure 18. Household revenues from agricultural activities (2020–2050) without climate change, compared to the year 2011



Key: PDR: Paddy rice; WHT: Wheat; GRO: Cereal grains; V_F: Vegetables, fruit, nuts; OSD: Oil seeds; C_B: Sugarcane, sugar beet; PFB: Plant-based fibers; OCR: Crops; VOL: Vegetable oils and fats; MIL: Dairy products; PCR: Processed rice; SGR: Sugar; OFD: Food products.

Source: Bulgaria CGE model results.

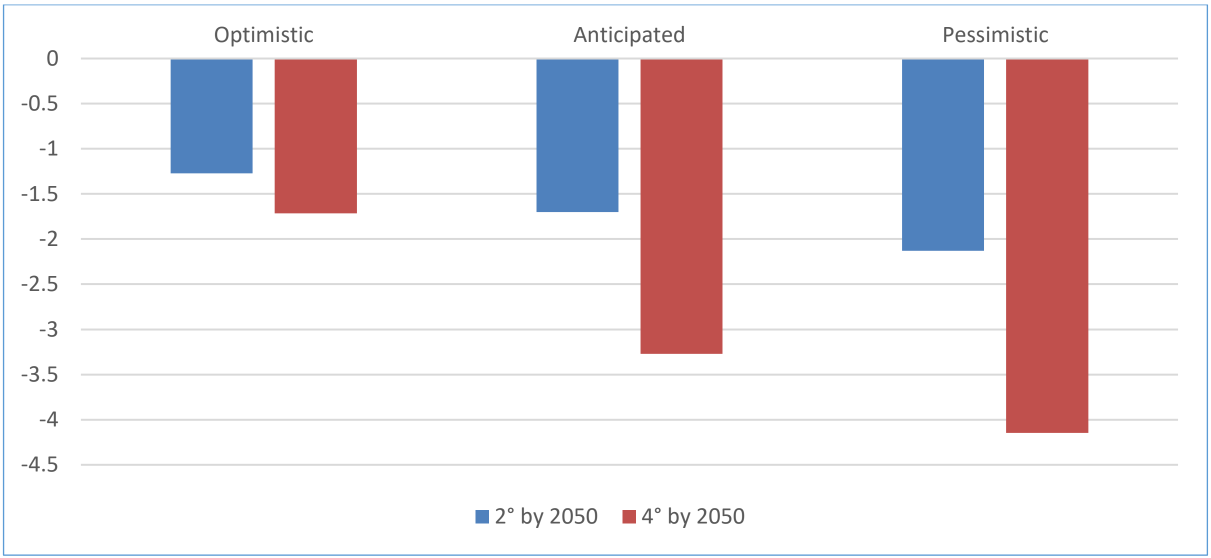
64. Main expense items in a household budget were housing, transport, electricity, and food in 2015. The structure of the household consumption basket is expected to stay the same, except with a decrease in food expenses due to decreasing food prices in the baseline that does not take into account climate change and its impacts.

3.2. Baseline with climate change impacts

65. Climate change can directly (or indirectly) affect the cost and availability of economic outputs and inputs alike. In turn, these changes both directly and indirectly influence the level and structure of overall economic activity.

66. GDP is projected to grow annually by about 1.7 percent by 2050. This growth rate is completely wiped out if Bulgaria faces the full impact of a 2°C rise in temperature by 2050. The negative impact of climate change outweighs economic growth by more than 1 percent if all the pessimistic 2°C and 4°C scenarios were considered. In general, it is safe to say that climate change presents an existential threat to the prospect of future economic growth in Bulgaria (especially because each and every impact is not accounted for in the model, given knowledge gaps and uncertainties). ***Figure 19*** displays these points.

Figure 19. Impact of climate change on real GDP growth by 2050
(percentage of change compared to the baseline without climate change)



Source: Model simulations.

67. These results fall between the range of the findings from available studies on the economic impacts of 2°C change in Southern Europe (see ***Box 2*** for a review of summary findings): the PESETA project (2014) estimates the overall macro-economic impact of climate change around 2.8 percent GDP in 2080; the TopDad project estimates a 0.15 percent slowdown in Southern European economic growth; and the Climate Cost project estimates 0.5-1 percent GDP loss by 2100.[8] These studies date from a few years back and unfortunately there are no updates yet regarding the potential macroeconomic impact of a 4°C temperature change.

[8] PESETA Final report (2014), p: 104, Figure 20 (reference scenario); TopDad report available at http://topdad.services.geodesk.nl/en/web/guest/long-term-macroeconomic-effects; Climate Cost project (2011) for 2100 available at http://www.climatecost.cc/images/Policy_Brief_ClimateCost_Draft_Final_Summary_vs_4.pdf

Box 2. The macro-economic impacts of a 2°C temperature change over Europe: findings from previous studies

The Climate Cost project estimated substantial costs from climate change in the absence of adaptation policies. More specifically, in a 2°C scenario, the project reported the following results for EU: (i) 80,000 additional people that will be directly affected by coastal flooding each year by the 2080s with expected annual damage costs of €17 billion per year; (ii) Over 35 percent of EU wetlands could be lost by 2080s unless protective measures are undertaken; (iii) Climate change will have positive and negative effects on energy demand levels, reducing winter heating demand but increasing summer cooling demand. The total supply side analysis implies annual European energy costs could be as high as US$95 billion by 2100; (iv) Deaths related to extreme heat are estimated around 74 thousand deaths per year by the 2050s; (v) Impacts of climate change on Salmonellosis (the leading cause of food-borne illness in Europe) may reach around €68 and €89 million per year in the 2050s; and (vi) One hundred thirty fatalities per year can be expected from sea level rise and storm surge by mid-century, with two-thirds in Western Europe.

The PESETA II project provided estimates of climate change impacts by 2080 for Europe. Main results from the study for Central Southern Europe (2°C scenario) are as follows: (i) while EU agriculture yields will fall by 2 percent, Central Southern European yields (including Bulgaria) are expected to increase by 2 percent; (ii) Central Southern Europe's energy demand is expected to fall by 9 percent compared to the respective control period (1961–1990); (iii) Damages from river floods could raise up to €5.2 billion per year compares (about current damage level for the entire EU: €4.4 billion in annual damage reported over 1998–2009); (iv) cropland area affected by droughts is projected to increase substantially to around 242,000 km^2 per year and 642 million people per year; (v) Additional flood-induced damages to road infrastructure for the period 2070–2100 is estimated around €40 million per year; (vi) Impact from sea floods damage may reach €100 million per year; (vi) Climate change translates into expected variation in tourists´ expenditures (and thus expected revenue loss for the tourism industry) of around €5 million per year; (viii) Impact on habitat suitability index is to increase by 6 percent (compared to 1961–1990); (ix) Heat-related events are estimated around 129 deaths per year.

The TopDad study developed economic assessment of climate change under "high emissions-high growth" and "low emissions-low growth" scenarios. The study does not provide a detailed assessment by region and concludes overall that due climate change, income per capita by 2050 will already be one third lower than the level anticipated at the end of this century under the "low emissions-low growth" scenario. The economic impacts under the "high emissions – high growth" pathway will also grow incrementally: from a 0.15 percent reduction in growth rate in Europe between 2010 and 2050 to a reduction of 0.2 percent per year in the second half of the century. This means that there will be fewer resources available for adaptation, while at the same time the impacts of climate change and the need for adaptation will be considerably higher. The study also highlights energy demand, tourism and extreme events as the main drivers of adverse impacts from climate change and concludes that challenges to adaptation cannot be mitigated only by high economic growth.

This literature review highlights several gaps in the integrated assessment of climate change economic impacts, notably (i) agriculture, where none of the above-mentioned studies has explicitly modelled the use of land and water under a changing, and (ii) focus on a 2°C scenario, while climate change might be more intense, as soon as 2050, absent collective and ambitious action. The model developed for Bulgaria in this study is thus an attempt to address these gaps. The simulation results from the model developed for this study are described below.

68. ***Figure 20*** presents sector wide impacts of the alternative climate change scenarios in Bulgaria by 2050. There are 57 sectors in the model, but the presentation and discussion here will aggregate those into 13 broad sector clusters to give a more general perspective of the results. The sectoral mapping used for aggregation is available in ***Annex 1***. The main conclusions are as follows:

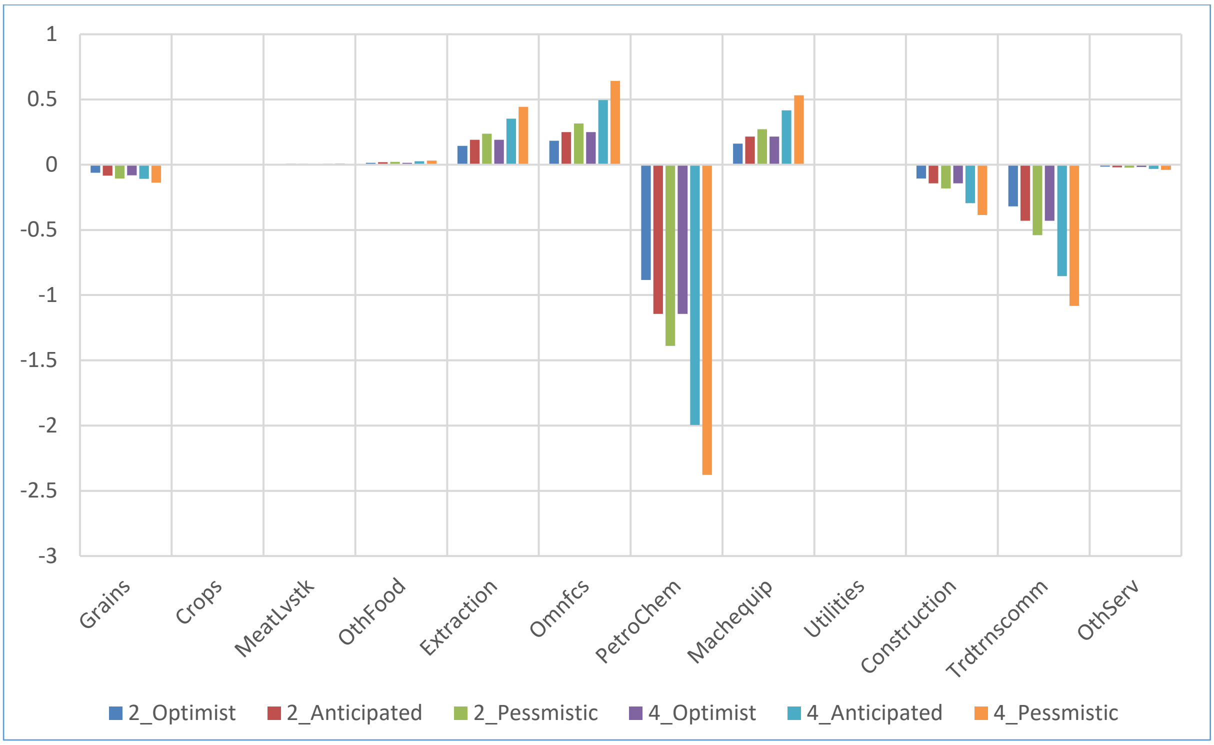
- First, climate change leads to decline in output of the agricultural sector, particularly Grains, as shown on ***Figure 20***.

- Second, there is a decline in output of the energy sector in all the scenarios that were considered, consistent with the assumption of overall reduced energy demand in response to warming temperature. The negative demand shocks to electricity and gas are much smaller (0.05 to 0.27 percent) than those in petroleum and coal products (5 to 29.8 percent reduction). This does not necessarily mean that the production in these sectors would also go down by that extent, because exports may increase, leading to a relatively lower reduction in output. The relative size of these sectors also matters, to understand the change in energy output. Electricity is the largest among the energy sectors (53 percent in production), while coal is the third largest (5 percent) after petroleum and coal products (35 percent). Coal (as distinct from coal products) actually expands since there is no negative shock on it as described above; this explains why the extraction sector is expanding as a whole in terms of production despite the reduction in the petroleum and coal products sector domestically. In the meantime, electricity hardly declines in production. Exports from Bulgaria are significant for electricity (US$1.1 billion), petroleum and coal products (US$2.5 billion) and coal (US$6 million), leaving some scope to expand exports in these sectors. As for gas, exports of gas extraction and distribution are negligible; therefore, changes in gas exports are almost zero, and have no effect on the sector as a whole. In other words, most of the changes to the gas sector are explained by changes in domestic demand, while most of the positive changes in the other energy sectors happen on the export front.

- Third, the other block of sectors experiencing a negative outcome is transport and communication. The overall decline in economic activity (as shown above by GDP changes) accounts for the decline in demand for output for these sectors.

- Fourth, the positive output response is observed in what is called the energy-intensive trade exposed sectors, which includes sectors such as chemicals, steel, aluminum, cement, and ceramics. The positive response following climate change is driven by positive terms of trade (ToT) change (see ***Figure 22***) that helps drive up export demand and mitigate declining domestic demand. In a general equilibrium model, prices and quantities are co-determined based on interactions among different markets, simultaneously. In this case, reduced domestic demand tends to push the prices down, but then export demand increases due to such a tendency; this results in a positive push from exports and negative push from domestic demand on output. The net effect is positive, with the result that energy prices also go up, due to greater overall demand for these sectors, largely driven by exports.

Figure 20. Impact of climate change on domestic output
(percentage of change compared to the baseline without climate change)

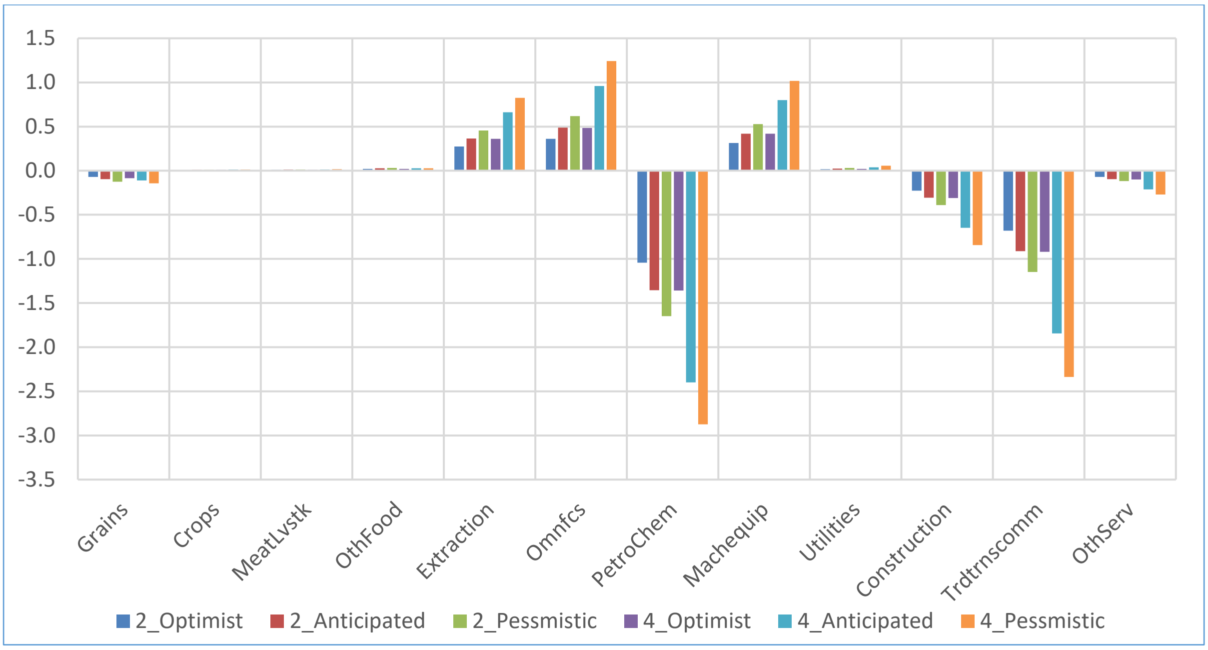


Source: Model simulations. See Annex 1 for sector description.

69. The overall pattern of price change follows the output storyline. That is, decline in output in the face of preexisting demand leads to rationing and higher prices are required to clear the market. Hence, sectors that are in the direct line of climate change see a decline in output and rising prices as a result.

70. In the economic model developed for this analysis, labor moves across sectors to equalize the wages paid to workers. That is, labor moves to the sectors with the highest demand. If a sector expands following an exogeneous shock, then there will be higher demand for production factors. However, the demand for a factor depends on the initial intensity of factor use. For example, the extraction sector uses more capital than labor while the converse is true for the agricultural sector. Therefore, ***Figure 21*** shows that following the impact of climate change in Bulgaria, jobs move out of sectors that are negatively affected. For example, there is substantial decline in labor demand from the petroleum and other chemical producing sectors toward services sectors and construction.

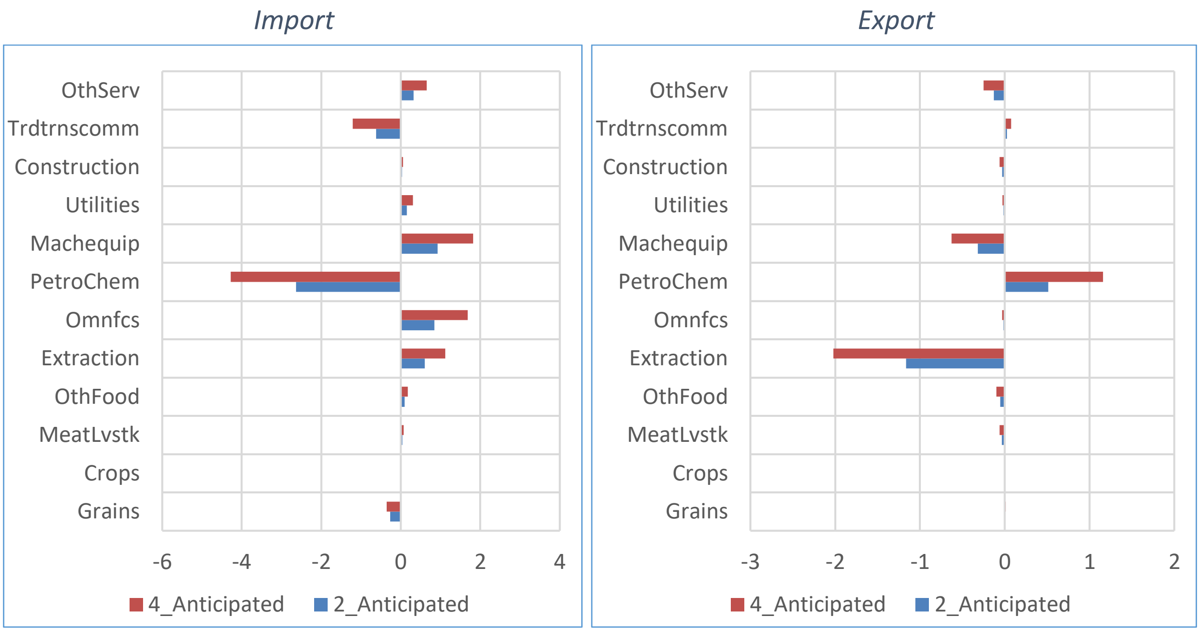
Figure 21. Climate change impact on sectoral allocation of labor (percentage of change compared to the baseline without climate change)



Source: Model simulations.

71. ***Figure 22*** represents the overall trade structure of Bulgaria following 2°C and 4°C rises in global temperature. It shows the total change in output as follows: First, the change in overall output structure that is shown in ***Figure 20*** has a direct bearing on what Bulgaria ends up trading with the rest of the world. As such, the left side of ***Figure 22*** depicts that Bulgaria will import goods whose domestic production is heavily affected by climate change. These happen to be sectors such as petroleum products, chemicals, and related products, as well as agriculture commodities.

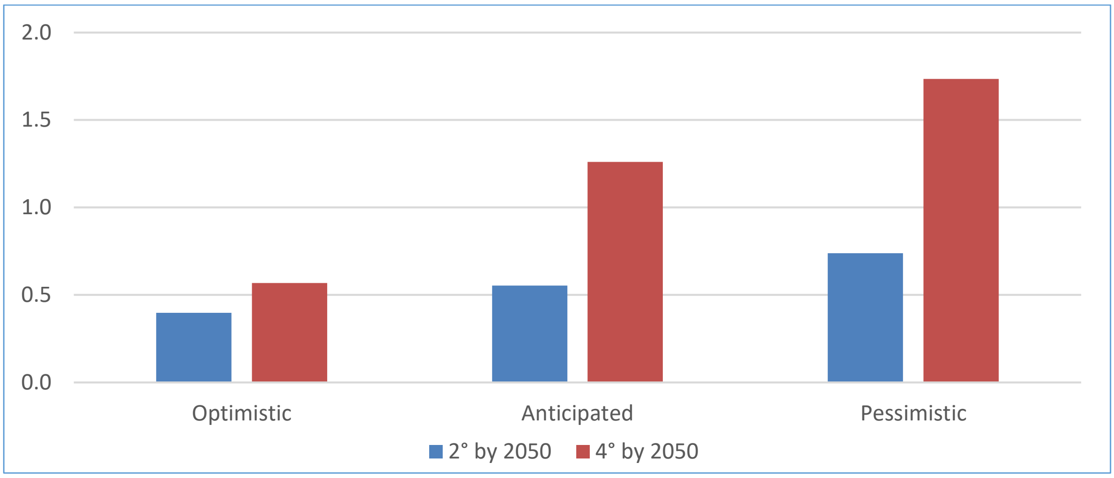
Figure 22. Impacts of climate change on trade (percentage of change compared to the baseline without climate change)



Source: Model simulations. See Annex 1 for sector description.

72. Second, declining domestic output in the face of climate change (***Figure 20***) will necessitate a rationing of the now limited output, leading to rising prices for goods and services (inflation).

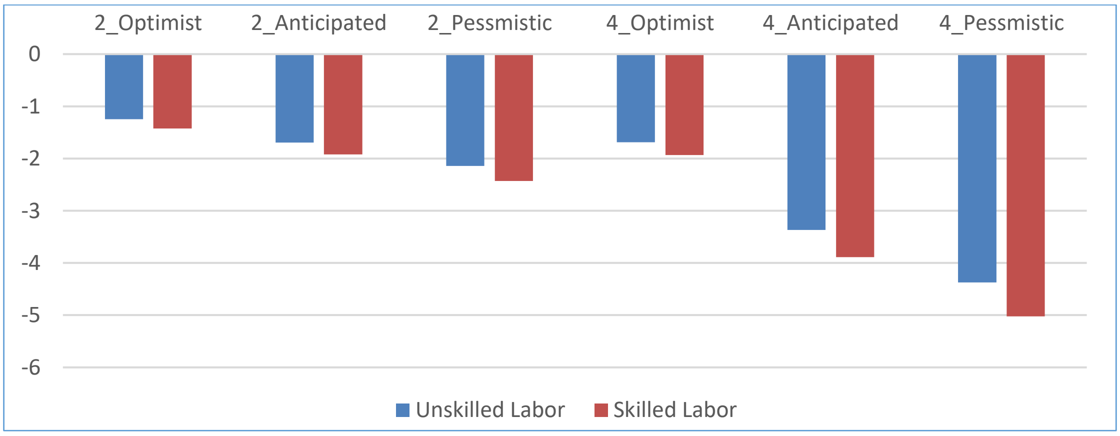
Figure 23. Impact of climate change on real domestic prices (percentage of change compared to the baseline without climate change)



Source: Model simulations.

73. ***Figure 23*** shows economy-wide real price changes from climate change. It can be seen that there is an across-the-board rise in domestic real prices following all alternative climate impact scenarios considered in this report. This follows and fits the storyline presented so far. To this effect, ***Figure 24*** presents the impact of climate change on real returns to skilled and unskilled labor in Bulgaria. These rising prices for commodities may result in a substantial reduction in real income—and an increase in poverty—for households spending a large share of their income on commodities whose price rose substantially. However, the well-being of households depends not only on changes in the cost of living but also on changes in earnings. ***Figure 24*** indicates that, in general, earnings from both skilled and unskilled labor will decline in all scenarios. Thus, combined with rising real prices and declining earnings from labor, more people are expected to fall below the poverty line. Under these climate scenarios, it is very likely that there will be more poor people living in Bulgaria by 2050.

Figure 24. Impact of climate change on real returns to factors (percentage of change compared to the baseline without climate change)

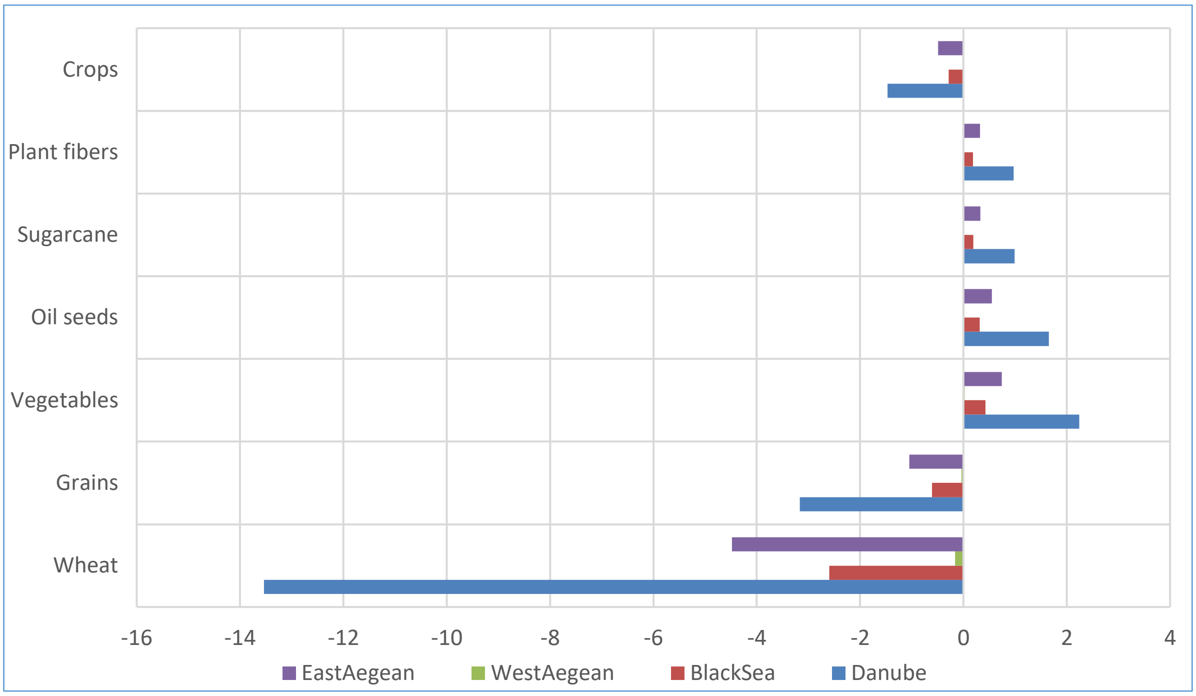


Source: Model simulations.

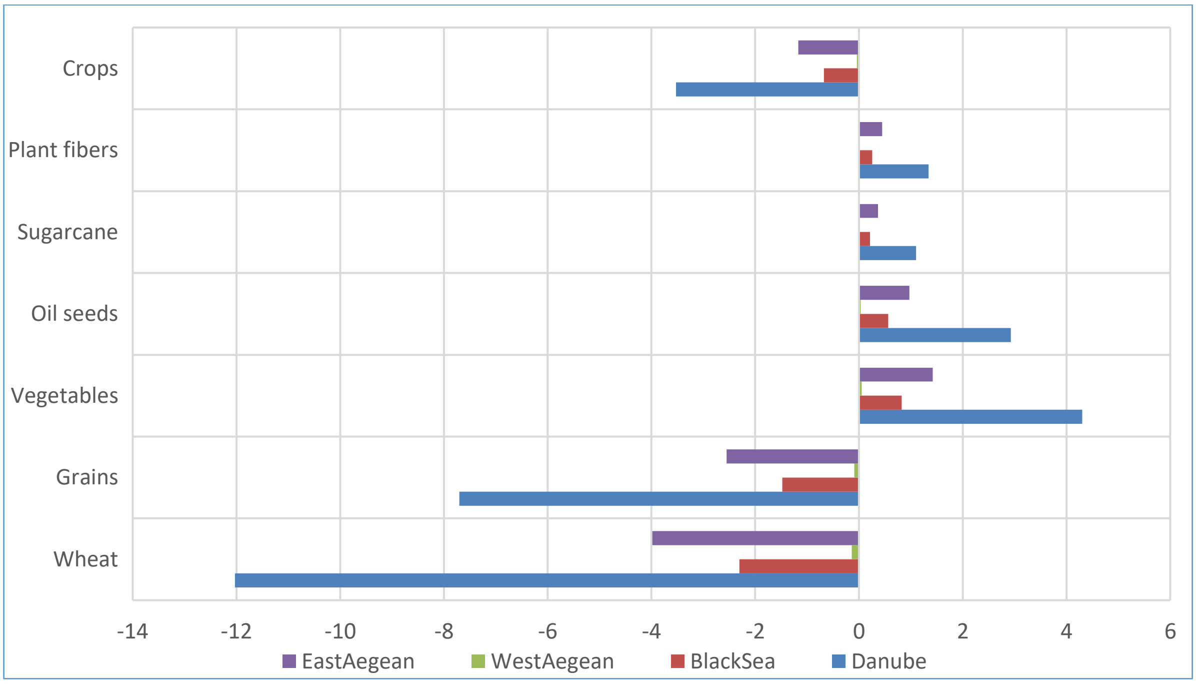
74. ***Figure 25*** highlights the sectoral impact of climate on output of select agricultural products at the RB level. Top panel shows the impact of an anticipated 2°C rise by 2050 while bottom panel shows the impact of an anticipated 4°C rise. Output of wheat, grains (such as barley, oats), and other crops sectors witness the highest negative impacts across all the four RBs in Bulgaria. The Danube RB where the agricultural productivity is highest is the region that suffers the most from climate change.

Figure 25. Climate change impact on agriculture output at the basin level (percentage of change compared to the baseline without climate change)

(2°C warmer world)



(4°C warmer world)

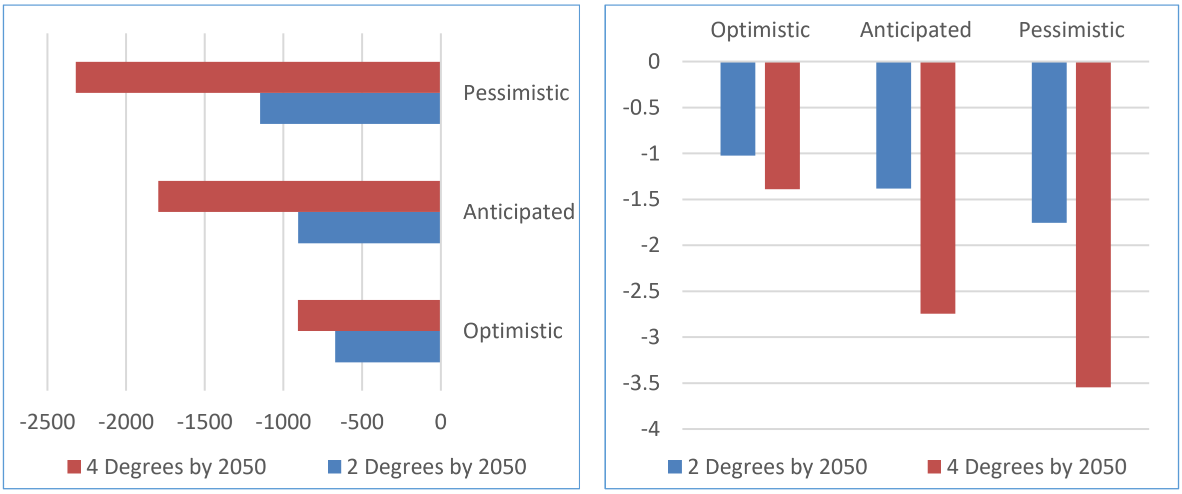


Source: Model simulations.

75. The following few paragraphs present a welfare approach to help gauge the impact of climate change. ***Figure 26*** presents estimated welfare losses for the two core scenarios along with both optimistic and pessimistic assumptions. In general, these results suggest that the market effects of climate change will have similar implications for economic welfare and for overall income, spending and production (or GDP, in short). There are, however, differences between the two measures. The source of difference relates to what is included or excluded from measures of welfare versus GDP. For example, GDP includes investment, which yields future consumption and government or public spending on goods and services. Welfare, as defined in the GTAP model, includes private consumption involving goods, services, government purchases, and a host of other variables. Nonetheless, as shown in panel B of ***Figure 26*** the overall estimated welfare consequences of climate change range from about 1 percent of GDP in 2050 in the most optimistic scenario to about 3.5 percent in the most pessimistic scenario.

Figure 26. Welfare changes due to climate change in comparison to the baseline without climate change

Panel A, US$, millions *Panel B, percent change*



Source: Model simulations.

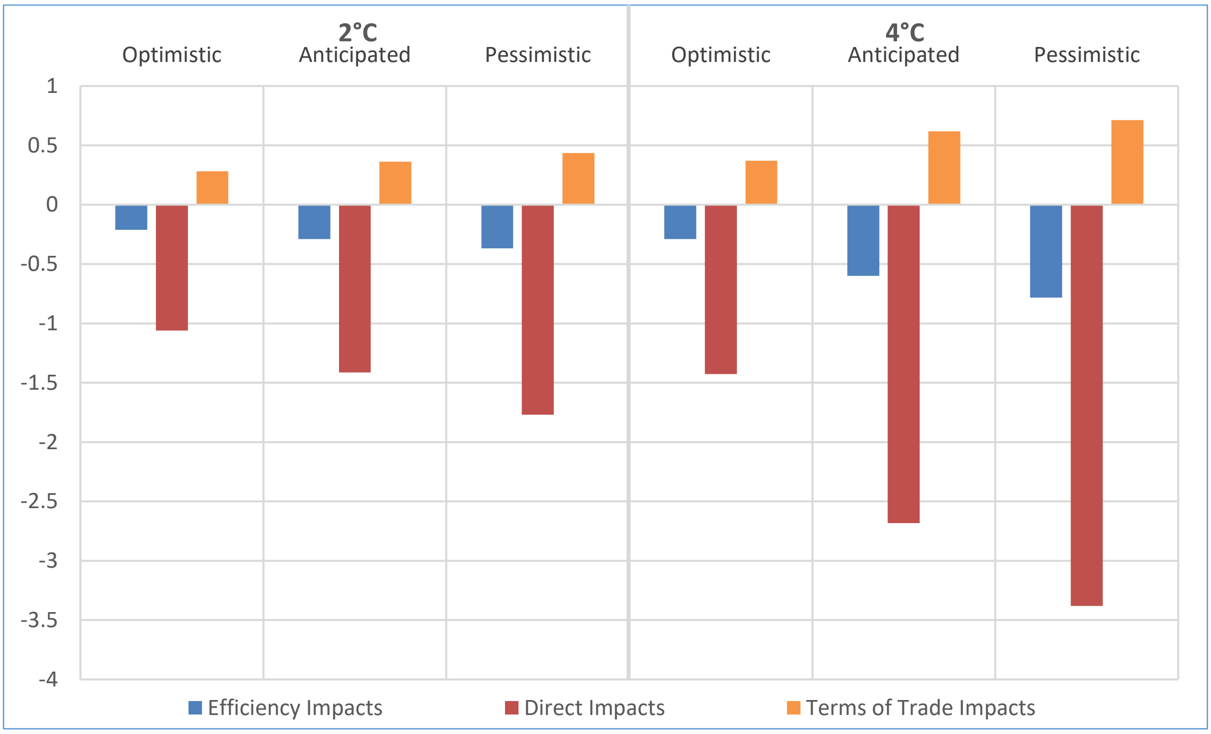
76. The welfare impacts of the climate shocks, expressed as a percentage of value added, can be further decomposed into three components: direct impacts, efficiency changes, and ToT effects. ***Figure 27*** illustrates this decomposition exercise for Bulgaria. The first component corresponds to what can be called the direct impact of climate shocks. For the scenarios under consideration, this contribution is negative in all cases, reflecting the general worsening of production conditions in Bulgaria, but with the severity varying across the alternative climate scenarios. The projections suggest that the biggest loss to economic welfare from this direct component will dominate the other two parts if the temperature rises by 4°C by 2050.

77. The second component of welfare change is the change in economic efficiency. The welfare approach captures the interaction between the impacts of climate change and existing economic policies. Such policies include an array of existing polices, for example, trade policies, agricultural and nonagricultural policies, subsidies, and the like. It is argued here that climate change coupled with suboptimal global trade policies will lead to an economic efficiency loss. Therefore, one would expect a negative association with climate change and

economic efficiency and see how such an impact contributes to welfare loss in Bulgaria. ***Figure 27*** shows that indeed climate change leads to loss of economic efficiency but such a loss is overshadowed by the other two components of welfare.

78. Given the relatively inelastic demand for food, the declines in production (***Figure 20***) result in significant increases in the domestic price of goods and services (***Figure 23***). These price changes will have implications for the third component of economic welfare: the ToT. In theory, a net exporting country gains when the world price of a particular good rises above its domestic price, which prompts other countries to demand more of the good from the least expensive place. Therefore, the value of the ToT effect, expressed as a percentage of initial value added, can be very important for nations that trade extensively. ***Figure 28*** shows the impact of climate change on ToT and its contribution to national welfare. In most cases, the ToT impact is not strong enough to outweigh the direct impact but nonetheless contributes to mitigate some of the welfare losses arising from climate change.

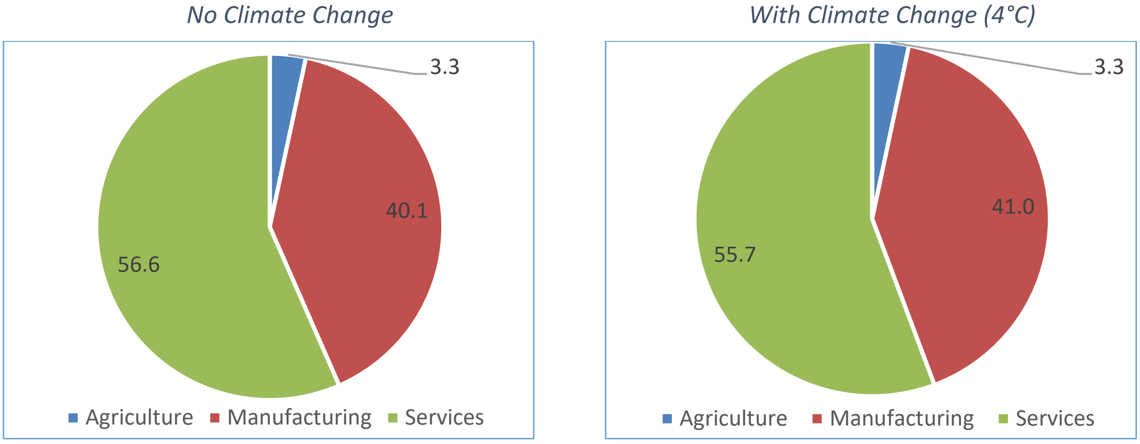
Figure 27. Decomposing welfare change
(as percentage of GDP, compared to the baseline without climate change)



Source: Model simulations.

79. ***Figure 28*** shows the overall structure of the Bulgarian economy without (left) and with (right) climate change. Climate change impact for this particular figure is represented for the anticipated 4°C global rise in temperature. While the previous sections have shown the sectoral adjustments, this figure shows that in general, there is going to be modest structural change following the impact of climate change. That is, the Bulgarian economy is still going to be mainly service-based even after considering the impact of climate change. Note however the share of manufacturing doubles in comparison to 2018 levels because that's the driver of growth (improvement in productivity benefiting capital-intensive and not labor-intensive sectors as discussed in previously in the report).

Figure 28. Structure of the Bulgarian economy by 2050 (percent share – Gross Value Added)



Source: Model simulations.

4. Adaptation to Climate Change: Overall Benefits and Potential Financing Mechanisms

80. The previous section has shown that the Bulgarian economy will be increasingly vulnerable to climate change risks. Rising temperatures, coupled with increased prevalence of heatwaves, add economic burdens ranging from health risks to lower agricultural output or higher electricity bills. Frequent floods exacerbate the productivity loss in agriculture. As a result, Bulgaria faces numerous areas of vulnerability especially in agriculture, tourism, and energy demand as analyzed in the literature. This section explores options for climate change adaptation through the creation of an adaptation fund that would finance targeted interventions across sectors. The model developed for Bulgaria is used to estimate the size of adaptation funding needs, potential financing mechanisms to mobilize resources accordingly, as well as the allocation of financial resources that would generate the maximum benefit for society. The findings from this section will inform the use of financial resources for climate change adaptation at the macroeconomic level. They are complemented by other research and analysis, also carried out under the present Advisory Services on adaptation, at the sectoral level, including cost-benefit analysis of adaptation measures.

81. In the literature, adaptation refers to actions that are taken in response to, or in anticipation of, projected or actual changes in climate, either to reduce the adverse impacts or to take advantage of opportunities offered by such changes (IPCC 2007). Adaptation options vary depending on the nature and magnitude of climate change impacts (Klein et al. 2001). This report focuses mainly on the cost of adaptation for Bulgaria without presenting the details of specific investment projects for adaptation such as shifting planting schedules or changing crop varieties, or more costly ones like investing in protective infrastructures such as river or sea dykes for flood control. In some extreme cases, retreat from coastal areas or abandoning certain economic activities (for example, winter mountain tourism) may be the best strategy.

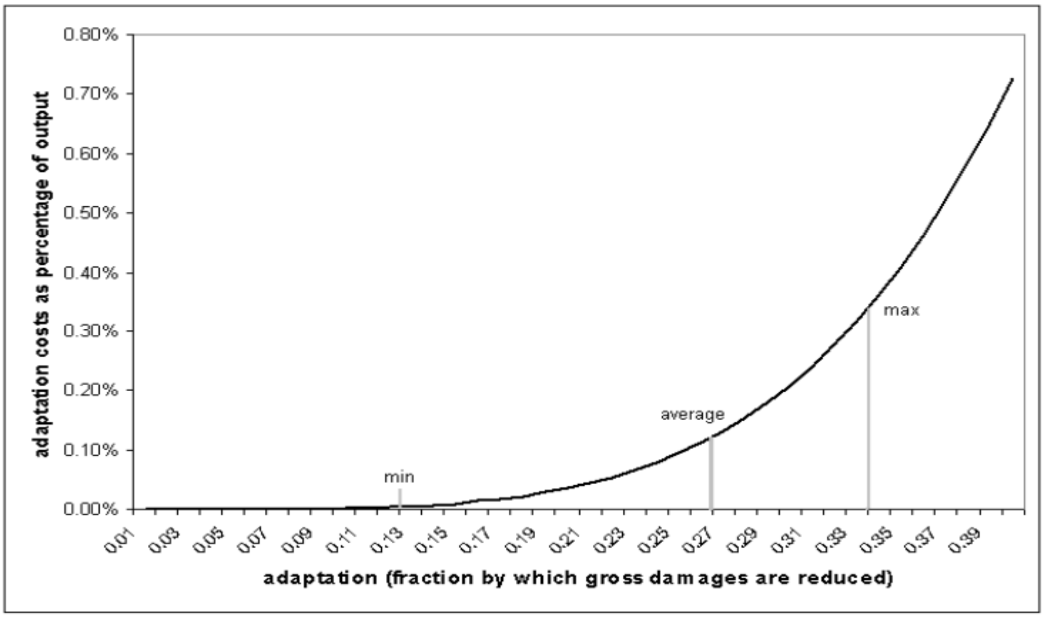
82. From a financial perspective, the adaptive capacity of countries differs and largely depends on the size of their economies, which determines the amount of available resources that can be devoted to adaptation. Generally, developed countries are considered to have higher adaptive capacities while developing and least developed countries, which are most vulnerable to climate change, need external support to build theirs (IPCC 2013). This section looks at the broad parameters of an adaptation financing mechanism for Bulgaria: first, the adaptation level to be targeted is analyzed; second, the magnitude of adaptation resources that need to be allocated to this purpose is estimated; third, the optimal allocation of these funds across sectors is simulated using the Bulgaria model.

Deriving a Marginal Adaptation Cost Curve, Top-Down

83. Adaptation to climate change seeks to address the potential damages from climate change. The essential question is to understand how much adaptation cost the Bulgarian economy can bear without compromising its growth potential. It is possible to define 'gross damages' as the initial damages caused by climate change if no adaptation measures were undertaken. If there is an attempt to limit climate change damages (adapt), then the damages would decrease. Reducing gross damages, however, comes at a cost, that is, the investment of resources in adaptation. For the purpose at hand, these costs are referred to as 'adaptation costs'.

Figure 30 shows the theoretical relationship between adaptation costs and the fraction of damages that are reduced through adaption as calibrated in the Dynamic Integrate Climate-Economy (DICE) model.

Figure 29. The adaptation cost curve

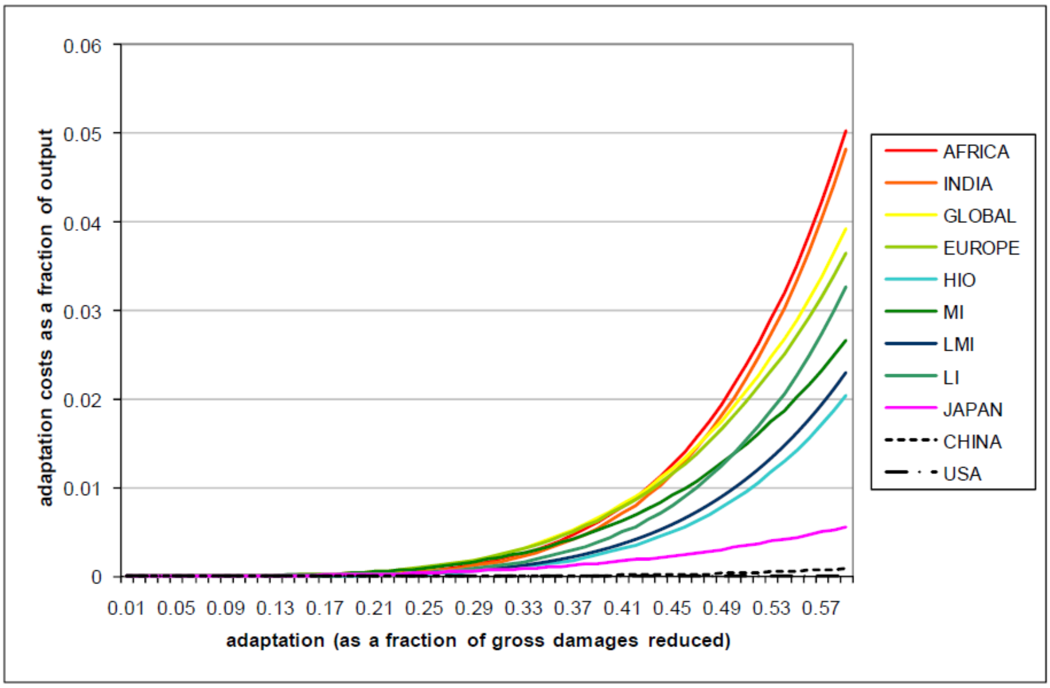


Source: de Bruin, Dellink, and Tol 2009.

84. ***Figure 29*** shows the marginal cost curve for adaptation that is implicitly present in the DICE model. It indicates that the adaptation cost of around 10 percent of gross damage reduction is extremely low, but the cost rises sharply beyond that point. The optimal level of adaptation (maximum reduction in damages without hampering economic growth) varies from 0.09 to 0.45, with an average of 0.33, that is, 33 percent of the gross damages can be reduced at 'no/low cost' to the economy. In the absence of comprehensive technical and economic information on adaptation measures and their costs at sectoral levels that could be readily integrated into the model, no marginal adaptation cost curve could be derived bottom-up. Instead, an approach like that of de Bruin, Dellink, and Tol (2009) is followed here, using an implicit, top-down cost curve (with sensitivity analysis).

85. ***Figure 30*** shows the estimated adaptation cost curves for 10 countries/regions and a global average (the GLOBAL line). The main message from this figure is that adaptation costs differ substantially across regions. For example, regions that face substantial climate change impacts will need to undertake extensive adaptation measures. The figure tells that taking such extensive measures comes at higher adaptation cost (loss of output in the figure).

Figure 30. Marginal adaptation cost curves across countries/regions



Note: HIO = Highly industrialized oil exporting, EE = Eastern Europe, MI = Middle income, LMI = Low middle income, LI = Low income.

Source: de Bruin, Dellink, and Tol 2009.

86. This section of the analysis aims to assess the impact of adaptation using the same CGE model as that outlined in the previous sections. This requires the modeling of the costs and benefits of both autonomous and planned adaptation. By construction, CGE models consider market-driven adaptation, which characterizes instantaneous resource allocation across two market equilibria in response to exogenous shocks that can be related to the economy or climate change. Primarily, demand and supply reactions to endogenous changes in relative prices are in effect the first autonomous adaptation mechanism. Autonomous adaptation may however not always be sufficient to fully address the impending impact of climate change. This requires a deliberate and planned action. This is what is called planned adaptation to climate change. Planned adaptation measures come in many shapes and forms and are meant to augment autonomous adaptation that occurs in the market place. Therefore, planned adaptation measures help expand the availability of economic resources that otherwise would have been damaged by climate change (Adger et al. 2007).

87. The CGE model developed for Bulgaria is a recursive dynamic model that was used to build the baseline growth path. For the adaptation simulations, the model was used in its static version, for the year 2050. This is important for two reasons. First, in a static CGE model, there is no inter-temporal optimization, that is, agents are seen as being myopic when it comes to between-period decisions, such as saving and investment. Second, climate change, by its very nature, is a long-term phenomenon and it is likely that economic agents will have the possibility to update their information beliefs and adjust their saving and investment decisions accordingly. To properly reflect the dynamic features of behavioral changes into the analysis

of adaptation, the Bulgaria CGE analysis took as reference the OECD analysis on long-term adaptation (OECD 2015, see ***Annex 2***), where a full-dynamic model was used.

Description of adaptation scenarios

88. Based on Roson and Sartori (2016), Bulgaria will face changes in three main activities: (a) agricultural productivity is projected to decrease, (b) energy demand is expected to fall due to warming temperatures, and (c) domestic and international tourism activities.

89. De Bruin, Dellink, and Tol (2009), Taheripour, Hertel, and Tyner (2011), and Taheripour et al. (2016) provide expected changes in productivity at the sectoral level arising from adaptation. ***Table 6*** compares the climate change and adaptation shocks used in this report and ***Tables 1.2 and 1.3 within Annex 1*** show the actual productivity differences across scenarios and sectors.

Table 6. Climate change and adaption measures used in the CGE model[9]

Policy shocks	Climate change scenario	Adaptation scenario
Productivity shock in agriculture	Yes	Yes, 33 percent lower[10]
Energy demand	Yes	Yes
SLR	Yes	Yes
Tourism	Yes	Yes, 33 percent lower
Fiscal policy	No	Yes, 2 percent climate contribution[11]
Capital shock	No	Yes, in agricultural and tourism sectors[12]

Source: Authors' formulation.

90. To finance the planned adaptation measures, three sets of policies were developed:

- Policy 1: Adaptation financed by fiscal policy (2 percent climate contribution on consumption commodities);
- Policy 2: Adaptation financed by foreign funds earmarked to investments in agriculture and tourism;
- Policy 3: Adaptation financed by foreign funds earmarked to investments across all productive sectors.

91. Each policy is simulated using the Bulgaria model and macroeconomic results are expressed for adaptation in a 2°C and respectively 4°C warmer world. Foreign funds for adaptation could mean structural funds from the European Union, or their successors, or other bi- or multi-lateral mechanism focused on climate finance.

92. The simulation results displayed in the following sections are percentage changes from the baseline scenario described above, by 2050.

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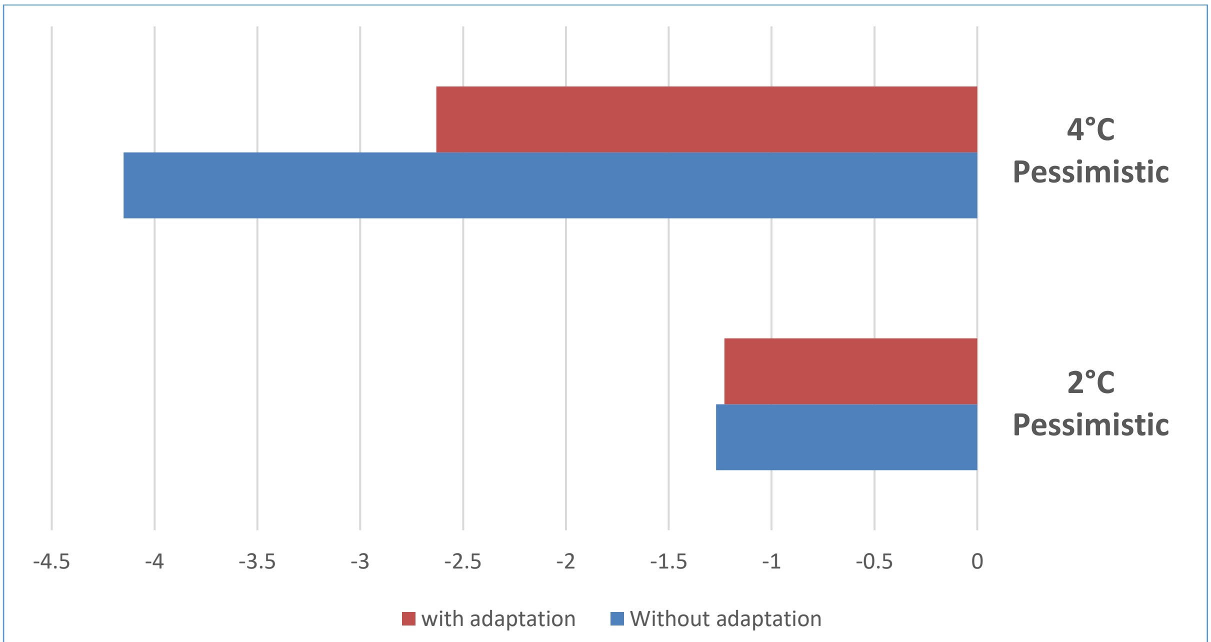
[9] See Tables 1.2 and 1.3 for specific shock values used for the simulations.
[10] In Table 7 of this report, this scenario is repeated for 10 percent, 20 percent, and 30 percent adaptation or reduction in damage from climate change.
[11] In Table 7, the 2 percent contribution is not included, as it is consistent with Policies 2 and 3.
[12] Capital expansion is assumed in all sectors in the case of the 'Capital' scenario, shown in Table 7 of this report.

4.1. Policy 1: Adaptation financed by fiscal policy

93. The Bulgaria study follows the work of de Bruin, Dellink, and Tol (2009) and assumes that development of an adaptation strategy will lead to a 33 percent reduction in gross damages from climate change at 'low fiscal cost', equivalent to 0.1 percent of GDP by 2050. These would refer to behavioral changes for producers and consumers toward climate-conscious actions. In addition, the adaptation scenario for Bulgaria assumes that adaptation expenditures are financed by a uniform 2 percent climate contribution, levied on consumption commodities, to generate fiscal space and funding for climate adaptation policies. This follows from work by de Bruin, Dellink, and Tol (2009), who similarly assume a 2 percent tax, in the spirit of the '2 percent levy' used to mobilize resources for the Adaptation Fund.

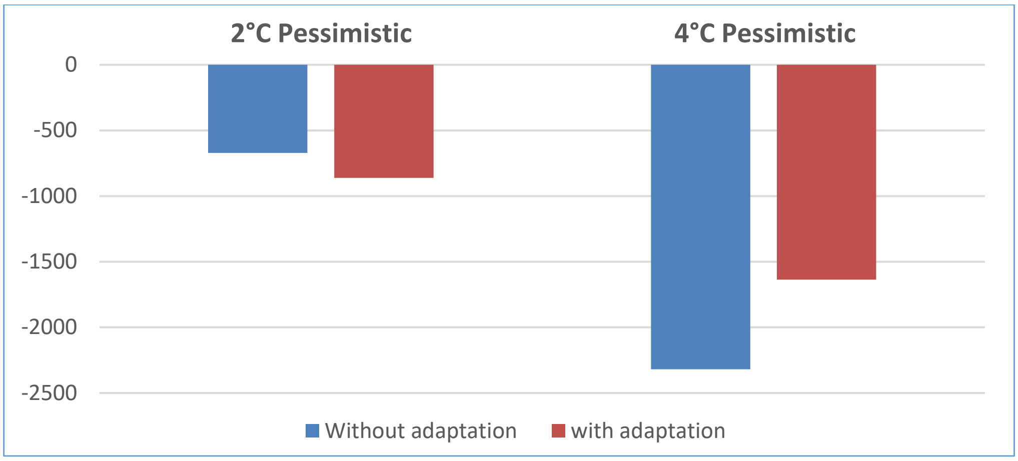
94. ***Figures 31 through 35*** present the overall outcome of adaptation for Bulgaria. The overall findings can be summarized as follows. First, in terms of real GDP growth (***Figure 31***), adaptation helps mitigate the negative impact of climate change across all climate scenarios. The benefits from adaptation are higher in the 4°C scenario, where the negative impact of climate change on growth is almost halved (from 4.3 percent to 2.6 percent GDP). Welfare changes (***Figure 32***) are equivalent variations that highlight expected benefits not only in terms of production (as in the case of GDP) but also in terms of efficient allocation of resources across productive sectors and improvements in competitiveness of the Bulgarian economy. As shown in ***Figure 32***, the 2°C scenario with adaptation policy leads to a decline in welfare, while in the 4°C scenario, adaptation policy leads to improved welfare. This is caused by the 2 percent climate contribution levied to finance the costs of adaptation and can somewhat indirectly indicate the costs of undertaking such an action. In a more extensive adaptation policy setting such as for the 4°C scenario, improvements in the economic efficiency and competitiveness in international trade override the adverse impact of the fiscal policy.

Figure 31. Adaptation and climate change impacts on real GDP (percentage of change compared to the baseline without climate change)



Source: Model simulations.

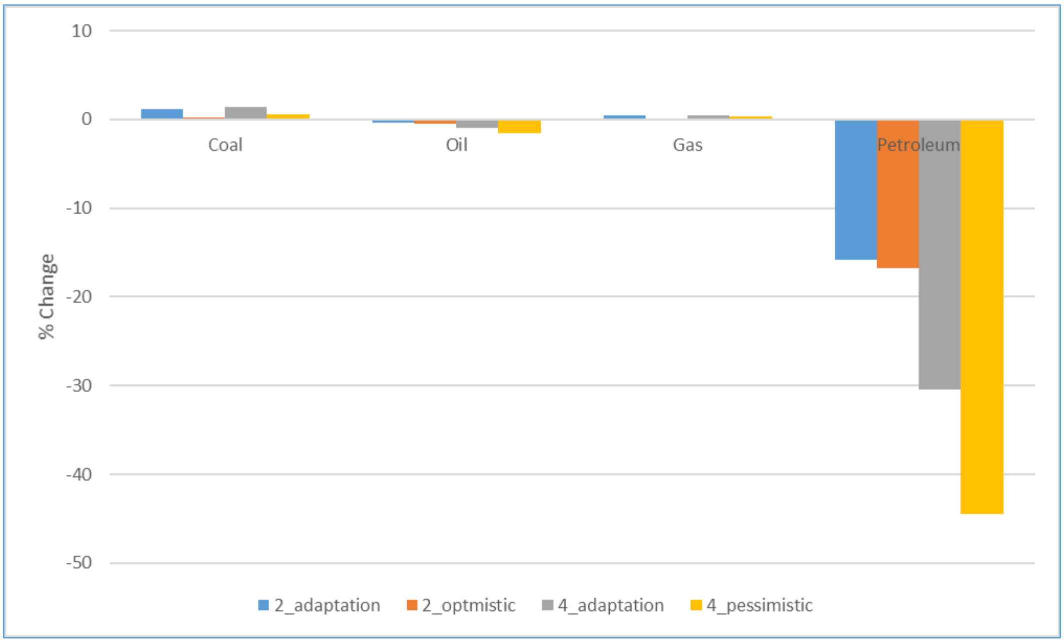
Figure 32. Welfare changes with and without adaptation, compared to the baseline without climate change (US$, millions)



Source: Model simulations.

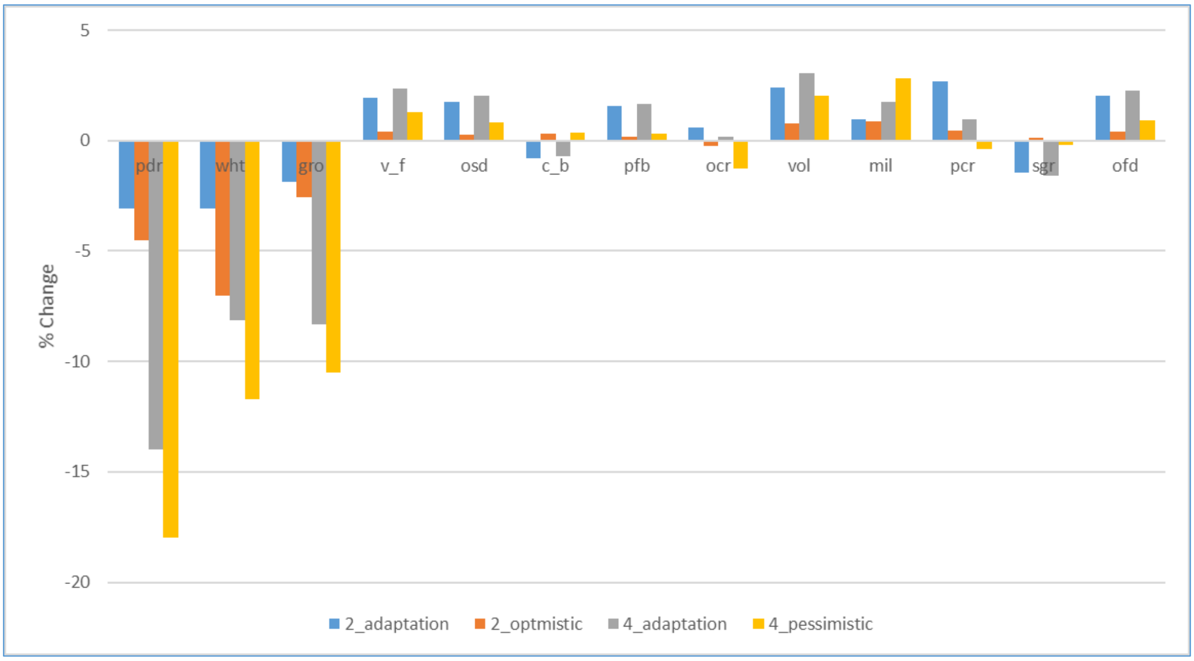
95. ***Figures 33 and 34*** show the role that adaptation can play in reducing some of the negative impacts of climate change on two sectors of importance in Bulgaria (agriculture and energy). In both sectors, adaptation measures refer to improvements in the total factor productivity of these sectors, which, assuming that labor productivity remains unchanged, means improved productivity of physical inputs to production, such as land, water, and infrastructure. ***Figure 33*** presents climate change impacts and the role of adaptation for the energy sector. The sub-sector representing refined petroleum products and other fuels (petroleum in ***Figure 33***) is the sub-sector most affected in any of the climate change scenarios considered in the current analysis and the one benefitting most of adaptation. Based on the increased temperature projections for Bulgaria, energy demand for heating (in cold days) will decrease significantly and pull down the overall demand for electricity used for heating despite a slight increase in electricity demand for air conditioning (in hot days). Adaptation in the energy sector is modelled as improved productivity in power generation that would reduce transmission losses and technological transfers.

Figure 33. Impact of adaptation and climate change on energy output (percentage of change compared to the baseline without climate change)



Source: Model simulations.

Figure 34. Impact of adaptation and climate change on agriculture output (percentage of change compared to the baseline without climate change)

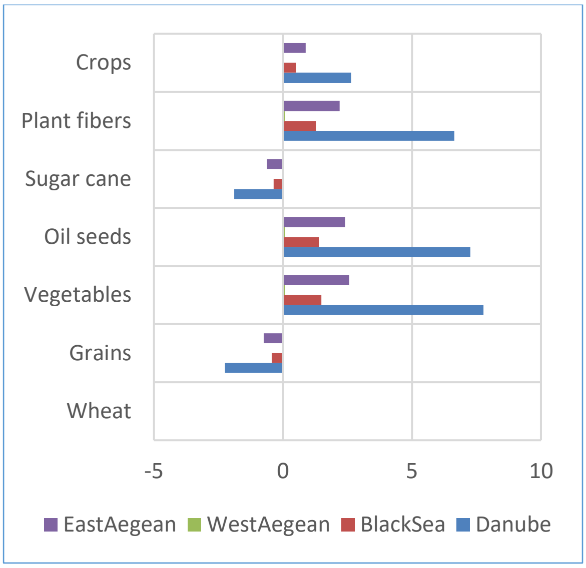


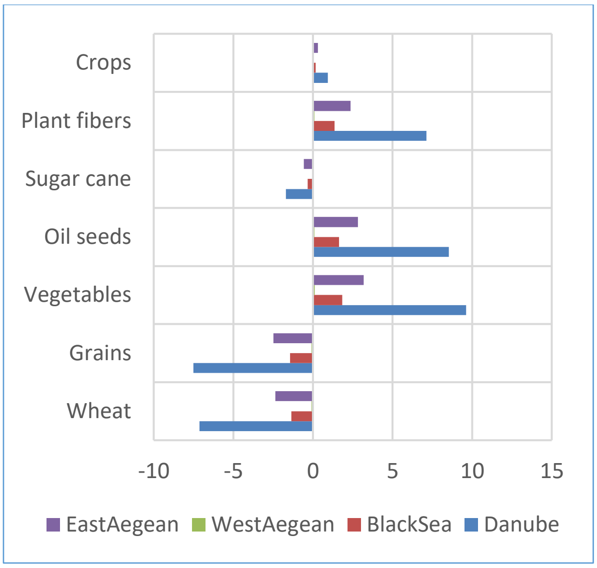
Legend key: PDR: Paddy rice; WHT: Wheat; GRO: Cereal grains; V_F: Vegetables, fruit, nuts; OSD: Oil seeds; C_B: Sugarcane, sugar beet; PFB: Plant-based fibers; OCR: Crops; VOL: Vegetable oils and fats; MIL: Dairy products; PCR: Processed rice; SGR: Sugar; OFD: Food products.

Source: Model simulations.

Figure 35. Impact of adaptation on agricultural output, basin-level results (percentage of change, compared to the baseline without climate change)

Panel A: Optimistic 2°C with adaptation *Panel B: Pessimistic 4°C with adaptation*





Source: Model simulations.

96. ***Figure 34*** compares adaptation outcomes in the 2°C and 4°C scenarios for the agricultural and some of the food processing sectors that rely on agriculture as an input to their production process. The overall findings are that climate change has a significantly differentiated impact on grains (for example, wheat, maize, and barley) and other crops such as vegetables and fruits. Change in output results from the combination of the direct impact of climate change on yield as well as changes in areas under cultivation. Huge drop in production for grains primarily reflects the former while minimal changes in production for other crops the latter. While the adaptation policy considered here helps reduce the impact of climate change on grains, it does not, however, totally offset its overall negative impact on agriculture and the food processing sectors. This calls for a differentiated approach to the climate change adaptation policy for the agricultural sector in Bulgaria. As shown in ***Figure 35*** (and in comparison, ***Figure 25***), model simulations predict the largest benefits from adaptation for grains. In terms of RBs, that's the Danube region which could experience the largest changes in production, from adaptation.

97. Overall, prices are expected to increase under climate change without adaptation (except for energy-intensive trade-exposed sectors). In the adaptation scenarios, the model forces investments in those sectors that produce the main consumption goods, leading to an increase in productivity and decrease in prices for final goods from these sectors.

4.2. Policy 2: Adaptation financed by foreign funds earmarked to investments in agriculture and tourism

98. This section proposes an adaptation strategy financed by foreign funds, such as structural funds from the European Union, or their successors, or other bi- or multi-lateral mechanism focused on climate finance, at no cost to the Bulgarian economy. The magnitude of this inflow is equivalent to the fiscal revenues proposed in the previous scenario, which is 0.1 percent of GDP.

99. Like in the previous section, this scenario also assumes a 'no-cost adaptation' path which reduces climate change impact by 33 percent. On top of that, received funds are earmarked to certain sectors of the economy (as investment) to hedge against losses in sectoral production and competitiveness because of climate change.

100. This inflow of funds rises the capital availability in Bulgaria by 2.5 percent. These funds are earmarked to productive sectors for public and private investments aiming at adaptation, leading to 10 percent, 20 percent, and 30 percent reductions in losses from climate change. The model is used to determine the level of a shock on capital productivity that would mimic this funding inflow for adaptation.

101. The adaptation funds are then used for investments to offset the adverse impact of climate change by 10 percent, 20 percent, and 30 percent in two key sectors which are agriculture and tourism. These two sectors are chosen as main beneficiaries of adaptation funds because of their high vulnerability to climate change and also because they are labor-intensive sectors. These two sectors are seen as major creators of economic opportunities for the future generations.

102. From ***Figure 36***, it can be seen that adaptation to a 4°C temperature rise generates stronger effects on sectoral output across sectors than adaptation to a 2°C temperature rise. Grains and other services (which include tourism) are the most affected: grain output decreases in both cases (in comparison to the baseline but increases in comparison to the no adaptation scenario), while tourism output increases. ***Figure 37*** suggests that adaptation almost eliminates all negative GDP effects in both optimistic and pessimistic scenarios. ***Figure 38*** indicates in turn that while they are hugely negative in both optimistic and pessimistic cases 'without adaptation', the negative effects from climate change on economic welfare are canceled out in the 'with adaptation' scenarios.

Figure 36. Impact of climate change and adaptation scenario on output (percentage of change compared to the baseline without climate change)

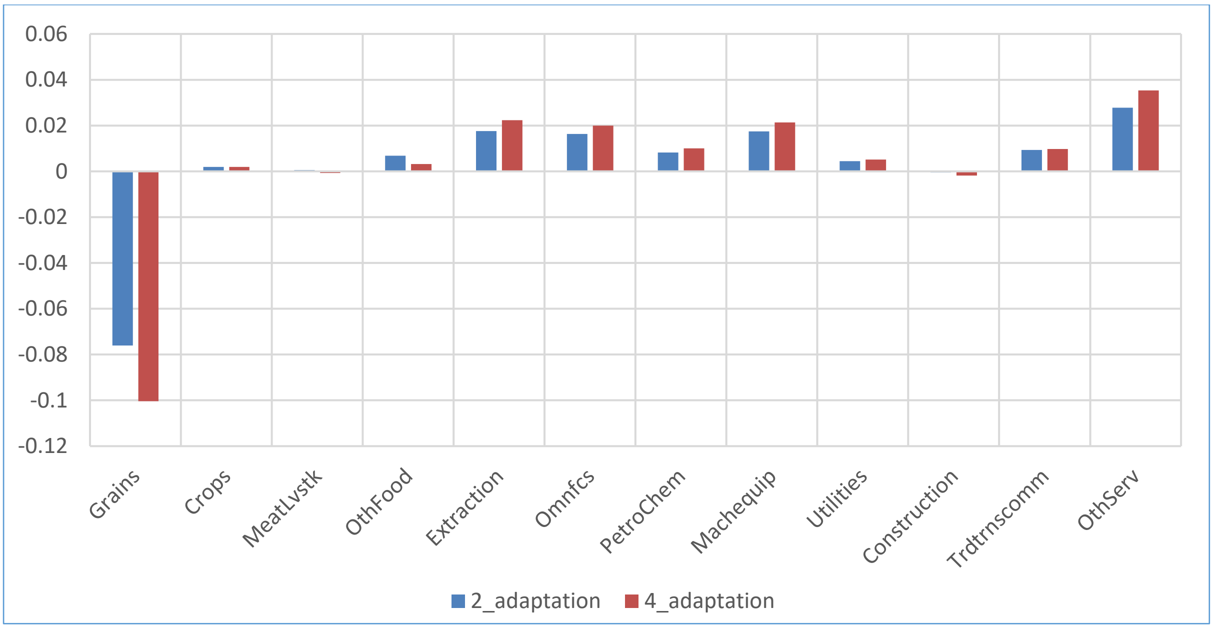


Figure 37. Adaptation and climate change impacts on real GDP (percentage of change compared to the baseline without climate change)

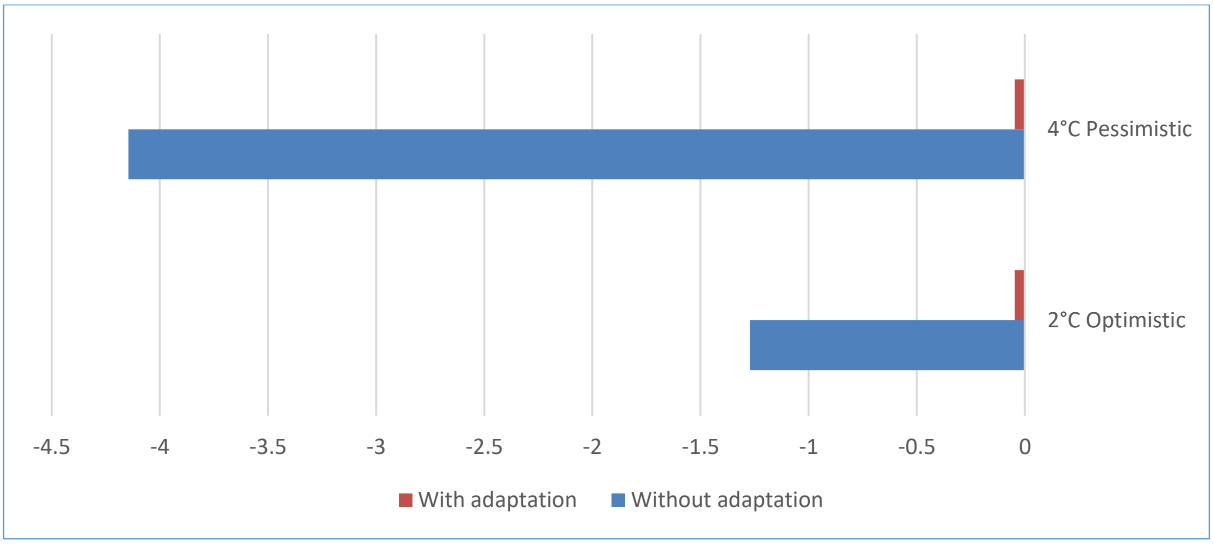
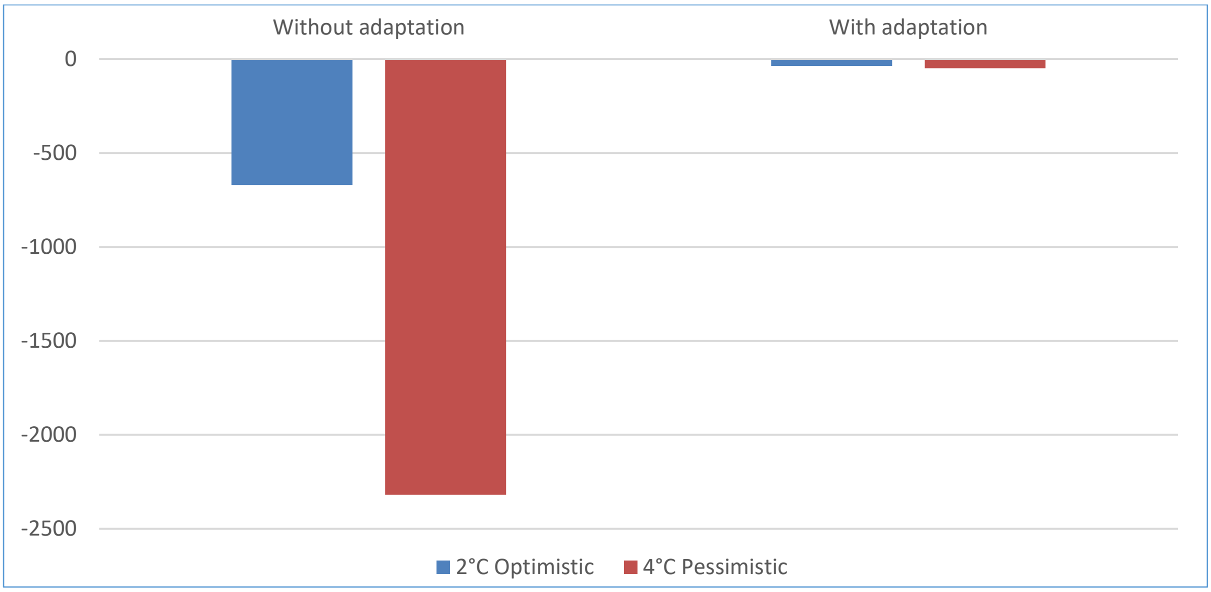


Figure 38. Welfare changes with and without adaptation (US$, millions, compared to the baseline without climate change)



103. ***Figure 39*** suggests that energy output would increase slightly in the adaptation scenario. This is partly because of the new investments made for adaptation that may require energy for adaptation. However, as ***Figure 40*** shows, agricultural sectors, particularly the grains sub-sector, would still suffer a lot due to climate change despite adaptation. All other sectors gain slightly, enabling the vegetable oils sector to expand its output quite visibly.

Figure 39. Impact of adaptation and climate change on the energy sector (percentage of change compared to the baseline without climate change)

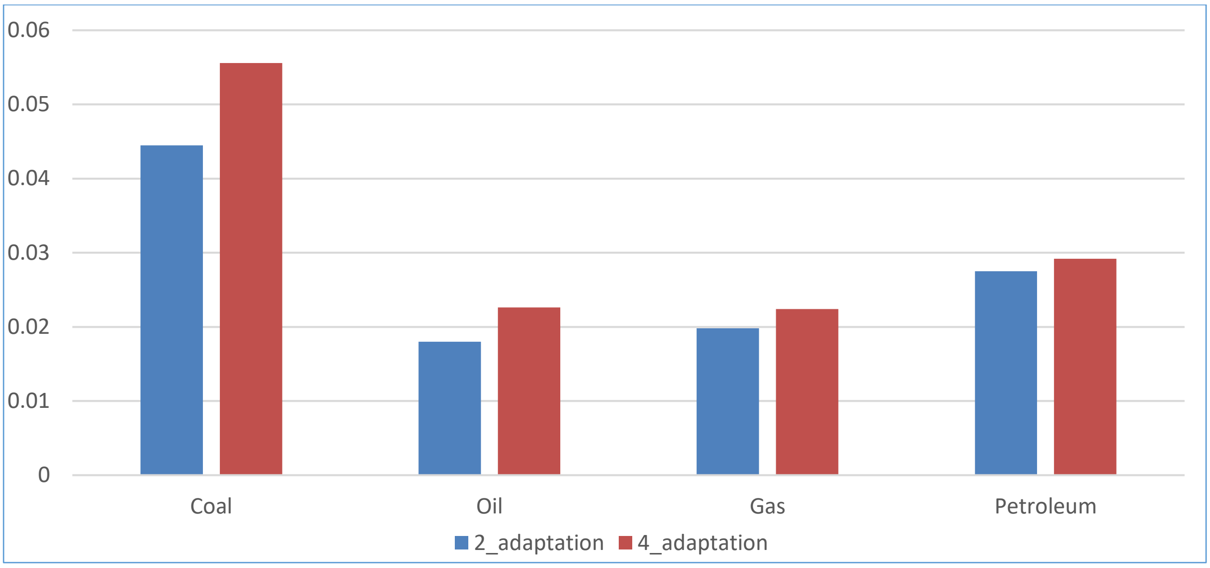
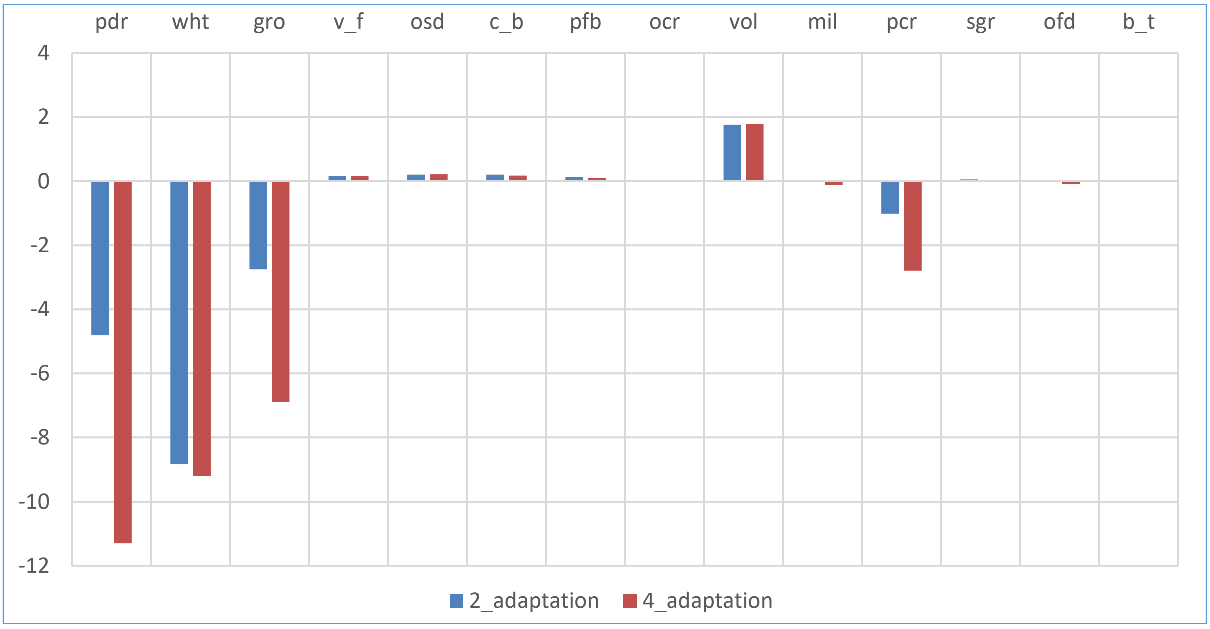


Figure 40. Impact of adaptation and climate change on the agriculture sector (percentage of change compared to the baseline without climate change)



104. ***Figure 41*** shows that trade balance would improve in all sectors except grains, due to adaptation. This is possibly because of greater investments and avoidance of extreme events in some sectors, which would trigger greater output in such sectors and hence greater exports and lower imports, boosting the trade balance. ***Figure 42*** indicates that imports fall or stagnate in all sectors except extraction and grains, while exports grow in all sectors except grains; this explains why the trade balance is rising in most sectors.

Figure 41. Changes in trade balance
(US$, millions compared to the baseline without climate change)

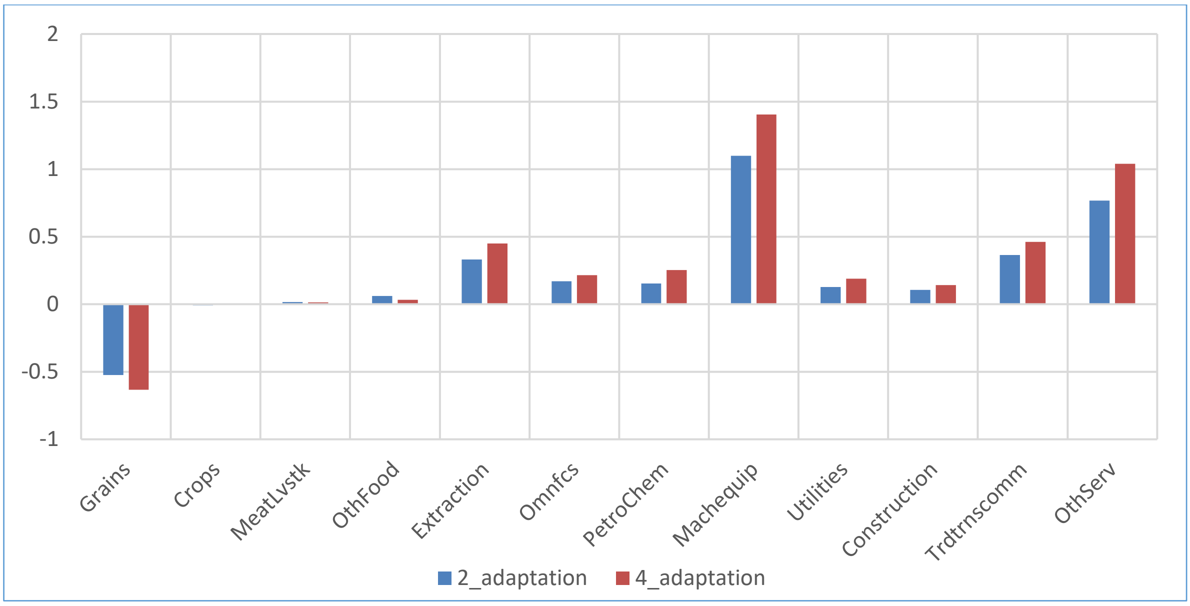
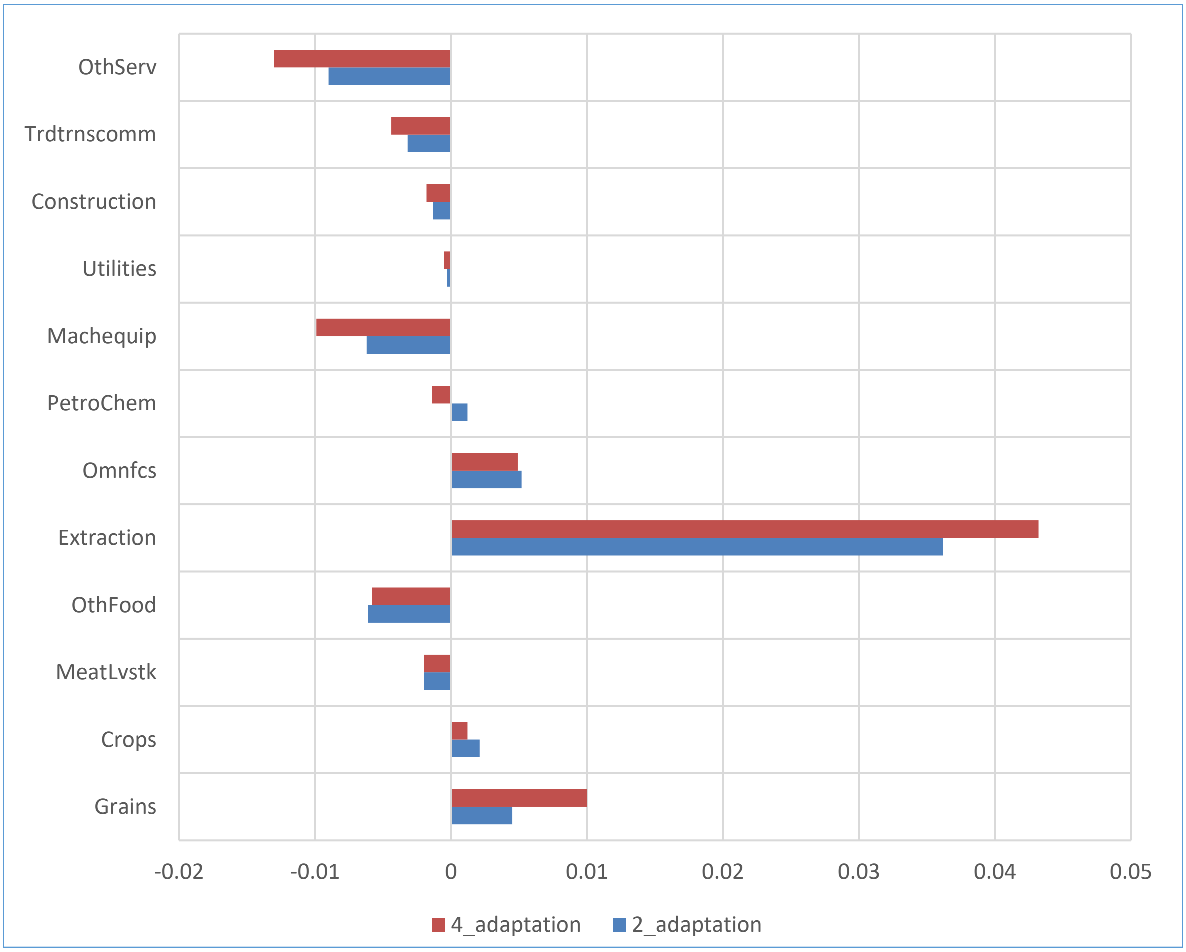
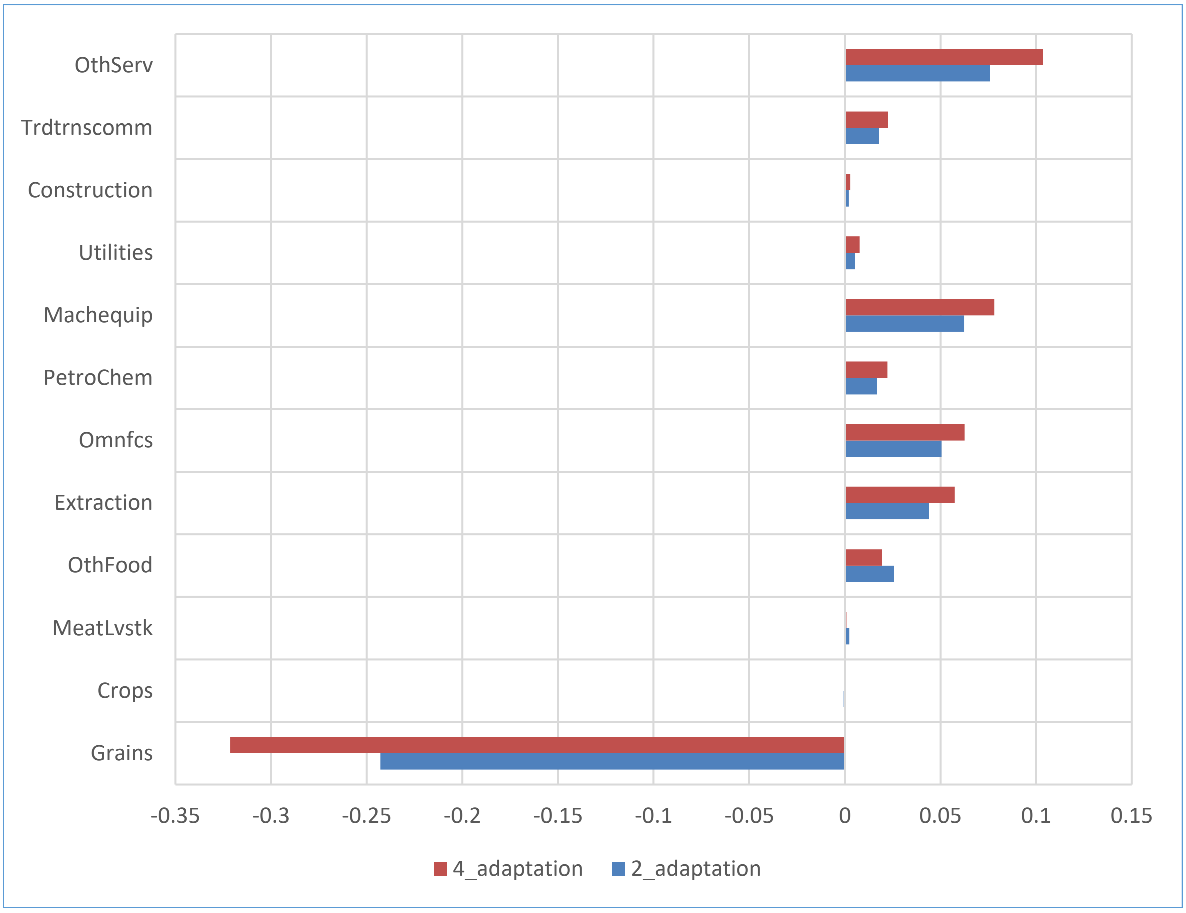


Figure 42. Impact of adaptation measure on imports (panel A) and exports (panel B)
(percentage of change compared to the baseline without climate change)

Panel A



Panel B



4.3. Policy 3: Adaptation financed by foreign funds earmarked across all productive sectors

105. This section develops an alternative adaptation policy which is to channel foreign funds for investments across all productive sectors. This new policy is called 'capital' and it refers to allocating adaptation funds not only to agriculture and tourism but to all sectors.

106. Like in the previous sections, model simulations are developed for 10 percent, 20 percent, and 30 percent reduction of the climate change damage for 2°C and 4°C scenarios.

107. ***Table 7*** summarizes macroeconomic outcomes from alternative adaptation options financed by foreign funds.

Table 7. Macroeconomic impact of adaptation policies financed by foreign funds: Policies 2 and 3

Macroeconomic variables	2°C				4°C			
	10 percent	20 percent	30 percent	Policy 3: Capital	10 percent	20 percent	30 percent	Policy 3: Capital
	US$, millions							
GDP	65,341	65,360	65,380	65,405	65,321	65,343	65,364	65,387
Welfare	−55	−41	−26	19	−67	−51	−36	8
Exports	1,463	1,726	1,984	3,979	1,254	1,530	1,805	3,606
Imports	200	419	636	4,571	183	400	617	4,496
Investment	−2,275	−2,153	−2,028	3,812	−3,169	−2,937	−2,705	3,047

Macroeconomic variables	2°C				4°C			
	10 percent	20 percent	30 percent	Policy 3: Capital	10 percent	20 percent	30 percent	Policy 3: Capital
	Percentage of change from baseline							
Consumer price index	−0.05	−0.05	−0.04	−0.06	−0.06	−0.05	−0.04	−0.07
Real wages (unskilled labor)	−0.14	−0.10	−0.07	−0.07	−0.19	−0.15	−0.11	−0.10
Household income	−0.15	−0.12	−0.09	−0.04	−0.18	−0.15	−0.11	−0.07
Investment	0.011	0.012	0.014	0.131	0.015	0.017	0.019	0.143

Source: Model simulations.

108. ***Table 7*** shows the range of adaptation measures and their impact on key macroeconomic variables of interest. The results are shown in two alternative scenarios of the anticipated climate change in Bulgaria, that is, 2°C and 4°C global temperature rise by 2050. The columns within these two broad categories represent the level of adaptation that is assumed to have occurred by 2050. For example, the first column ('10 percent') means that Bulgaria was able to introduce a planned adaptation measure that reduced the impact of climate change by 10 percent by 2050. The 'Capital' column shows an adaptation measure where capital is allowed to grow in all sectors that happen to employ this important factor of production. In short, this last scenario represents the case where there is an economy-wide improvement in the use of capital in Bulgaria. In the other scenarios, capital is allowed to change/improve only in the agricultural and tourism sectors.

109. The general picture from ***Table 7*** can be summarized as follows. First, the bigger the adaptation effort, as measured in the percentage of damages reduced, the greater the overall benefit to society, that is, there is an improvement in welfare, albeit in small magnitude. Second, the 'Capital' column shows a positive gain if the adaption policy improves the use of capital in all sectors in Bulgaria. Third, the impact of all these alternative measures of adaptation seems to have little impact on consumer price index, real returns to unskilled labor, and household. While the general trend reported in ***Table 7*** shows negative outcomes for all these variables, the magnitudes are rather small. This may not be surprising in a general equilibrium setup where unskilled labor is allowed to move across sectors following changes in output. That is, the fact that labor is allowed to move across sectors helps mitigate some of the negative impacts of climate change and/or adaptation by moving to sectors where there is a new opportunity.

110. In all the measures summarized above, 30 percent reduction in climate damages is the most optimal adaptation scenario if the capital growth is only focused on agricultural and tourism sectors and 2°C is the least damaging possibility.

111. The capital scenario is even more optimal than the other scenarios, even with just 10 percent reduction in damage by climate change. It results in greater availability of capital in every industry, thereby infusing a lot of economic positivity across the board, with expansion in output and value added, partly outweighing the climate damage in some sectors.

Box 3. Greenhouse gas implications

This analysis also estimated annual greenhouse gas emissions by 2050, in all scenarios (see on ***Table 8***). In the baseline scenario, emissions amount to over 69.3 million metric tons of carbon dioxide ($MtCO_2$) in 2050. In all the other scenarios (climate change with or without adaptation), emissions are slightly lower than this, by 1 or 2 percent in most cases, 4 percent in only one instance. This is because of the contraction of economic activity arising from climate change (and not totally offset with adaptation). In the model, emissions are a function of economic activity and therefore the former rises and falls with the latter.

In the 2°C optimistic scenario without adaptation for instance, emissions amount to about 68.5 $MtCO_2$, which is about 0.8 $MtCO_2$ less than in the baseline scenario. However, the same scenario, with adaptation, leads to slightly higher emissions, at 68.6 $MtCO_2$ since adaptation eases the downward pressure on economic activity, but still below the baseline. In general, adaptation leads to higher emissions than no adaptation, all other things being equal (extent of rise in temperature and optimistic/pessimistic scenario, to be specific). Furthermore, the pessimistic scenarios result in lower emissions than the corresponding optimistic scenarios, again because of the greater economic activity in the optimistic scenario (since such a scenario assumes lower damages to the economy as a whole). Such a pattern may also be noted between the 2°C and 4°C scenarios, the former resulting in greater emissions than the latter, due to the smaller climate damages in the former than the latter.

Those are only preliminary estimates of the greenhouse gas implications of the different climate change impact/adaptation scenarios considered in this study. An in-depth analysis of the synergies between adaptation and mitigation would require further refinements to the model (notably on energy and agriculture, forestry and other land use sectors, considerations of all greenhouse gases) for a more accurate of description of economic activities and their impact on emissions.

Table 8. Annual greenhouse gas emissions, by 2050, across all scenarios*

Scenarios			Greenhouse gas emissions ($MtCO_2$)
Baseline			
Without adaptation	2°C	Optimistic	68.504
		Pessimistic	67.911
	4°C	Optimistic	68.262
		Pessimistic	66.526
With adaptation	2°C	Optimistic	68.573
		Pessimistic	67.977
	4°C	Optimistic	68.352
		Pessimistic	67.561

**: CO2 only, from all sectors.*

Source: Model simulations.

5. Conclusion

112. Bulgaria is likely to face serious impediments to economic growth till 2050; demographic slowdown and barriers to economic diversification are the most important among them. Climate change will add to these challenges.

113. The present analysis evaluates the social and economic implications of climate change and adaptation actions in Bulgaria and highlights the costs of inaction and the benefits of climate action within an economy-wide framework. It provides elements in answer to the following questions: what are the most vulnerable sectors to climate change, how effective is adaptation to its most significant impacts, and what are overall funding needs and potential financing mechanisms?

114. This analysis is the first attempt to build an integrated assessment model on climate adaptation for Bulgaria, by coupling a macro-economic model with environmental modules. Given significant knowledge gaps, not all the channels through which climate change is likely to affect natural resources, human settlements, and economic activities can be captured in the model. Despite this partial coverage, the model nonetheless represents climate change impacts in the sectors considered the most vulnerable to climate change, such as agriculture, coastal zones, energy, human health, and tourism. The analysis considers two climate change scenarios, contrasting a climate sensitive-scenario (a 2°C warmer world) and a carbon intensive-scenario (a 4°C warmer world).

115. In terms of vulnerability to climate change, the present analysis finds that economic growth in Bulgaria can be fully wiped out by 2050 because of climate change. GDP is projected to grow annually by 1.7 percent by mid-century and the negative impact of climate change systematically outweighs economic growth in a 4°C warmer world, and in most cases, in a 2°C warmer world. Impact on economic growth by 2050 ranges from -1.3 to -4.3 percent across the climate change scenarios considered. These results fall between the range of the findings from available studies on the economic impacts of 2°C change in Southern Europe. For instance, the PESETA project (2014) estimates the overall macroeconomic impact of climate change around 2.8 percent of GDP in 2080; the TopDad project estimates a 0.15 percent slowdown in Southern European economic growth; and the Climate Cost project estimates a 0.5 to1 percent GDP loss by 2100. These studies date from a few years back and unfortunately there are no updates yet regarding the potential impact of a 4°C temperature change.

116. Beyond the impact on GDP, it is equally important to highlight the welfare impacts of climate change. Welfare losses by 2050 range from 1 to 3.5 percent of GDP, from the most optimistic scenario to the most pessimistic one. Welfare losses can be broken down into three components: direct impacts, efficiency, and terms of trade. Findings from the model simulations first show that the direct impacts of climate change are the main driver of welfare losses, reflecting a general worsening of production conditions in Bulgaria, growing in severity with more intense warming. Second, climate change coupled with sub-optimal economic policies leads to further welfare losses, linked to economic inefficiency, but those are one order of magnitude lower than losses from direct impacts. Third, the impact of climate change on the terms of trade translates into welfare gains, of about the same magnitude (in absolute value) as

the welfare losses linked to efficiency. As a result, terms of trade welfare gains can mitigate welfare losses linked to economic inefficiency but cannot outweigh the much larger welfare losses linked to the direct impacts of climate change.

117. At the sectoral level, the model simulations show that agriculture is among the most vulnerable sectors, with differentiated impact on grains (like wheat, maize, or barley) and other crops (like vegetables and fruits). While the adaptation policies considered here help mitigate the impact of climate change on grains, they do not, however, totally offset its negative impact on the agriculture sector. This calls for a differentiated approach to climate change adaptation policy for this sector in Bulgaria. Grains experience the highest negative impacts across all the four river basins in Bulgaria. The Danube river basin (where the agricultural productivity is the highest) is the region that suffers the most from climate change.

118. The energy sector, comprised of refined petroleum products and other fuels, is another sector that is highly impacted under any of the climate change scenarios considered in the present analysis. Energy demand for heating (in cold days) will decrease significantly and pull down the overall demand for electricity used for heating despite a slight increase in electricity demand for air conditioning (in hot days).

119. Another cluster of sectors experiencing a negative outcome is transport and communication. The overall decline in economic activity accounts for the decline in demand for output for these sectors.

120. Finally, a positive output response is observed for the energy-intensive trade-exposed sectors, which includes sectors such as chemicals, steel, aluminum, cement, and ceramics.

121. Climate change is also very likely to push more people into poverty in Bulgaria. An economy-wide increase in real price is observed across all climate change scenarios. Rising prices for commodities are likely to result in a substantial reduction in real income – and an increase in poverty – for those households that spend a large share of their income on those commodities whose price rose substantially. However, the well-being of households depends not only on changes in the cost of living, but also on changes in earnings. In general, earnings from both skilled and unskilled labor will decline in all analyzed scenarios. More people are therefore expected to fall below the poverty line under the combined effect of rising real prices and declining earnings from labor.

122. The scope of the present macroeconomic analysis is to inform high-level policy dialogue, on the rationale to adapt to climate change (comparing the costs of action with the costs of inaction) and on overall funding needs and potential financing mechanisms for adaptation. In the absence of comprehensive technical and economic information on adaptation measures and their costs at sectoral levels that could be readily integrated into the model, no marginal adaptation cost curve could be derived bottom-up. Instead an implicit, top-down cost curve is being used, based on similar integrated modeling exercises, around the assumption that that adaptation can reduce 30 percent of the gross impact from climate change at little cost to the economy (0.1 percent in GDP).

123. Findings first demonstrate the large benefits from adaptation, whereby adaptation can help mitigate the adverse impact of climate change. The benefits from adaptation are higher in

the 4°C scenario, where the negative impact of climate change on growth is almost halved (from 4.3 percent to 2.6 percent GDP). In terms of resource mobilization, the model simulations show that it is possible to finance adaptation via a 2 percent climate contribution levied on consumption goods without hampering the prospects for growth. This climate contribution leads to a slight negative impact on consumer welfare in the 2°C scenario only; in the 4°C scenario, where there is more scope for adaptation, improvements in economic efficiency and competitiveness in international trade override the adverse impact of this fiscal policy.

124. Other alternatives include orienting foreign funds, such as structural funds from the European Union, or their successors, or other bi- or multi-lateral mechanism focused on climate finance, towards adaptation. In terms of allocating adaptation funding, the model simulations show that orienting adaptation resources across sectors (and not only to the most vulnerable sectors) yields more benefits to the Bulgarian economy and citizens, since it increases availability of capital in productive sectors, with expansion in output and value added, partly outweighing the negative impacts from climate change.

125. These results are based on the first attempt to build an integrated assessment model on climate adaptation for Bulgaria. There was a particular focus on agriculture as one of the most vulnerable sectors to climate change and the model can analyze well the link between natural assets such as land and water that are vulnerable to climate change and primary production factors for agriculture. Based on policy interest and available microeconomic and technical information at sectoral level, the model could be further enhanced to similarly improve the representation of climate vulnerability and adaptation potential in other sectors or to analyze mitigation issues. Those are potential directions for further research.

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Annex 1. Classification and Mapping Used for Analysis

Table 1.1. GTAP 57 sector classification and mapping used for analysis (13 aggregate sectors)

No.	GTAP 57	Long name	Aggregate sectors
1	pdr	Paddy rice	Grains
2	wht	Wheat	Grains
3	gro	Cereal grains nec	Grains
4	v_f	Vegetables, fruit, nuts	Crops
5	osd	Oil seeds	Crops
6	c_b	Sugarcane, sugar beet	Crops
7	pfb	Plant-based fibers	Crops
8	ocr	Crops nec	Crops
9	ctl	Cattle, sheep, goats, horses	MeatLvstk
10	oap	Animal products nec	MeatLvstk
11	rmk	Raw milk	OthFood
12	wol	Wool, silk-worm cocoons	Crops
13	frs	Forestry	Extraction
14	fsh	Fishing	Extraction
15	coa	Coal	Extraction
16	oil	Oil	Extraction
17	gas	Gas	Extraction
18	omn	Minerals nec	Extraction
19	cmt	Meat: cattle, sheep, goats, horse	MeatLvstk
20	omt	Meat products nec	MeatLvstk
21	vol	Vegetable oils and fats	OthFood
22	mil	Dairy products	OthFood
23	pcr	Processed rice	OthFood
24	sgr	Sugar	OthFood
25	ofd	Food products nec	OthFood
26	b_t	Beverages and tobacco products	OthFood
27	tex	Textiles	Omnfcs
28	wap	Wearing apparel	Omnfcs
29	lea	Leather products	Omnfcs
30	lum	Wood products	Omnfcs
31	ppp	Paper products, publishing	Omnfcs
32	p_c	Petroleum, coal products	Chemineral
33	crp	Chemical, rubber, plastic prods	Chemineral
34	nmm	Mineral products nec	Chemineral
35	i_s	Ferrous metals	Extraction
36	nfm	Metals nec	Extraction

No.	GTAP 57	Long name	Aggregate sectors
37	fmp	Metal products	Extraction
38	mvh	Motor vehicles and parts	Omnfcs
39	otn	Transport equipment nec	Machequip
40	ele	Electronic equipment	Machequip
41	ome	Machinery and equipment nec	Machequip
42	omf	Manufactures nec	Omnfcs
43	ely	Electricity	Utilities
44	gdt	Gas manufacture, distribution	Utilities
45	wtr	Water	Utilities
46	cns	Construction	Construction
47	trd	Trade	Trdtrnscomm
48	otp	Transport nec	Trdtrnscomm
49	wtp	Sea transport	Trdtrnscomm
50	atp	Air transport	Trdtrnscomm
51	cmn	Communication	Trdtrnscomm
52	ofi	Financial services nec	OthServ
53	isr	Insurance	OthServ
54	obs	Business services nec	OthServ
55	ros	Recreation and other services	OthServ
56	osg	PubAdmin/Defence/Health/Educat	OthServ
57	dwe	Dwellings	OthServ

Table 1.2. Parameter values for the central cases of climate change shocks

Policy shocks	2°C			4°C		
	A	B	C	D	E	F
Productivity shocks	Optimistic	Anticipated	Pessimistic	Optimistic	Anticipated	Pessimistic
aoall("pdr","Bulgaria")	−1.53	−3.06	−4.59	−3.53	−7.06	−10.59
aoall("wht","Bulgaria")	−3.065	−6.13	−9.195	−3.19	−6.38	−9.57
aoall("gro","Bulgaria")	−1.345	−2.69	−4.035	−3.345	−6.69	−10.035
Energy demand shocks				0		
aoall("ely","Bulgaria")	−0.05	−0.1	−0.15	−0.09	−0.18	−0.27
aoall("gas","Bulgaria")	−0.05	−0.1	−0.15	−0.08	−0.16	−0.24
aoall("p_c","Bulgaria")	−5.15	−10.3	−15.45	−9.93	−19.86	−29.79
SLR shocks						
qo(ENDWS_COMM,"Bulgaria")	−0.0002	−0.0004	−0.0006	−0.00037	−0.00074	−0.00111
qo("Capital","Bulgaria")	−0.0002	−0.0004	−0.0006	−0.00037	−0.00074	−0.00111
Tourism shocks				0		
qpd("ros","Bulgaria")	0.178	0.356	0.534	0.356	0.712	1.068

Source: Roson and Sartori 2016 and Berrittella et al. 2004.

Table 1.3. Shock values for the adaptation scenario

Policy shocks	2°C	4°C
	A	F
Productivity shocks	Optimistic	Pessimistic
aoall("pdr","Bulgaria")	−1.0251	−7.0953
aoall("wht","Bulgaria")	−2.05355	−6.4119
aoall("gro","Bulgaria")	−0.90115	−6.72345
Energy demand shocks		
aoall("ely","Bulgaria")	−0.0335	−0.1809
aoall("gas","Bulgaria")	−0.0335	−0.1608
aoall("p_c","Bulgaria")	−3.4505	−19.9593
SLR shocks		
qo(ENDWS_COMM,"Bulgaria")	−0.000134	−0.00074
qo("Capital","Bulgaria")	−0.000134	−0.00074
Tourism Shocks		
qpd("ros","Bulgaria")	0.11926	0.71556

Source: Based on Roson and Sartori 2016 and Berrittella et al. 2004.

Table 1.4. Sector description

Short name	Long name
PDR	Paddy rice
WHT	Wheat
GRO	Cereal grains nec
V_F	Vegetables, fruit, nuts
OSD	Oil seeds
C_B	Sugarcane, sugar beet
PFB	Plant-based fibers
OCR	Crops nec
VOL	Vegetable oils and fats
MIL	Dairy products
PCR	Processed rice
SGR	Sugar
OFD	Food products nec

Source: GTAP database.

Annex 2. Comparing Results with an Integrated Modelling Exercise: OECD Report (2015)

This section compares the results of this study with those reported in OECD (2015) and starts by first describing the model and some important results of the study. The OECD paper uses the Environment Directorate's Linkage (ENV-Linkage) model, a recursive and multi-region, multi-sector dynamic CGE model of the global economy. In addition to ENV-Linkage, the OECD analysis also relies on the Adaptation in Dynamic Integrate Climate-Economy (AD-DICE) model to run some long-term simulations that go beyond 2060. The projected long-term costs of climate change start with building a baseline projection of the world economy till 2060 and beyond when necessary. This baseline represents the case where the world economy evolves without any climate change. The anticipated climate change impacts are then overlaid on this baseline to help assess how the new shocks change the 'observed' world economy. The model setup divides the world into thirteen global groupings[13] and aggregate the 57 GTAP commodities into eight sectors.[14] While the discussion on the climate impacts generally focuses on aggregate regions listed in the footnote, the study also reports results on some major individual economies that make up the aggregate divisions. The modelling is based on existing estimates of how selected climate impacts affect the drivers of economic growth of major world regions at the macroeconomic and sectoral level. A multitude of impact of climate change is considered in the analysis and the list includes changes in crop yields, loss of land and capital from SLR, impact of extreme events such as hurricanes, morbidity from heat and cold exposures, changes in energy demand, and changes in tourism flows. In general, the study reports that the combined effect of the above selected impacts on global annual GDP is projected to rise over time to likely levels of 1.0 percent to 3.3 percent by 2060, with a central projection of 2 percent GDP loss. There are, however, substantial regional variations in this estimate of impacts of climate change.

The first important notable difference between Bulgaria CGE analysis and the OECD paper is that this specific analysis used the standard and static GTAP model while the OECD report relied on a recursive dynamic CGE model that is augmented AD-DICE which is a class of integrated assessment models. While static CGE models provide a useful benchmark for policy analysis, their use in climate change modeling has been criticized in a number of ways. First, in the static CGE model, there is no optimization over time, that is, agents are seen as being myopic when it came to between-period decisions such as savings and investment. Second, climate change by its very nature is a dynamic phenomenon. The fact that agents are allowed to update their information beliefs and adjust their saving and investment decisions accounts for the observed nontrivial GDP impacts of climate change under the static GTAP model. The Bulgaria CGE analysis took as reference the OECD report in integrating climate change impact into the baseline.

[13] These groupings are OECD America, OECD Europe, OECD Pacific, Middle East and North Africa, Latin America, Sub-Saharan Africa, South and South-East Asia, Rest of Europe and Asia.
[14] The aggregate sectors are agriculture, fisheries, forestry, energy and extraction, energy-intensive industries, other industries, transportation and construction, and other services.

A second source of difference between the two studies is the nature and extent of climate change damages modelled in the simulation exercises. Our model derived the necessary parameters from few reliable sources and focused on three impacts of climate change: agricultural productivity, energy demand, and tourism. The OECD study on the other hand relies on a larger literature and studies the impact of a range of climate change impacts.

The other important difference has to do with the sectoral and regional aggregation used in the Bulgaria CGE analysis and is very different from the one reported in the OECD study. A related point is that this study uses Version 9 GTAP database with 2011 as a base year while the OECD report relies on a slightly earlier version. These are important differences with the OECD study due to differences in the analytical structures.