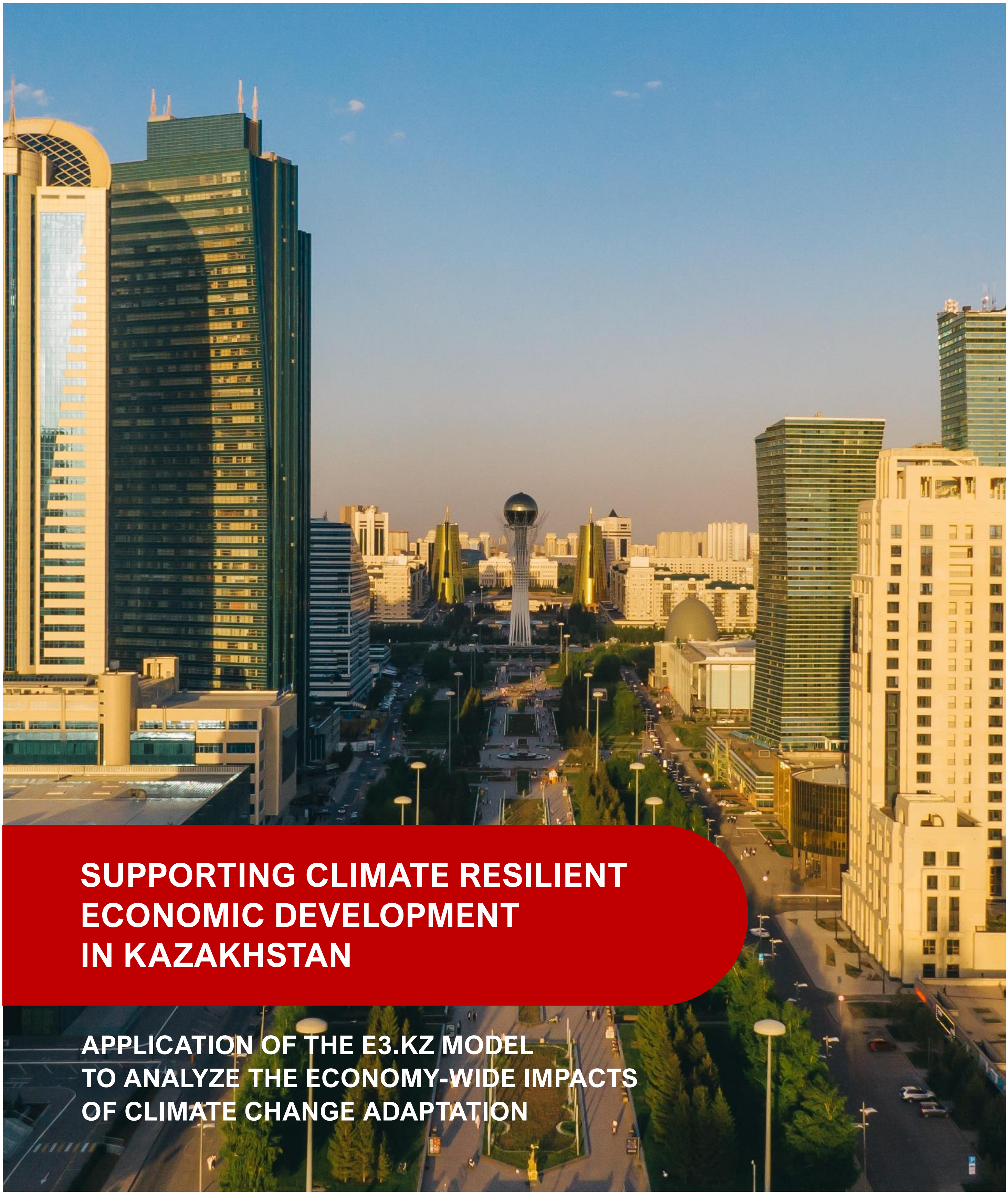


SUPPORTING CLIMATE RESILIENT ECONOMIC DEVELOPMENT IN KAZAKHSTAN

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

Published by:

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

On behalf of:

Federal Ministry for the Environment, Nature Conservation and Nuclear Safety

of the Federal Republic of Germany

In cooperation with:

ECONOMIC RESEARCH INSTITUTE QAZAQSTAN

GWS SPECIALISTS IN EMPIRICAL ECONOMIC RESEARCH

SUPPORTING CLIMATE RESILIENT ECONOMIC DEVELOPMENT IN KAZAKHSTAN

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

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

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

Registered offices:
Bonn and Eschborn, Germany

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

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

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

Authors:
Dr Anett Großmann, Frank Hohmann
Dr Christian Lutz, Saskia Reuschel
GWS - Gesellschaft für Wirtschaftliche Strukturforschung | Institute of Economic Structures Research, Osnabrück

Contributions:
Aidyn Bakdolotov, Ramin Kazymov, Shyngyz Shuneyev | Economic Research Institute
Sebastian Homm, Stefanie Springorum, Anne Weltin, Dana Yermolyonok | GIZ
Anika Terton | International Institute for Sustainable Development

Editor:
Dana Yermolyonok, Karaganda

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

Photo sources:
Cover page: ©pixabay.com

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

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

Germany, 2022

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

APPENDIX

LIST OF ABBREVIATIONS

BAU	Business as usual
CBA	Cost-benefit analysis
CBAM	Carbon border adjustment mechanism
CAREC	Central Asia Regional Economic Cooperation
CGE	Computable General Equilibrium
CHP	Combined Heat and Power
COACCH	Co-designing the Assessment of Climate Change costs
COMSTAT	Committee of Statistics in Kazakhstan
CRED	Climate Resilient Economic Development
DICE	Dynamic Integrated Climate-Economy-Model
DIM	Disaster Impact Models
DIOM-X	Dynamic Input-Output Model in Microsoft Excel
EAEU	Eurasian Economic Union
ERI	Economic Research Institute
EWE	Extreme Weather Events
FUND	Climate Framework for Uncertainty, Negotiation and Distribution
GDP	Gross domestic product
GHG	Greenhouse gas emissions
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GWS	Institute of Economic Structures Research (Gesellschaft für wirtschaftliche Strukturforschung)
IAM	Integrated Assessment Model
ICT	Information and Communications Technologies
IEA	International Energy Agency
IO	Input-Output
IPCC	Intergovernmental Panel on Climate Change
LEDS	Low-emission development strategy
MNE	Ministry of National Economy of the Republic of Kazakhstan
NAP	National Adaptation Plan
NDC	Nationally Determined Contributions
NPISH	Non-profit institution serving households
PAGE	Policy Analysis for the Greenhouse Effect
PESETA	Projection of Economic impacts of climate change in Sectors of the European Union based on bottom-up Analysis
RCP	Representative Concentration Pathways
REF	Reference scenario
RICE	Regional Integrated model of Climate and the Economy
SD	System Dynamics

SPEI	Standardized Precipitation Evapotranspiration Index
TFEC	Total final energy consumption
TIMES	The Integrated MARKAL-EFOM System
UIB	University of the Balearic Islands

GLOSSARY

Adaptation to climate change	Adaptation to climate change can be defined as a "set of organization, localization and technical changes that societies will have to implement to limit the negative effects of climate change and to maximize the beneficial ones" (Hallegatte et al. 2011). The United Nations Framework Convention on Climate Change (UNFCCC) defines adaptation as “adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities”. (UNFCCC 2013)
Climate change	Climate change “means a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.” (UNFCCC 1992).
Climate hazard	A physical process or event (hydro-meteorological or oceanographic variables or phenomena) that can harm human health, livelihoods, or natural resources. A hazard is not simply the potential for adverse effects. (https://climatescreeningtools.worldbank.org/content/key-terms-0).
Cost-benefit analysis	A systematic approach to estimate costs and benefits of a project. It compares the discounted value over the whole lifetime of the project – the net present value (NPV) – of the costs and the benefits. A project is recommended if the benefits outweigh the costs (NPV > 0).
Extreme weather events	“The occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable” (IPCC 2012, p. 117) with respect to a given reference period and a specific region.
Macroeconomic model	A macroeconomic model shows the economy and its interrelationships in a simplified way. It consists of variables which describe the economic actors (e. g. households) and sectors (e. g. agriculture) as well as their behavior (e. g. consumption). Model equations show the relationship between the variables. Results of a model can be forecasts of model variables or effects on model variables through shocks when conducting a scenario analysis.
Scenario	Scenarios are consistent sets of quantified assumptions describing the future development. Scenarios should not be considered as precise forecasts. Instead, they show possible development paths that are reactions to the assumptions made.

EXECUTIVE SUMMARY

Climate change poses major challenges for Kazakhstan. On the one hand, Kazakhstan committed itself in December 2020 to achieve carbon neutrality by 2060, which requires a transformation of today's resource-based economy and thus Kazakhstan contributes to limiting global warming. On the other hand, Kazakhstan is confronted with gradual long-term changes of the climate such as increasing temperatures, changed precipitation patterns as well as more frequent, more severe and recurring extreme weather events such as droughts and floods.

The outstanding importance of climate change for Kazakhstan was also stated by the President of the Republic of Kazakhstan Mr. Tokayev at the General Debate of the 75th session of the UN General Assembly: "Kazakhstan is very vulnerable to various effects of climate change" (UNGA 2020).

Climate change not only affects the environment but also causes immense economic costs, affects key industries and endangers jobs, wealth and life of Kazakh people. Floods and storms destroy infrastructures while droughts cause yield losses in agriculture. Increasing temperatures have adverse impacts on human health as well as energy demand and supply. Apart from theses direct impacts, further losses result from e. g. impaired production due to power outages.

Adaptation to climate change aims at limiting the adverse impacts of climate change while maximizing the beneficial ones. Various adaptation options and evaluations exist for certain economic sectors and climate hazards. Usually not well-known are the macroeconomic impacts and intersectoral effects of climate change and adaptation which goes beyond single economic sectors analyses.

However, the knowledge of the economy-wide effects of climate change and sectoral adaptation measures in terms of GDP, employment and CO_2 emissions is vital for Kazakhstan to develop climate resilient economic development strategies. Environmentally extended economic models in combination with scenario analysis support policymakers with these issues.

An extensive exchange with Kazakh partners, experts and the cooperation between the Ministry of National Economy (MNE) of the Republic of Kazakhstan, the Institute of Economic Research (ERI), GWS and GIZ resulted in the development of the e3.kz macro-econometric model for Kazakhstan. The model application ensures evidence-based policy-making in the context of climate change adaptation.

Climate change and adaptation scenarios were designed comprising information and data on the most relevant climate hazards, their sector-specific impacts as well as suitable adaptation options. Subsequently, these scenarios were analyzed with the model e3.kz to quantify the long-term macroeconomic impacts.

Overall, the macroeconomic analysis shows that climate change puts food and energy security at risk. Economic growth, jobs and income are endangered not only in directly impacted economic sectors as long as no adaptation measures are taken.

Selected adaptation measures for the key priority sectors agriculture, energy and infrastructure were examined regarding their economy-wide impacts by applying the e3.kz model. Comparing most relevant model indicators allow policymakers to identify those adaptation measures that are highly effective and have positive effects on the economy, employment, and the environment (win-win options).

The exemplary analyses show that adaptation measures provide co-benefits but also shed light on possible trade-offs with other strategies in Kazakhstan:

(1) The adverse impacts of climate change can be reduced in directly impacted sectors and also other sectors along the value chain.

(2) Measures that primarily support the domestic economy, e. g. through construction activities as in the case of the (re-)construction of water canals or climate resilient infrastructure, are even more beneficial. Jobs and income are created in Kazakhstan.

(3) The positive economic effects are curtailed if products must be imported, such as drip irrigation systems or electrical equipment.

(4) As long as investment costs are at the expense of other government consumption expenditures, as shown at the example of “green belt mass afforestation”, or result in higher prices – exemplary shown in the “(re-)construction of storm-proofed buildings”, then affected sectors are strained by these effects. Financial support from international donors would further improve the effects for the macroeconomy.

(5) Combating climate change requires a holistic approach including both mitigation and adaptation action. The e3.kz model results show that higher economic activity increases CO_2 emissions if no countermeasures are taken. Nature-based solutions such as the “deployment of wind power and energy efficiency improvements in the housing sector” to increase the resilience of the energy sector or the “green belt mass afforestation” to reduce the adverse impacts from extreme wind demonstrate that co-benefits of adaptation and mitigation measures can be created.

The effectiveness and design of adaptation measures as well as supporting policy instruments (such as subsidies) influence not only sector-specific effects, but also macroeconomic impacts. Combining adaptation measures may help to exploit existing opportunities to further reduce the impacts of climate change.

The results are subject to several uncertainties due to the nature of climate change and the current limited knowledge on adaptation costs and benefits. However, the results increase awareness on the topic and provide the basis to prepare climate-sensitive development plans and economic development strategies at the national level in Kazakhstan which has budgetary sovereignty and plans for the long term.

Although the financial and economic impacts are relevant for policymakers to decide which adaptation measure is “most effective”, other criteria – which are beyond scope of the model – must be considered as well such as health aspects, ecosystem services (biodiversity, regulation of the water balance), distributional effects, other greenhouse gas emissions and international / political implications to get a more comprehensive evaluation and to formulate an appropriate adaptation strategy.

1 INTRODUCTION

Climate change poses major challenges for Kazakhstan. On the one hand, Kazakhstan committed itself in December 2020 to achieve carbon neutrality by 2060, which requires a transformation of today's resource-based economy and thus Kazakhstan contributes to limiting global warming. On the other hand, Kazakhstan is confronted with gradual long-term changes of the climate such as increasing temperatures as well as more frequent, more severe and recurring extreme weather events (EWE) like droughts and floods. Both aspects – adaptation to and mitigation of climate change – must be considered in long-term economic planning. The shift to a green economy requires immense investment, which should also be climate resilient to avoid major damage. The outstanding importance of climate change for Kazakhstan was also stated by the President of the Republic of Kazakhstan Mr. Tokayev at the General Debate of the 75th session of the UN General Assembly: *"Kazakhstan is very vulnerable to various effects of climate change" (UNGA 2020)*.

With climate change causing immense economic costs and affecting key industries such as agriculture, energy and transport, policy makers need powerful tools to evaluate possible economic risks and benefits (awareness raising) as well as different adaptation strategies (preparedness) to be able to initiate the transition to a climate resilient economy. Knowledge of the economy-wide effects of climate change and sectoral adaptation measures is vital for Kazakhstan to develop climate resilient economic development strategies. Environmentally extended economic models in combination with scenario analysis support policymakers with these issues.

To ensure evidence-based policy-making on adaption to climate change, the macroeconomic model e3.kz[1] model has been developed in cooperation between the Ministry of National Economy (MNE) of the Republic of Kazakhstan, the Institute of Economic Research (ERI), GWS and GIZ.

The e3.kz model is such a tool which supports in understanding and quantifying the economic impacts of climate change and the economic evaluation of adaptation measures by conducting scenario analysis: Different adaptation options can be evaluated with regard to their economy-wide effects and their implications for the environment. By defining appropriate indicators, adaptation options can be evaluated against each other to find favorable solutions or appropriate combinations of adaptation measures. This approach goes beyond the classic cost-benefit approach, which is usually limited to a single economic sector analysis.

A macroeconomic analysis with the e3.kz model goes a step further and evaluates the economy-wide impacts of climate change and sector-specific adaptation measures. **Thus, the e3.kz model results do not only show the direct effects but also the indirect and induced macroeconomic consequences** (GDP, jobs, imports, sector-specific production) **for Kazakhstan due to economic interrelationships.** On the one hand, **model results** of the climate change scenario **show what could happen under climate change (awareness raising under uncertainty).** On the other hand, **policymakers can identify those adaptation measures that are highly effective and have positive effects on the economy, employment, and the environment (win-win options).**

[1] E3 models contain three interlinked model parts, consisting of an economy model (1) enhanced by energy (2) and emission (3) modules. The abbreviation kz indicates Kazakhstan for which the model is built.

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

(1) Developing methods and tools for modelling the economic impacts of climate change

(2) Capacity building through training and coaching: Supporting the lead executing agencies and implementing partners to become independent users of the macro-economic models

(3) Supporting the lead executing agencies and relevant stakeholders in integrating the results in policy-making processes and adaptation planning (planned products and activities of policy advice support)

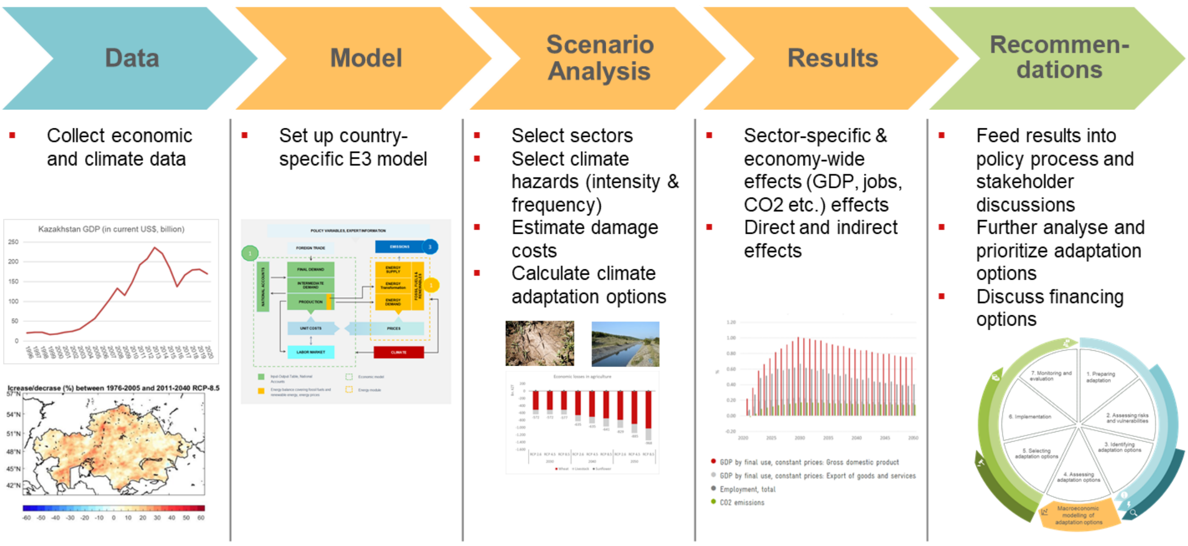


Figure 1: CRED Process: Macroeconomic modelling for evidence-based policy making

Source: GIZ.

Figure 1 shows the CRED process under which the modeling activities are conducted. The process started with the compilation of economic and climate data, followed by the set-up of the e3.kz model which was then applied to climate change and adaptation scenarios. The macroeconomic results are then fed into stakeholder discussions and policy processes (Dekens and Hammill 2021) to support an evidence-based adaptation solutions.

This report is organized as follows:

Chapter 2 first provides an overview of a selection of different modeling approaches as well as the selected CRED approach that addresses the estimation of the macroeconomic impacts of climate change.

Chapter 3 addresses climate change and its economic impacts in Kazakhstan. The current economic situation in Kazakhstan, past and future climatic trends as well as their impacts on specific economic sectors are introduced. An overview of monetized damage data from past climate events which is an important prerequisite to model the economy-wide impacts of climate change is provided as well.

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

Chapter 5 explains how climate change is implemented into the macro-econometric model e3.kz by conducting scenario analysis. The economy-wide impacts of EWEs are illustrated with case studies.

Chapter 6 presents selected adaptation measures for the three focus sectors of agriculture, energy and infrastructure aiming to reduce or even avoid climate damages. The macroeconomic impacts of the adaptation measures are quantified and provide economic arguments to support the selection of appropriate measures for the National Adaptation Plan (NAP) process.

Chapter 7 illustrates possible entry points for macroeconomic modelling in the policy making process and highlights the benefits. Furthermore, ways for anchorage and institutionalization of the modelling activities in Kazakhstan are described.

Chapter 8 draws on lessons learned from the CRED project on approaches for modelling the economic impacts of climate change and adaptation.

2 MODELLING APPROACH

2.1 APPROACHES FOR MODELLING ECONOMY-WIDE EFFECTS OF CLIMATE CHANGE

2.1.1 INTERNATIONAL MODELLING APPROACHES

Various approaches to estimate the macroeconomic effects of climate change are described in the literature. Probably the best-known calculations have been made since the early 1990s by William Nordhaus. They led to the development of one of the first integrated assessment models DICE (Nordhaus 1992), which attempted to represent the interrelationships between climate change and the global economy in a dynamic model, and were honored with the Nobel Prize in 2018. Other models followed, such as the FUND model run by Richard Tol[2], the REMIND model from the Potsdam Institute or RICE as a regionally specified variant of DICE. These models have in common that they are subject to neoclassical utility maximization and that the damages of climate change, summarized in a damage function, are a side condition to reach an equilibrium. In these models, climate change-induced damages are represented in more or less complex, more or less empirically determined dependencies on more or less differentiated climate change indicators. A particularly simple variant is a directly estimated influence of increased temperature on the target variable, for example in the form of a linear or exponential dependence. More sophisticated variants estimate individual damage functions for individual climate indicators, such as drought, heat, heavy rainfall, or floods for different economic sectors such as agriculture, the energy sector, or tourism (PAGE in the Climate Cost project, also FUND by Anthoff et al. 2011).

There is extensive scientific discussion on these models, revolving around the validity of discount rates, the optimal social discount rate (Weitzman 1998), fat tails of the distribution function of climate risk (Hwang et al. 2016), and other scientifically exciting questions and challenges. The models applied do not explicitly consider time and show states of the economy in an initial equilibrium, which are compared to an equilibrium after taking into account climate impacts or additionally adaptation measures. The comparative static comparison of two equilibrium states does not give insights into transformation pathways, or only to a very limited extent. These approaches have contributed significantly to the estimation of economic impacts at the global level and to quantify economic costs of inaction.

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

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

b) or for Germany in the studies EconCCAdapt[5] and most recently in Lehr et al. (2020). In addition, many individual sector-specific studies are available.

Applied macroeconomic analysis of climate change is a complicated task which is increasingly met with a combination of bottom-up sector specific models and macroeconomic models (Ciscar et al. 2012; Ciscar et al. 2014; Nordhaus 2017; Bosello and Parrado 2020; Schinko et al. 2020). Because climate change is a global phenomenon, most applications have focused on large scale aggregation of geographical regions. However, downscaled modelling provides useful policy insights from a regional perspective based on unique vulnerabilities and socioeconomic characteristics.

Macroeconomic models can be used for modelling the impacts of climate change and climate change adaptation at the national level. In the model approaches, macroeconomic top-down models are linked with the detailed results of sector models or bottom-up models. The national accounts form the basis of an macroeconomic model. In addition, the interdependences of the economic sectors are depicted in Input-Output (IO) tables. Using national accounts and IO data, the sectoral impacts including direct, indirect and induced effects of climate change, and adaptation measures and instruments can be recorded. The following overview of the modelling approaches found in the literature will help the reader to understand the results of different modelling approaches and put them into perspective.

According to the Network for Greening the Financial System (NGFS 2020), economic models assessing climate risks can be divided into integrated climate-economy models and adapted macroeconomic models (Table 1). The main difference lies in the linkage of climate and economic models and their interactions. While Integrated Assessment Models (IAM) combine both the economic damages from climate change and the impact of GHG emissions on the climate, adapted macroeconomic models consider in particular the impacts of climate change on the economy. The degree of modelling detail varies considerably for all model types. An overview gives for example Botzen et al. 2019, IPCC 2014, Lehr et al. 2020, and Máñez Costa et al. 2016.)

[5] https://www.oekonomie-klimawandel.de/

Table 1: Types of economic models to assess climate risks

Lineage	Model type	Description	Example
Integrated climate-economy models[1]	Cost-benefit IAMs	Highly aggregated model that optimises welfare by determining emissions abatement at each step	DICE, DSICE (Cai et al., 2012, Barrage, 2020)
	IAMs with detailed energy system and land use	Detailed partial (PE) or general equilibrium (GE) models of the energy system and land use. General equilibrium types are linked to a simple growth model	PE: GCAM, IMAGE GE: MESSAGE, REMIND-MAgPIE, WITCH[2]
	Computable General Equilibrium (CGE) IAMs	Multi-sector and region equilibrium models based on optimising behaviour assumptions	G-CUBED, AIM, MIT-EPPA, GTAP, GEM-E3
	Macro-econometric IAMs	Multi-sector and region model similar to CGE but econometrically calibrated	E3ME, Mercure et al., 2018
	Stock-flow consistent IAMs	Highly aggregated model of climate change and the monetary economy that is stock-flow consistent	Bovari et al., 2018
Other climate-economy models	Input-output (IO) models	Model that tracks interdependencies between different sectors to more fully assess impacts	Ju and Chen, 2010 Koks and Thissen, 2016
	Econometric studies	Studies assessing impact of physical risks on macroeconomic variables (e.g GDP, labour productivity) based on historical relationships	Khan et al., 2019 Burke et al., 2015 Dell et al., 2012
	Natural catastrophe models and micro-empirical studies	Spatially granular models and studies assessing bottom-up damages from physical risks	SEAGLASS (e.g. Hsiang et al., 2017)
Modified standard macroeconomic models	DSGE models	Dynamic equilibrium models based on optimal decision rules of rational economic agents	Golosov et al., 2014 Cantelmo et al. 2019
	E-DSGE	Slightly modified standard frameworks (that allow for negative production externalities)	Heutel, 2012
	Large-scale econometric models	Models with dynamic equations to represent demand and supply, coefficients based on regressions	NiGEM (e.g. Vermeulen et al., 2018)

1 IAM taxonomy adapted from Nikas et al., 2019.

2 Model documentation available at *www.iamcdocumentation.eu/index.php/IAMC_wiki*

Source: NGFS 2020, p. 23

Economic models can be distinguished according to their underlying economic theory explaining the functioning of and interaction within an economy. Basically, these are computable general equilibrium (CGE), static IO and macro-econometric (or dynamic) IO models (Lehr et al. 2020, NGFS 2020, Máñez et al. 2016, Pollitt and Mercure 2018). These model types are based on inherent assumptions explaining differences in model results (see for example Großmann et al. 2016, Mercure et al., 2019). In the context of the economic analysis of climate change effects, these economic models are partly combined[6] with climate models to create Integrated Assessment Models (IAM), in which climate models are linked to CGE models using a loss function, and Disaster Impact Models (DIM), in which the economic effects of catastrophic events on the regional economy are assessed and in which regionalization of CGE or IO models takes place.

6 Climate models and economic models have so far only been linked in a highly aggregated way in impact assessment models on a global level, and for only one or a few economic sectors. Especially with national models, a "soft" link is common, in which information from climate models is translated into economic quantities and then entered into the economic model (see section 5.1).

CGE Models

CGE models are especially used for the analysis of climate change impacts at sector level and their economy-wide effects (e. g. ENV-Linkages in OECD 2015, GEM-E3 in Ciscar et al. 2011). These models are optimization models and in their most basic form characterized by market clearing assumptions, fully flexible prices and immediate substitution. In this regard, CGE models are suitable for long-term issues under the assumption of functioning markets but climate change and adaptation costs tend to be underestimated (Botzen et al. 2019, p. 183, OECD 2015, p. 30).

In contrast to IAMs using simplified damage functions which link climate change with economic indicators, ENV-Linkages and GEM-E3, for example, use a different approach which is shown in Figure 2 (Ciscar et al. 2011, OECD 2015, Ortiz, Markandya, 2009).

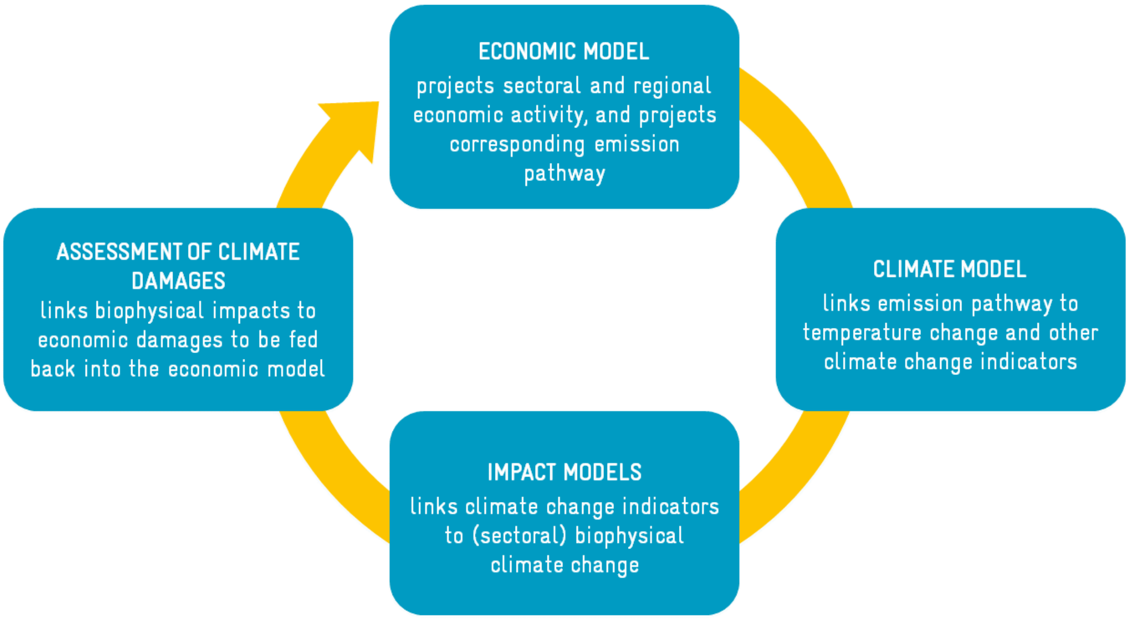


Figure 2: Linking economic and climate change models

Source: OECD 2015, p. 30

The economic model includes sectoral detail and derives emission pathways from economic activity. The emissions serve as input into climate models which derive climate indicators such as temperature increase. The climate indicators are then used in biophysical sector models to obtain specific impacts (e. g. crop yield or energy demand changes). Climate damages which can affect both the supply and demand side finally serve as input into the economic model.

In the PESETA project (which uses GEM-E3), the impacts of climate change are modeled in the economy either through damage to the capital stock, through sectoral productivity losses or as welfare losses of private households (Feyen et al. 2020). The latter may result from additional energy demand for cooling or involuntary additional expenditures for the repair of flood damage. A similar approach is used in the COIN project for Austria (Steininger et al. 2015).

Static IO models

Static IO models are based on IO tables which provide a detailed view on inter-industry linkages and the demand/ supply relationship (United Nations 2018, Miller and Blair 2009, Leontief 1986). IO models go back to Leontief who mathematically illustrated the effects of additional demand in a single industry and its economy-wide direct and indirect impacts. The static IO approach is appropriate for short-term analysis due to its constant economic structure. In contrast to most CGE models, immediate substitution does not exist. Temporary supply constraints due to losses in production must be modeled by specific changes in the so-called input coefficients representing necessary inputs for the sector-specific output. However, long-term adaptation processes cannot be represented in a static IO model due to the lack of consideration of adjustment processes over time. Adaptation costs tend to be over-estimated as this model type does not allow for substitution processes when confronted with higher costs (Botzen et al. 2019, pp. 172, Lehr et al. 2020, Máñez Costa et al. 2016). Disaster Impact Research applies, for example, IO models to estimate direct and indirect impacts of e. g. reconstruction activity to repair the damage caused by EWEs at national and subnational (e. g. Bockarjova et al. 2004, Okuyama et al. 2004).

Macro-econometric (or dynamic) IO models

Macro-econometric (or dynamic) IO models (Almon 1991, 2014, West 1995) build upon the advantages of static IO models but largely resolve their limitations and inherent assumptions, amongst others the absence of time and of capacity constraints. Prices indicate shortages due to capacity constraints. Due to the explicit consideration of time in dynamic models, they can reflect the economic development year after year and can therefore show the temporal adjustment path of recovery periods from climate change effects and adjustment process of adaptation.

As with static IO models, dynamic IO models are typically demand-side driven. However, the demand is determined endogenously and not given exogenously. Income which is influenced by the current labor market situation as well as consumer prices is an important determinant for consumer demand. This implies another benefit of dynamic IO models: apart from direct and indirect effects also (income-) induced impacts can be evaluated.

Macro-econometric IO models rely on a comprehensive data set that allows to model volume and price reactions based on empirical estimations as opposed to CGE models that are using parameters calibrated to a base year. Trends which were detected in the past are assumed to be valid in the future and relax the assumption of a constant economic structure and/or import dependency, which is much more realistic for a mid- to long-term projection. Future technological changes and innovations may be considered and make the model more useful to analyze structural changes (Mercure et al., 2019). Nevertheless, the assumption of constant parameters (which are derived from past observations) is less and less valid with increasing distance in time.

The macro-econometric IO modelling approach is e. g. applied to evaluate climate change impacts and adaptation measures in Germany using the model PANTA RHEI (Lehr et al. 2016, EconCCadapt project[7]), for the EU islands and at EU level using the model GINFORS (Lehr et al. 2018, Aaheim et al. 2015, European Commission 2021a) and E3ME (Cambridge Econometrics 2019). Similar to the approach described in Figure 2, damages and losses from EWEs were collected by screening literature and damage databases e. g. from reinsurance companies, translated into model variables and then implemented

[7] https://www.oekonomie-klimawandel.de/

as economic impulses into the models. Damages were modeled, for example, as a reduction in the capital stock in the machinery and real estate sectors. The non-usability of transport infrastructure due to flooding does not represent physical damage, but leads to higher costs (economic losses) due to the use of other means of transport and routes, which were captured in the model as well. Productivity losses were modeled by higher imports in the respective sectors, so that the lower production level is at least partially compensated (Lehr et al. 2016, 2020).

2.1.2 MODELLING APPROACH CHOSEN FOR KAZAKHSTAN

Based on the international experiences, it is obvious that various approaches for modelling the economic impacts of climate change and adaptation exist. So far, there is no one fits all solution. Each approach has its advantages and limitations (Keen 2020, Keppo et al. 2021). For this reason, several models that complement each other are sometimes used at the same time (e. g. Feyen et al. 2020, Lehr et al. 2018). Additionally, an assessment of the economic and environmental modeling capacity in Kazakhstan (TALAP 2019) showed that there is a gap between macroeconomic and climate modeling communities. So far, there was no understanding among the modelling actors in Kazakhstan of how to integrate climate change impacts into economic modeling.

During on-site and remote meetings, a common understanding was created together with various Kazakh partners and experts (amongst others ERI, Zhasyl Damu, TALAP, Committee of Statistics) on the main goal of the CRED project, the modeling approach as well as key requirements and necessary data.

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

For Kazakhstan, the macro-econometric (dynamic) IO modeling approach is a suitable solution. On the one hand, international experiences as well as other climate change adaptation projects of GWS show that this approach fulfills the necessary requirements and can be successfully implemented (Aaheim et al. 2015, Lehr et al. 2016, 2018, 2020). On the other hand, IO models already exist at the implementing partner institution ERI, so that this experience can be built upon. As Kazakhstan is in the process of transition to a “green economy”, the dynamic IO model was extended to an E3 (economy, energy, emission) model, so that it is also possible to identify synergies and trade-offs of adaptation and mitigation strategies as well as Nationally Determined Contribution goals.

In combination with scenario analysis, the modeling approach is suitable to study the economy-wide impacts of climate change and adaptation. In contrast to static models – which compare a situation before and after a change (comparative static analysis) – the proposed dynamic IO model is time-dependent and considers the economic development and transition processes. Furthermore, the requirements for data and the model approach are kept moderate for a sustainable solution which is also important for the model ownership. However, the model approach is flexible, can be expanded in many ways and allows for integrating expert input.

2.2 THE KAZAKH E3.KZ MODEL

The model e3.kz (economy, energy and, emission model for Kazakhstan) is a projection and simulation model which was developed jointly with Kazakh partners to evaluate the economy-wide impacts of climate change and adaptation measures. E3.kz models the Kazakh economy, the energy system and the CO_2 emissions in a holistic and consistent model framework which has the advantage to calculate impacts simultaneously for every year until the end of the simulation period, in this case 2050 (Figure 3). Each module is based on a comprehensive and up-to-date dataset given as time series which allows for deriving model relationships empirically.

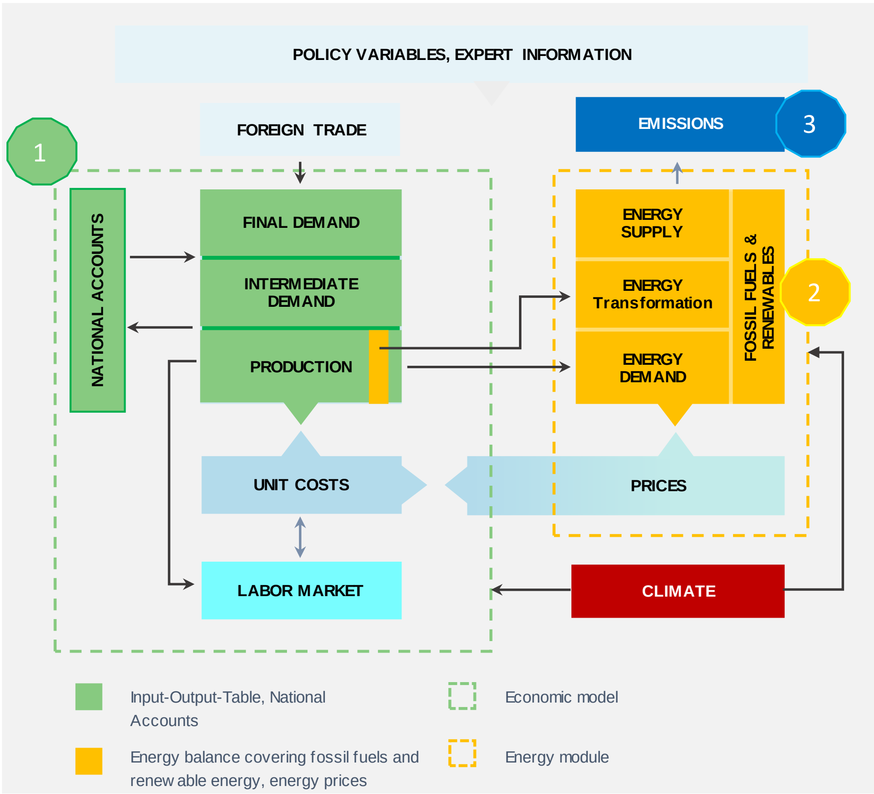


Figure 3: E3.kz model overview

Source: Own illustration, based on GWS, 2022.

Economy module

The core of the **economic** modelling part of the e3.kz model is a dynamic (or macro-econometric) IO model which is based on the INFORUM approach (Almon 1991, 2014). These models exist in different forms and degrees of complexity (e. g. Eurostat 2008, pp. 527, Großmann, Hohmann 2016, Lehr et al. 2016, Lewney et al. 2019, Stocker et al. 2011). A common feature is that they are based on IO tables and national accounts depicting the key and supporting industries, their interlinkages as well as the domestic and foreign drivers for economic growth. The economic cycle is mapped in its entirety - from production to income generation, income redistribution and use of income.

Following the top-down, demand-side driven approach, each of the GDP components is determined first and then allocated to the single economic sectors using constant shares for each final demand category. The relationship between demand and supply is represented by the Leontief production function.

Supply and price elements are considered as well to account for supply constraints possibly caused by EWEs. From the IO table, the cost structure for intermediate goods (e. g. energy) can be identified from the supply chains. The cost structure of each sector can be derived from primary inputs (including compensation of employees, net taxes on production). Production prices are determined on the basis of these costs. Volume and price reactions in this macro-econometric IO model are determined empirically, take the passing on of costs into account as observed in the past and thus include the competitive situation on the different product markets and the labor market. Using econometric methods allows for imperfect markets and bounded rationality (Meyer, Ahlert 2019). Expectations of economic actors are myopic and follow routines developed in the past (Lutz et al. 2014). Thus, e3.kz is not a CGE model where prices balance supply and demand and households and companies optimize their behavior.

Employment and income trends are part of the model to monitor their impacts on jobs and wealth. Labor demand follows the economy activity in the sectors considering labor productivity. The macroeconomic wage rate is derived from the Phillips curve approach taking the overall labor productivity and labor scarcity indicator – measured as the ratio of population at working age and total labor demand – into account.

The modelling approach which covers not only quantity effects but also income and price effects provides multipliers that determine the dynamics of the system:

- Leontief multiplier: Shows the direct and indirect effects of demand changes (e. g. consumption, investments) on production;
- Employment and income multiplier: Increased production leads to more jobs and thus higher incomes resulting in higher demand (induced effect);
- Investment accelerator: Indicates the necessary investments to maintain the capital stock needed for production based on the demand for goods.

Energy Module

The **energy** module describes the relations within the energy sector in greater detail than in the economic model. It depicts the energy demand, supply and transformation by different fossil fuels and renewables as stated in the energy balance. The energy demand is mapped in detail for the largest consumers such as industry, private households and transport. The key drivers of sector-specific energy demand are the economic development of the sectors, the respective energy intensity of the production processes and energy price developments. The energy demand of private households is estimated with population. The energy supply is determined by the energy demand of all sectors. Energy is either produced domestically or imported. Primary energy inputs are captured for power generation as well as heat generation.

Emission module

The **emission** module comprises the energy-related CO_2 emissions[8]. Reductions in the use of fossil fuels caused by deployment of renewable energy or increased energy efficiency can be seen in CO_2 savings.

The **e3.kz model** is fully developed in **Microsoft Excel** using the **model building framework DIOM-X**. The framework is built upon the Excel built-in programming language **Visual Basic for Applications** (VBA) and was developed for creating Dynamic Input-Output Models in Excel (Großmann, Hohmann 2019). Model users conduct scenario analysis by adjusting the values of model variables in one Excel worksheet. Thus, there is no need to learn programming.

The **full model database, model equations and results are stored in a single Excel workbook** to ensure that all aspects of the model can be examined, adjusted and extended.

2.3 SCENARIO ANALYSIS

2.3.1 SCENARIOS AND "WHAT-IF" ANALYSIS

Scenario analysis is a method for dealing with the uncertainties of the future. Different assumptions of how the future might be evolve can be tested (e. g. best and worst case). However, scenarios should not be considered as precise forecasts. Instead, they show possible development paths that are reactions to the assumptions made.

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

Scenarios are consistent sets of quantified assumptions describing the future development. "If" describes assumptions in the scenario settings which are injected into the model. "What" comprises the economy-wide impacts and consequences resulting from the assumptions made. Thus, a scenario helps to better understand what could happen and who / what is affected and how?

Various policy options and measures can be analyzed by conducting scenario analysis depending on the main purpose of the model application and key research question. The e3.kz model was developed to answer questions such as: What are the economy-wide impacts of sector-specific climate change impacts and adaptation options? Examples are presented in sections 5.1 and 6.2. The comparison of model results from different scenarios to a reference scenario not including a certain policy or measure helps to identify the option which is appropriate for a particular issue. Policy-makers need to identify

[8] Other emissions that are not energy-related are currently not part of the e3.kz model. However, an expansion to other GHG emissions is possible as long as the underlying processes (e. g. methane emissions in agriculture) are mapped in the model.

and prioritize those criteria (e. g. GDP or employment effects) that are most important for them to finally select the better or best policy option(s).

The **reference scenario** extrapolates the economic relationships observed in the past into the future. It is **not a precise forecast** of the future. Instead, it serves as a benchmark for other scenario analyses. The reference scenario **does not include explicit consideration of climate change and adaptation**.

Climate change scenarios **explicitly contain** the **economic damages and losses caused by climate change** (e. g. droughts, or heat waves). Model results show the economy-wide impacts by **comparing the reference and climate change scenario**.

Adaptation scenarios are built upon the **climate change** scenarios and consider the **costs and benefits of** suitable **adaptation measures** to reduce the risks of climate change. Model results show the economy-wide impacts of adaptation by **comparing the climate change scenario and adaptation scenario**.

All alternative scenarios are calculated for future years, so that differences between the reference scenario only occur afterwards. The results of the alternative scenarios are presented as differences from the reference scenario (time-related relative and absolute as well as intertemporal, Figure 4). In addition, the development of selected variables is shown according to the focus of the analysis. The differences between the scenarios can then be attributed to the different assumptions in the scenarios and the triggered reactions in the model.

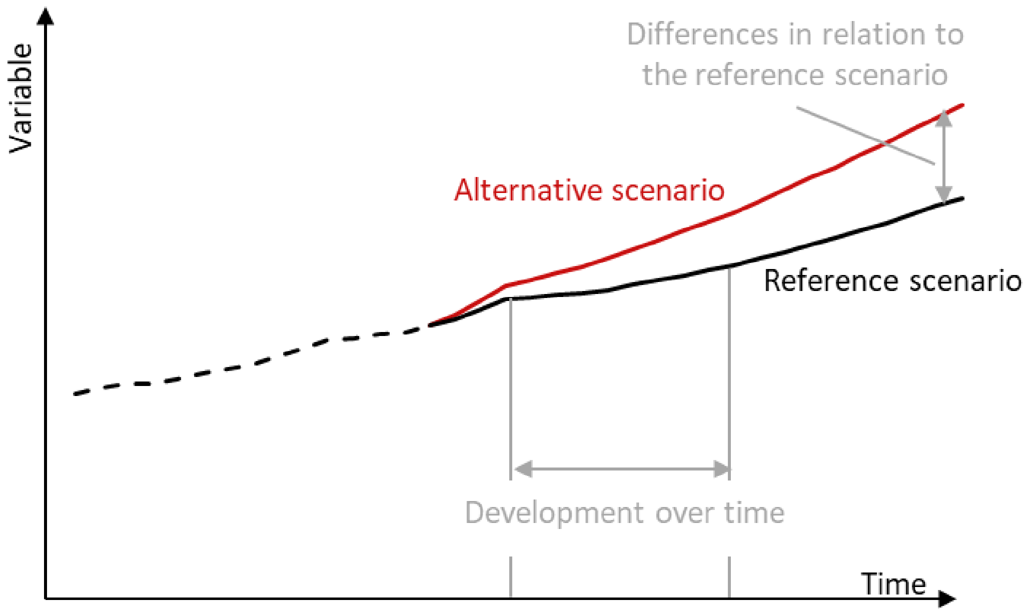


Figure 4: Comparative scenario analysis

Source: GWS.

2.3.2 HOW TO CONDUCT SCENARIO ANALYSIS – THE CASE OF CLIMATE CHANGE AND ADAPTATION SCENARIOS

The e3.kz model is applied to simulate the economic effects of different climate change scenarios and adaptation measures in Kazakhstan. The modeling approach has the advantage to provide an integrated analysis by considering the 3 E's. The model describes the interrelations of the economy and the main connections to the environment, i. e. the use of energy resources and CO_2 emissions into the environment. Thus, possible synergies or trade-offs of adaptation scenarios with other strategies such as mitigation can be explored.

The analysis of climate change adaptation starts with the development of climate change scenarios including the frequency (e. g. every ten years) of e. g. a heat wave and its economic damages (e. g. reduced labor productivity). These scenarios are based on the reference scenario which reflects the continuation of the economy and also expectations about the future economic development as given in the BAU scenario by the „Low emission development strategies" (LEDS)-project without considering climate change. The effects of climate change are not very apparent in current and historical macroeconomic data. Either climate change did not cause any observable damage to the economy, was not relevant for the economic performance or could not even be detected as an impact from climate change because repairing climate change damages may result in positive GDP effects (so called defensive spending). In addition, the damage may have been avoided or reduced by adaptation measures.

Comparing the climate change scenarios with the reference shows the economy-wide impacts of the EWEs.

Afterwards, adaptation scenarios are created including measures that are minimizing or even preventing climate change impacts. Comparing climate change and corresponding adaptation scenarios reveal the economy-wide and sector-specific impacts (in terms of e. g. GDP growth, employment) of preventive measures (Figure 5).

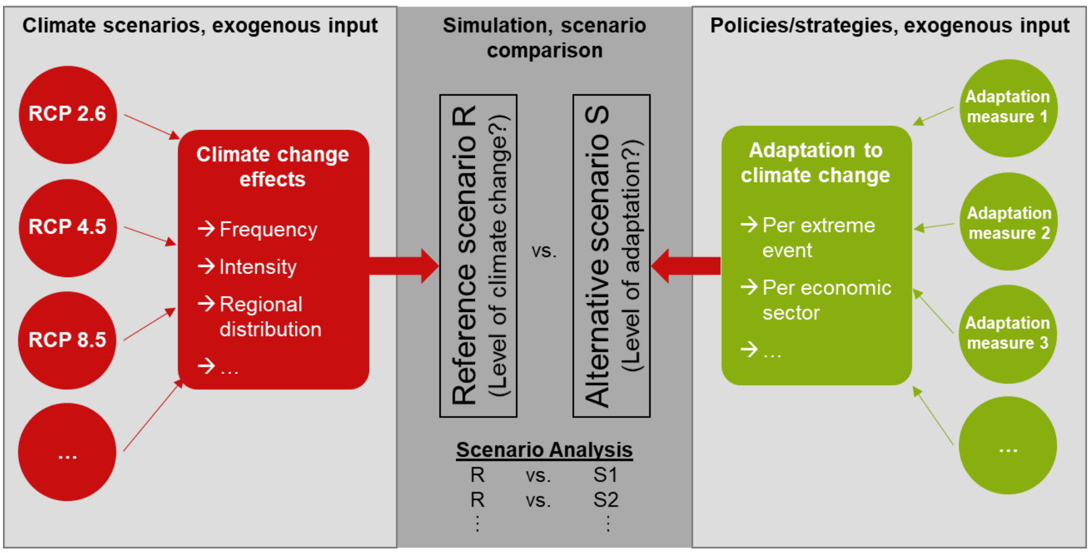


Figure 5: Comparison of climate change and adaptation scenarios

Source: Own illustration

The basic steps of building a (climate change and adaptation) scenario are shown at a glance in Figure 6.

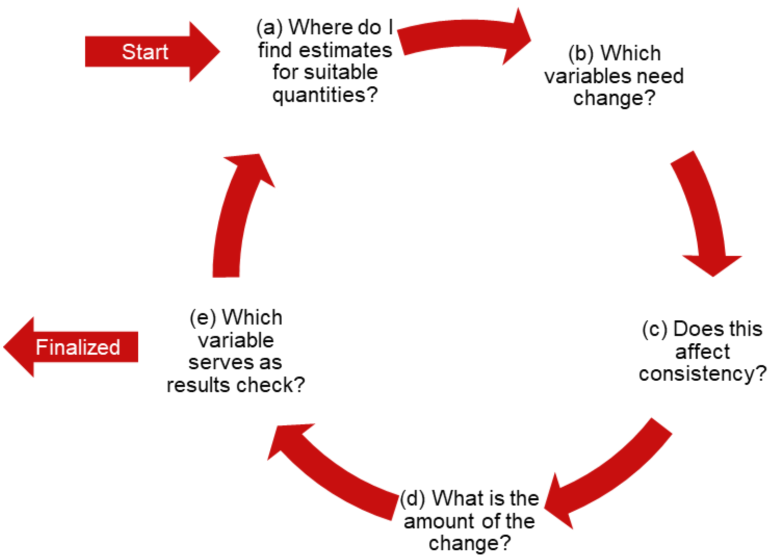


Figure 6: Steps of building a scenario

Source: Own illustration

First of all, sources (literature, experts) for the aforementioned information need to be identified (a). Then, appropriate model variable(s) need(s) to be selected which are relevant to implement the climate change effects (b). These effects that change under climate change often cannot be found one-to-one in the data set of model variables of an economic model. Thus, they must be translated into appropriate model variables by taking care of model consistency (c). In a next step (d), the scope of direct change(s) is given for the selected variable(s). Each assumption in a scenario needs to be quantified, carefully checked and evaluated with expert knowledge (e). The model cannot check the plausibility of an assumption. Implausible assumptions yield implausible results and might even stop model execution prematurely if the model fails to solve. In that case, the scenario specification must be revised and the scenario buildings steps must be repeated.

Chapter 5 and 6 describe the application of the scenario technique in combination with the model e3.kz to evaluate the economic effects of climate change and adaptation on the Kazakh economy.

3 CLIMATE CHANGE AND ITS EFFECTS IN KAZAKH-STAN

3.1 COUNTRY INFORMATION

Kazakhstan is a land-locked Central Asian country with a vast territory of 2.7 million square kilometers surrounded by the Caspian Sea in the West, the Altay Mountains in the East and the Tian-Shan mountains in the South (Ministry of National Economy 2020a). It borders Russia to the North, China in the East and Kyrgyzstan, Uzbekistan and Turkmenistan in the South.

Total population is steadily increasing since 2003 and reached 18.5 million in 2019 of which 58% is living in urban areas (Figure 7). The largest city is Almaty with almost two million inhabitants, followed by the capital city Nur-Sultan (formerly known as Astana) and Shymkent city each of them with around one million inhabitants (Ministry of National Economy 2020a, p. 8).

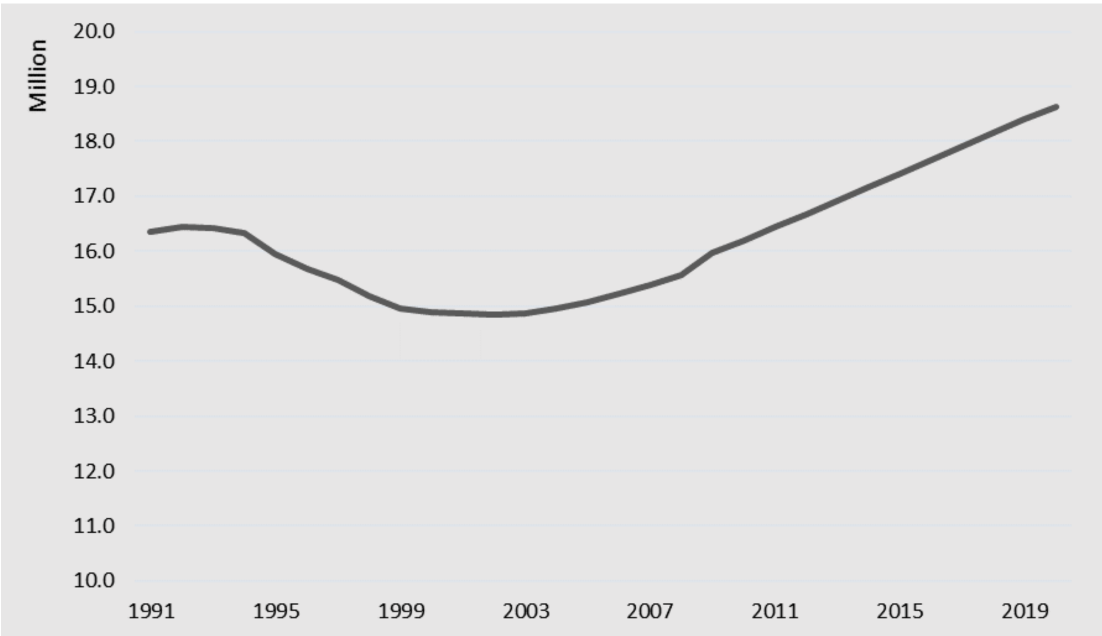


Figure 7: Population 1990-2020

Source: Own illustration based on Ministry of National Economy, 2020a.

The declaration of independence in 1991 has been the starting point for societal, political and economic transformations in Kazakhstan. In the first years after independence, in the midst of a very steep economic decline, initial steps toward democratic liberalization were made. In the mid-1990s economic recovery began and has progressed rapidly with the discovery of a giant oil field in 2000.

Kazakhstan is one of the successful post-Soviet republic countries to make the transition from a centralized economy to a market-based economy. (Bertelsmann Stiftung, 2020). According to the Heritage Foundation Index of Economic Freedom, Kazakhstan is classified as “moderately free” (Batsaikhan and Dabrowski 2017). Kazakhstan is a member of the Central Asia Regional Economic Cooperation (CAREC) program, working since 2001 on improvements in regional economic cooperation, particularly in the areas of transport, energy, trade, and economic corridors development (CAREC Program 2021).

The existing cooperation with Russia and Belarus was intensified through its further development into the Eurasian Economic Union (EAEU) in 2015 (FES 2015).

The Kazakh economy benefits from the country's natural resources. In particular in the west and south-west of Kazakhstan important oil and gas fields (Mangystau, Atyrau, Aktobe) exist. An important hard coal mining area is located in Karaganda – in the Middle-East of the country. Furthermore, Kazakhstan has reserves of other raw materials such as uranium, copper, iron ore and rare earths.

Due to the dependence on oil and gas, a diversification of Kazakhstan's economy is being driven forward (World Bank 2018a). The intensification of value creation through further processing of raw materials is an attempt to make the country less dependent on world market prices. Important industrial centers which produce metals and chemical and plastic products are located in Almaty, Karaganda, Shymkent, Pavlodar and Aktobe. Furthermore, in December 2020, Kazakhstan committed itself to become climate neutral by 2060 which is way more ambitious than the "Green Economy" concept (Green Economy Concept, 2013)

Since 2000, Kazakhstan experienced strong economic growth, interrupted by the global financial and economic crisis in 2008-2009 and a slowdown starting in 2014 (Figure 8). Between 2000 and 2019 Kazakhstan's economy grew at an average rate of 6.4%. In 2019, the GDP amounted to KZT 48 trillion, which is KZT 2.6 million per capita (COMSTAT 2021a).

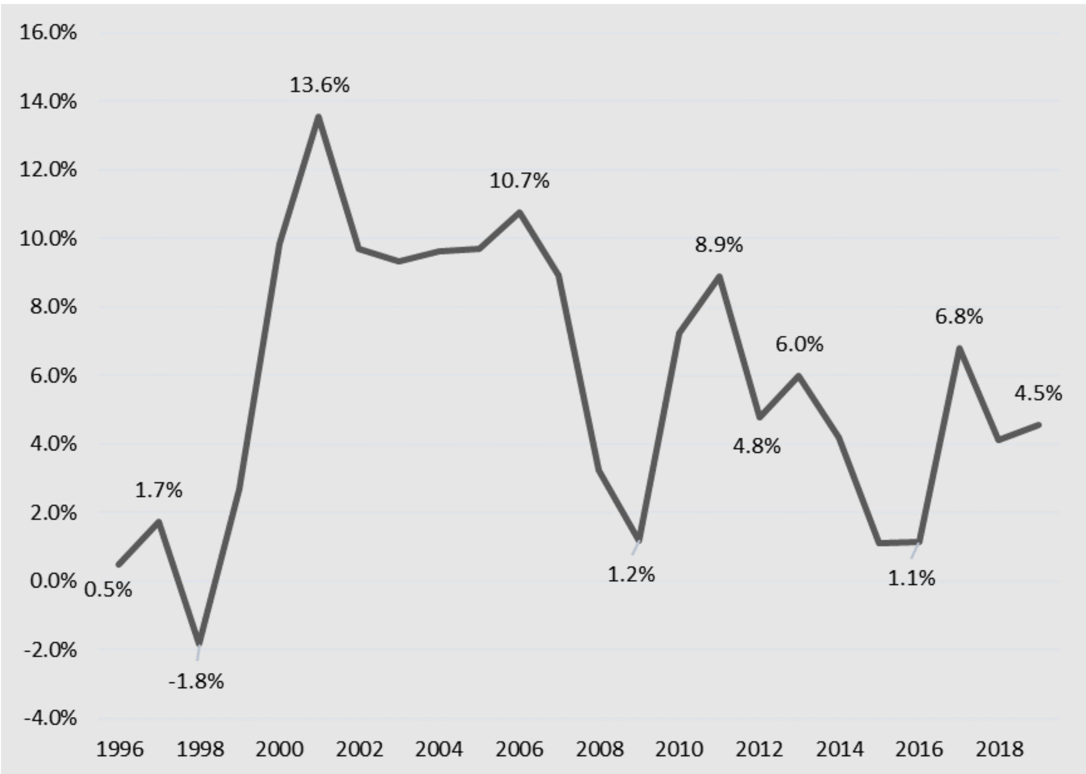


Figure 8: Real GDP growth rate (% p.a.) 1996-2019

Source: Own illustration based on COMSTAT 2021a

The economic growth positively impacted social indicators and progress has been made in terms of poverty and unemployment reduction. Kazakhstan has developed to an upper-middle-income country in 2006 (Asian Development Bank 2018). The poverty rate declined from 55% in 2006 to 20% in 2015 (World Bank 2018a). Additionally, economic growth was also accompanied by job creation. The unemployment rate declined from 10.4% in 2001 to 4.9% in 2018 (Comstat 2021c). In 2019, Kazakhstan ranked 51st on the Human Development Index – a composite statistic of life expectancy, education and income indices – with a value of 0,825 (UNDP 2020b).

More than 50% of GDP is attributed to consumption of private households and non-profit institution serving households (NPISH, Figure 9). Gross capital formation has a GDP share of 28%. Exports of goods and services amount to 37% whereas crude oil exports contribute to around 50%. Total imports including imported intermediate products as well as final goods amount to 28%, thus foreign trade balance accounts for 9%. Kazakhstan is dependent on imports, especially from manufactured products. According to the IO table (2018)[9], for example, 85% of total demand in electrical equipment are imported and 91% of machinery.

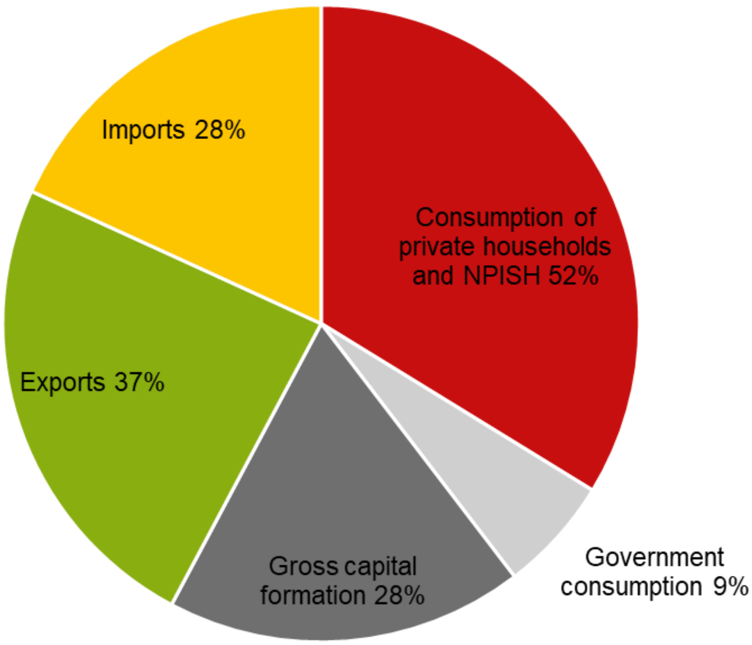


Figure 9: Structure of GDP by expenditures, 2019

Source: Own illustration based on COMSTAT 2021b

Key economic sectors in Kazakhstan are trade (17%), mining and quarrying (14.4%) and manufacturing (11.5%) as shown in Figure 10. Other services account for around 31% of which transportation / storage and real estate account for 8% each. Agriculture contributes with 4.5% to GDP. According to the strategy document "Kazakhstan 2050", agriculture is one of the key sectors to develop and diversify the national economy (OECD 2020, ADB 2018).

[9] https://old.stat.gov.kz/getImg?id=ESTAT289858

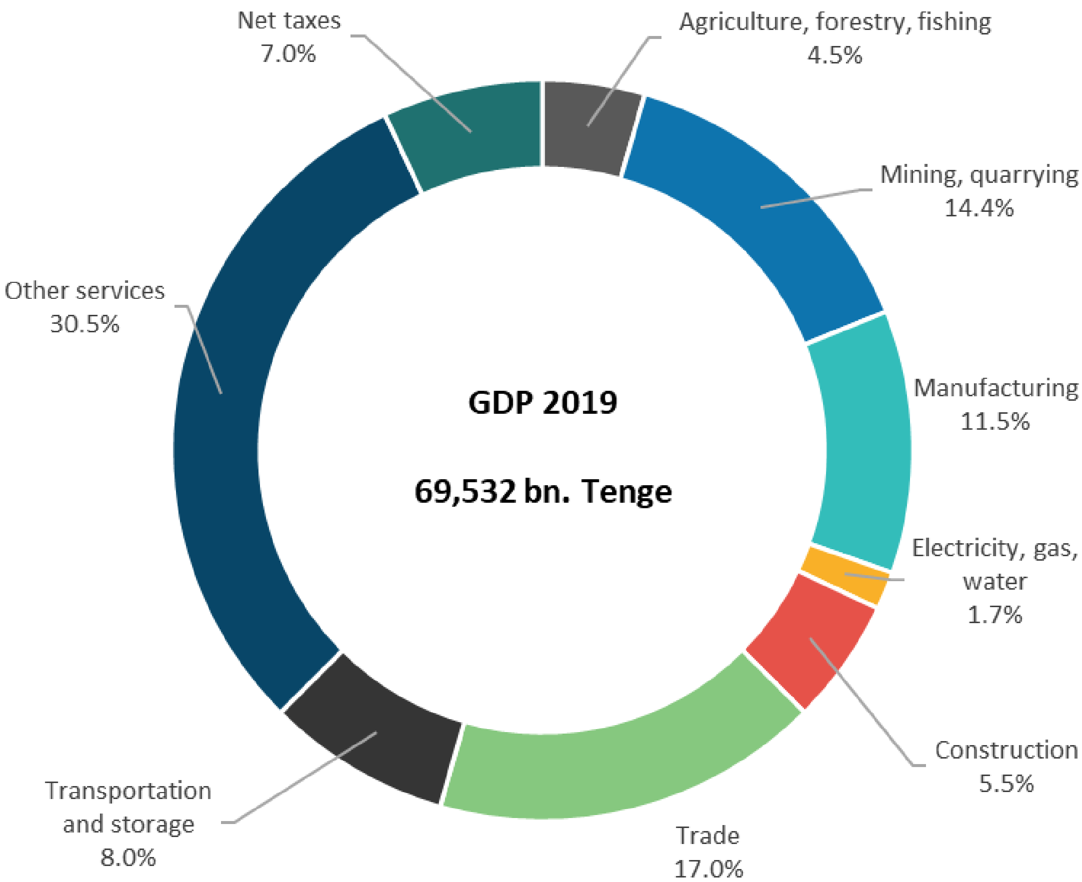


Figure 10: Structure of GDP by economic sectors, 2019

Source: Own illustration based on COMSTAT 2020

With its location in the center of the Eurasian continent, transport and logistic services as well as trade infrastructure are important for the country. Apart from the gas and oil pipeline network, road infrastructure is the most dominant accounting for 88%. Rail network accounts for 9% and waterways at 3% are less relevant. Rail transport dominates freight transit.

Kazakhstan is part of the Belt and Road Initiative, also known as the New Silk Road, proposed by China to improve cooperation on a transcontinental scale. A World Bank analysis shows that the Belt Road Initiative and its transport corridors has the potential to substantially improve trade, foreign investment, and living conditions for citizens in the initiative's participating countries (World Bank 2019).

Figure 11 shows the development of employment by economic activity from 2001 to 2019. During this period, the total number of employed persons increased from 6.7 million to 8.8 million. In 2001, the most important economic sector in terms of employed persons was agriculture with a share of 35%, while in 2019 the trade sector with 16% was predominant followed by agriculture with 13%. Also, a relevant number of persons is employed in the service sectors (43%, of which education accounts for 13%), trade (16%) as well as transportation / storage, manufacturing and construction (each sector accounts for 7% in 2019).

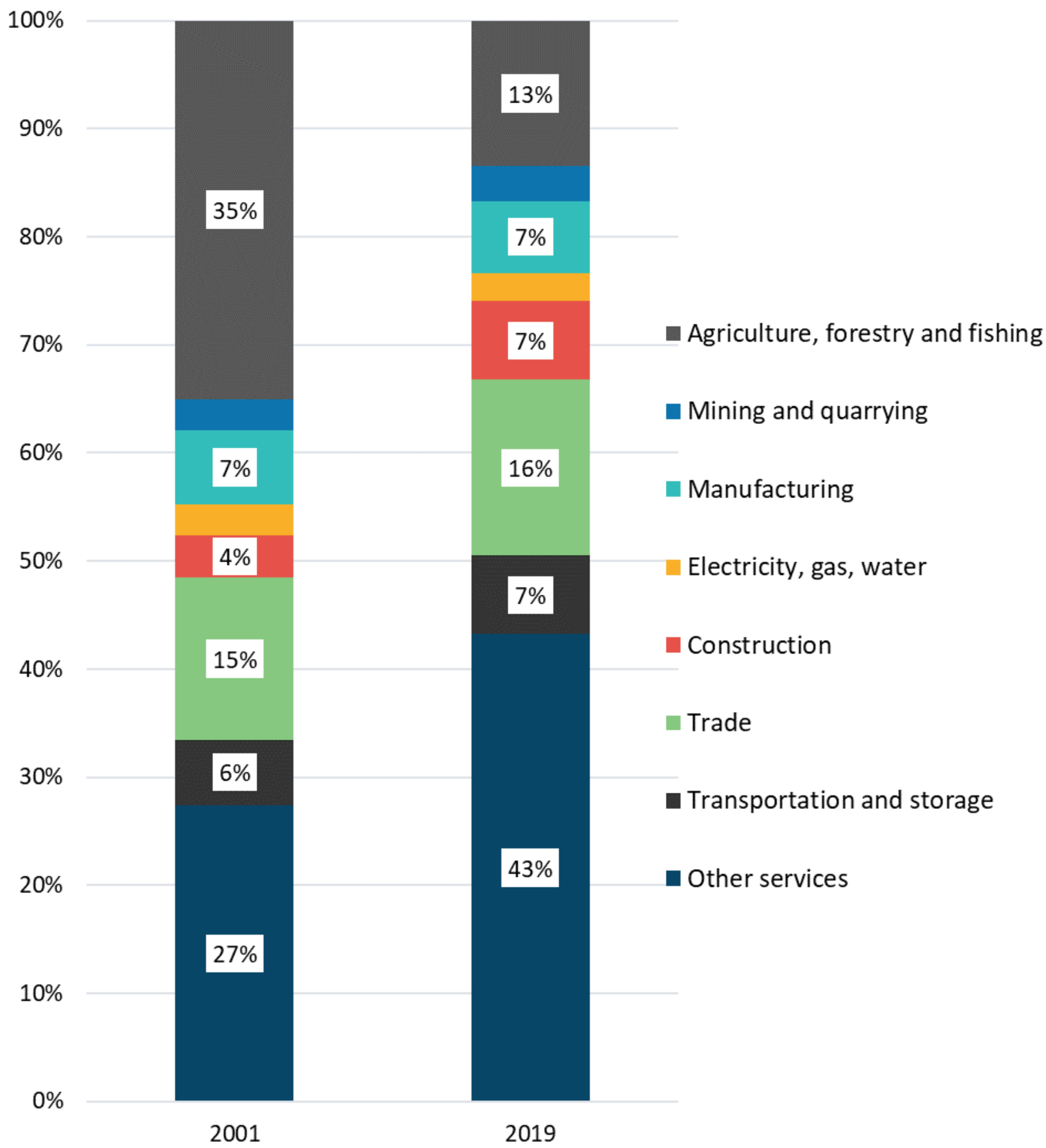


Figure 11: Employment by economic activity, 2001 and 2019

Source: Own illustration based on COMSTAT 2021d

The energy sector (incl. mining and energy supply) employs about 5% although the GDP share is around 16% (COMSTAT 2020). In contrast, the agricultural sector accounts for only around 5% of GDP but is a major employer. In 2019, around 1.2 million people (or 13% of total employment), were employed in this sector. The largest segment with a share of 50% is wheat production for which more than 70% of the cropland is used for. Wheat production mainly takes place in northern Kazakhstan. The large share of the cropland is cultivated by either agro-holdings, large farms or small and medium ones. Less than one percent of the cropland is cultivated by around 1,000 family-owned, subsistence farms. Livestock and vegetable farming in the rest of the country is dominated by small farms. Farm livestock includes cattle, sheep and goat, horses, camels and pigs, the leading segments are sheep and cattle breeding. Wheat production not only contributes to food security in Kazakhstan, it also makes up the majority of agricultural exports (UNDP 2019).

3.2 CLIMATIC CONDITIONS AND THREATS

3.2.1 OVERVIEW AND PAST TRENDS

Kazakhstan is characterized by a continental climate with hot summers, harsh winters and limited precipitation. Given the size and topography of the county, temperatures and precipitation vary greatly from region to region. In the West, the Caspian Sea forms the natural border. Further East is the Caspian depression, the lowlands of Turan and the Kazakh lowlands, which gradually turn into the Kazakh hill country. High mountains are located in the East and Southeast of the country reaching altitudes of 7,000 meters. However, the territory is predominated by flatland or rolling terrain (World Bank 2021).

The majority of the country is located at arid natural zones such as deserts, semi-deserts and dry steppe. Humid and forest-steppe is located only in the North (Ministry of Energy of the Republic of Kazakhstan 2017).

Climate regimes ranging from arid deserts in the central and western regions to mountains in the South, East and South-east with highest precipitation in the country. In the North, the winter is long and cold with average temperatures of -20°C sometimes peaking at -52 C and in the summer the average temperature is 18°C. In the South, summer is very warm with average temperatures of 20°C and mild -5°C in winter. Central and Western Kazakhstan show long hot summers and cold winters (USAID 2017, World Bank 2021).

The average annual air temperature increased gradually in the last decades by 0.28°C every ten years with the most rapid warming in winter (World Bank, 2021) which leads to rapid glacial melt of the Tien Shan glacier by 14-30% since 1950 (USAID 2017). Furthermore, an increase in the number of hot days with air temperatures above 25°C as well as an increase in the duration of heat waves has been observed especially in the Western and Southern regions. Droughts occur in two out of five years. Every five to seven years the droughts are severe (World Bank 2015, FAO 2017). The latest drought was in 2021 in Southern and Westerns regions of Kazakhstan with record temperatures up to 46.5°C leading to rapid runoff of rivers and reservoirs (IFRC 2021).The risk of forest fires and the spread of diseases is amplified by heat waves and droughts.

Past countrywide precipitation is low throughout the year and does not show a definite trend in the variability on an annual average. The combination of increased temperatures, low precipitation and intensive water use for agriculture is causing the Aral Sea to continue to dry out. A tendency to increased precipitation except during the autumn season is observed (Ministry of Energy of the Republic of Kazakhstan 2017).

However, the highly seasonal pattern of precipitation and high mountains make the country vulnerable to floods, mudflows and landslides. Floods occur mainly in the mountainous regions of Southern and Eastern Kazakhstan, and sometimes also in lowland rivers in Western, Northern and Central Kazakhstan (MNE et al. 2017, USAID 2018, floodlist[10]). Flooding occurs, for example, in the form of flash floods and river flooding which is caused in particular by intense and persistent rainfall, as well as by rapid melting of snow and glaciers (e. g. Tien Shen) and breaching of glacial lakes (UNESCAP n. d.). Floods caused by wind are common in the Ural river delta and the coastal zone of the Caspian Sea with wind surges of sea water (Plekhanov et al. 2019, UNESCAP n. d.).

[10] http://floodlist.com/tag/kazakhstan

Flooding is also partly caused by dams breaking due to the masses of water and poor condition (e. g. 2010 Kyzyl-Agash Dam failure, 2011 Jumabek dam failure[11] und 2014 dam failure in Kokpekty (UNESCAP n. d., p. 17, OECD 2019a). As Kazakhstan has many transboundary rivers (OECD 2019a, p. 29), dam failures in neighboring countries also have immense consequences in Kazakhstan, e. g. the Sardoba dam collapse in 2020 in Uzbekistan[12].

In 2015, there were about twice as many hydrometeorological emergencies in particular heavy precipitation, floods and mudslides as usual (MNE et al. 2017). Mudflows are a typical consequence from heavy rain (75%) and by 22% from moraine lake outbreaches (Dochshanova 2016). The most recent mudflow in Almaty occurred in 2015. In 2019, the dam prevented the city from mudflow damages[13].

Other EWEs associated with climate change to which Kazakhstan is exposed are droughts, heatwaves and storms. As shown in Table 2, heavy rain events, storms, and blizzards are the most frequent EWEs for the period 1990 to 2015.

Table 2: Average annual number of EWEs in Kazakhstan

EWE	Number of EWEs	
	1990-2002	2003-2015
Heavy rain	20,1	49,3
Strong wind	38	45,8
Heavy snow	9,1	24,9
Strong blizzard	42,4	23,5
Hail	2,5	3,2
Strong fog	18,6	6,8
Strong dust storm	2,7	0,8

Source: Kozhakhmetov and Nikiforova 2016

In the period 1967 to 2015, most EWEs occurred in South, Southeast and Northern Kazakhstan (Figure 12). While the West and South of Kazakhstan are more exposed to droughts, the lowland rivers in Western, Northern and Central Kazakhstan as well as the mountainous regions in the South-East and the South experienced more floods (UNESCAP 2021b). Mudflows threaten around 13% of the country's area, in particular the Southeast where over 26% of Kazakh population is living including the city of Almaty. During the last 150 years, around 800 mudflows have been registered (UNDP 2011).

11 https://en.tengrinews.kz/disasters/thousands-evacuated-from-flood-areas-in-kazakstan-259812/ (last accessed, 13.3.2021)

12https://www.thethirdpole.net/en/regional-cooperation/uzbekistan-dam-collapse/
https://reliefweb.int/sites/reliefweb.int/files/resources/Kazakhstan%20-%20Floods%20-%20Emergency%20Plan%20of%20Action%20%28EPoA%29%20DREF%20Operation%20n%C2%B0%20MDRKZ009.pdf

13 https://astanatimes.com/2019/08/almaty-emergency-department-manages-mudflow-alarm-in-nauryzbay-district/ (last accessed at 2021, September, 21st)

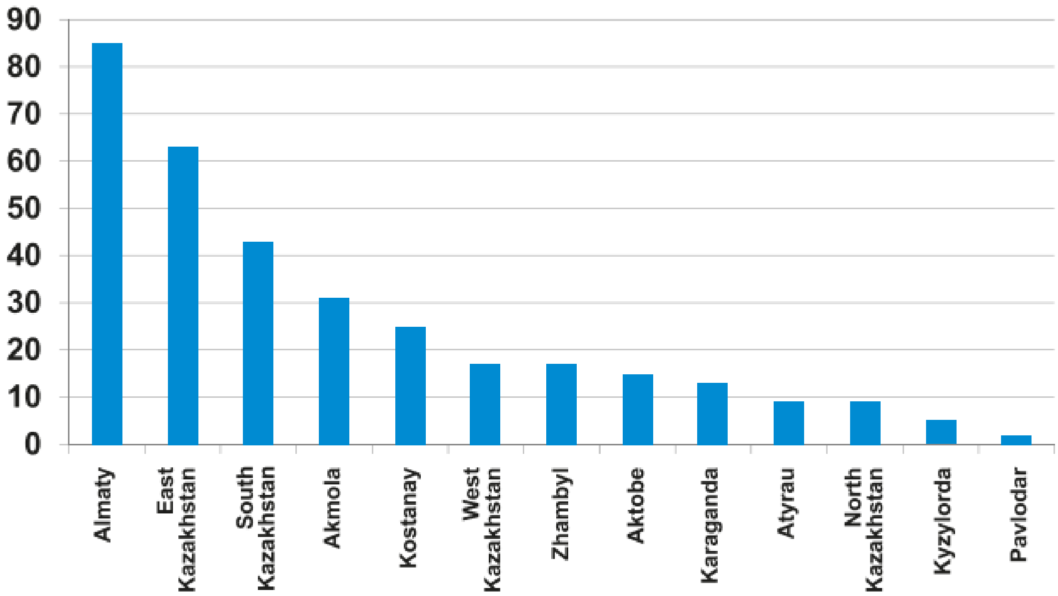


Figure 12: Number of EWEs in Kazakhstan by regions, 1967-2015

Source: Kozhakhmetov and Nikiforova 2016

3.2.2 CLIMATE PROJECTIONS

Climate projections expect increasing average air temperatures in the range of 2.1 to 2.6°C by 2050 (2.7 to 4.7 °C by 2085), an expansion of the drought zones in the North and Center as well as longer heatwaves. Furthermore, an increase in average annual precipitation until 2050 is anticipated by 0.8% to 15% depending on the region and season, despite a decrease in the summer period. Due to climate trends, an increase in EWEs is expected to exacerbate such as heat waves, landslides and mudflows (Ministry of Energy of the Republic of Kazakhstan 2017, p. 151, GERICS 2018, USAID 2017). The warmer and drier climate promotes the spread of deserts and semi-deserts and increases the risk of droughts and wildfires. At the same time, cold days in winter decrease (MNE et al 2016, p. 4). Glaciers will continue to melt and further increase the risk of river floods, mudflows and landslides. Sea level of the Caspian Sea may rise, but projections are rather uncertain (UNDP et al. 2002, pp.118, GERICS 2018, p. 8).

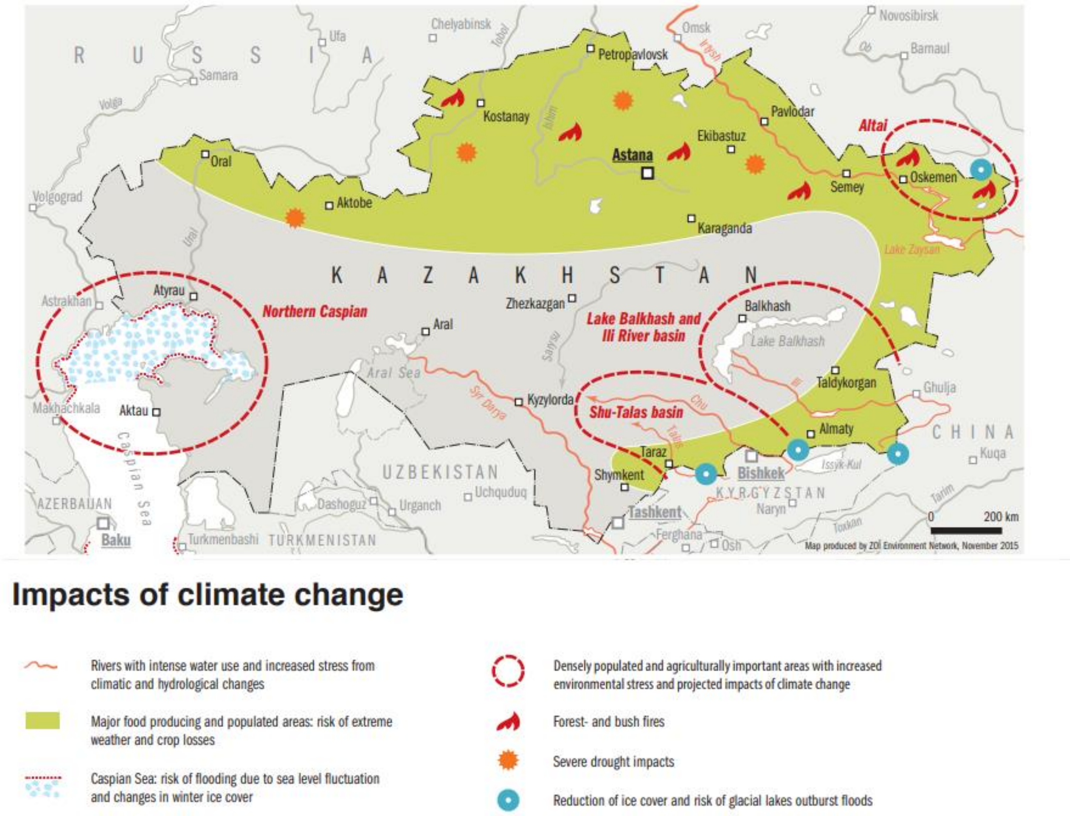


Figure 13: Impacts of climate change

Source: Zoi 2016

The University of the Balearic Islands (UIB) provides time series data for significant areas, cities or infrastructures, illustrating the evolution of climate hazard indicators in Kazakhstan for the RCP[14] 8.5 scenario and the RCP 2.6 scenario. The evolution is indicated by either the number of days or events per year. For each period, the evolution is estimated as the difference between the average over the period (2011-2040, 2041-2070) and the historical average (1976-2005). The following hazards are covered:

- Droughts,
- Heat waves,
- Extreme precipitation,
- Extreme temperature,
- Wildfires and
- Extreme wind.

A detailed description of the definition and estimation of climate hazard indicators is given in the report by Navarro and Jordà 2021.

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

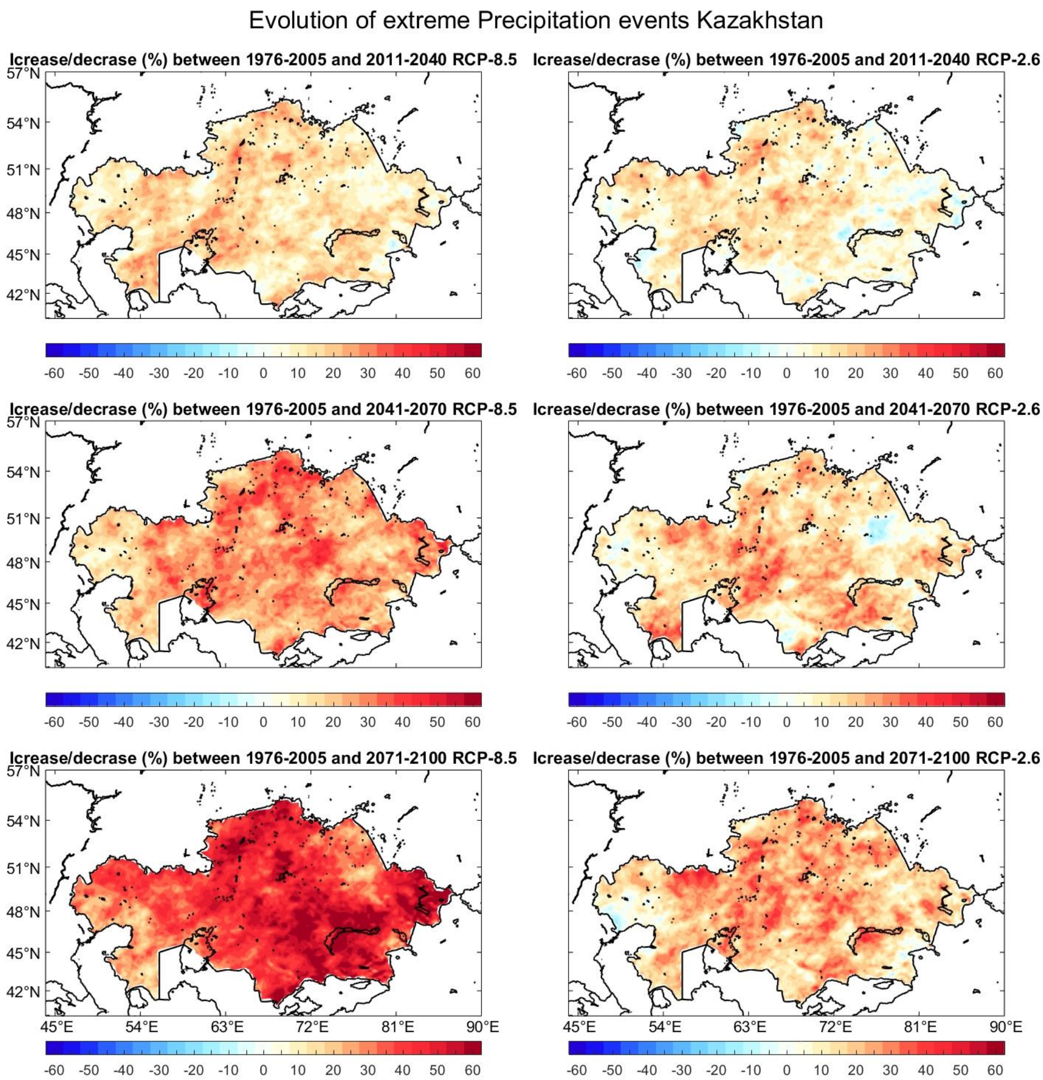


Figure 14: Evolution of extreme precipitation in Kazakhstan for RCP 2.6 and 8.5 until 2100

Source: Navarro and Jordà 2021

Figure 14 exemplarily shows the percentage change of extreme precipitation events in future periods compared to the historical period (1976-2005). Maps in the left (right) column show the results for the RCP 8.5 (2.6) for different time periods. The EWE are increasing over time, for example in North Kazakhstan and South-East Kazakhstan. In particular East and South-East Kazakhstan are affected by extreme precipitation already in the historical period (Figure 15).

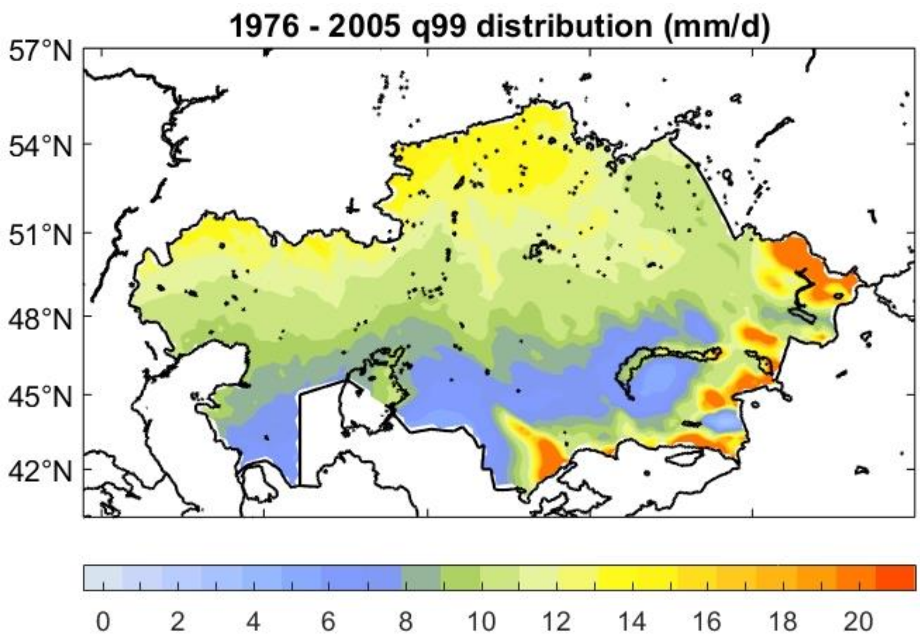


Figure 15: Extreme precipitation (99th percentile of accumulated precipitation) for the historical period

Source: Navarro and Jordà 2021

For each of the six EWEs, such maps were produced by UIB. The resolution (25 x 25 km grids) of the climate model is much higher than what the e3.kz model is able to use. Thus, for selected nine vulnerable areas and locations (Figure 16), yearly time series are provided for all six climate indicators reflecting the evolution of the frequency. The selection was made on the basis of the existing infrastructure, important economic sectors or metropolitan areas which is (or is expected to be) impacted from climate change. For example, drought is a major risk for the agricultural sector, in particular the rain-fed crop production in North-Kazakhstan. Also local hydro power plants (e. g. Oskemen) might be affected from droughts. Floods occur mostly in South- and East-Kazakhstan threatening large cities like Almaty, destroying infrastructure and impairing logistics.

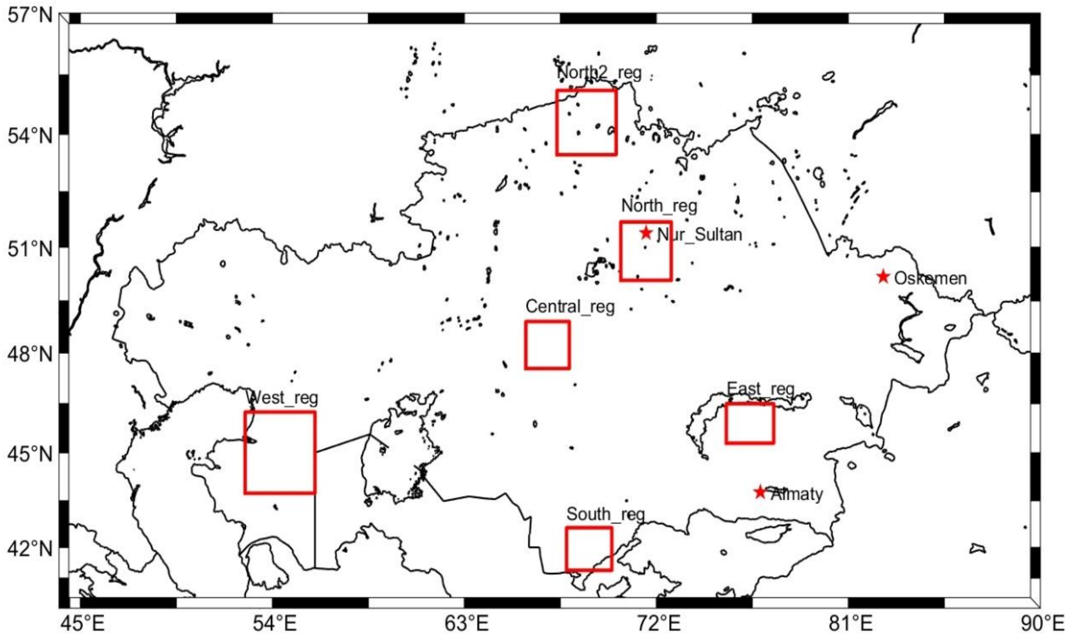


Figure 16: Selected locations for climate indicators

Source: Navarro and Jordà 2021

Table 3 contains the average annual growth rates of the number of events per year for selected locations in Kazakhstan for the scenario RCP 8.5. The evolution of the frequency of country specific climate hazards serves as link between the benchmark damages (see section 3.2.3) and climatic developments. Adjustments will be made to the benchmarks in scenarios by assuming that, for example, an average increase of extreme precipitation by 0.4% will also increase the benchmark damages likewise. The combination of the future evolution of climate change events and observed climate change damages results in a time series of damages for the respective EWE.

Table 3: Average annual growth rates of the number of events per year by selected locations, RCP 8.5, 2021-2050

		RCP 8.5 - (high scenario: global temperature increase of +4.8 °C)									
		Almaty	*Nur_Sultan*	*Oskemen*	*Central_reg*	*East_reg*	*North_reg*	*West_reg*	*South_reg*	*North2_reg*	***Kazakhstan***
Drought	*2021-2030*	4.3%	0.7%	0.0%	1.3%	0.0%	0.2%	4.6%	1.3%	-0.7%	**1.3%**
	2031-2040	3.4%	1.7%	25.3%	1.3%	0.0%	1.0%	4.1%	1.9%	-0.6%	**2.0%**
	2041-2050	2.9%	2.3%	9.0%	1.3%	0.0%	1.7%	3.6%	2.2%	-0.6%	**2.3%**
Heat Wave	*2021-2030*	4.4%	3.8%	4.1%	3.9%	4.9%	3.9%	3.8%	3.7%	3.6%	**4.0%**
	2031-2040	3.7%	3.5%	3.5%	3.3%	4.1%	3.5%	3.4%	3.2%	3.4%	**3.5%**
	2041-2050	3.2%	3.1%	3.0%	2.9%	3.5%	3.0%	3.0%	2.9%	3.1%	**3.1%**
Extreme Temper-ature	*2021-2030*	3.2%	3.1%	3.0%	3.1%	3.3%	3.1%	3.0%	3.3%	3.1%	**3.1%**
	2031-2040	3.0%	2.9%	2.8%	2.9%	3.1%	2.9%	2.8%	3.1%	3.1%	**3.0%**
	2041-2050	2.7%	2.7%	2.6%	2.7%	2.8%	2.7%	2.6%	2.9%	2.9%	**2.7%**
Extreme Wind	*2021-2030*	0.0%	-0.1%	-0.1%	0.0%	-0.1%	-0.1%	0.1%	-0.4%	-0.3%	**-0.1%**
	2031-2040	0.0%	0.0%	-0.1%	0.0%	-0.1%	0.0%	0.1%	-0.4%	-0.2%	**-0.1%**
	2041-2050	0.0%	0.0%	-0.2%	-0.1%	-0.1%	0.0%	0.1%	-0.4%	-0.1%	**-0.1%**
Extreme Precipita tion	*2021-2030*	0.4%	0.3%	0.3%	0.4%	0.4%	0.4%	0.3%	0.4%	0.5%	**0.4%**
	2031-2040	0.4%	0.4%	0.3%	0.4%	0.4%	0.4%	0.2%	0.4%	0.4%	**0.4%**
	2041-2050	0.4%	0.4%	0.3%	0.4%	0.5%	0.4%	0.1%	0.5%	0.4%	**0.4%**
Wild Fire	*2021-2030*	0.2%	0.0%	0.0%	3.1%	0.0%	0.0%	0.1%	0.1%	0.0%	**0.1%**
	2031-2040	-0.1%	0.0%	0.0%	3.0%	-0.1%	0.0%	0.0%	0.0%	0.0%	**0.0%**
	2041-2050	-0.3%	0.0%	0.0%	2.8%	-0.2%	0.0%	0.0%	0.0%	0.0%	**-0.1%**

Source: Navarro and Jordà 2021.

According to the RCP 8.5 scenario, in particular the number of heat waves, extreme temperature and drought events will exacerbate. Annual growth rates of heat wave events in Kazakhstan are specified with 3 to 4%, extreme temperature events with approximately 3% and droughts with 1.3 to 2.3% (Table 3). While the number of heat waves and extreme temperature events is expected to develop similar in the selected areas, drought events will occur more often in Almaty, Oeskemen and the Western region. In the case of extreme precipitation events, an annual increase of 0.4% is expected. The number of extreme wind and wildfire events is likely to remain more or less at the current level.

3.2.3 SECTOR IMPACTS

"*Kazakhstan is very vulnerable to various effects of climate change*" stated the President of the Republic of Kazakhstan Mr. Tokayev at the General Debate of the 75th session of the UN General Assembly.

As presented in the previous section, climate change is likely to exacerbate with more frequent and more intense EWEs. Thus, the economic impacts are likely to amplify and will cause higher costs, affect key economic processes and endangers jobs, wealth and life of Kazakh people. The most vulnerable sectors are agriculture, forestry, industry and transport as well as water and health (USAID 2017). The climate impacts for the economic sectors are manifold and differ with respect to the kind of damage. Table 4: Potential climate change impacts on economic sectors Table 4 provides an overview.

Source: USAID 2017

Climate change is a global phenomenon. Economic impacts of climate change are therefore not only to be expected from climate events in Kazakhstan, but also from other countries struggling with climate change. Transboundary impacts can be expected, for example, when international transport routes or value chains are disrupted.

Table 4: Potential climate change impacts on economic sectors

Climate change pattern and EWE	Agriculture	Energy	Infrastructure (transport, buildings, industry)	Health
Changing average and extreme temperature	• Wheat yield reduction due to crop land degradation related to heat stress • Reduced pasture productivity related to heat stress • Increased sunflower yields	• Reduced thermal power generation capacity due to insufficient cooling water • Reduced hydropower generation capacity • Increased demand for cooling in summer, reduced demand for heating in winter • Reduced efficiency of solar panels • Reduced efficiency of transmission lines • Economic losses due to power outages	• Melting road surfaces • Buckling of railway lines • Damages to roads due to melting of seasonal ground frost • Expansion of bridge joints • Impaired shipping	• Vector-borne infectious diseases • Health hazards caused by heatwaves • Changes in fitness and activity level • Increased demand for health care services • Increased morbidity and mortality
Changing precipitation patterns and extreme precipitation, floods, mudflows, landslide	• Wheat yield reduction due to crop land degradation related to reduced soil moisture • Reduced pasture productivity • Damaged crops and livestock due to floods	• Damages to the physical infrastructure (e. g. transmission lines, power plants, coal mines, pipelines, offshore platforms) causing disruption of energy supply • Reduced hydropower generation capacity • Reduced efficiency of transmission lines • Economic losses due to power outages	• Wash out of road surfaces • Damage to rail and road infrastructure Disruption of transport due to flooding of roads, railways, tunnels etc. • Impaired shipping	• Degraded water quality • Water-borne disease outbreaks • Decrease in service reliability • Increased mortality and morbidity related to EWEs, especially mudflows
Droughts	• Increased wheat yield variability • Increased incidence of pests and diseases (Hessian fly and wheat rust)	• Reduced hydropower generation capacity	• Impaired shipping	• Expansion of infectious disease vectors (ticks and mites) • Degraded water quality causing gastrointestinal disease
Extreme wind	• Soil degradation	• Damage to physical infrastructure e.g. wind farms, distribution networks	• Damage to assets such as bridges, buildings, production facilities • Disruption to ports and airports	• Accidents • Deaths and injuries • Decrease in service reliability

Climate change pattern and EWE	Agriculture	Energy	Infrastructure (transport, buildings, industry)	Health
		• Economic losses due to power outages		
Wild fire	• Destroyed harvest	• Damages to the physical infrastructure	• Damages to the physical infrastructure	• Deaths and injuries

Sources: Based on OECD (2018), UNESCAP (2021a), USAID (2012, 2017), World Bank (2011).

Agriculture

Agriculture is one of the economic sectors most vulnerable to climate change. Drought has been identified as a very significant risk especially for the rain-fed wheat production (World Bank, 2015, 2016; MNE et al., 2017). In combination with low precipitation in summertime and extreme temperatures, water can be scarce and desertification in flatland areas in Western, Northern, and Central Kazakhstan speeds up. The most important regions for wheat – Akmola, Kostanay – have the highest World Bank damage category.(2016).

Main challenges associated with these climate change impacts are soil degradation and desertification. Other consequences are reduced soil moisture and salinity, desertification, increased incidences of pests and diseases, all affecting and amplifying the yield variability.

Livestock farming is more prevalent in the South and suffers from the reduced availability of pasture during summer and autumn as well as lower livestock productivity as a result of increased temperature and reduced water availability (World Bank 2021). Depending on the season, grassland vegetation productivity is expected to increase in spring due to precipitation increase by 10-40% but may decrease in the second vegetation period by 30-90% (Republic of Kazakhstan 1998). In 2021, a very severe heat wave led to a drought, killed animals in Southern and Western regions of Kazakhstan due to food and water scarcity (IFRC 2021).

Furthermore, temperature increase causes glacier melting which amplifies flood risk in Southern and Eastern regions in the medium term but threatening water supply by mid-century (USAID 2017).

These trends are expected to intensify the risk of land degradation and erosion resulting in lower agricultural productivity in Kazakhstan. The vulnerability of national development, food security and natural environment is exacerbating by climate change.

Energy

Climate change also impacts the **energy sector** in many ways[15]. Energy production can be impaired due to insufficient cooling and low water levels caused by higher evaporation with increasing temperature, heatwaves and limited precipitation during droughts[16]. Hydropower accounts for approximately 10% of Kazakhstan's electricity production with major plants in Oskemen (Bukhtarma, Shulbinsk) which is planned to be expanded by 15-20% by 2050. A major issue is that 50% of the hydropower plants are

[15] The World Bank (2011) gives an overview of possible impacts for this sector from a global perspective.

[16] https://climateknowledgeportal.worldbank.org/country/kazakhstan/climate-sector-energy

located in areas with high or extremely high water stress (Karatayev et al. 2017). During the drought year 1998, according to the IEA energy balance of that year, a drop of 20% in the hydro power generation potential could be observed in Kazakhstan. This is in line with international studies, which estimate that the hydropower potential will reduce by 25% in European countries and even worse in Southern Spain with up to 49% (Wang et al. 2020).

Temporarily, the glacial melt has a positive effect for hydro power stations which are fed by glacier water as the one close to Almaty but in the long run climate change impacts water supply negatively. Hydro power potential is also jeopardized by increased withdrawals by neighboring countries along transboundary rivers which are threatened by climate change as well (MNE et al 2017, pp. 184, USAID 2017). Additionally, the extraction of fossil fuels has high demand for water and might be impaired with increasing water scarcity (Karatayev et al. 2017).

Furthermore, higher temperatures in summer increase the energy demand for cooling by 0.5 to 8.5% if temperature increases by one degree. On the other hand, heating demand in wintertime may decrease (World Bank 2021). In particular, the impacts of temperature rise and heat stress is amplified by the Urban Heat Island[17] effect in major cities. Research shows that labor productivity in the service sector and outdoor work (agriculture and construction) suffers from hot temperatures in summer (ILO 2019).

The energy infrastructure is particularly vulnerable to destructive EWEs, such as storms, floods and landslides, which are expected to occur more frequently. Heavy rain can cause the ground to shift and swell resulting in landslides which damage pipelines and create leaks. According to UNESCAP, 43% of the energy infrastructure is located in high and extremely high flood risk areas.

The water level of the Caspian Sea as an inland water body is dependent on the inflow of rivers and evaporation. The forecast is subject to many uncertainties (GERICS 2018). However, some scientists project a sea level rise due to increasing precipitation in the contributing Volga Basin, which may have consequences on near-shore oil facilities and off-loading of oil at terminals in Kazakhstan, or other impacts (World Bank 2015).

Especially, the extensive, partly obsolete energy transmission and distribution infrastructure – pipelines, power lines, transformer station etc. – is endangered (UNECE 2019a). For example, in 2015, a flood and mudflow caused extensive damage to powerlines in Almaty (USAID 2017). Heat and high humidity also have a negative impact on transmission capacity (EEA 2019). In Kazakhstan, significant power losses occur due to unfavorable weather and poorly insulated power lines known as corona discharge and joule heating (KEGOC 2018). On top of the additional cost of repairing the damage, energy producers will lose revenue from the amount of electricity not being sold.

Due to the high importance of the energy system as a key economic sector, the national development and energy security is affected. Damages directly occurred in the energy sector cause indirect losses in other industries due to the disruption of energy supply (OECD 2018).

In the energy and agriculture sector **water resources** play an important role either for irrigation or for power generation (USAID, 2017). Glacier melting contributes to river flows in particular during summer. Accelerated melting of glaciers in the medium term leads to altered river flows and flooding risks. By mid-century, glacial loss will cause water scarcity. Furthermore, increasing temperatures pose a threat

[17] The Urban Heat Island phenomenon refers to the difference in temperature between the warmer city and the cooler rural surroundings, which is particularly large during a cloudless and windless night (DWD 2021). Higher temperature in the cities can be caused by dark surfaces, heat sources in residential and industrial areas, a lack of vegetation and air pollution (World Bank 2021).

to surface waters, which may warm and dry out (USAID 2017). The consequences can already be seen in the shrinking of the Aral Sea. Lake Balkhash is also at risk (World Bank 2021).

Health

The expected climate trends are likely to amplify **health** issues and thus increase the demand of health care services. Heat-related mortality and morbidity may increase as well as changes in the incidence of diseases transmitted by insects or changes in water and air quality. In particular in highly populated areas, the urban heat island effect poses a risk to humans (World Bank 2021). More injuries and fatalities may occur in combination with more frequent and destructive floods.

Infrastructure

A well-functioning **infrastructure** (e. g. transport, building, water) is an important foundation for economic and social development. For example, transport is an important economic sector not only relevant for domestic transportation. Kazakhstan has a good strategic position as a transit country connecting Europa and China (EBRD 2015-2020) and plans to develop the New Silk Road.

The infrastructure is highly susceptible to increasing temperature, precipitation and EWEs even more if the condition of roads, railways, buildings etc. is not satisfactory. Increasing temperature may "lead to road surface deterioration, cause expansion of bridge joints and paved surfaces, and buckling of railways tracks" (UNESCAP 2021a) causing costs for reconstruction and reduced speed of transportation. In buildings heat stress may impact labor productivity and well-being of humans (ILO 2019).

Accelerated glacier melt and extreme precipitation are causing floods, mudflow or landslides physically damaging the infrastructure. Increased soil moisture may impact the structural integrity of roads, bridges and tunnels. Extreme precipitation and floods could wash out road surfaces, damage bridges and railway tracks (UNESCAP 2021a). Moreover, floods damage the interior furnishings or, in the worst case, can wash away the entire house. Extreme wind events may blow off roofs, cause trees to fall and flying objects cause damage to power lines, information and communications technologies (ICT) infrastructure as well as gas and water supply systems. Dust storms, which additionally reduce the visibility, may increase the risk of traffic accidents and contribute to land degradation.

3.3 OVERVIEW OF MONETARY DAMAGES ASSOCIATED WITH PAST CLIMATE EVENTS

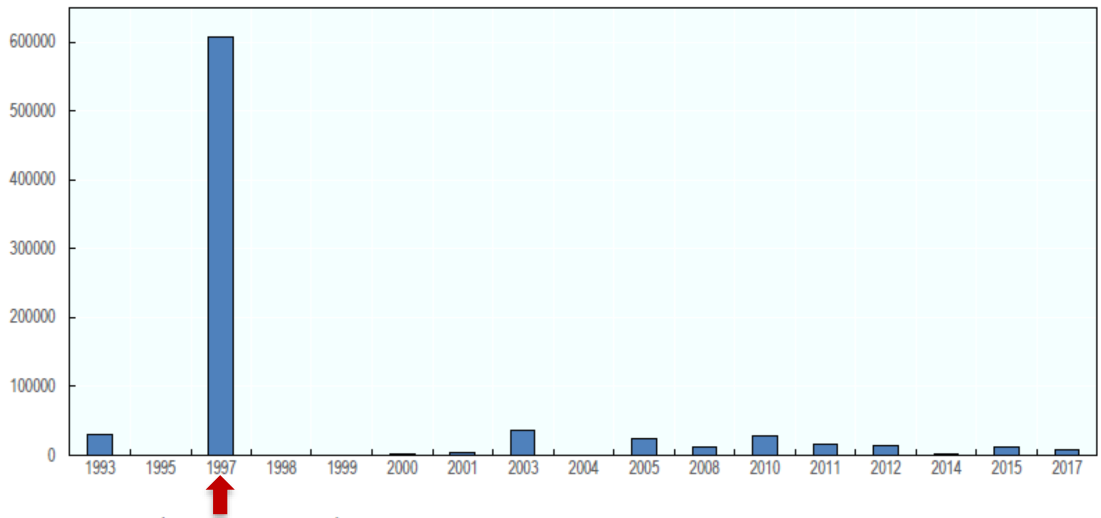
The previous section 3.2 has provided an initial overview of past climatic threats and their impacts in Kazakhstan and how climate may evolve in the future. In order to better understand the modeling studies on the economic effects of climate change and adaptation measures carried out in the remainder of this report, this section provides a synopsis of past climate change events and their monetized damages which gives an initial indication of future economic risks of climate change.

It is important to mention, that there are no official methods to estimate climate event-related damages in Kazakhstan so far. Government authorities do not possess full and accurate damage data. Damage estimates are done randomly and by various sources which are neither consistent nor accurate. (UN-ESCAP n. d., p. 18). According to the World Bank[18], in particular, there is *"lack of data on material damage (in monetary terms) caused to economic sectors by extreme weather events."* A first indication of the socio-economic impacts gives Figure 17. Based on the data from the EM-DAT database, in the

> The **recording of climate damage has so far been unsystematic and rather patchy**. It is therefore partly unknown who suffers from the consequences of climate change and how high the total amount of damage is. **It can be presumed that the damage incurred to date is even higher**. Consequently, it is even more important to step up adaptation efforts to reduce future damage.
>
> The **establishment of a climate damage register** may help to resolve current issues.

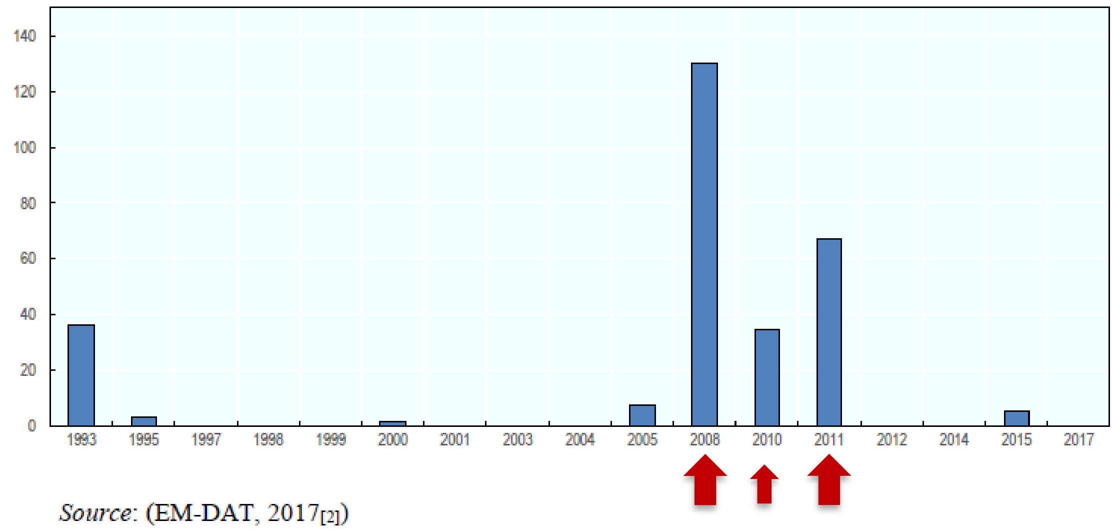
last 25 years, 22 major events occurred. During a wildfire event and a cold spell in 1997, the highest number of people were affected. The greatest economic damage was caused by a riverine flooding in South Kazakhstan in 2008 (130 million USD) and in April 2011 in West-Kazakhstan (67 million USD). Major damages are typically caused by floods.

The range of economic losses varies depending on the infrastructure affected, the type and extent of the EWE. The extent to which the population is affected depends on the regional population density and the possibility of averting danger. As Figure 16 shows, the impact on population and economy does not necessarily correlate. People can get into safety as long as they are informed whereas infrastructure is not movable and the construction of protective measures takes time.



Source: (EM-DAT, 2017[2])

[18] https://climateknowledgeportal.worldbank.org/country/kazakhstan/adaptation (last accessed on September 19th, 2021)



Source: (EM-DAT, 2017[2])

Figure 17: Major disasters and their impacts (top figure: population affected, bottom figure: damages in million USD) in Kazakhstan since 1993-2017.

Source: OCED 2019.

Various sources of information were contacted in course of the CRED project to get an overview of the costs in the form of monetary damages and benefits for the last 20 years. However, not all impacts are recorded and are not always sector-specific. Losses (or indirect damages) which may occur due to e. g. power outages or by using other modes of transport and / or routes are usually not quantified.

Main sources of information are amongst others state agencies e. g. Kazhydromet and the Committee of Emergency Situations of the Ministry of Internal Affairs, national and international scientific literature and public media coverage[19] (e. g. Broka et al. 2016, Ministry of Energy et al. 2017, OECD 2019a, Reliefweb[20]). The Ministry of Agriculture and sub-national level authorities in the regions were contacted to collect data on droughts.

The desk research – conducted together with local experts – summarizes the following information for selected climate events e. g. extreme precipitation, extreme wind, drought and heatwave (for an excerpt please refer to Appendix 2 and Appendix 1):

- Date / year of the climate event
- Regional occurrence
- Nature of damage (e. g. destroyed buildings, yield loss)
- Quantified / monetized damage (in specified currency (KZT or USD) or percent)
- Losses (e. g. increases in travel time and higher operating costs incurred by road users when forced to lengthen their journeys because of impassable roads; production losses due to power outages)
- Affected economic sector(s) (e. g. agriculture, energy, transport)
- Number of affected people

[19] For example, total.kz reported on the consequences of a drought in Kazakhstan. (https://total.kz/ru/news/gossektor/825_millionov_tenge__viplacheno_postradavshim_ot_zasuhi_fermeram_kazahstana_date_2021_10_29_19_24_41?fbclid=IwAR2nk-A2wpp1JyuHep37brPpWJ2VyoNdkphxVxFchP_igfYIn-Ha4Sdr8p8)

[20] https://reliefweb.int/disasters

Table 5 summarizes the monetary damages. As stated above, not all damages are reported. For example, in 2000 / 2001 a very severe drought happened but no monetized damage data was available. During that drought, precipitation levels reached only 40% to 60% of the normal value and river flows dropped to between 35% and 40% below average levels which results in damaged crops not only in rain-fed areas (World Bank 2005). Hydropower and fisheries were affected as well. Between 1994 and 1998, Kazakhstan faced agricultural losses from droughts in five consecutive years (World Bank 2006). The most significant droughts occurred in 1998, 2008, 2010 and 2012 with yield losses between 26% (2008) and 55% (2012, World Bank and FAO 2019).

Furthermore, available data must be interpreted with care. Depending on the data source, reported damages show in rare cases a big range. For example, the damage of the flood event in 1993 is estimated ranging from KZT 67 million to 30billion. KZT. In some cases, monetary damages cannot be clearly assigned to the EWEs. Most severe flooding is caused by a combination of extreme precipitation and a sudden rise in temperature that leads to snow melt. Thus, the differentiation of floods caused by snow melt and floods caused by extreme precipitation (column two and three in Table 5) cannot be separated clearly.

Table 5: Selection of reported monetary damages in Mio. KZT (numbers rounded)

Year	Snow melt / Floods*	Extreme precipitation** / rainfall flood	Landslide, mudflows, slope wash-out	Extreme Wind***	Drought	Wildfire
1991	3	3		0.2		15
1992	0.2					
1993	–	67 - **30,000**	9	13		
1994	873	72	88	3	n.a.	281
1995	382 + 5[1]	1,230	34	144	n.a.	260
1996	55 + 21[2]	374	43	81	n.a.	37
1997	291	153		93	n.a.	128
1998	863	3,165	3	**732**	**75,000**	36
1999	200	16	62	19		29
2000	195	10		18	n.a.	13
2001	40			3		10
2002	504	**22**		10		50
2003	113		11	209		6
2004	5			129		22
2005	35			99		21
2006				0.5		387
2007	4	4		3		**502**

2008	**15,284**			**900**	n.a.	**581**
2009				21		91
2010	**5,400**			11	17,000	332
2011	**9,782**					5
2012	440-1,192				153,000	**532**
2013	4		464			332
2014	1,185-2,974			2,500	140	77
2015	**17,600-19,600**			501		119
2016	60-811			29		29
2017		**4,771**		511		216
2018	1,095			57		210
2019	515			37		**564**
2020				24		**532**
Total	**64,846-100,071**		***714***	***6,148***	***245,140***	***5,417***

* including groundwater level rise[1], sea level fluctiation[2]

** including heavy snowfall

*** including blizzards, wind surge, dust storm, snowstorm, whirlwind, squall wind

Source: Data compilation by Kazhydromet, Aibat Muzbay, GWS.

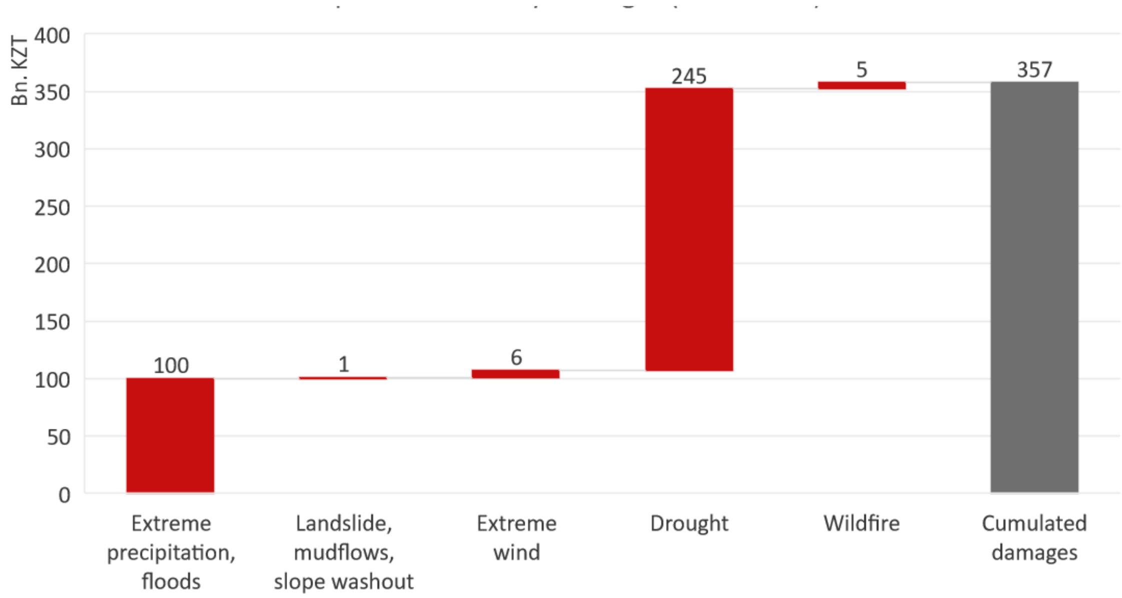


Figure 18: Cumulated reported monetary damages in Bn. KZT, 1991-2020

Source: own illustration based on data compilation by Kazhydromet, Aibat Muzbay, GWS.

The greatest economic damage over the past period was caused by droughts totaling to KZT 245 billion whereas floods amounted to KZT 65 to 100 billion. With greater distance, wild fire events and heavy wind events follow with cumulated damages of KZT approximately 5 billion respectively KZT 6 billion.

While Northern Kazakhstan shows higher damage due to droughts, the South reveals more flood damage.

The highest recorded loss from a single event was from a drought amounting to 153,000 million KZT in the year 2012. It is noticeable that for all climate events so-called major events can be detected which are significantly more devastating than average events. This includes the heavy precipitation events resulting in a flood in 1993, 2008, 2011 and 2015.

Extreme precipitation is in particular threatening for the economy in South-, East-Kazakhstan but also the Central and Northern regions. The recorded damages show a wide range from a few million KZT to 30 billion KZT. In 1993 and 2008, very severe flooding occurred, which were caused by extreme precipitation in combination with sudden warming with estimated economic damages of KZT 15,000 to 30,000 million. In the last ten years, six heavy rain events caused damages between KZT 1,000 to 5,400 million.

A very severe extreme wind event occurred in 2014 causing a damage eight times higher than the average damage. Damages of wild fire events ranges between KZT 5 million to 581 million.

The data analysis not only reveals which climate events are the most devasting but also that economic losses and human impacts are greater the more densely populated the area and the more developed the infrastructure is. In that sense, it must be taken into account which EWE occurs in which region and to what extent. For example, in urban or industrial areas the damage is likely to be higher than in rural areas due to the value of assets that can be destroyed.

In cities such as Almaty, heavy precipitation events are particularly severe because the share of sealed surfaces is high and the water absorption of the soil is low. Th' city's sewage system is designed for normal rainfall events and cannot absorb unusually huge amounts of water, resulting in backups. A similar situation can be observed with frozen soils, which are then unable to absorb the floodwater, at least partially.

Table 6 summarizes the economic sectors impacted from climate change and the kind of direct damages mentioned in the reviewed literature, public media and data sets provided e. g. by Kazhydromet. In particular, agriculture, forestry, construction, water, transport, energy and industry sector are affected by climate change. The kind of damage (e. g. damages buildings, destroyed crops) is similar although caused by different EWEs. However, the reason for the damage can be different. For example, damages to the infrastructure may be caused by too much water or too strong wind. Nevertheless, the extent of the damage can differ significantly.

Agricultural products (crops and animals) can suffer from damages from too much (extreme precipitation and flood) and too little water (drought), heat waves as well as fires. Different kinds of infrastructure (e. g. transport, buildings, water) are each affected by extreme wind and extreme precipitation. Heavy rain washes out roads and bridges and thus damages their foundations. Extreme heat warms and expands the material of roads, causing them to blow up. They also cause different types of damage to buildings. While extreme wind mainly destroy the roofs and windows through flying objects and fallen trees, floods damage the interior furnishings or, in the worst case, can wash away the entire house. The damage in the economic sectors is usually described in terms of number, e. g. two bridges are destroyed and 1,000 houses flooded but the damage is not monetized, so only a rough sectoral estimate can be made.

Table 6: Reported non-monetary damages of EWEs

Economic sectors affected	Extreme precipitation, floods, landslide, mudflows	Extreme Wind	Drought	Heat wave	Wildfire
Agriculture	Damaged crops		Damaged crops	Damaged crops	Burned crops
	Damaged agricultural lands				
	Killed livestock		Killed livestock	Killed livestock	
Forestry	Damaged logs	Knocked down trees			Burned forest areas
Construction	Damaged buildings	Damaged roofs			
	Damaged bridges				
	Destroyed dams				
Industry	Flooded economic objects	Damages production sites			
Energy	Damage to electricity supply	Damage to power lines, gas pipelines	Hydro power plants affected	Hydro power, combined heat and power (CHP) plants affected	
Water	Damaged pipes				
	Destroyed sewer network and water supply				
ICT	Damage to communication infrastructure	Damage to communication infrastructure			
Transport	Blocked road and train traffic	Blocked road and train traffic		Bent rails, asphalt melting	
	Damages roads				
	Damaged cars	Damaged cars			

Source: Own representation based on data compilation by Kazhydromet, Aibat Muzbay, GWS.

Physical, direct damages may cause further (production and revenue) losses due to disruptions, failures and delays in the supply chain (OECD 2018). Floods, mudflows and landslide could interrupt transport routes and cause delays in the supply of raw materials. Damage to industrial infrastructure may impede production. Costs from power outages could vary considerable depending on affected industries

(Figure 19), duration, time and magnitude of the blackout. According to the World Bank enterprise survey in Kazakhstan (2019), power outages caused losses in sales of 1.7% on average and sector-specific losses ranging from 0.5% (fabricated metal products) to 7.7% (other manufacturing, Figure 19). It must be noted that the power outages are not distinguished with respect to the cause of the outage.

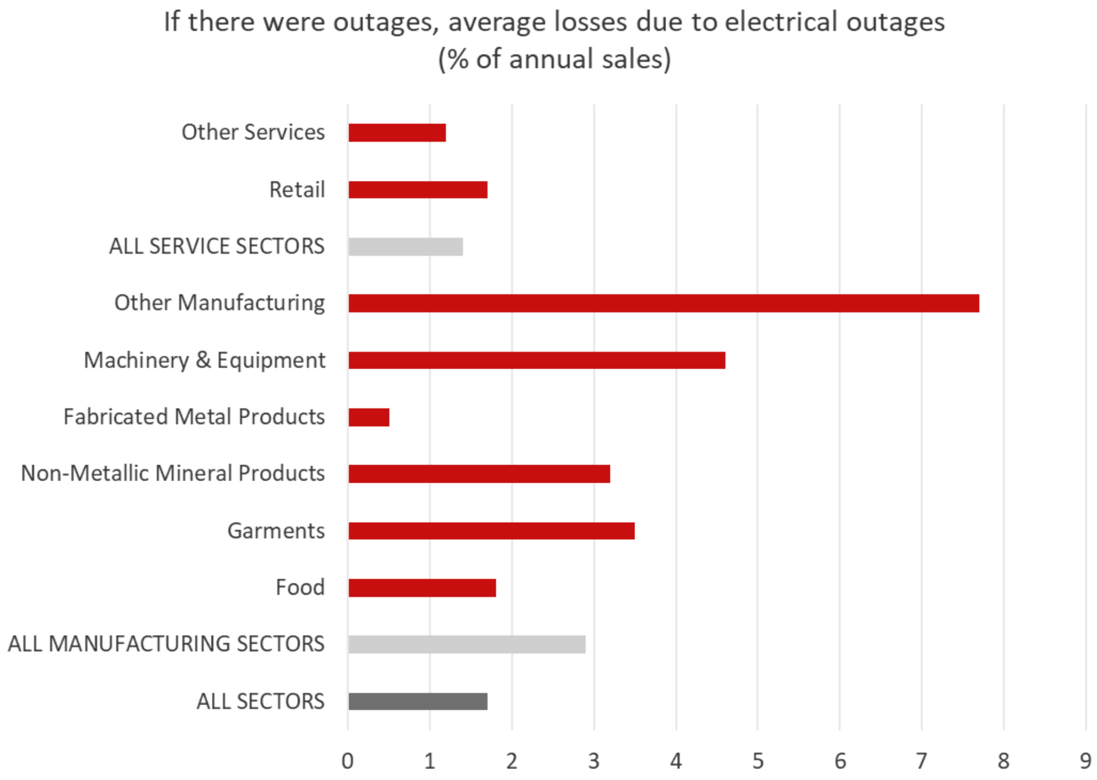


Figure 19: Average losses in annual sales due to power outages

Source: World Bank Enterprise survey 2019

In addition to data on past damages, there are also estimates of future damages, for example for the agricultural sector, which also serve as an input for climate change scenarios (section 5.1). With the help of detailed bottom-up models, damages and benefits are determined for climate scenarios. For example, according to UNDP (2020), wheat yields are estimated to decline by 33% (or 457 billion KZT in 2019 prices) of the current potential by 2030 and 12% (608 billion KZT in 2019 prices) by 2050. A similar pattern is foreseen for grazing capacity, with livestock productivity reduction of 10% (or 108 billion KZT by 2030) to 15% (or 170 billion KZT by 2050) of the current potential. In the most severe climate scenario, the decrease could reach 10% to 20%. In contrast, sunflower seed yields are supposed to profit from climate warming which leads to an increase of 8% (almost two billion KZT) by 2030 and around 4% (almost one billion KTT) by 2050 compared to current gross output. Overall, crop production is more vulnerable to risk than livestock (World Bank 2016).

4 REFERENCE SCENARIO

4.1 ASSUMPTIONS

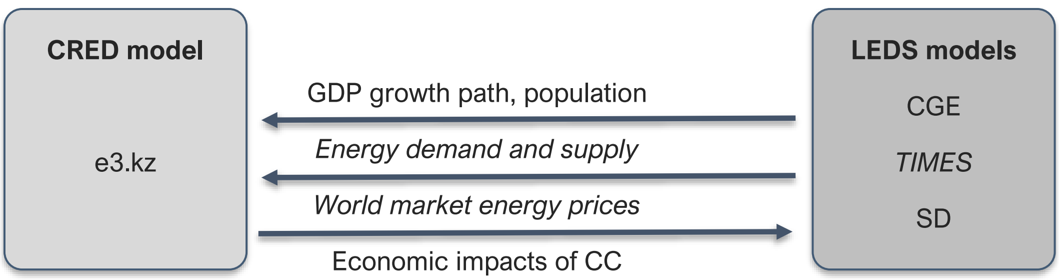
The reference scenario extrapolates the economic relationships observed in the past into the future. Model variables, model parameters and assumptions are carefully selected in order to provide a reliable projection and to provide a solid basis for other scenario analyses. Nonetheless, the reference scenario is not to be interpreted as a projection in terms of the most realistic development. It serves as a benchmark to compare model results of other scenario analyses, i. e. climate change and adaptation scenarios.

Nevertheless, the reference projection should meet certain expectations and should be comparable to other projections for Kazakhstan. Exogenous variables and expectations for the development of the population and in the energy sector (including production, consumption, and prices) are aligned as far as possible with the Business-as-usual (BAU) results of the LEDS-project.

Accordingly, no further efforts to decarbonize the Kazakh economy are expected in the reference scenario. Fossil fuels dominate the energy sector and energy efficiency remains low (for more details, please refer to DIW Econ 2021). The world market prices for fossil raw materials develop according to the World Bank (until 2035), the IEA "Stated Policies" scenario (until 2040; IEA 2020) and the LEDS-project projections. The production of fossil fuels is important for the development of exports and the

Adaptation to and mitigation of climate change must be considered in long-term economic planning and the two projects CRED and LEDS support the national partners in this respect. **CRED** aims at supporting respective ministries in developing **climate-sensitive development plans** and economic development strategies. **LEDS** has the main objective to determine the goals and specific tasks of **Kazakhstan's transition to climate neutrality** by 2060.

The **models created and applied in the two projects differ** with respect to the research questions and thus are based on different modeling approaches, data and scenarios. However, an exchange on the main assumptions, data and results was initiated. The figure shows the data exchange between the e3.kz CRED model and the LEDS models in a nutshell.



overall economic development of the country. Until 2035, the production of crude oil and natural gas increases according to the projections of the LEDS project. In the following years, they decrease and reach in 2050 approximately the level of 2018. Oil exports follow the trend, while gas is increasingly consumed domestically, resulting in a steady decline in gas exports. In 2050, these are less than half of the 2020 value.

The macroeconomic impacts of the COVID-19 pandemic in 2020 are based on COMSTAT estimates[21]. The subsequent recovery process and the long-term growth path are adapted as much as possible to the unpublished LEDS project proceedings[22].

4.2 RESULTS

4.2.1 ECONOMIC DEVELOPMENT

During the COVID-19 pandemic in 2020, the steady economic growth since 2000 was interrupted. The decline in real GDP growth amounted to just below 2% and was thus not as strong as in other countries. Real exports contracted by nearly 12%. To support the Kazakh economy, the government increased consumption expenditures by about 31%. Anti-crisis economic recovery measures in 2020 and subsequent years include economic support measures through tax relief and suspensions and early investment plans (UNESCAP 2020). Gross fixed capital formation increased by almost 2%. Despite work restrictions and income losses, consumer spending by private households declined by no more than approx. 3%[23]. The country's high dependence on the global economy also leads to declining imports as economic growth contracted.

The expected economic growth and the development of the GDP components following the expenditure approach until 2050 – largely aligned with the LEDS project projection – are shown in Table 7. The economy is expected to continue to grow until 2050, but at a slower rate. In the first projection period the average annual growth is 4% (2020-2030), followed by 1% 2030-2040 and 0.5% (2040-2050, Table 7). On the one hand, export growth is lower than before, especially due to lower oil and gas exports. Additionally, following the LEDS assumptions, the impacts of the EU-Carbon Border Adjustment Mechanism (CBAM[24]) are taken into account (DIW Econ 2021). On the other hand, population growth will also decelerate by 2050, which will also have an impact on consumer demand and cause growth rates to fall over time.

Investment will initially continue to grow at an average annual rate of 4.5% as the economy continues to expand, but at a declining rate, as will GDP. Investments will be made to both maintain and expand production capacities. Following the LEDS results of the BAU scenario, from 2030 onwards, investments decrease by 3% (0.7%) per year from 2030 to 2040 (2040 to 2050).

Consumer spending by private households continued the growth trend of the past starting with an annual average growth of 4.3% (2020 to 2030) and 0.8% in the period of 2040 to 2050 (Table 7). Employment and the income situation continue to develop positively and support consumption growth. The slower population growth compared with the past is having a decelerating effect.

Government consumption expenditure also shows positive growth between one and two percent per year, following GDP growth with a time lag.

[21] https://stat.gov.kz/official/industry/11/statistic/7 (GDP by final use, last accessed August 20th, 2021).
[22] GIZ Project "Supporting Green Economy in Kazakhstan and Central Asia for a low carbon economic development"
[23] https://stat.gov.kz/official/industry/11/statistic/7 (GDP by final use, last accessed August 20th, 2021).
[24] "The European Union is planning to introduce a carbon border adjustment mechanism (CBAM) starting in 2023, which will put a carbon price on certain emission-intensive imports to the EU. Several countries, such as the UK, the USA and Canada are likely to follow. For countries with carbon-intensive exports to the EU (and other potential CBAM adopters) – Kazakhstan is among them – the introduction of CBAM will significantly affect export capabilities and revenues, unless they themselves introduce ambitious carbon pricing." DIW Econ 2021, p. 13

Due to the country's dependence on imports, these will increase further with positive economic growth. The manufacturing sector in particular (machinery, electrical equipment, computers) is highly dependent on imports.

Table 7: Real GDP and main components (expenditure approach), average annual growth rates

	2000 – 2010	2010 – 2020	2020 – 2030	2030 – 2040	2040 – 2050
GDP	6.1%	3.9%	4.0%	1.0%	0.5%
Final consumption expenditure: households	7.2%	5.6%	4.3%	3.7%	0.8%
Final consumption expenditure: government	6.9%	7.0%	2.1%	2.3%	1.2%
Gross fixed capital formation	9.9%	5.9%	4.5%	-3.0%	-0.7%
Export of goods and services	1.9%	-0.2%	3.8%	-3.8%	0.2%
Import of goods and services	2.8%	2.8%	4.0%	0.8%	0.7%

Source: Until 2020 historical data based on COMSTAT, e3.kz results (2021-2050)

The real production values for 19 economic sectors are shown in Table 8. Economic sector development follows macroeconomic development, taking into account inter-industry relationships. Export-oriented sectors generally show a stronger connection to foreign demand, while consumption-oriented sectors are more dependent on domestic demand.

The reference scenario does not imply large structural changes or economic diversification. Thus, economic sectors which have shown large growth in the past will do so in the future. The assumptions of the energy sectors are an exception.

Declining oil and gas exports are reflected in lower production in the mining sector in the period 2030 to 2050. Lower investment results in lower output, particularly in the manufacturing and construction sectors. Lower production in professional, scientific and technical activities is also related to investment.

Household and government consumption expenditures mainly support the service sector, but the former also consumes goods for everyday use.

Table 8: Real production for 19 economic sectors, average annual growth rates

	2000 – 2010	2010 – 2020	2020 – 2030	2030 – 2040	2040 – 2050
Agriculture, forestry and fishing	5.4%	3.4%	4.0%	1.7%	1.0%
Mining and quarrying	9.0%	2.5%	1.0%	-1.2%	-1.3%
Manufacturing	5.9%	1.8%	3.1%	-1.5%	0.7%
Electricity, gas, steam and air conditioning supply	8.7%	2.8%	1.9%	0.4%	0.4%
Water supply; sewerage, waste management and remediation activities	9.3%	-2.0%	3.6%	0.5%	0.9%
Construction	17.1%	6.8%	4.0%	-2.6%	-0.3%
Wholesale and retail trade; repair of motor vehicles and motorcycles	5.2%	3.9%	3.4%	-1.3%	0.5%
Transportation and storage	5.4%	4.3%	3.0%	-0.3%	0.4%

Accommodation and food service activities	9.5%	0.7%	4.7%	1.9%	0.5%
Information and communication	30.3%	7.3%	4.2%	2.2%	1.1%
Financial and insurance activities	16.1%	-0.9%	3.7%	1.4%	0.8%
Real estate activities	-7.5%	22.0%	4.8%	3.0%	0.9%
Professional, scientific and technical activities	-1.6%	1.3%	3.2%	-0.6%	0.3%
Administrative and support service activities	2.5%	6.6%	3.3%	0.9%	0.8%
Public administration and defense; compulsory social security	17.4%	0.2%	2.4%	2.7%	1.4%
Education	-11.8%	28.2%	2.9%	3.1%	1.3%
Human health and social work activities	1.4%	20.5%	4.6%	3.5%	1.1%
Arts, entertainment and recreation	-0.2%	14.7%	3.7%	2.8%	1.2%
Other service activities	5.2%	-2.8%	11.4%	2.6%	0.8%

Source: Historical data until 2020 based on COMSTAT, e3.kz results (2021-2050)

Developments on the labor market are influenced by economic and demographic trends. The labor supply is basically derived from the population at working age (16 to 62 years). This will continue to rise until 2050 in line with the population projection used in the LEDS project (Figure 20). As long as the level of qualification and skills meets the job requirements, no labor shortages are expected. A shortage of labor – as observed in many European countries due to demographic change (declining and aging population) and also to be expected in the future – is not yet apparent in Kazakhstan.

Sectoral employment follows the production activity of the respective economic sectors taking into account the sector-specific labor productivity which is increasing allover but at different rates (Table 9).

Table 9: Employment in 1,000 persons, average annual growth rates

	2001–2010	2010 – 2020	2020 – 2030	2030 – 2040	2040 – 2050
Total employment	1.9%	0.7%	0.9%	0.1%	0.3%
Agriculture, forestry and fishing	-0.2%	-6.5%	0.8%	0.4%	0.2%
Mining and quarrying	0.1%	3.6%	0.8%	-0.4%	-0.4%
Manufacturing	2.0%	0.3%	-0.1%	-1.1%	0.3%
Electricity, gas, steam and air conditioning supply	-0.7%	1.2%	0.6%	0.1%	0.1%
Water supply; sewerage, waste management and remediation activities	1.9%	3.7%	0.5%	0.2%	0.3%
Construction	8.0%	1.0%	1.8%	-1.1%	-0.1%
Wholesale and retail trade; repair of motor vehicles and motorcycles	2.0%	1.5%	0.8%	-0.6%	0.2%
Transportation and storage	2.3%	1.9%	1.1%	-0.1%	0.2%
Accommodation and food service activities	6.9%	6.3%	0.0%	1.1%	0.4%
Information and communication	0.6%	3.9%	1.7%	0.6%	0.4%

Financial and insurance activities	8.1%	6.1%	-0.2%	0.2%	0.3%
Real estate activities	10.3%	1.3%	-0.2%	1.0%	0.3%
Professional, scientific and technical activities	5.2%	5.5%	0.9%	-0.2%	0.1%
Administrative and support service activities	2.8%	5.5%	1.8%	0.1%	0.3%
Public administration and defense; compulsory social security	3.1%	2.6%	2.0%	0.7%	0.7%
Education	3.5%	3.1%	1.2%	0.8%	0.7%
Human health and social work activities	2.7%	3.3%	0.9%	1.0%	0.6%
Arts, entertainment and recreation	0.0%	4.4%	1.5%	0.6%	0.0%
Other service activities	7.2%	10.4%	-1.9%	1.0%	0.4%

Source: Historical data until 2020 based on COMSTAT, e3.kz results (2021-2050)

As before, most persons are employed in trade, agriculture and education with more than one million employees each, followed by construction, transportation, health care and manufacturing with between 500 and 750 thousand employed persons.

More restrained economic growth from 2030 onwards will also have a dampening effect on labor demand (Figure 20). As a result, unemployment rises.

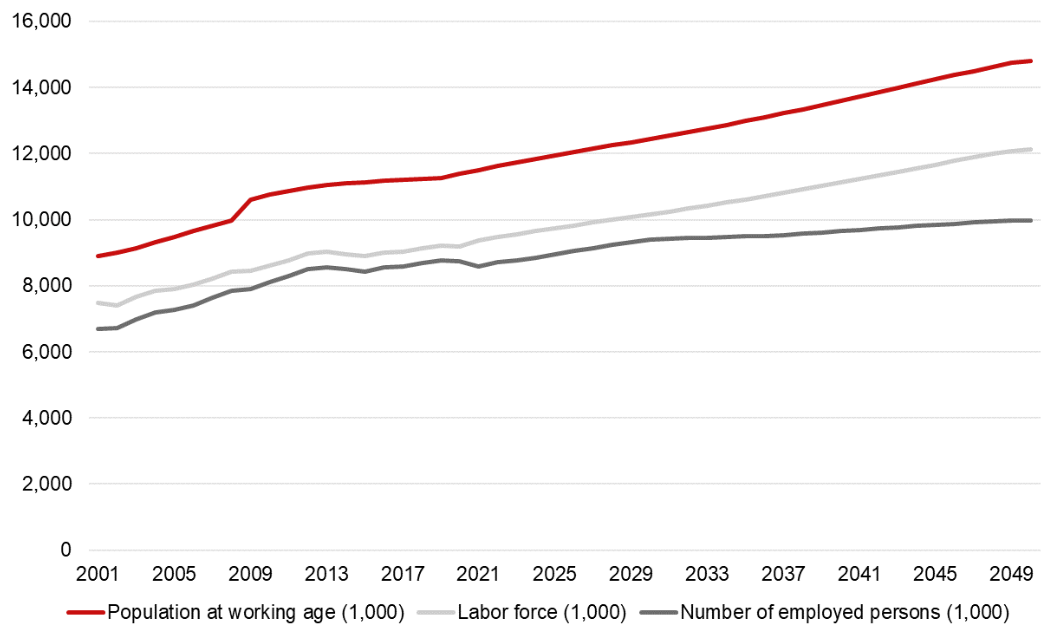


Figure 20: Labor market indicators, 2001-2050

Source: Historical data until 2020 based on COMSTAT, e3.kz results (2021-2050)

4.2.2 ENERGY AND EMISSIONS

The driver of future sectoral energy demand is the expected economic growth in the respective economic sectors, assuming a continuation of the efficiency developments observed in the past. Thus, in the reference scenario, total energy demand will further increase but with a lower rate than economic growth (Figure 21). The decoupling process will further proceed even with no additional policy measures.

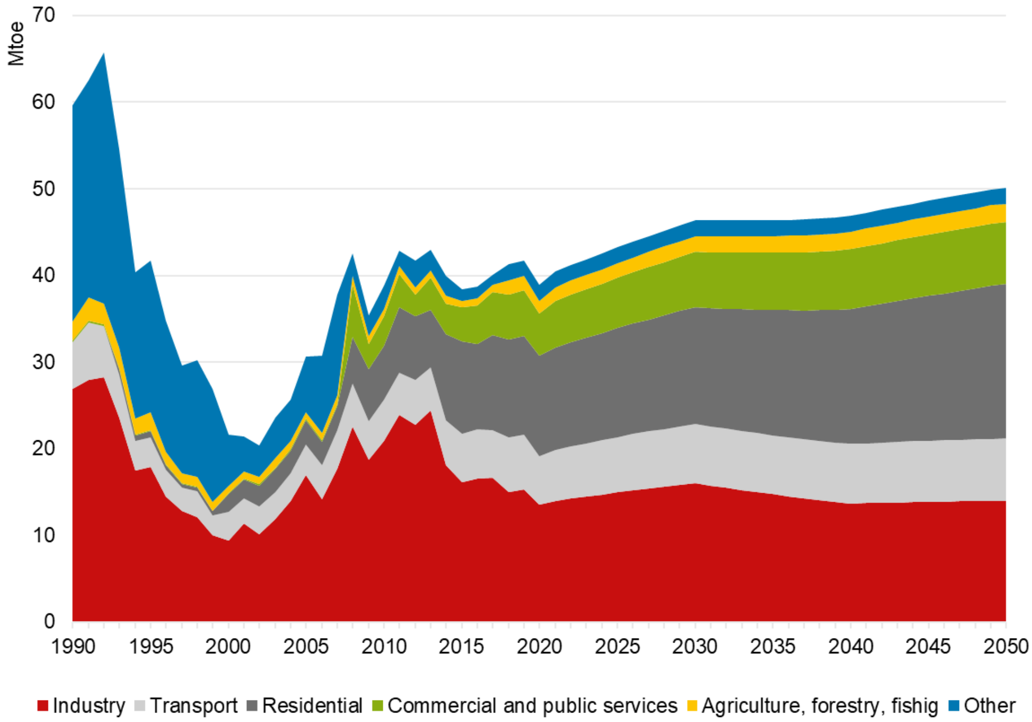


Figure 21: Total final energy demand by sectors, 1990-2050

Source: Historical data until 2019 based on COMSTAT and IEA, e3.kz results (2020-2050)

In 2018, the biggest energy consumers are the industry (36%) and the residential sector (27%), followed by commerce and public services (13%) and transport sector (15%).

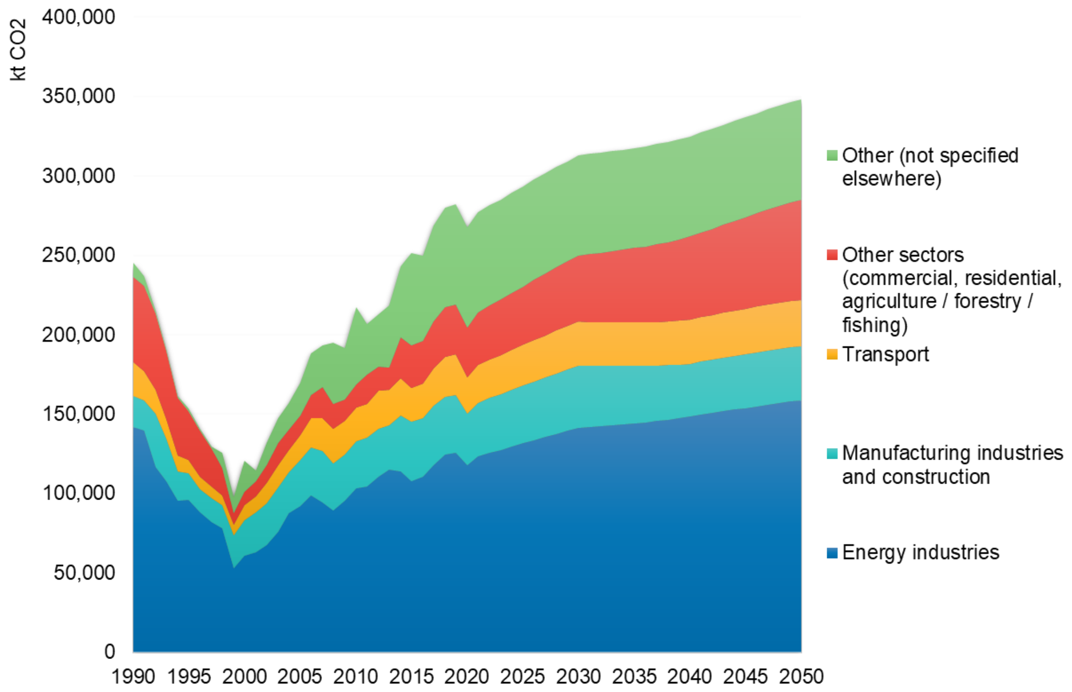


Figure 22: CO_2 emission by sectors, 1990-2050

Source: Historical data until 2019 based on UNFCCC, e3.kz results (2020-2050)

A stronger use of renewable energy in final energy demand is not presumed. According to the preliminary results of the LEDS project, the expansion of hydropower as well as wind and solar power for electricity generation increases by 22% in 2050 compared to 2019, or eightfold in the case of photovoltaic and wind power (DIW Econ 2021). The low energy efficiency development and constant shares of renewable energies lead to further increases in fuel combustion-related CO_2 emissions (Figure 22).

5 ECONOMICS OF CLIMATE CHANGE

5.1 IMPLEMENTING CLIMATE CHANGE IMPACTS IN THE E3.KZ MODEL

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

However, in order to get an idea of the possible future economic impacts of climate change and in particular of the mentioned EWEs, the macro-econometric model e3.kz and the scenario technique are applied (c.f. section 2.2 and 0).

The model e3.kz is based on a comprehensive, historical data set describing the past development of the Kazakh economy, the energy sector and the emissions. Usually, economists derive future developments from past observations. Unfortunately, economic impacts from climate change are not directly visible in the time series data. Either climate change did not cause any observable damage to the economy, was not relevant for the economic performance or could not even be detected as an impact from climate change because repairing climate change damages may result in positive GDP effects (so called defensive spending). In addition, the damage may have been avoided or reduced by adaptation measures.

Furthermore, economic and climate models are operating on different temporal and spatial scales. While climate models have a high spatial resolution and a long-term horizon, e3.kz models the Kazakh economy at the national level and has a mid-to long-term perspective until 2050. Additionally, climate models are very computing intensive while the e3.kz model computes in less than a minute on an average desktop computer or laptop. Thus, climate models are not integrated into e3.kz. Instead, scenario analysis is applied to model climate change and adaptation which follows a four-step approach:

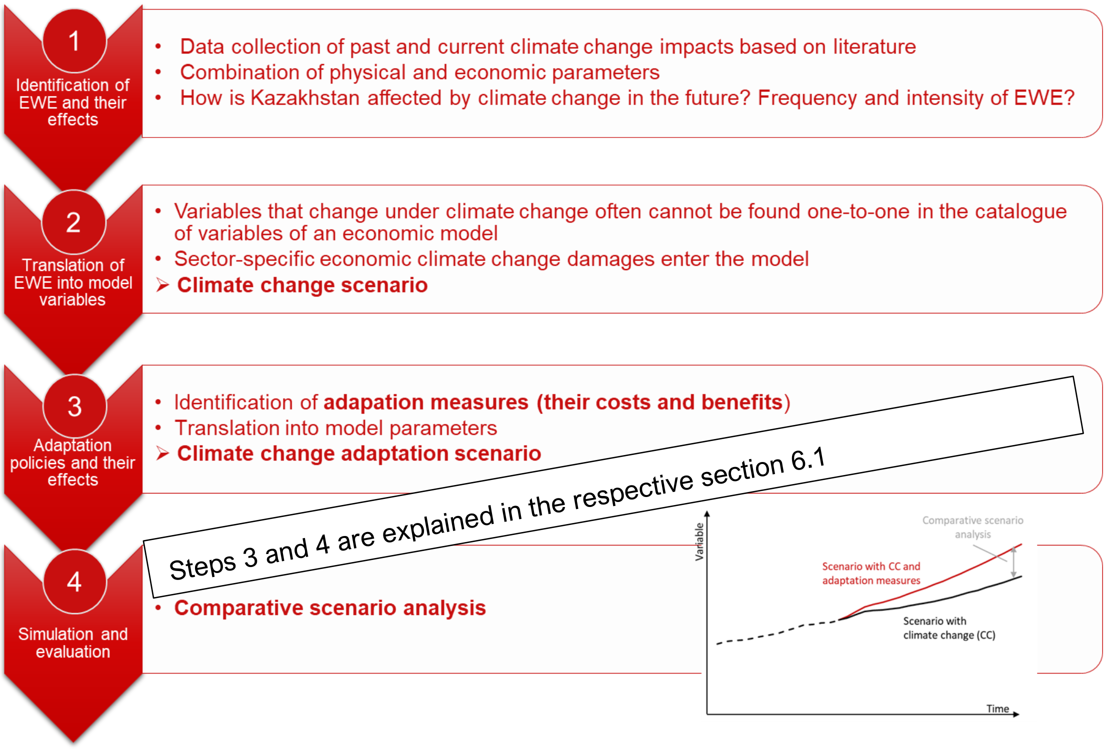


Figure 23: Four step approach to implement climate change and adaptation in an economic model

Source: Own illustration based on Lehr et al. 2020

Following this approach helps to understand the economic impacts of climate change and how potential adaptation measures help to minimize or even avoid these effects.

(1) Identification of EWE and their effects

For the model, a climate change scenario is created which explicitly links frequency and intensity of climate hazard projections (section 3.2.2) and its sectoral economic impacts (section 3.3). The impact chain concept (Fritzsche et al. 2014) is used to identify relevant interfaces and effect chains of a climate hazard (e. g. a drought may impact agricultural production and hydro power generation). The aim is to derive and link biophysical and sectoral economic effects (e. g. water scarcity affects agricultural output or the energy production potential).

The following table provides an overview on how to implement climate change impacts at sectoral level.

Table 10: EWEs and their sectoral impacts

Climate events	Directly impacted economic sector(s)	Output from biophysical model(s) or observed climate impact(s)
Drought	Agriculture	Harvest loss
	Energy	Limited energy supply from hydro power
Wild fire	Agriculture	Harvest loss
	Forestry	Harvest loss Reforestation

Heat wave	Health	Increased health expenditures Working hours lost through illness
	Energy	Limited energy supply due to insufficient cooling in CHP plants Increased energy demand in summer for air conditioning
	Various economic sectors (e. g. service sector, agriculture, construction	Lower labor productivity
Extreme temperature	Energy	Limited energy supply due to insufficient cooling in CHP plants Limited energy supply from hydro power due to higher evaporation Increased energy demand in summer for air conditioning Decreased energy demand in winter
	Transportation	Deforming of roads and rails
Extreme precipitation / flood / extreme wind	Energy	Damages to pipelines, power lines, dams Production losses in various economic sectors due to power outages
	Transportation	Damages to roads and bridges Damages to vehicles Alternative routes / increased fuel demand
	Buildings	Damages to buildings, household items
	Industry	Damages to production facilities Output losses due to impaired production

Source: Own illustration inspired by Ciscar et al. (2014) and Lehr et al. (2020)

In particular, sector-specific and in many cases also region-specific[25] damage data from past climate events are used to identify and value the direct climate change impacts. Since no official and comprehensive data set exists, the economic damages must be derived from single past climate events in the country. These are collected by screening of scientific (national and international) literature, media and expert surveys. The damage data (section 3.3) serves as a benchmark for estimating future climate change impacts. Adjustments will be made to the benchmarks in scenarios to reflect the expected intensity of climate hazards by assuming that, for example, the doubling of hazards per year will also double the benchmark damages. The combination of the future evolution of EWEs and observed climate change damages results in a time series of damages for the respective EWE.

[25] The effects of climate change (especially climate damage) can occur nationally (e. g. drought, heat wave), regionally (e. g. storm) and locally (e. g. heavy rain).

If time series with damage data are provided by literature and / or experts, they can be directly used as in the case of output losses in agriculture (UNDP 2020a).

Future occurrence and intensity of country specific climate hazards (drought, heatwave, flooding etc.) are provided for the RCP 2.6 and 8.5 scenarios by experts from the University of the Balearic Islands (UIB) associated with CORDEX[26] (Navarro and Jordà 2021). The frequency of a climate hazard, e. g. every five years, is derived from past observations or expert knowledge.

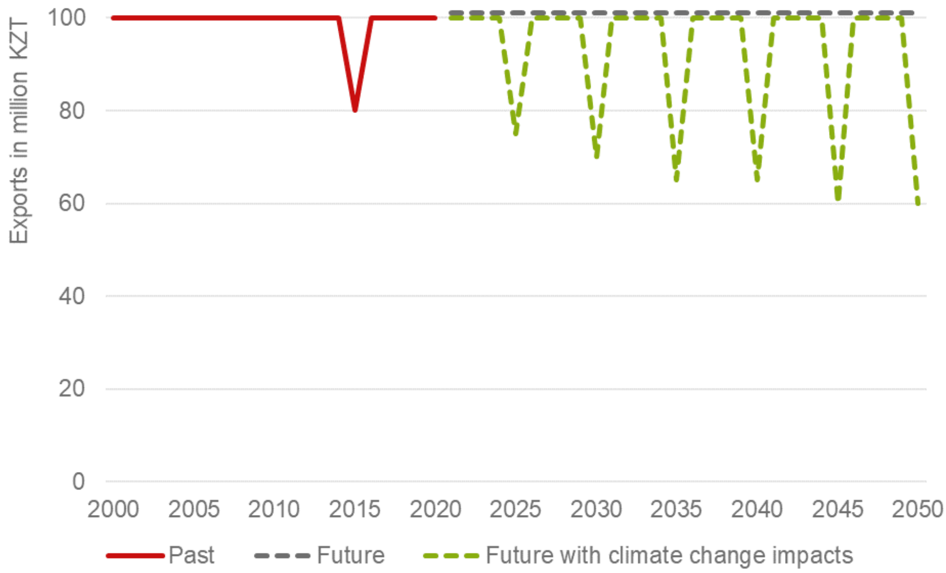


Figure 24: Example for the forward projection of past production data and integration of climate change effects

Source: Own illustration

Figure 24 illustrates the necessity to explicitly integrate climate change effects into the e3.kz model. The example illustrates an output of 100 million KZT for the past, except for the year 2015. In 2015, there is an exemplary decline of 20% due to a climate hazard with immediate recovery. Time series analysis would most likely expect a similar pattern for the future or a behavior as indicated with the orange line and thus, ignoring that without adaptation climate change impacts will become more frequent and severe. Hence, the climate change impacts must be explicitly determined in a scenario as indicated with the green line in Figure 24.

[26] Coordinated Regional Climate Downscaling Experiment.

(2) Translation of EWE into model variables

The identified climate change effects need to be translated into model parameters. The structure of the e3.kz model may require translations. For example, changes in production are implemented in e3.kz by adjusting either demand or imports. Basically, the initial impacts of climate events are implemented as effects on human behavior, production factors and / or infrastructure (indicated by ● in Figure 25), e. g.

- Household consumption expenditures by various products,
- Exports by various products,
- Investments goods,
- Imports by various products,
- Employment in various economic sectors,
- Prices for various products,
- Intermediate demand and
- Lower output from (hydro) power generation.

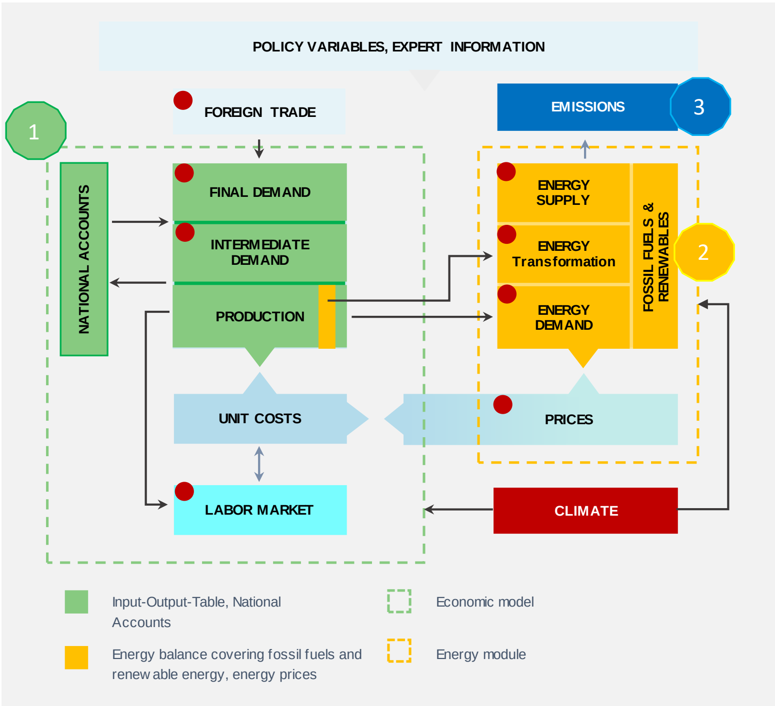


Figure 25: Implementing climate change damages into e3.kz

Source: Own illustration, based on GWS, 2022.

For example, damages to the capital stock, in particular destroyed buildings, production facilities or transport infrastructure (roads, bridges, pipelines, warehouses), must be reconstructed and cause additional (unvoluntary) investments. Damages to private property initiate additional (unvoluntary) consumption of private households. The involuntary expenditures must be financed – either by the investing sector or private households themselves or possibly by the government or any international donors.

For any additional investment, it is presumed that sufficient capacities (labor, production facilities) are available to meet the stronger demand. Even in the case of increased imports due to limited domestic production, it is assumed that there will be no supply restrictions from abroad.

The sector-specific direct impacts cause chain reactions within the E3 modelling system. The resulting impacts for other economic sectors not directly impacted by climate change as well as macroeconomic effects (e. g. GDP, jobs, production in other sectors) can then be evaluated by comparing the climate change scenario with a hypothetical no-climate change scenario (reference scenario).

Economy-wide effects of various extreme weather events – Case studies

In the next subsections, case studies exemplary illustrate the economy-wide impacts in terms of e. g. economic growth, jobs and CO_2 emissions of selected EWEs calculated with the model e3.kz. All scenarios are based on the RCP 8.5 scenario which is the most pessimistic scenario in terms of concentrations of GHG in the atmosphere assuming a global temperature increase of +4.8°C compared to the preindustrial level. In contrast, RCP 2.6 is the most optimistic scenario with a global temperature increase of +2°C compared to the preindustrial level considering that all countries follow the Paris Agreement and drastically reduce the GHG emissions since the beginning of the 21st century. The intensity (or number per year) of the climate hazards for selected areas are taken from the UIB projections which are given for the RCP 8.5 (and RCP 2.6) scenario summarized at the beginning of each subsection. For more information on the various climate hazard indicators and projections, please refer to Navarro and Jordà 2021.

Benchmark damages are based on real EWE observed in the past (section 3.3). The damage data collection of climate hazards show that they range from minor to major damages depending on the severity of an EWE and the regional occurrence. If an EWE occurs in economically strong and / or populous regions, greater economic damage can be expected than in regions with smaller economic strength and populations.

The reference scenario (chapter 4) sets the basis for modeling the economic impacts of climate change following the approach described in section 5.1. In the next sections, effects of selected climate hazards are modelled applying scenario analysis. The analysis is not limited to the isolated evaluation of individual EWEs. Instead, several EWEs with their sector-specific impacts can be considered in one scenario as well.

The selection of the EWEs, economic sectors and adaptation options is the result of the collaboration with the Kazakh partners ERI and Zhasyl Damu as well as other experts. In this context, the identification of climatic threats (c. f. section 3.2) and the knowledge of past events and monetary damages (c. f. section 3.3) have guided the scenario design, which was jointly elaborated step by step in training and coaching sessions. Assumptions and scenario results have been discussed with sector experts (e. g. in agriculture) throughout different workshops.

These scenarios are the starting point for analyzing the macroeconomic impacts of climate change and adaptation (see also section 6.2). By varying scenario assumptions, ranges (best and worst cases) as well as new findings and data can be evaluated in terms of their macroeconomic effects. The analysis of different "what-if" scenarios helps to reduce the uncertainty regarding the macroeconomic impacts of climate change and adaptation. The climate change scenarios are built upon hazard-specific and region-specific damage data. These scenario assumptions are fed into the e3.kz model and cause chain reactions in the model system. The results are presented for the macroeconomy to show inter-sectoral linkages and the economy-wide effects (without regional effects).

The macroeconomic results may lead to the impression that the economic effects are "small" in particular when singularly looking at percentage differences between a hypothetical "no climate change" scenario and a "climate change" scenario. Looking at the absolute numbers, it becomes even clearer that climate change is having a significant impact, in particular when considering that the consequences appear even more severe at the subnational level.

5.1.1 ECONOMY-WIDE EFFECTS OF DROUGHTS

Scenario assumptions and implementation

In the past, most of the extreme droughts took place in North and Central Kazakhstan which was on average between 0.3 and 0.6 events per year according to the “SPEI < - 2”[27]. Regarding the climate model simulations for the RCP 8.5 scenario, the number of drought events will occur more frequently in the future, in particular in Central Kazakhstan and Almaty. The Northern region which is affected most as of today shows a slight decrease of 1% per year from 0.6 to 0.4. The other regions are confronted with an increasing number of drought events per year (Figure 26).

For the “drought” scenario, the drought intensity is based on the evolution of droughts in the Northern region where an increase to 0.4 droughts per year is anticipated. Droughts are expected to occur every four years.

[27] The Standardized Precipitation Evapotranspiration Index (SPEI) is based on precipitation, temperature and humidity data. The SPEI < -2 is classified as extreme drought (Navarro and Jordà 2021).

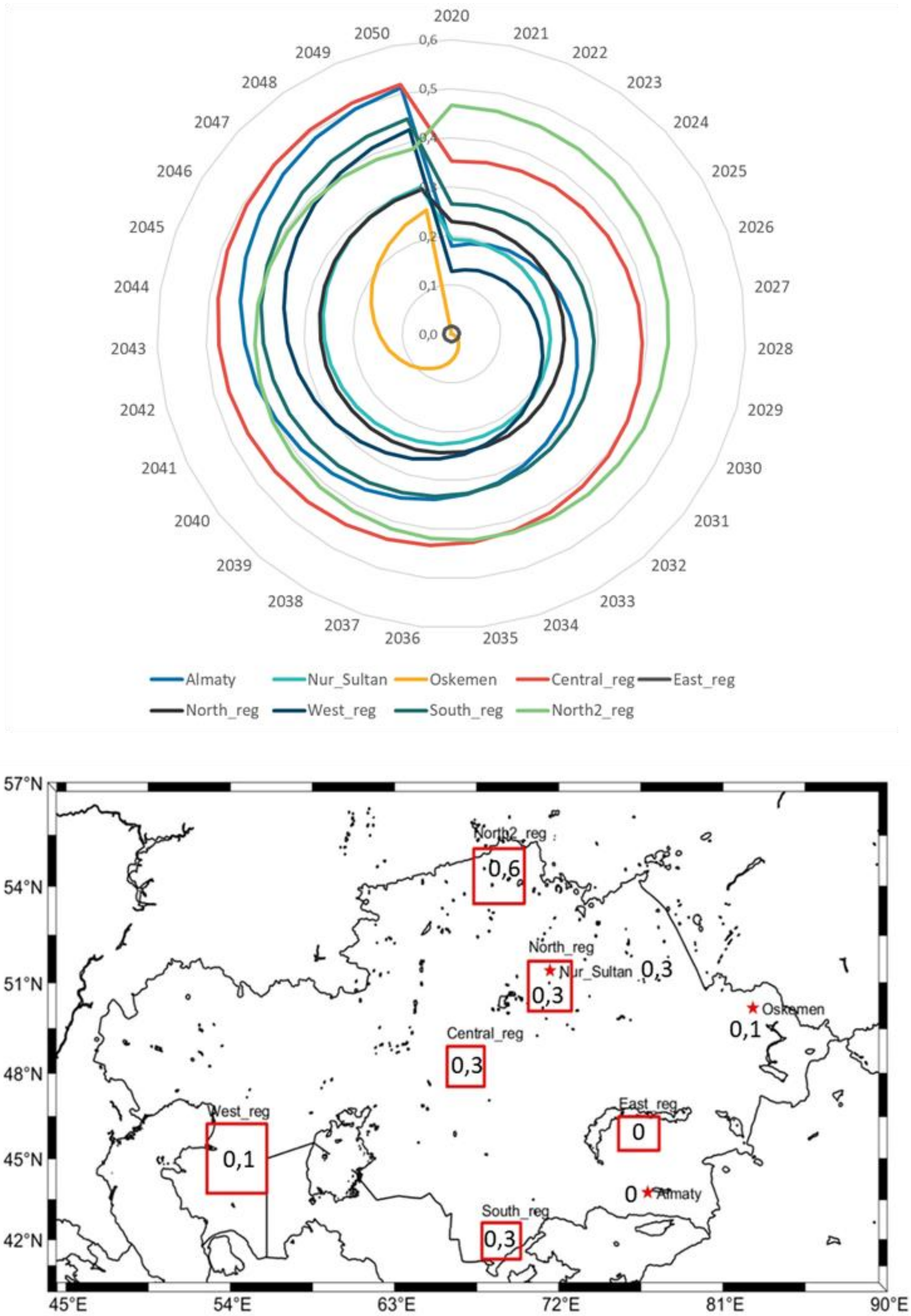


Figure 26: Number of extreme drought events (top figure) per year, 2020-2050 and selected regions (bottom figure) with average number of extreme drought events 1976-2005

Source: Navarro and Jordà 2021

As described in the sections 3.2.3 and 3.3, droughts are impacting mainly the agriculture and energy sector which is summarized in Table 11.

In agriculture, the prevailing wheat production is most affected by water scarcity especially in the North where rain fed wheat production is predominant. According to UNDP (2020), wheat yield losses are expected to increase up to 608 bn. KZT by 2050. Depending on the severity of a drought, the crop is partially or even completely destroyed or the quality of the crops is inferior so that only lower prices can be obtained.

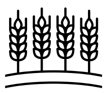
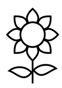
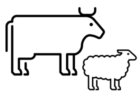
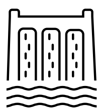
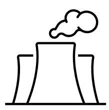
Livestock production is also negatively affected due to lower pasture productivity. As a result, yields are expected to decrease by 170 bn. KZT by 2050 (UNDP 2020a). In contrast, sunflower seed yields are supposed to increase slightly (0.9 to 1.8 bn. KZT) because they are better adapted to droughts.

An increase in water consumption is not assumed due to the fact that wheat production in the Northern Region is mainly rain-fed. Even if irrigation systems are available, costs are only incurred through water use if water is not provided free of charge.

Droughts and the associated lower water levels could also create energy security concerns. Not only hydro power but also thermoelectric power plants are affected due to cooling needs.

An international study on the impacts of droughts on water resources and electricity supply has figured out that the hydro power potential on average is reduced by five percent and thermoelectric power by four percent (van Vliet et al. 2016). According to the IEA energy balance data for Kazakhstan, during the severe drought in 1998 the impact was even worse and accounted for a reduction of 20%. While for the thermoelectric power potential the assumption from the global study is used, for hydro power the scenario relies on the declined power production in 1998.

Table 11: Impacts of a drought

Sector	Drought impacts	Sources
	Wheat yield losses (457 bn. KZT until 2030, 608 bn. KZT until 2050)	UNDP, 2020
	Increased sunflower yields (1,8 bn. KZT until 2030, 0.9 bn. KZT until 2050)	UNDP, 2020
	Decline in livestock production (109 bn. KZT until 2030, 170 bn. KZT until 2050))	UNDP, 2020
	Decreased hydro power production due to lower water levels (-20%)	IEA energy balance 1998
	Reduced thermoelectric power potential due to in-sufficient water availability (-4%)	Van Vliet et al. 2016

Source: Own illustration.

The possible effects of a drought are then implemented into the e3.kz model using the underlying data. To consider that an increasing number of droughts is likely to cause greater impacts, the historical benchmark data for the energy sector is combined with the expected increase of future drought events given by UIB projections (Figure 26). Agricultural yield changes for wheat, livestock and sunflowers are already indicated in the UNDP study until 2050.

Scenario results

Based on the assumption that droughts occur every four years, eight of these events occur in the simulation period until 2050.

Droughts are impacting the economy negatively. GDP is up to 2.4% resp. 2,028 bn. KZT lower compared to a situation with no drought (Figure 27). Export chances cannot be realized and are up to 1.1% resp. 1,262 bn. KZT lower. Higher imports for wheat and electricity dampen the economic growth.

For example, during the drought in 2021, the government has also restricted agricultural exports and at the same time increased imports in order not to endanger the food security in Kazakhstan.[28] It is also assumed that electricity is imported, as domestic power production is limited by the water shortage. The neighboring country Kyrgyzstan was also able to purchase electricity from its neighboring countries during a drought (Pannier 2021). The failures in hydro power generation are not as severe as in Kyrgyzstan due to the fact that the share of hydro power in electricity production with approximately 13% is low compared to Kyrgyzstan with a share of 90%.

Furthermore, lower employment and income levels reduce the spending opportunities of private households. Other imports are decreasing due to lower economic activity and support economic growth. The import dependency is generally high and thus lower demand for intermediate and finished products results in lower imports (Figure 27). However, imports are still increasing by maximum 2.6% resp. 411 bn. KZT.

Drought intensity is increasing over time and causes increasingly stronger economic costs. Between the drought years the economy recovers over time but not fully due to lagged reactions in investments and government consumption.

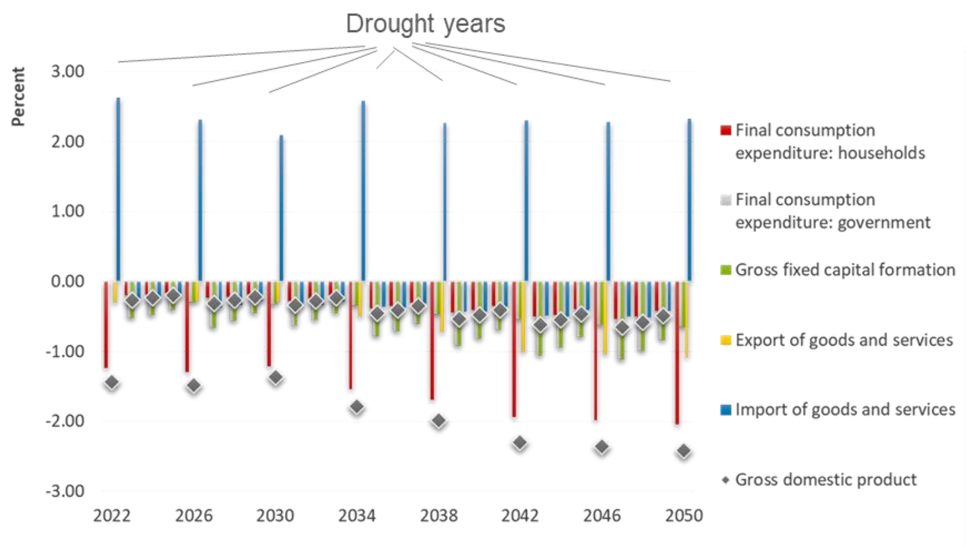


Figure 27: "Drought" scenario (RCP 8.5): macroeconomic effects, 2022-2050, deviations from a hypothetical "No drought" (REF) scenario in percent

Source: Own illustration based on e3.kz results

In drought years, production is in particular constrained in the agriculture and energy sector (Figure 28). Other sectors that are not directly affected by the drought are also influenced via economic

---

[28] https://www.agriculture.com/markets/newswire/drought-hit-kazakhstans-wheat-supplies-bolstered-by-high-stocks-russian-imports (last accessed, September 24, 2021)

interlinkages. For example, the demand of the agriculture sector for intermediate products such as pesticides sold by the chemical industry is lower. Also the food production industry records a lower production level because less agricultural products are available to be processed.

Lower consumer expenditures by private households (Figure 28) on food, beverages and food services, among other things, cause further production adjustments.

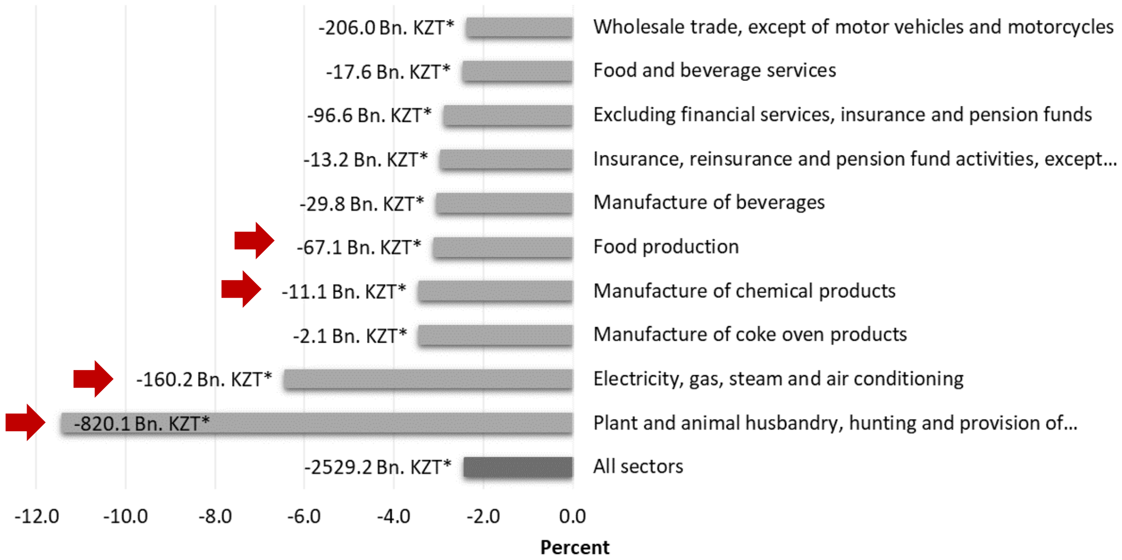


Figure 28: "Drought" scenario: real production by economic sectors, drought year 2050, deviations from a hypothetical "No drought" (REF) scenario in percent (x-axis) and bn. KZT (*)

Source: Own illustration based on e3.kz results

Employment follows the production considering the sectoral labor-intensities which is highest in the agriculture and many service sectors (e. g. wholesale and retail trade). Figure 29 shows the change in employment compared to the reference scenario. Total employment is up to 1.4% resp. 141 thousand persons lower per year compared to a situation without a drought. Employed persons in the agriculture sector suffer the most due to the high labor intensity. Jobs in the energy sector are less affected because labor intensity is lower.

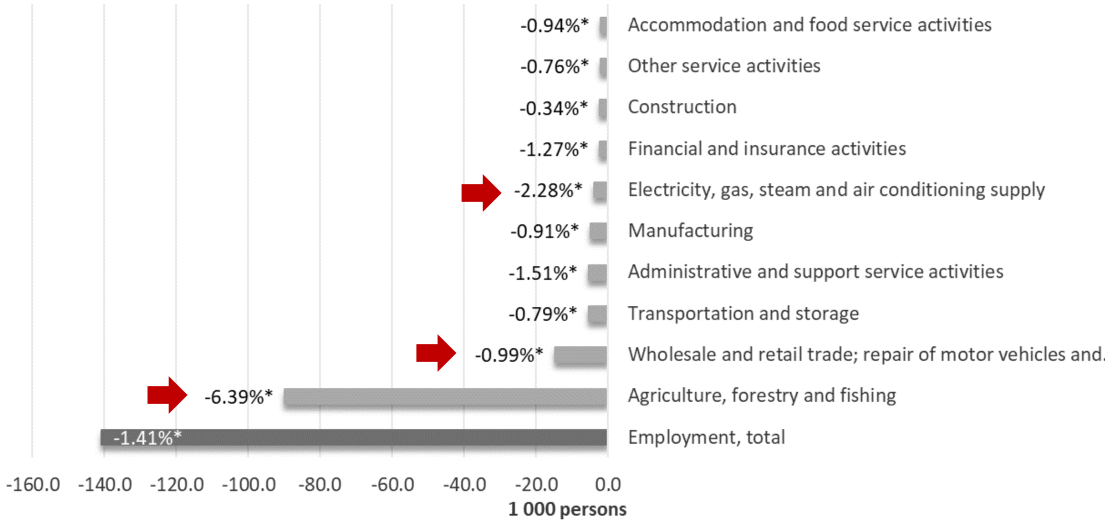
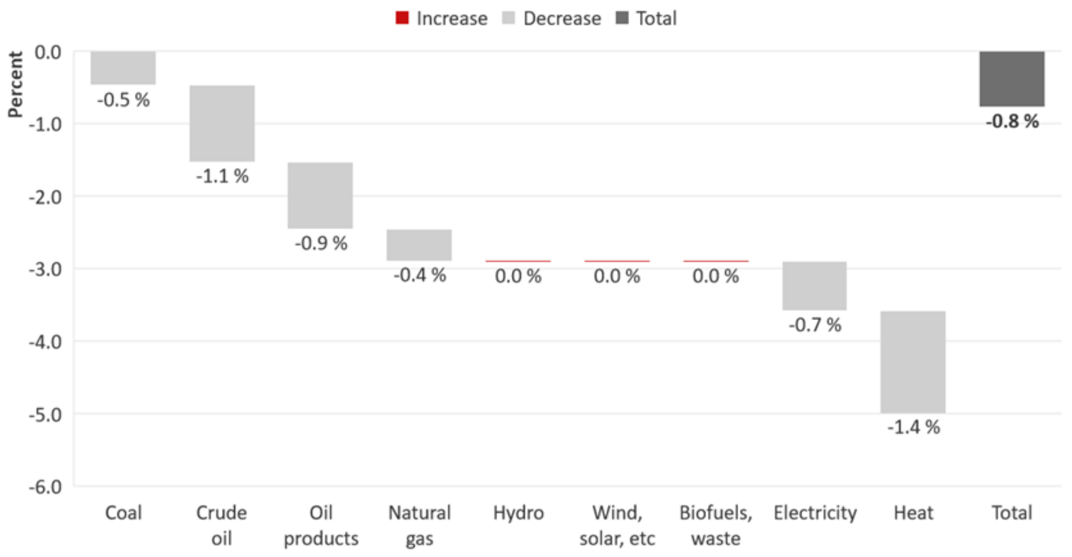


Figure 29: "Drought" scenario: employment by sectors, drought year 2050, deviations from a hypothetical "No drought" (REF) scenario in 1,000 persons

Source: Own illustration based on e3.kz results

The impacts on the environment are positive. Limited economic growth caused by droughts results in lower final energy consumption (Figure 30) and CO_2 emissions (Figure 31). In 2050, TFEC is by 449 ktoe resp. 0.8% lower compared to a "no drought" scenario which is based on less fossil fuels. The use of renewable energy remains at the same level as in a "no drought" scenario indicated by a zero percentage deviation resp. zero ktoe.



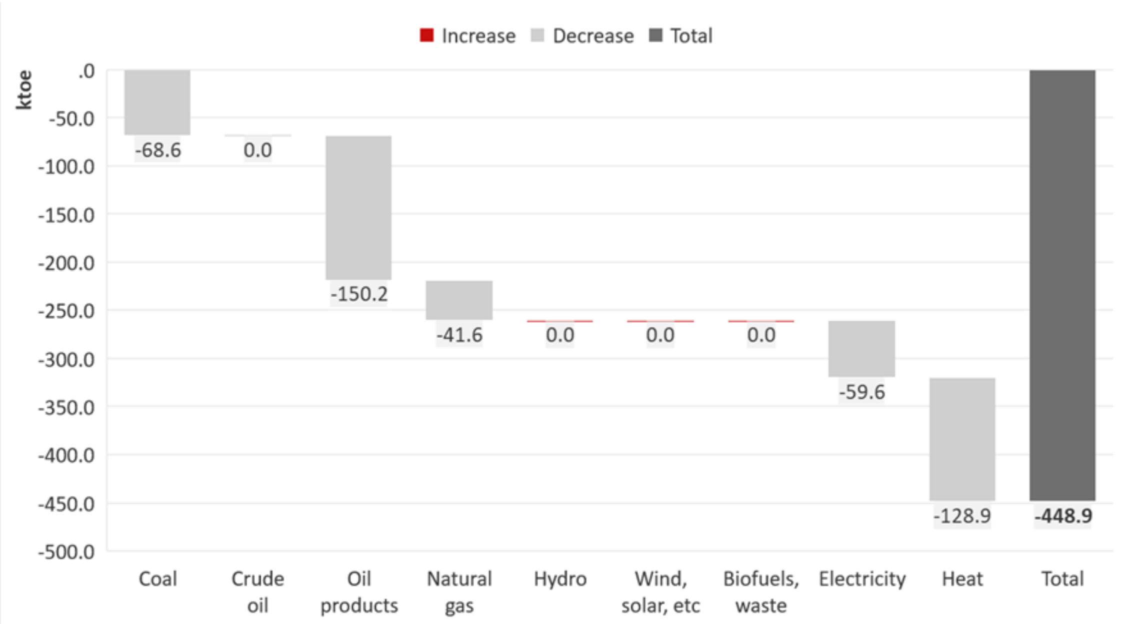


Figure 30: "Drought" scenario: energy demand, drought year 2050, deviations from a hypothetical "No drought" (REF) scenario in ktoe (top figure) and percent (bottom figure)

Source: Own illustration based on e3.kz results

Another positive impact is related to the temporary lower production of the thermoelectrical plants mainly operating with fossil fuels which results in a decreasing total primary energy supply in particular for coal and natural gas.

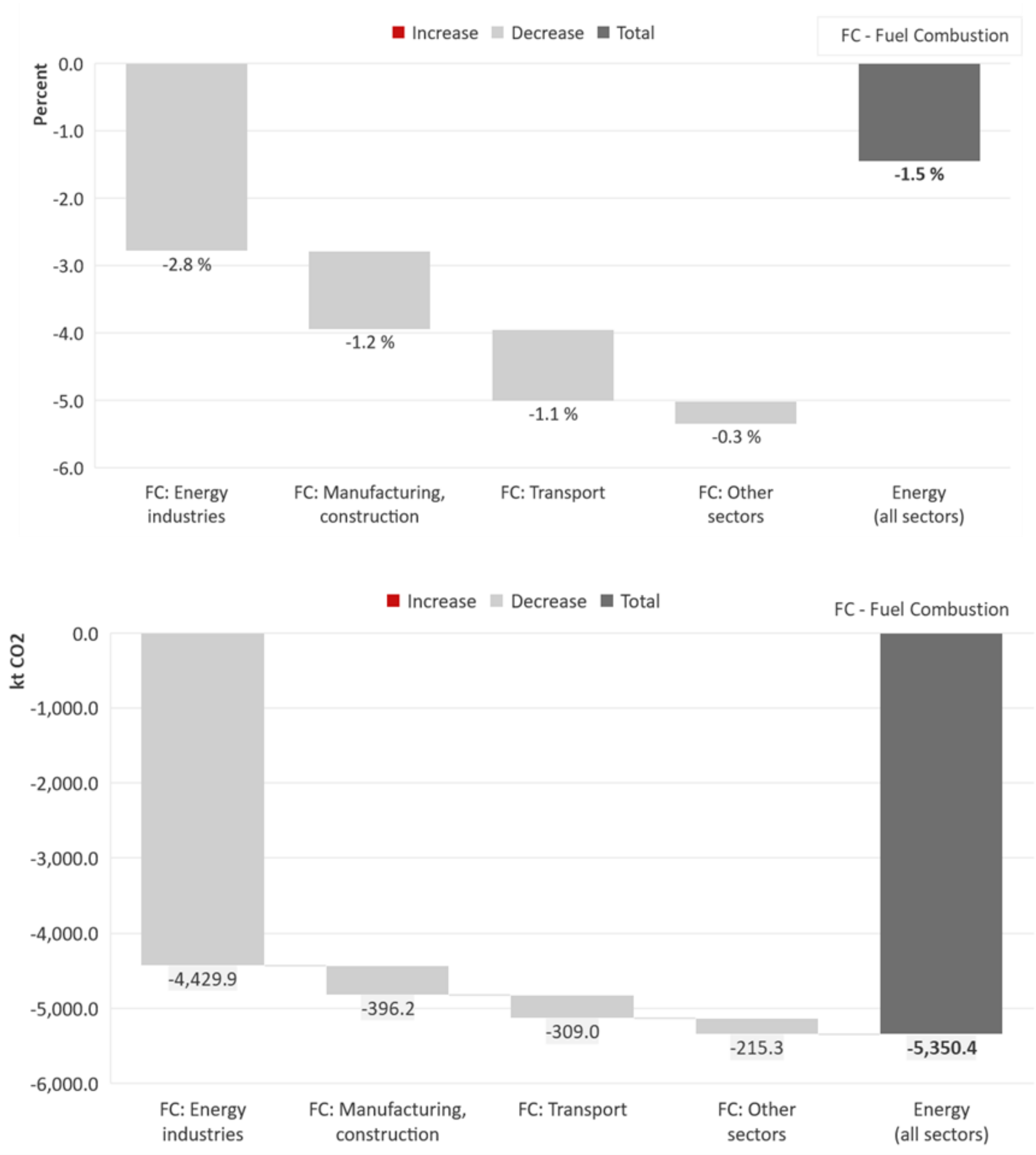


Figure 31: "Drought" scenario: CO_2 emissions, drought year 2050, deviations from a hypothetical "No drought" (REF) scenario in kt CO_2 (top figure) and percent (bottom figure)

Source: Own illustration based on e3.kz results

The lower energy demand of fossil fuels leads to an overall reduction in emissions of 1.5% or 5.4 Mt CO_2 (Figure 31). In the energy industries, CO_2 emissions can be reduced the most compared to a "no drought" scenario.

Figure 32 summarizes the key impacts of the “drought” scenario.

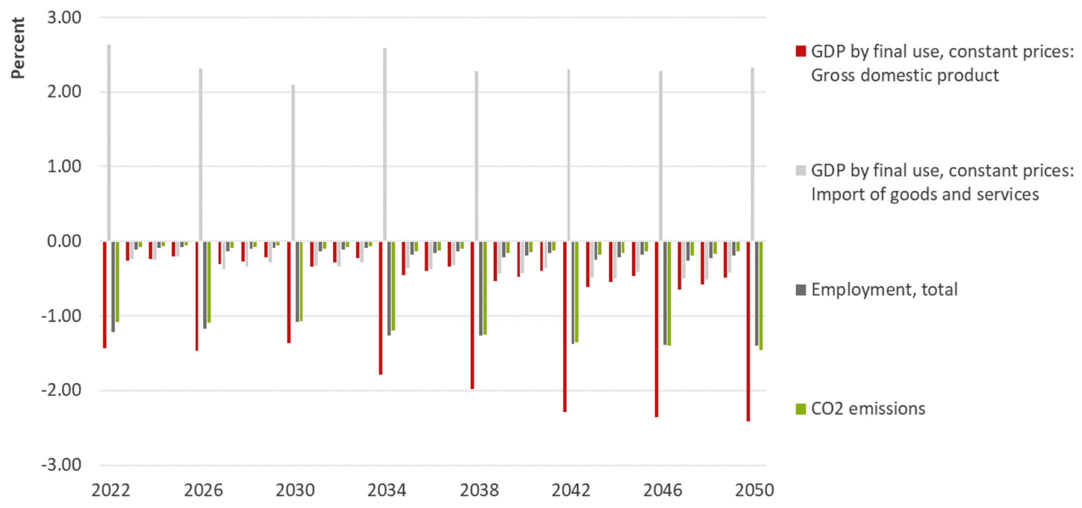


Figure 32: "Drought" scenario: key impacts, 2022-2050, deviations from a hypothetical "No drought" (REF) scenario in percent

Source: Own illustration based on e3.kz results

5.1.2 ECONOMY-WIDE EFFECTS OF HEAT WAVES

Scenario assumptions and implementation

According to Navarro and Jordà (2021), a heat wave is defined as an event with temperatures higher than the 99th quantile computed from the historical period with five or more consecutive days. Figure 33 (bottom) indicates the respective threshold temperatures in the selected regions according to that definition. The threshold for heat waves differs with regard to the temperature in the regions and ranges from 22°C in Nur-Sultan and Northern regions to 32°C in Southern region. According to climate projections, heat waves in Kazakhstan will increase strongly from about 0.4 to max. 1.2 per year (Figure 33).

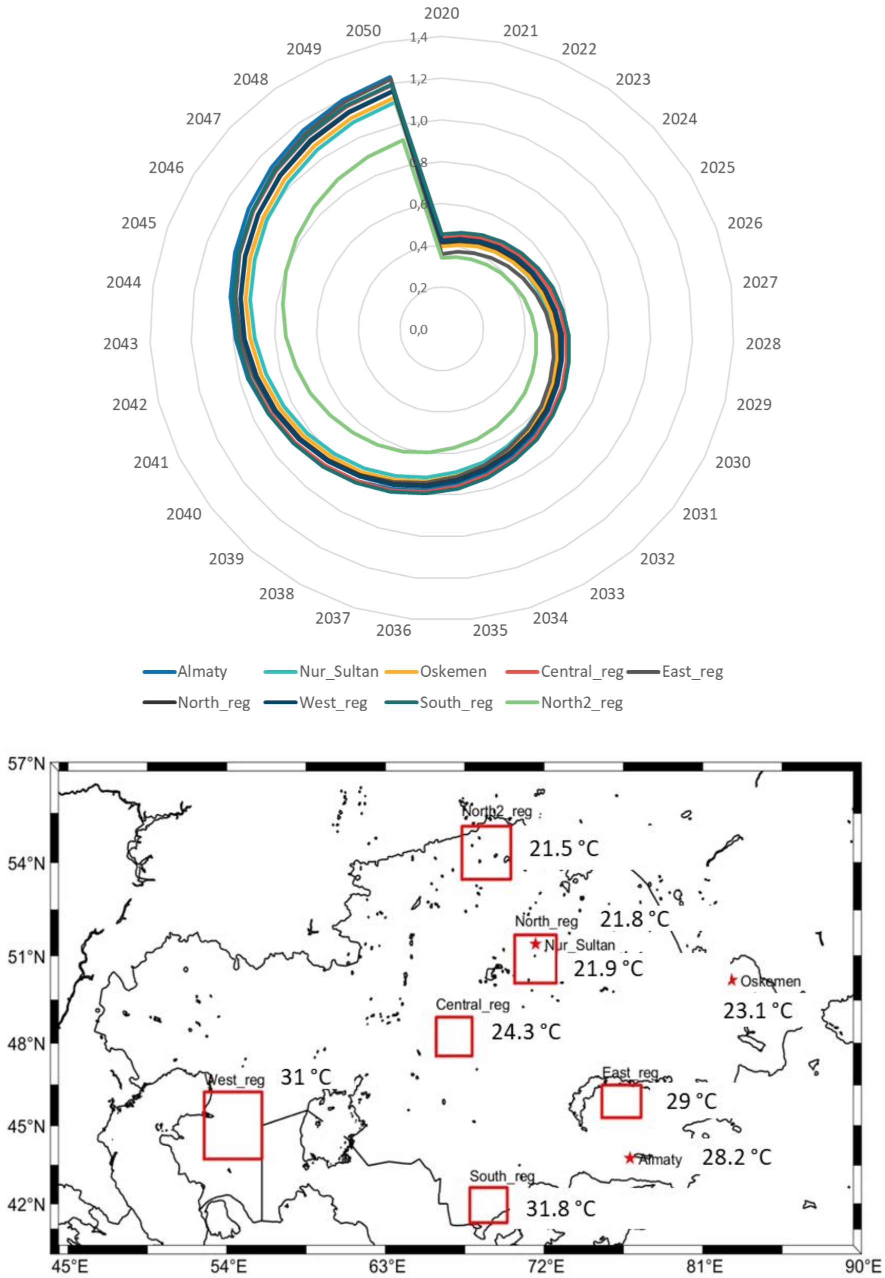
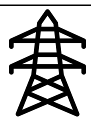
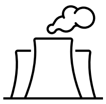
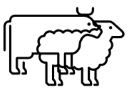


Figure 33: Number of heat wave events per year, 2020-2050 (top figure) and selected regions (bottom figure) with threshold values 1976-2005

Source: Navarro, Jordà 2021

Table 12 shows possible impacts for various economic sectors which were already presented in section 3.2. As in the drought scenario, agriculture and the energy sector are assumed to be affected. High temperatures lead to increased evaporation and thus to water scarcity. Lower wheat yields and pasture productivity may result. Price increases for agricultural products are to be expected.

Table 12: Impacts of a heat wave

Sector	Impact	Source
	Increased government expenditures for health care services due to heat stress (+0.3%)	Own assumption based on estimations for Germany (Hübler 2014)
	Increased demand for beverages due to heat (+3%)	Own assumption based on Mirasgedis et al. 2014 and experiences in Germany during a heat wave in 2018
	Higher electricity demand for cooling (+6%)	Own assumption based on experiences in Germany
	Decreased hydro power production due to lower water levels caused by higher evaporation (-20%)	IEA energy balance 1998
	Reduced thermoelectric power potential due to insufficient cooling (-4%)	Van Vliet et al. 2016
	Wheat yield losses due to water scarcity (457 bn. KZT until 2030, 608 bn. KZT until 2050)	UNDP 2020a
	Increased sunflower yields (1,8 bn. KZT until 2030, 0,9 bn. KZT until 2050)	UNDP 2020a
	Decline in livestock production (109 bn. KZT until 2030, 170 bn. KZT until 2050))	UNDP 2020a
	Production losses due to less productive workers working outside (agriculture and construction)	Based on ILO 2019

Source: Own illustration

Power generation capacity is constrained for both hydropower and CHP plants due to inadequate cooling. As described in the drought scenario, electricity imports increase to compensate for the power shortage. In addition, higher electricity demand for cooling purposes is expected.

According to international experience, higher beverage consumption and more heat-related health expenditures due to morbidity (e. g. cardiovascular illnesses) as well as food and water-borne diseases (e. g. salmonellosis) are to be expected. Furthermore, heat-related mortality may increase whereas cold-related mortality decreases. These impacts are difficult to estimate and depend on many factors such as age, pre-existing conditions, etc. and thus not considered.

The impacts of heat stress on labor productivity for agriculture, the industry sector, construction and service sectors are leaned on the results from the ILO (2019) study for Kazakhstan. According to this, in total 300 full-time jobs were lost to heat stress in 1995 but by 2030 an increase to 1,100 is expected. Agriculture and construction are most affected, each accounting for 0.05% of working hours. No impacts are expected for the service sector and almost no impacts (0.01%) for industries. The productivity losses imply lower output in the affected sectors.

All historical benchmark damages are linked to the expected increase of the number of heat waves (Figure 33) to consider higher damages when climate change is exacerbating. If times series of damage data already exist, such as for agricultural yield and labor productivity losses due to high temperatures, these are adopted in e3.kz.

Scenario results

In the heat wave scenario, it is assumed that a heat wave occurs every five years (2022, 2027, etc.) that has the impacts shown above.

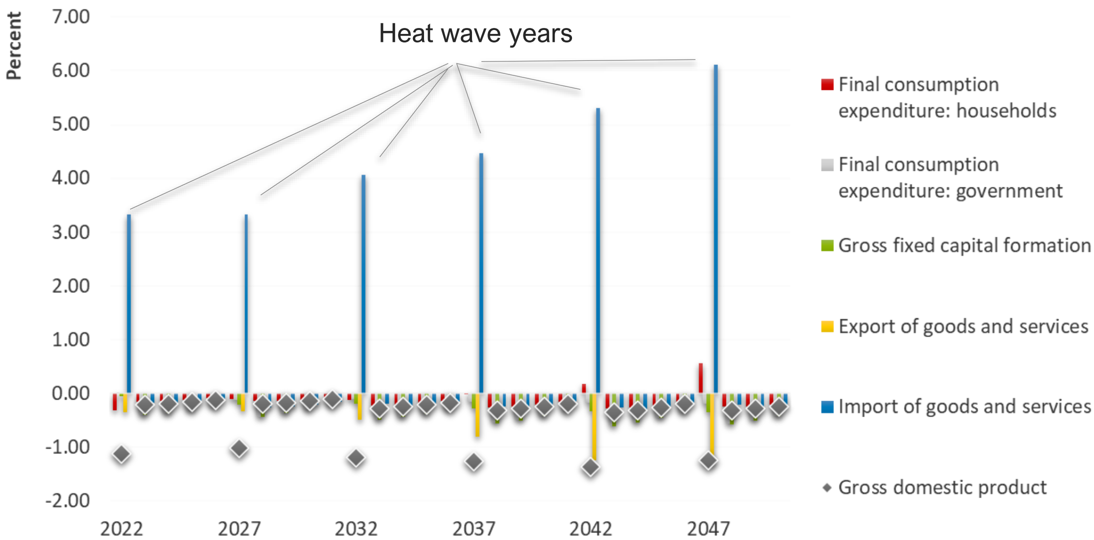


Figure 34: "Heat wave" scenario (RCP 8.5): macroeconomic effects, 2022-2050, deviations from a hypothetical "No heat wave" (REF) scenario in percent

Source: Own illustration based on e3.kz results

The economy-wide impacts are negative. GDP is up to 1.4% resp. 1,074 bn. KZT lower compared to a situation without a heat wave (Figure 34). The increasing imports of agricultural products and electricity as well as lower agricultural exports dampen the GDP. The weaker economic growth on the one hand leads to declining investments and government consumption which are growth dependent. On the other hand, the high import dependency partly reduces total imports..

Household consumption expenditures are increasing over time because the impact of an increased cooling demand and beverage consumption compensates the restrictions due to lower employment and income (Figure 34). A positive but minor impact stems from the additional heat-related health expenditures. These impacts must be interpreted with care and should not be seen as an economic recovery plan. Such "bad" GDP effects are so-called defensive spending. Heat-related expenditures are assumed to be additional expenditures in this case that do not displace other consumption expenditures.

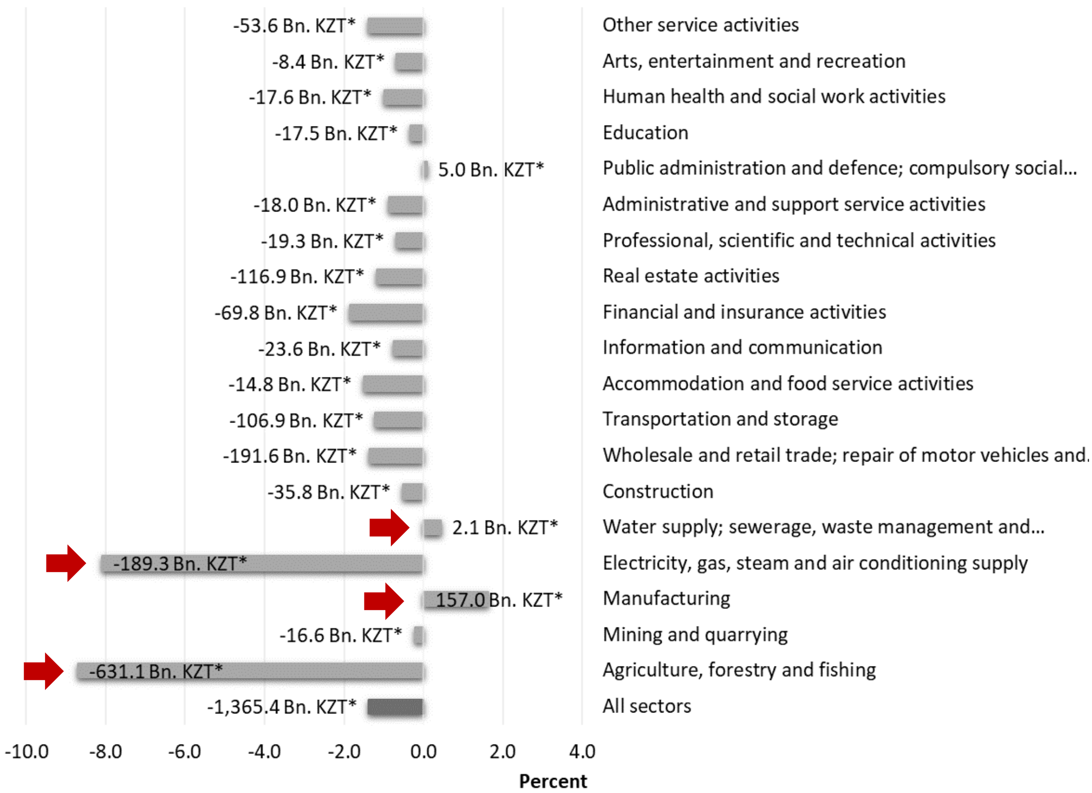


Figure 35: "Heat wave" scenario: real production by economic sectors, heat wave year 2042, deviations from a hypothetical "No heat wave" (REF) scenario in percent (x-axis) and bn. KZT (*)

Source: Own illustration based on e3.kz results

Production is constrained by the heat waves in particular in the agriculture and energy sector (Figure 35). Other sectors such as manufacturing of beverages and water supply increase their production due to higher demand.

Heat stress in agriculture and construction lowers output in the sectors (c. f. Figure 35) but no heat-related suspension of staff is expected. Nevertheless several sectors are affected by output losses, causing reactions in employment of up to -0.95% resp. -93 thousand persons compared to a situation without a heatwave. People in agriculture are affected the most (Figure 36).

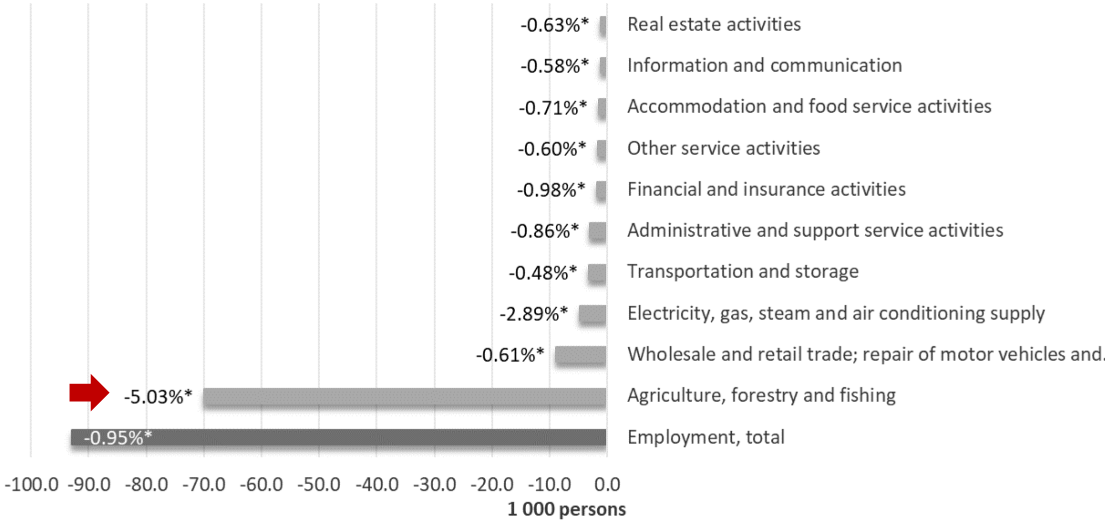
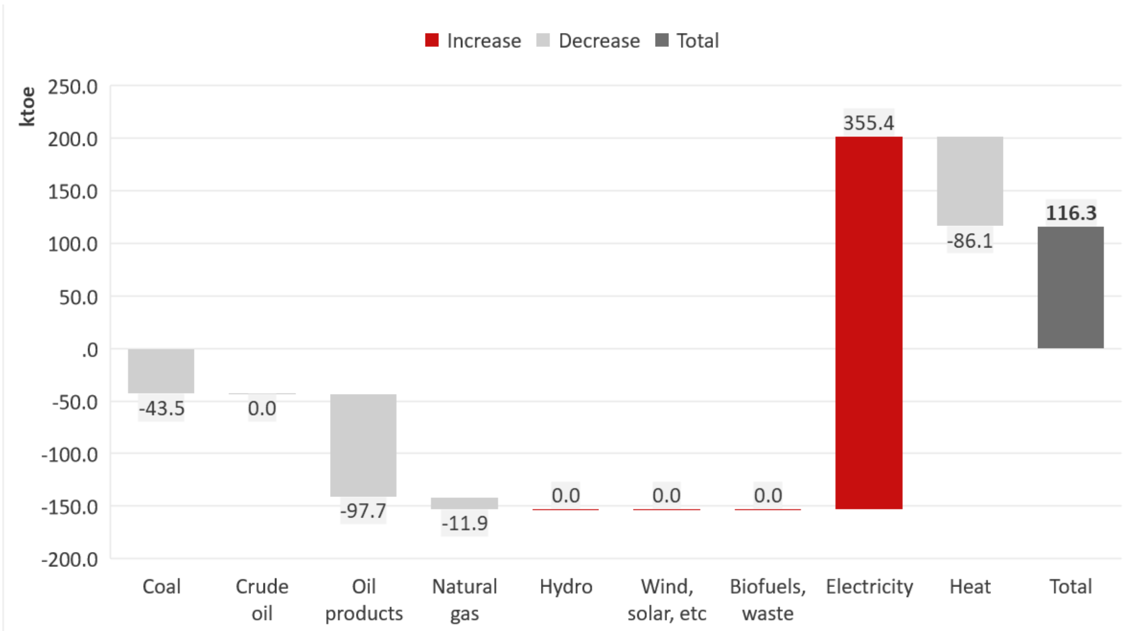


Figure 36: “Heat wave” scenario: employment by sectors, heat wave year 2042, deviations from a hypothetical "No heat wave" (REF) scenario in 1,000 persons (x-axis) and percent (*)

Source: Own illustration

On the one hand, limited economic growth results in lower energy demand. On the other hand, according to the scenario settings, electricity demand is increasing for additional cooling which prevails (Figure 37). In the heat wave year 2042, electricity demand would be 355 ktoe resp. 4.4% higher compared to a “no heat wave” scenario. Total final energy demand increases by 116 ktoe resp. 0.2%.



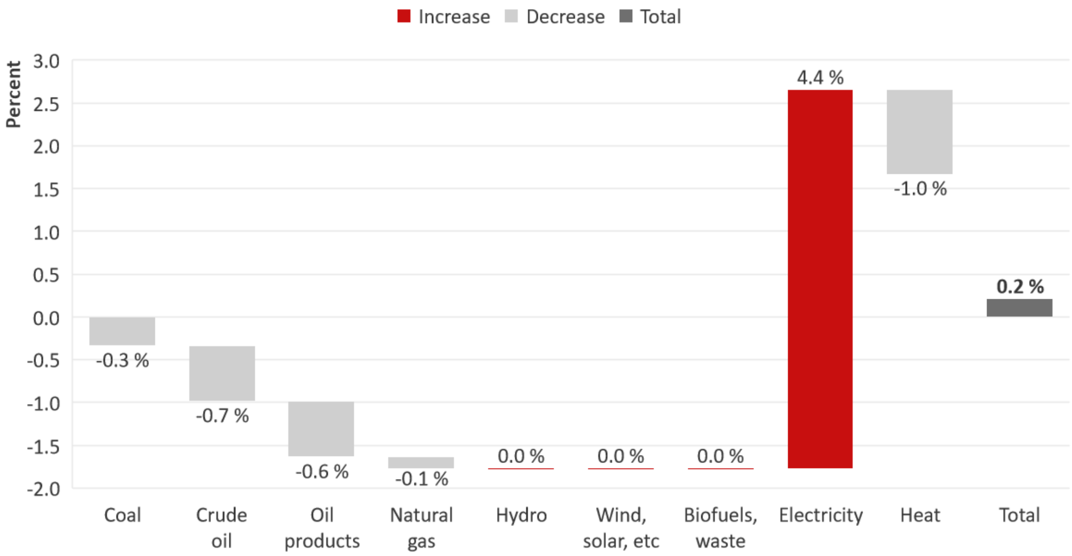


Figure 37: “Heat wave” scenario: energy demand, heat wave year 2042, deviations from a hypothetical "No heat wave" scenario in ktoe (top figure) and percent (bottom figure)

Source: Own illustration based on e3.kz results

At the same time, power generation from thermal power plants and hydropower is impaired resulting in higher electricity imports. Due to this fact, CO_2 emissions (in particular for the energy industries) are lower although energy demand increases (Figure 38). As long as the imported electricity is generated from hydropower or other renewable energy, the environmental effects are positive.

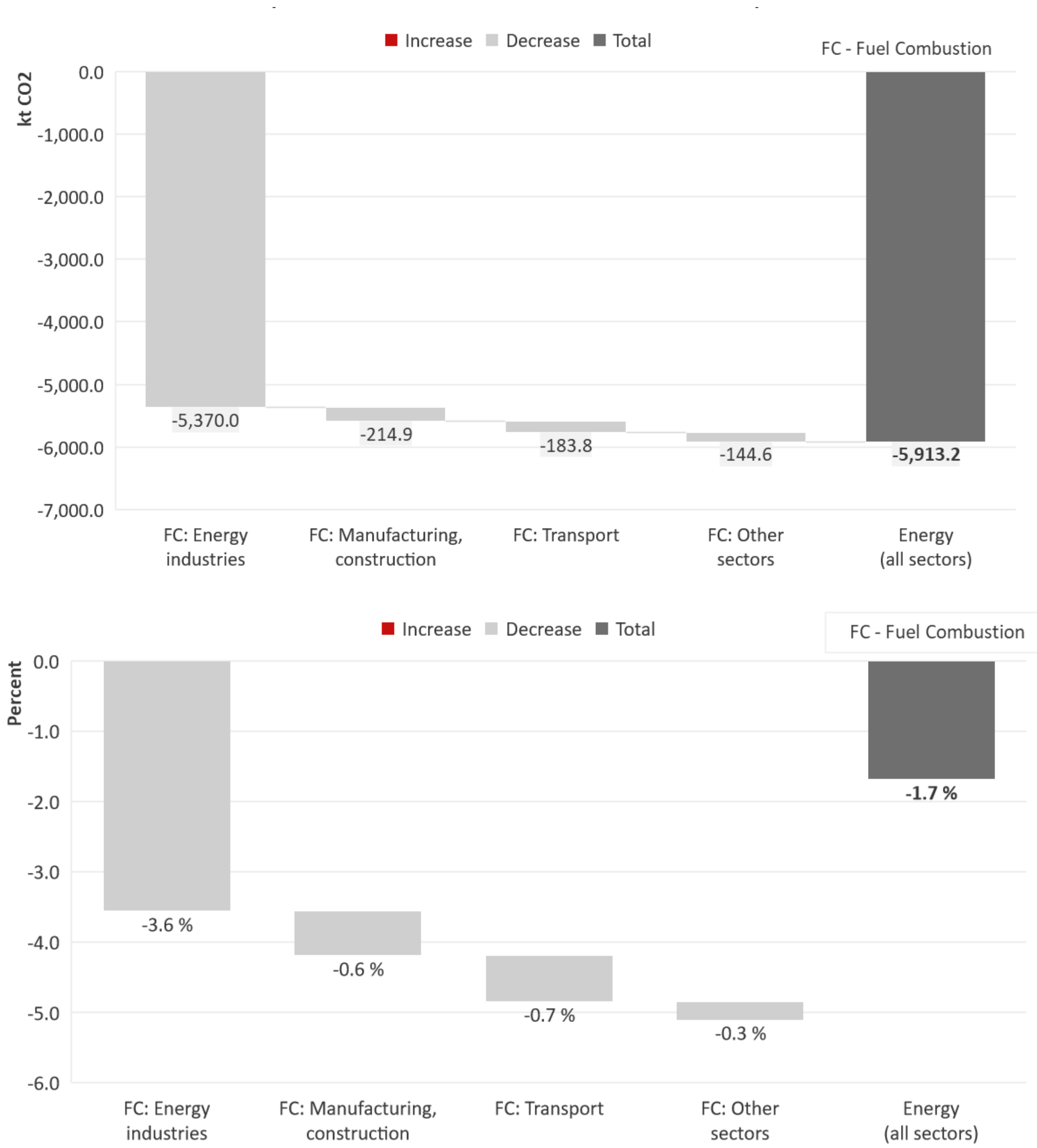


Figure 38: "Heat wave" scenario: CO_2 emissions, heat wave year 2042, deviations from a hypothetical "No heat wave" (REF) scenario in kt CO_2 (top figure) and percent (bottom figure)

Source: Own illustration based on e3.kz results

Figure 39 summarizes the key impacts of the “heat wave” scenario.

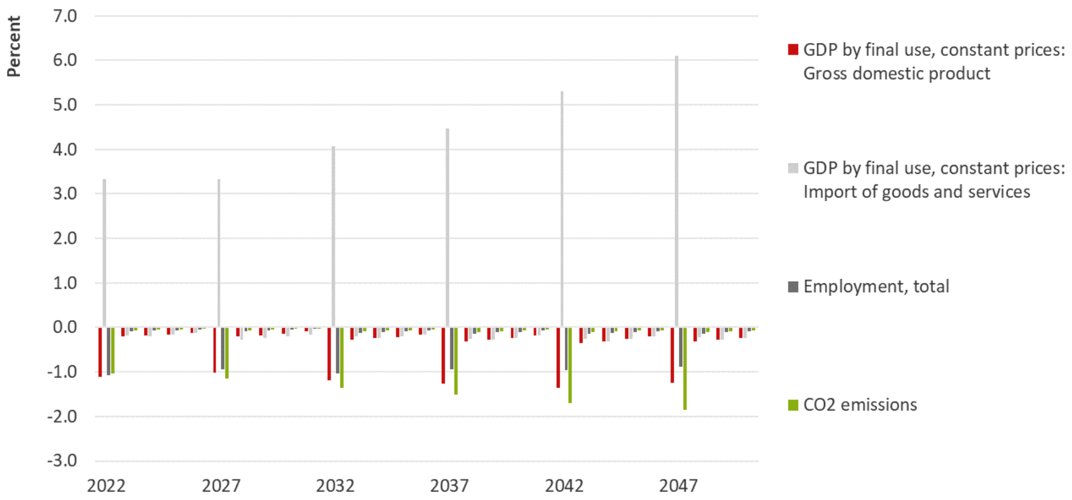


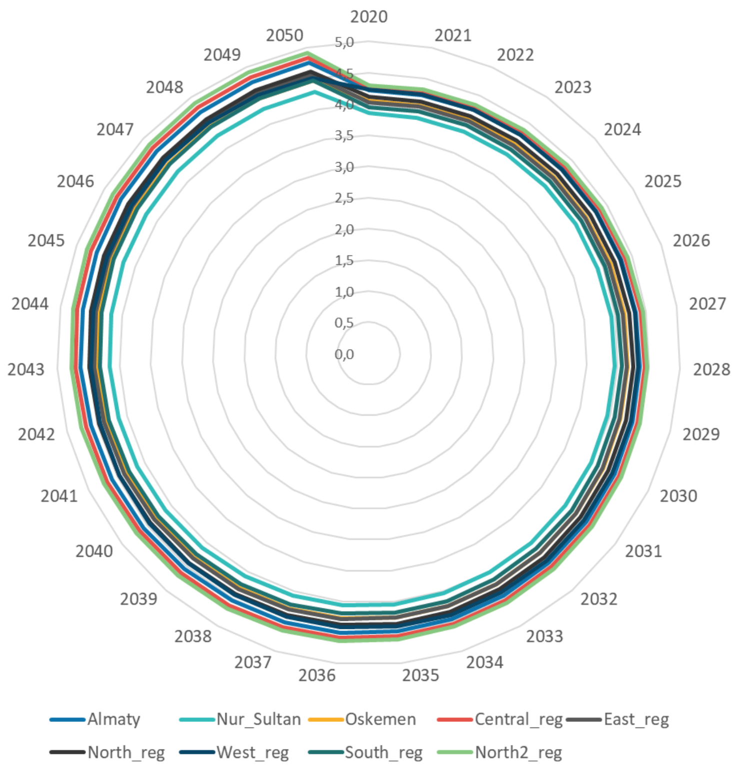
Figure 39: “Heat wave” scenario: key impacts, 2022-2050, deviations from a hypothetical "No heat wave" (REF) scenario in percent

Source: Own illustration based on e3.kz results

5.1.3 ECONOMY-WIDE EFFECTS OF EXTREME PRECIPITATION

Scenario assumptions and implementation

Extreme precipitation and related floods are major climate risks in South- and East-Kazakhstan and according to the climate model simulations for the RCP 8.5 scenario, they will become even worse. The number of days with extreme precipitation events as defined by Navarro and Jordà (2021) will increase from approx. four to almost six days per year in the selected regions (Figure 40). The amount of extreme precipitation ranges from six mm/day in the eastern region to 27 mm/day in Oeskemen.



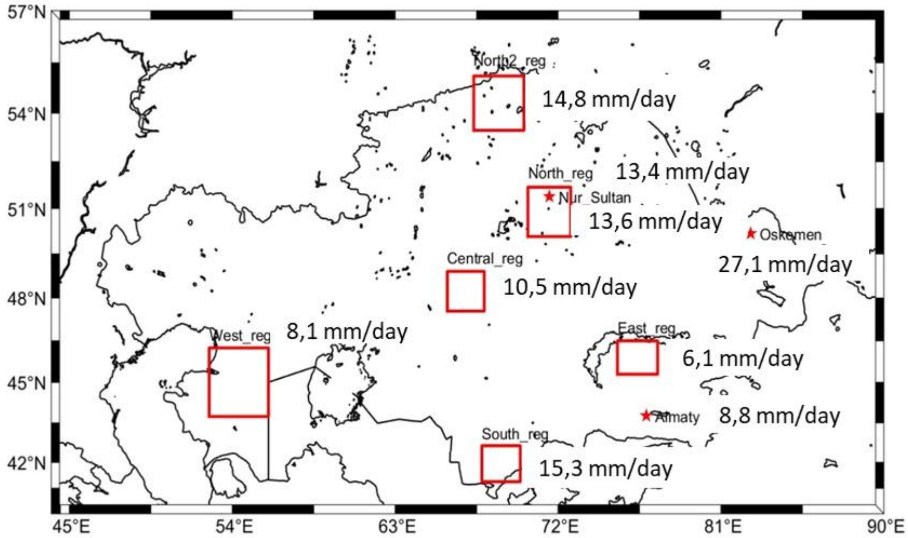


Figure 40: Number of days with extreme precipitation events per year, 2020-2050 (top figure) and selected regions with threshold values 1976-2005 (bottom figure)

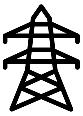
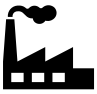
Source: Navarro and Jordà 2021

For the "extreme precipitation" scenario, the intensity is based on the evolution of these hazards in Kazakhstan where an increase from approx. four to five events per year is expected.

The number and extent of flood events varies from region to region. According to past observations, in the mountainous regions in the South-East of Kazakhstan, floods occur regularly due to snow melt. In other regions, such as South Kazakhstan and in the low lands, river floods occur less frequently but cause severe damages such as the flood in South Kazakhstan 2008.

Depending on the location where the event occurs, the extent of the damage and the impact on the society and the economy will vary. Non-climatic factors such as population density, degree of surface sealing in urban versus rural areas, land use, and infrastructure endowment influence the extent of damage. In this example, the damage to the infrastructure is assumed to be 15 bn. KZT which is an average damage per major event according to the damage data collection from past extreme precipitation events (c. f. section 3.3).

Table 13: Impacts of floods

Sector	Impacts	Sources
	Reconstruction of damaged buildings (31% resp. 4.5 bn. KZT)	GFDRR et al. 2015
	Replacement of unusable household goods (e. g. electrical appliances, furniture) (3% resp. 144 mln. KZT)	GFDRR et al. 2015
	Reconstruction of damaged road infrastructure (63% resp. 9.2 bn. KZT)	GFDRR et al. 2015
	Replacement of damaged cars (2,5% resp. 235 mln. KZT)	GFDRR et al. 2015
	Reconstruction of damaged water and sanitation system (6% resp. 900 mln. KZT)	GFDRR et al. 2015
	Reconstruction of destroyed energy infrastructure e. g. power transmission lines, oil pipelines (112 bn. KZT) Revenue loss due to joule heating and corona discharge (30 bn. KZT)	Based on assumption on replacement cost per unit and number of units to be replaced KEGOC 2018[29]
	Production losses in economic sectors due to power failure	Enterprise Survey World Bank 2019
	Higher costs due to involuntary reconstruction investments in the transport, energy, water and real estate sector	Own assumption

Source: Own illustration

Table 13 shows examples of possible direct economic impacts. These are illustrative examples and do not necessarily occur simultaneously during one extreme precipitation event. Typical recorded damages are destroyed and flooded buildings, killed livestock, destroyed crops and pasture in the agricultural sector, flooded and destroyed roads, bridges and infrastructure in the water and energy sectors such as pipes and power lines.

Detailed data on the allocation of the amount of economic damages in the different sectors namely, buildings, infrastructure, energy or transport are not available. Thus, own assumptions are used to illustrate possible effects.

[29] https://kegoc.kz/en/investment-projects

Flood-related damage changes with flood frequency and severity. The impact of an increasing number of floods per year is captured by linking past economic damages from flooding with the UIB data.

Furthermore, an extreme precipitation event might have different impacts in the future due to the fact that new areas are built up and developed which increases the value of assets (MNE et al. 2017, p. 169). This impact can be modeled by assuming the expected increase of the value of the capital stock per year. For example, regional population growth might be an indicator for an increase in residential buildings. In this presented scenario, this effect is not covered and thus damages could be even worse.

Scenario results

This scenario assumes that an extreme precipitation event occurs every five years starting in 2022 with the impacts outlined above.

In the years with an extreme precipitation event, GDP in constant prices is up to 0.9% resp. 771 bn. KZT lower compared to a situation without a climate hazard (Figure 41). The economy partially recovers between the years with extreme precipitation. At the beginning of the simulation period, the investment path is higher due to repairing needs of damaged building, transport, water and energy infrastructure. Over time, growth dependent investments prevail and reduce investments.

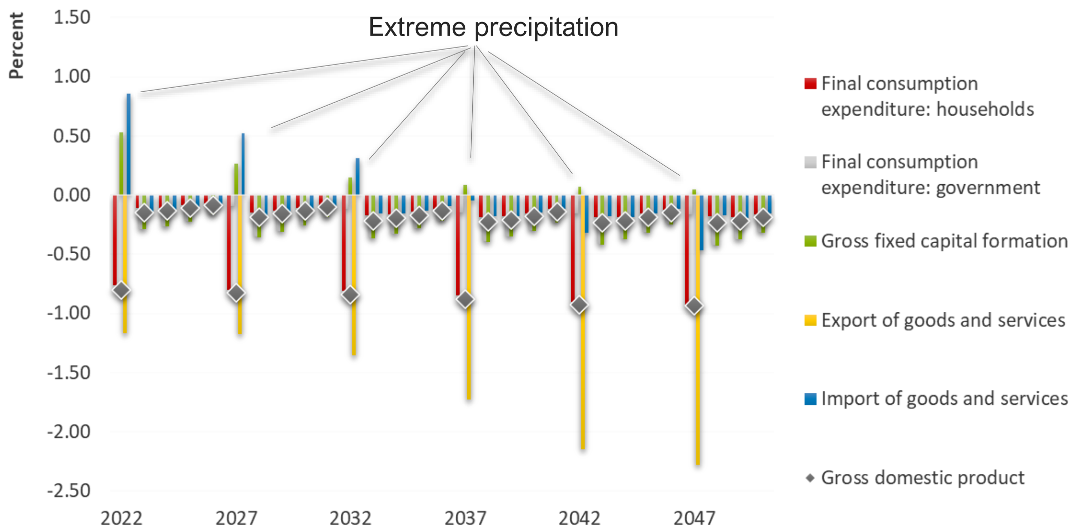


Figure 41: "Extreme precipitation" scenario (RCP 8.5): macroeconomic effects, 2022-2050, deviations from a hypothetical "No extreme precipitation" (REF) scenario in percent

Source: Own illustration based on e3.kz results

Imports are increasing as well. On the one hand, increased demand for manufactured products such as cars and electrical equipment leads also to increasing imports due to the high import-dependency. On the other hand, production losses due to electrical outages must be compensated by imports to satisfy the demand. As the economy grows at a slower pace, imports will also decline until 2050.

Damages to the energy infrastructure affect not only the oil industry, which suffers from lower exports due to damaged oil pipelines, but also a broad range of economic sectors are impacted by power outages (World Bank 2019). This applies to export-oriented sectors such as producers of basis ferrous metals, basic precious metals and other non-ferrous metals, which are facing lower exports. Closed retail stores and restaurants as well as interrupted communication hampers consumer demand. The resulting lower sectoral production shows Figure 42. Manufacturers of electrical equipment are positively affected by replacement investments in the energy sector.

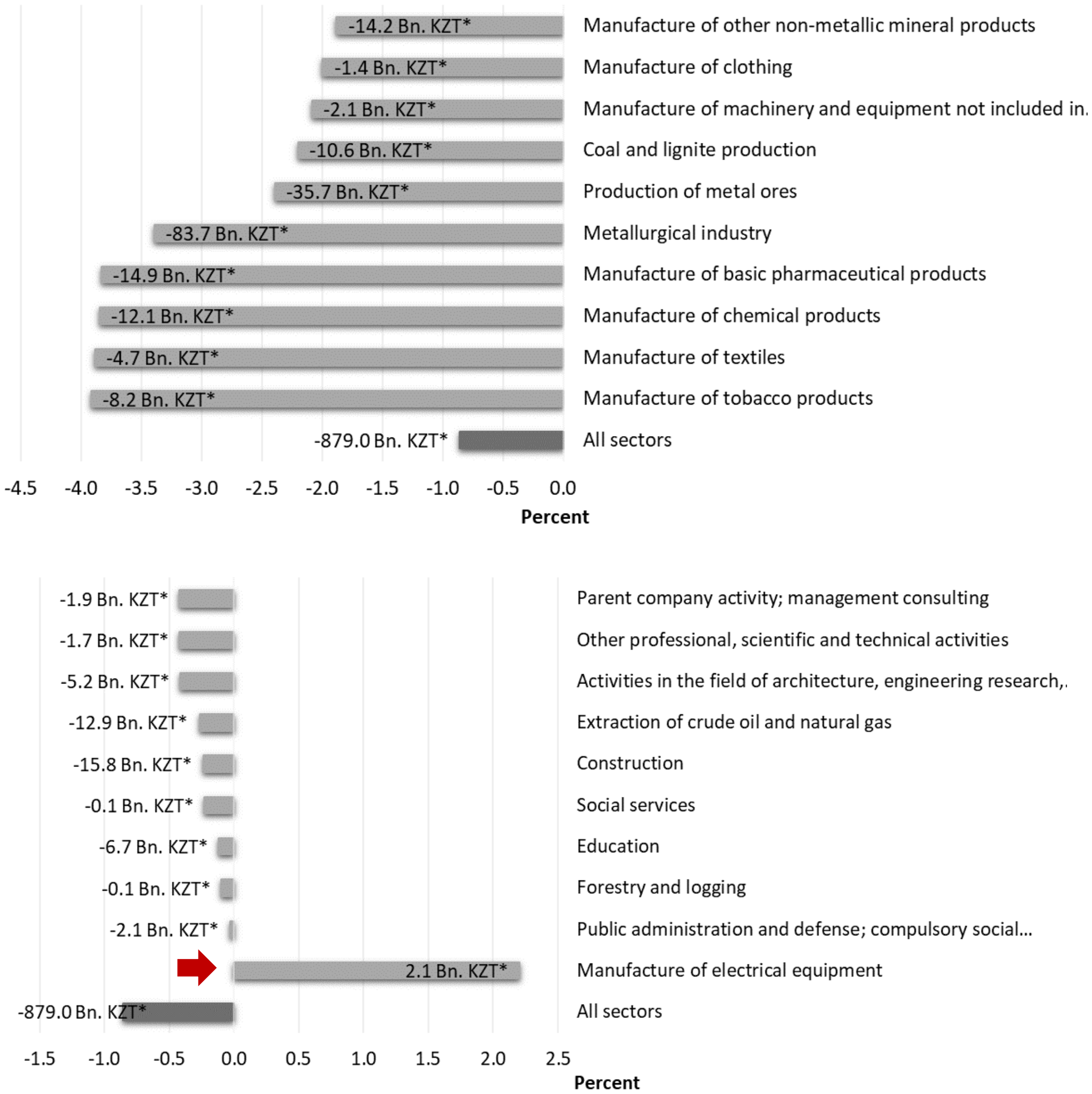


Figure 42: "Extreme precipitation" scenario: real production by economic sectors, extreme precipitation year 2047, deviations from a hypothetical "No extreme precipitation" scenario in percent (x-axis) and bn. KZT (*)

Source: Own illustration based on e3.kz results

Repairs to buildings and roads have a positive impact on the construction sector and other sectors along the value chain such as non-metallic mineral producers. However, these are offset by the overall negative economic effects.

Employment follows the sectoral production, taking the sector-specific labor productivity into account. Overall, the employment level is at max. 0.3% resp. 25 thousand people per year lower than without extreme precipitation events. Employed persons in manufacturing, trade and transportation are mainly impacted (Figure 43). As a result, national income is lower and reduces spending opportunities of households.

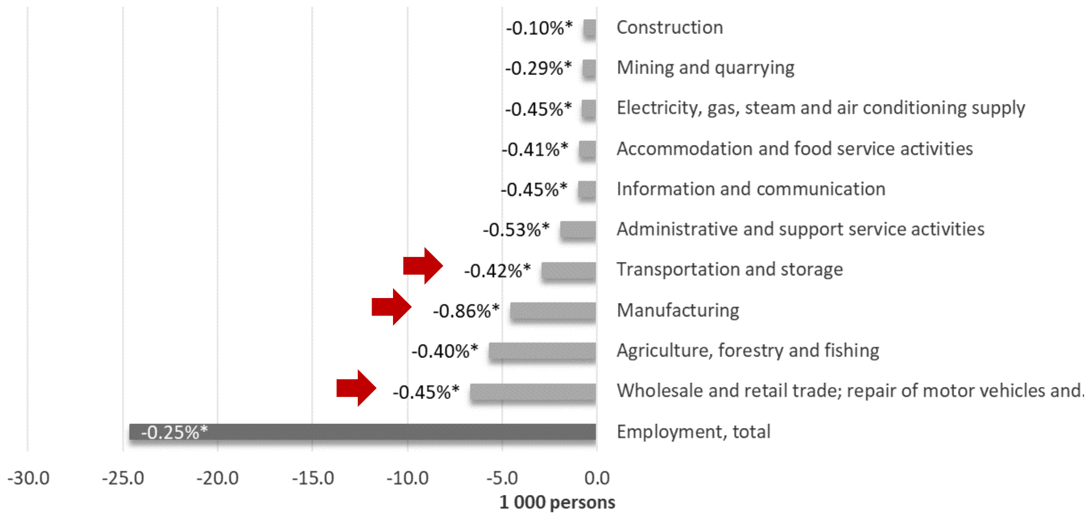
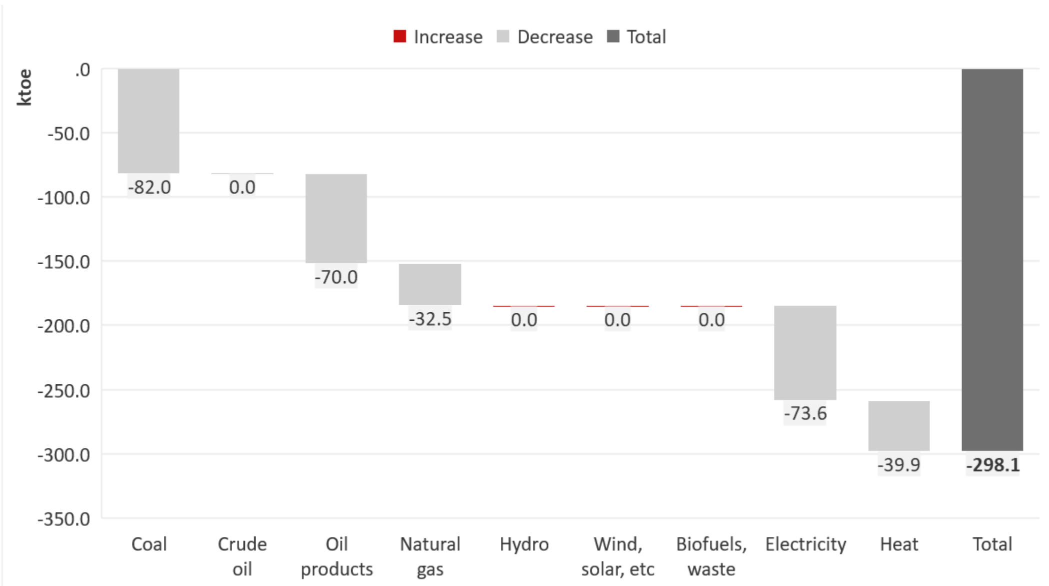


Figure 43: "Extreme precipitation" scenario: employment by sectors, extreme precipitation year 2047, deviations from a hypothetical "No extreme precipitation" scenario in 1,000 persons

Source: Own illustration based on e3.kz results

The lower economic activity results in less final energy demand which is 298 ktoe resp. 0.5% lower in 2047 compared to a "no extreme precipitation" scenario (Figure 44). Energy demand by fossil fuels decreases accordingly to the use of demanding sectors such as the manufacturing industries.



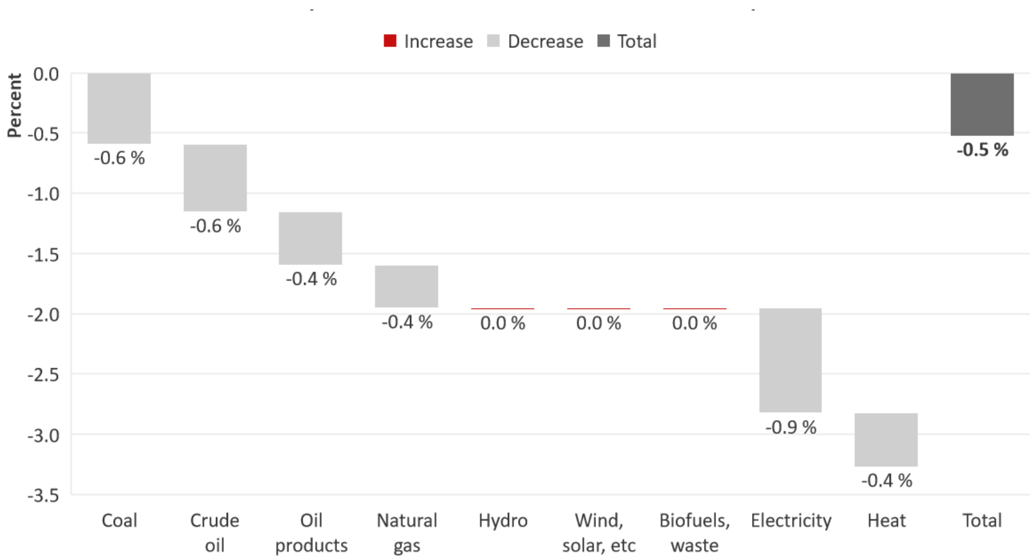


Figure 44: "Extreme precipitation" scenario: energy demand, Extreme precipitation year 2047, deviations from a hypothetical "No extreme precipitation" scenario in ktoe (top figure) and percent (bottom figure)

Source: Own representation

CO_2 emissions in manufacturing, construction and other sectors decrease due to lower production (Figure 45). However, energy industries show an increase in CO_2 emissions. The power losses due to joule heating and corona discharge must be compensated by higher energy production leading to an additional use of coal and gas.

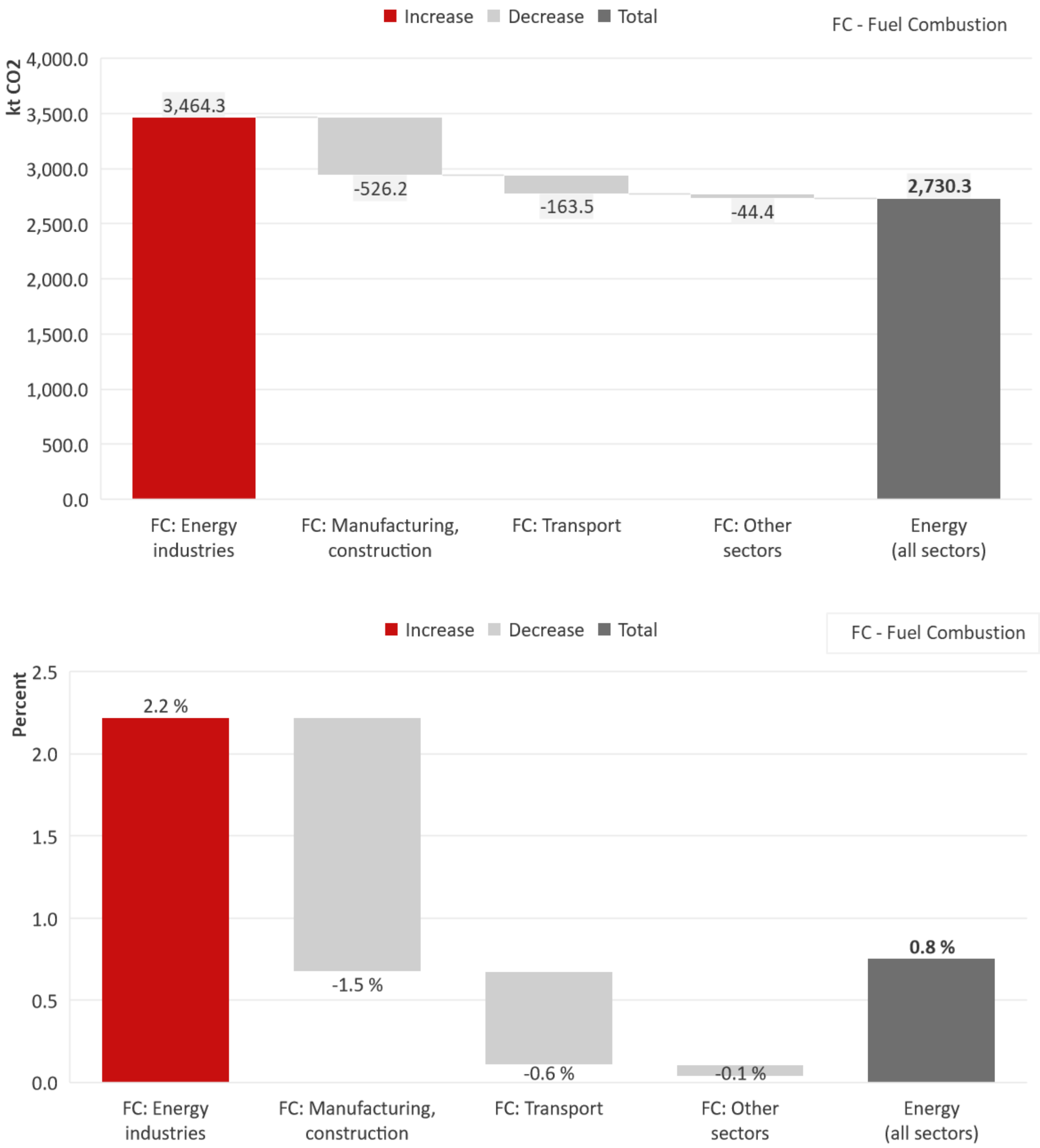


Figure 45: “Extreme precipitation” scenario: CO_2 emissions, Extreme precipitation year 2047, deviations from a hypothetical "No extreme precipitation" scenario in ktoe (top figure) and percent (bottom figure)

Source: Own representation

Figure 46 summarizes the key impacts of the "Extreme precipitation" scenario.

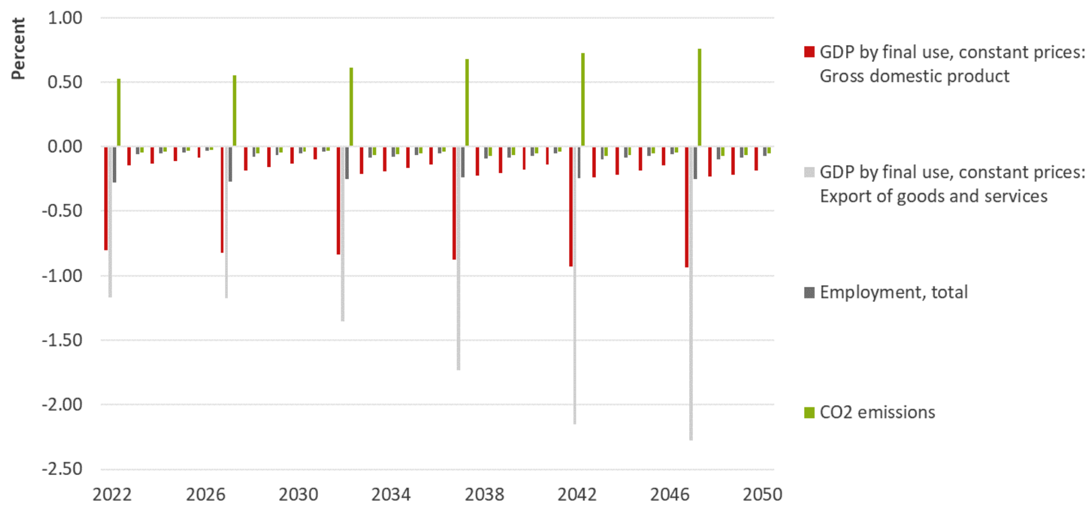


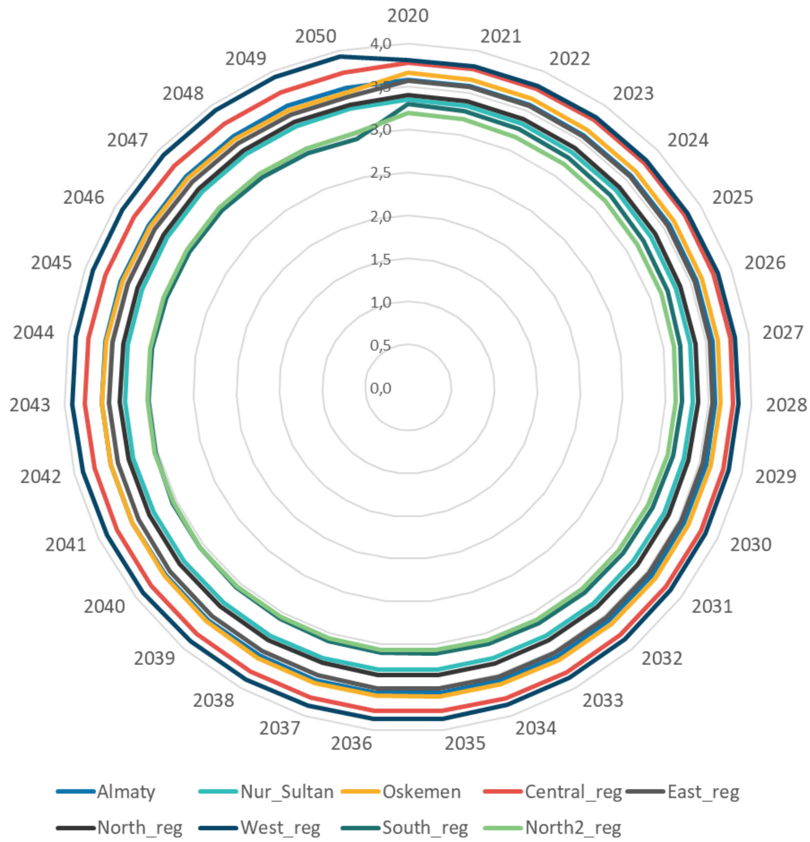
Figure 46: "Extreme precipitation" scenario: key impacts, 2022-2050, deviations from a hypothetical "No extreme precipitation " (REF) scenario in percent

Source: Own representation

5.1.4 ECONOMY-WIDE EFFECTS OF EXTREME WINDS

Scenario assumptions and implementation

The number of extreme wind events per year will mainly remain more or less at the same level as of today. For most of the regions, three to four times a year such an extreme event occurs (Figure 47).



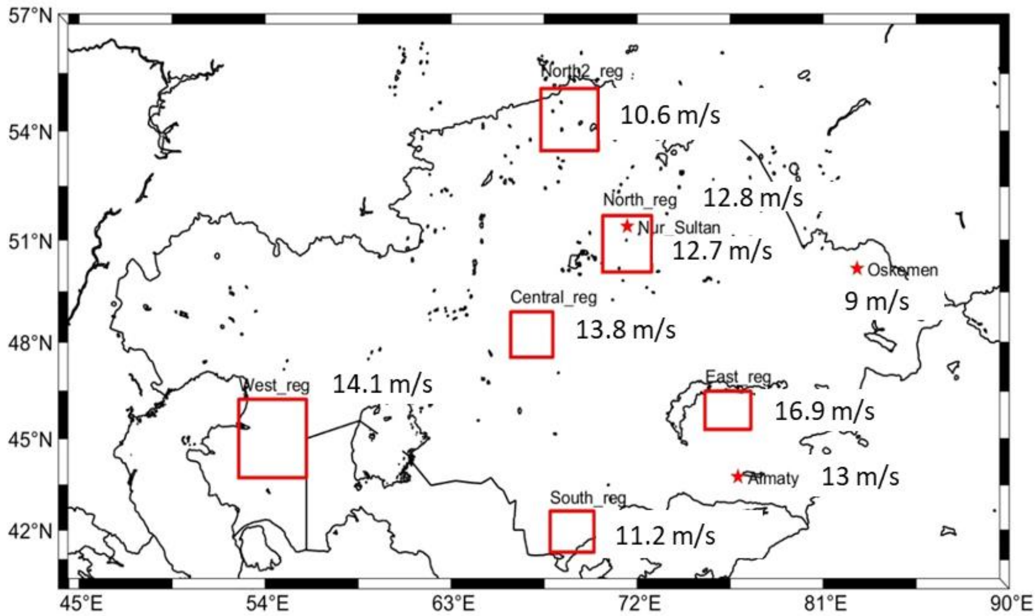


Figure 47: Number of days with extreme wind events per year, 2020-2050 (top figure) and selected regions with threshold values 1976-2005 (bottom figure)

Source: Navarro and Jordà 2021

While in the Western region a slight increase of wind events is expected, in the Southern region, Oeskemen and the very North region the number is decreasing. At the national level, the number of extreme wind events will decrease by 0.1% p.a. The threshold for extreme wind differs in the regions and ranges from nine m/s in Oeskemen to 17 m/s in the East.

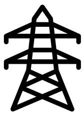
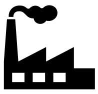
Potential impacts of extreme wind events observed in the past are summarized in Table 14. Based on the collected damage data (section 3.3), the extent of damage ranges from a few million KZT to 2.5 billion KZT. Winter storms (blizzards) result in greater damage, as they are often associated with poor visibility, causing greater damage to traffic due to accidents.

A monetarization of the damage for individual economic sectors is not available. Damage to buildings, cars and power lines was often mentioned, as well as partial damage to gas supply systems and telephone cables. Blocked roads and railroads due to falling trees were rarely mentioned.

For the scenario presented here, the damages shown in Table 14 were taken into account and it was assumed that the extent of the damage is 900 million KZT, which corresponds to an average damage of a major event. The more events per year occur, the higher the damage. In the scenario it is assumed that four of these events occur per year in Kazakhstan.

All benchmark damages are then linked to the growth rates of the projected number of extreme wind events (Figure 47). Subsequently, this time series of damage data is implemented in the model e3.kz to calculate the economy-wide impacts.

Table 14: Impacts of an extreme wind event

Sector	Impact	Source
	Reconstruction of (partly) damaged buildings (80% of total damage resp. 3 bn. KZT; residential property owners 50:50 private property and real estate sector)	Own assumption based on damage data (see section 3.3) Shares are adopted from GFDRR et al. 2015
	Replacement of damaged cars (5% of total damage resp. 180 mln. KZT)	Own assumption based on damage data (see section 3.3) Shares are adopted from GFDRR et al. 2015
	Reconstruction of destroyed energy infrastructure e. g. power transmission lines (15% of total damage resp. 540 mln. KZT)	Own assumption based on damage data (see section 3.3) Shares are adopted from GFDRR et al. 2015
	Production losses in service sectors (food and beverage and communication services) due to power failure	Enterprise Survey World Bank 2019
	Higher costs due to involuntary reconstruction investments in the energy and real estate sector	Own assumption

Source: Own illustration based on e3.kz results

Scenario results

It is assumed that major extreme wind events occur every four years starting in 2022.

The damages caused by a regional extreme wind event have minor negative, impacts on the macroeconomy. The GDP growth path is slightly lower (-0.03% resp. 29 Bn. KZT) than without a storm (Figure 48). Replacement investments to repair the damaged buildings and energy infrastructure have a positive impact but they are outperformed by the overall decreasing investments due to lower economic activity. In the energy and real estate sector prices are increasing due to investment costs.

In the case of residential property, private households bear the financial burden of restoring their homes at the expense to 50% of non-essential expenses such as expenditures for food and beverage services. The remaining 50% are assumed to be financed from savings. The replacement of damaged cars increases the imports of cars due to the high import dependency of the sector.

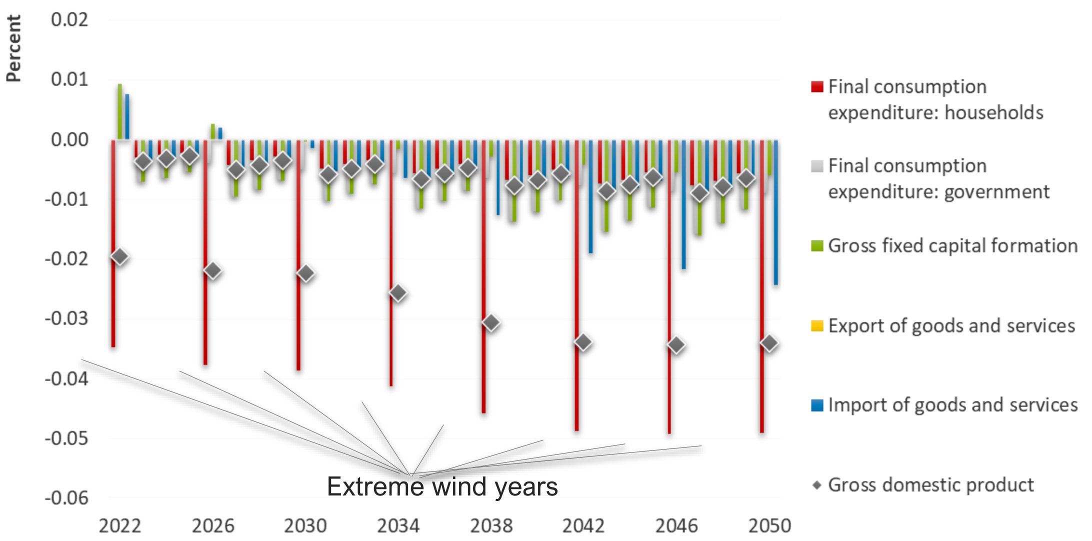


Figure 48: "Extreme wind" scenario (RCP 8.5): macroeconomic effects, 2022-2050, deviations from a hypothetical "No extreme wind" scenario in percent

Source: Own illustration based on e3.kz results

Production failures in the service sectors "food and beverage activities" and "communication services" result in losses of -0.4% of annual sales which is one third of the specified value in the World Bank Enterprise Survey for Kazakhstan 2019. This is based on the assumption that not all power outages in the country are due to climate change. Sectoral production effects are up to 0.45% lower compared to a situation without an extreme wind event (Figure 49). Restaurants have to close and communication is interrupted due to power outages causing for example spoiled food. Losses in the service sectors have larger impacts than direct physical impacts in the energy sector.

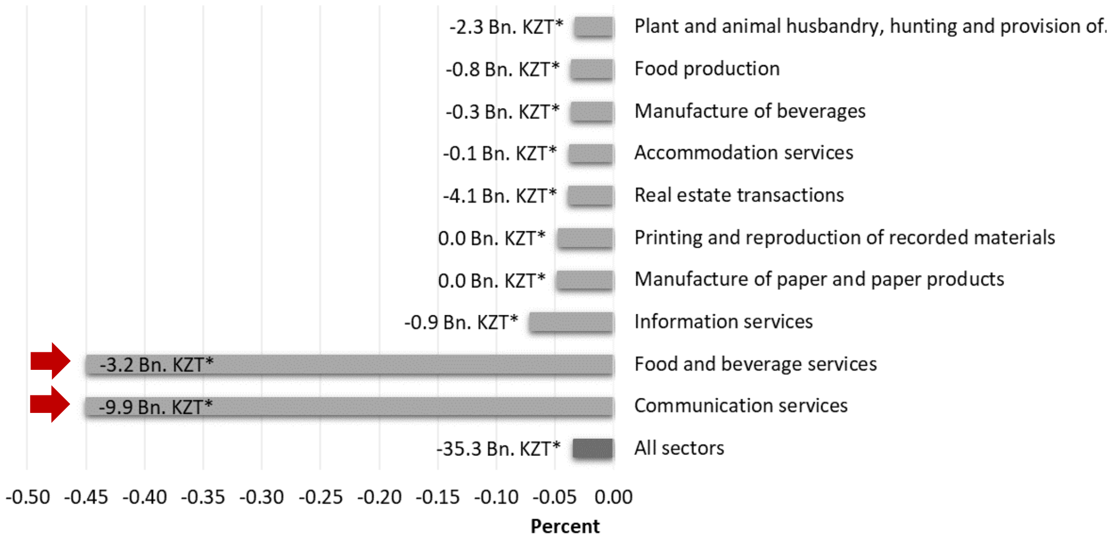


Figure 49: "Extreme wind" scenario: real production by economic sectors, Extreme wind year 2050, deviations from a hypothetical "No extreme wind" (REF) scenario in percent (x-axis) and bn. KZT (*)

Source: Own illustration based on e3.kz results

Decreased production levels lead to lower employment, in particular in the two service sectors mentioned above. In total, employment is 1,800 persons resp. 0.02% lower compared to a "no extreme wind" scenario in the year 2050. Consequently, income is lower which reduces the spending opportunities of households in general.

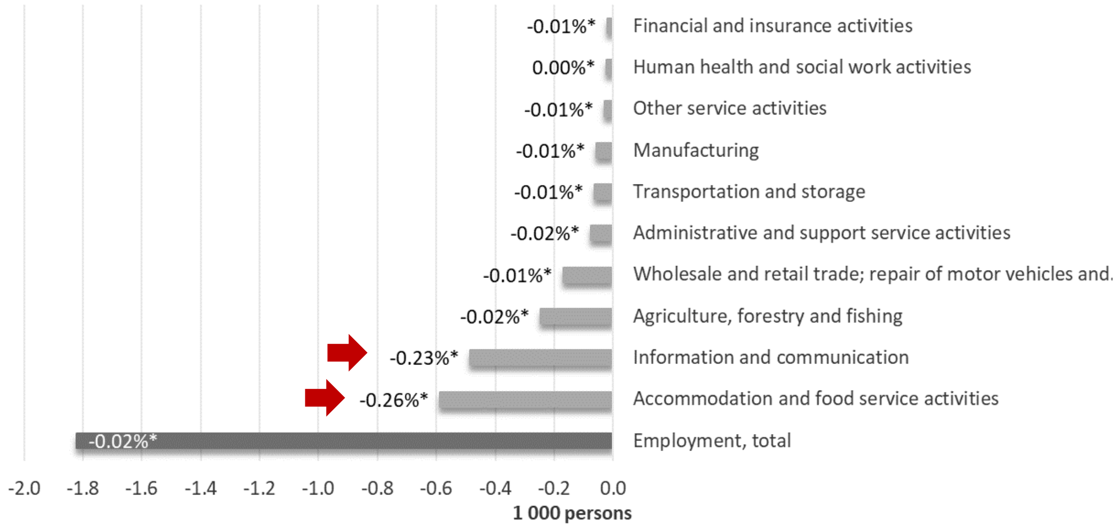


Figure 50: "Extreme wind" scenario: employment by sectors, extreme wind year 2050, deviations from a hypothetical "No extreme wind" scenario in 1,000 persons (x-axis) and percent (*)

Source: Own illustration based on e3.kz results

Total final energy consumption and CO_2 emissions follow the economic growth path and thus are slightly lower compared to a "no extreme wind" scenario.

Figure 51 summarizes the key impacts of the "Extreme wind" scenario.

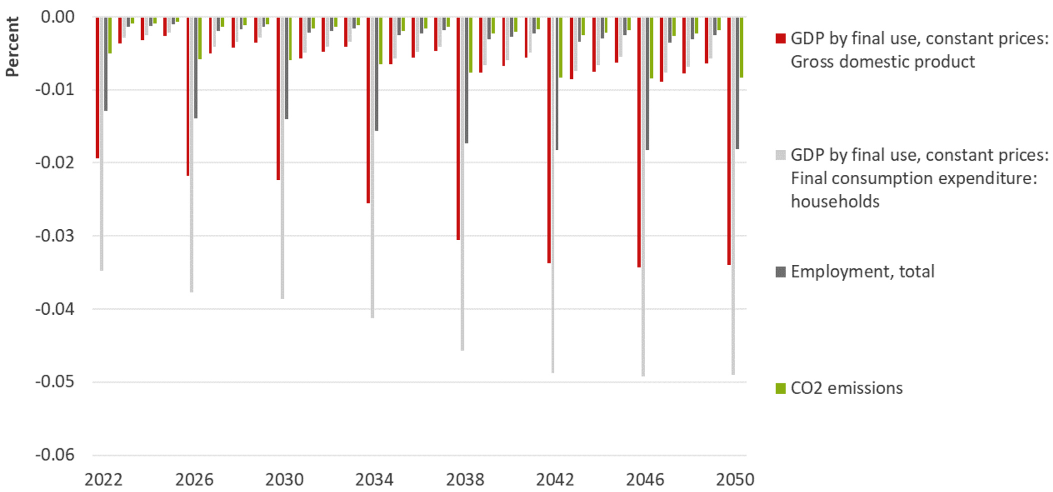


Figure 51: "Extreme wind" scenario: key impacts, 2022-2050, deviations from a hypothetical "No extreme wind" scenario in percent

Source: Own illustration based on e3.kz results

6 ECONOMICS OF ADAPTATION TO CLIMATE CHANGE

Climate change causes immense economic costs and affects key industries as the previous sections show exemplary. Thus, it is vital for Kazakhstan to reduce the vulnerability to climate change impacts by adapting to climate change.

A variety of definitions of adaptation to climate change exist. In general, it can be defined as a "*set of organization, localization and technical changes that societies will have to implement to limit the negative effects of climate change and to maximize the beneficial ones*" (Hallegatte et al. 2011).

The United Nations Framework Convention on Climate Change (UNFCCC) defines adaptation as "*adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities*" (UNFCCC 2013).

Adaptation options can be proactive or reactive. While proactive adaptation anticipates likely future impacts of climate change, reactive adaptation implements "build back better" measures to increase climate resilience of e. g. infrastructure after experiencing the negative impacts of climate change. All adaptation options must address the climate-related risks on a respective economic sector.

The process of the development of adaptation strategies is shown in Figure 52. At each stage, key questions must be answered with the support of experts and modeling tools leading to an adaptation strategy.

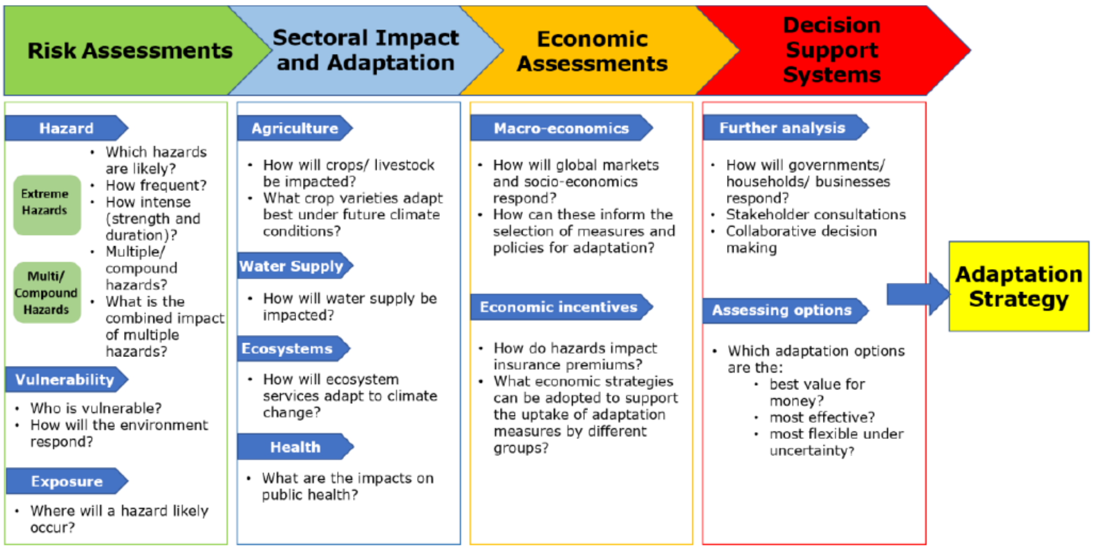


Figure 52: Integration and support of macroeconomic modeling in the development of climate adaptation strategies

Source: European Commission (2020), p. 6

In the first stage, possible risks and vulnerabilities from climate change need to be identified (c. f. section 3.2 and 3.3). As of today, data availability is usually scarce and must be compensated for by expert knowledge.

In the second stage, the identified climate risks need to be assessed with respect to their direct impacts on certain sectors of the economy (c. f. section 5.1) as well as possible adaptation measures that contribute to limit the negative impacts of climate change. CBAs are an important cornerstone to identify the costs and benefits of sectoral adaptation measures on which the macroeconomic analysis is built upon. Close contact with field experts is advisable and beneficial in this context.

A **CBA** estimates the costs and benefits of a (sectoral adaptation) project. It **compares the discounted value over the whole lifetime of the project** – the net present value (NPV) – **of the costs and the benefits**. **A project is recommended if the benefits outweigh the costs** (NPV > 0). If more than one alternative is evaluated, the alternative with the highest NPV is the most suitable for the respective sectoral climate change related issue. (see also UNFCCC 2011, GIZ 2013)

In stage three, an economic model such as e3.kz helps to quantify also indirect and induced impacts in other sectors and the total economy to evaluate adaptation options (see section 6.2). However, **a pre-selection of adaptation measures should be made before starting the macroeconomic modeling activities** (for more see section 6.1).

The macroeconomic evaluation builds on available CBA and other detailed studies which are usually limited to a single economic sectors analysis. The macroeconomic analysis goes beyond the classic CBA evaluating the impacts of sectoral and typically regional adaptation options for the national economy (e. g. GDP and its components) and for economic sectors (e. g. employment, production).

Decisionmakers are enabled to prioritize and to adopt **the most effective adaptation measure for the respective sector or a combination of measures** that also have positive effects on the economy and job creation (win-win measures). **Model indicators such as GDP and its components, employment, production, energy-related CO_2 emissions are used to analyze the impacts on the whole economy and for economic sectors.** The results provide the basis to prepare climate-sensitive development plans and economic development strategies at the national level in Kazakhstan which has budgetary sovereignty and plans for the long term (e. g. a NAP).

Although the financial and economic impacts are relevant for policymakers to decide which adaptation measure is “most effective”, **other criteria – which are beyond the scope of the model – must be considered as well** such as health aspects, ecosystem services (biodiversity, regulation of the water balance), distributional effects, other GHG emissions and international / political implications **to get a more comprehensive evaluation and to formulate an appropriate adaptation strategy**.

However, adaptation measures are difficult to assess due to the following reasons (Lehr et al. 2020):

1. Uncertainty about the impacts of climate change:

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

2. Climate is changing dynamically:

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

3. Socio-economic systems react slowly:

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

4. Adaptation to climate change sometimes requires fundamental reorientation:

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

5. Adaptation takes place on a regional scale:

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

6. Data for modeling adaptation are often more incomplete and subject to greater uncertainty than data for modeling mitigation. CBAs of adaptation options are an important prerequisite but not yet very comprehensively available.

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

6.1 IMPLEMENTING ADAPTATION MEASURES IN THE E3.KZ MODEL

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

Despite the difficulties mentioned, the macroeconomic analyses in the following sub-sections with the model e3.kz give an economic evaluation of selected adaptation measures for the focused sectors agriculture, energy and (transport and building) infrastructure. Starting point are ideally country- and sector specific CBAs of investments into particular adaptation options which already show suitable solutions for the respective sectoral climate change related issue. Otherwise, best-practice adaptation options of comparable situations in other countries serve as an initial indication.

Not all adaptation options that are considered appropriate to mitigate the impacts from climate change must and can be analyzed with the e3.kz model. The following criteria provide a starting point for selecting those adaptation options that should be examined with this model (Lehr et al. 2020):

Adaptation measure has a high or medium need for action and is of policy relevance

The necessity and urgency of the need for action results from the observable climate impacts and the damage caused by climate change as well as from the expected future development. Since there has been no systematic and complete recording of climate damages to date, it is likely that the overall damages are greater. Consequently, adaptation measures should be implemented even more decisively and faster.

The economic importance of an industry also plays a decisive role. For example, agriculture is very important for Kazakhstan's economic and social development. Thus, the implementation of sectoral adaptation measures is expected to be of political relevance and should be analyzed in terms of their economy-wide impacts.

Adaption measures must be appropriate to the climate impacts in the respective sector

Only those adaptation measures should be analyzed regarding their macroeconomic effects that are appropriate to reduce the impacts of climate change under investigation. For example, an adaptation measure in agriculture should have positive impacts on crop yields. CBAs provide such data (benefits) and the costs associated with the measure. **The availability of ideally country- and sector specific CBAs** is another selection criteria.

Adaptation measure is expected to have (relevant) economic impacts

The application of the e3.kz model only makes sense if the expected macroeconomic effects are relevant and, in particular, if interactions between economic sectors are expected. The macroeconomic relevance may result from the costs and / or the benefits of the respective adaptation measure.

It is important to remember that "minor" macroeconomic impacts (at national level) can mean large impacts at the regional level.

Furthermore, possible impacts, be it co-benefits or adverse side effects, on other development strategies and commitments such as the aim to achieve carbon neutrality by 2060 must be considered as well.

Adaptation measure can be mapped into an economic model

The simulation of climate change adaptation can be distinguished between *measures* and policy *instruments*. Adaptation measures include actions that that aim to reduce climate change impacts. Policy instruments are possibilities for the government to regulate (regulatory instruments such as building codes), initiate or incentivize (economic instruments such as investment programs) the measures. While measures with their costs and benefits can be mapped into the e3.kz model, some instruments can only be mapped if additional assumptions are made and expected impacts are clarified (see Table 15). For example, a command and control measure is treated as binding, meaning that all people comply to the regulation. A voluntary agreement is considered to have been fulfilled.

Table 15: Representability and mapping of instruments in economic models

Type of instrument	Map into an economic model
Command and control	The regulation is treated as binding.
Price	Prices are implemented.
Direct subsidy	Subsidy is regarded as successful.

Voluntary agreement	If this results in a physical / monetary change, it is mapped.
Management of information and knowledge	
Inspection	
Planning	

Source: Adapted from Lehr et al. (2020)

Once suitable adaptation options have been selected for a macroeconomic analysis, the following steps 3 and 4 must be taken to implement adaption options into the model e3.kz (Figure 53).

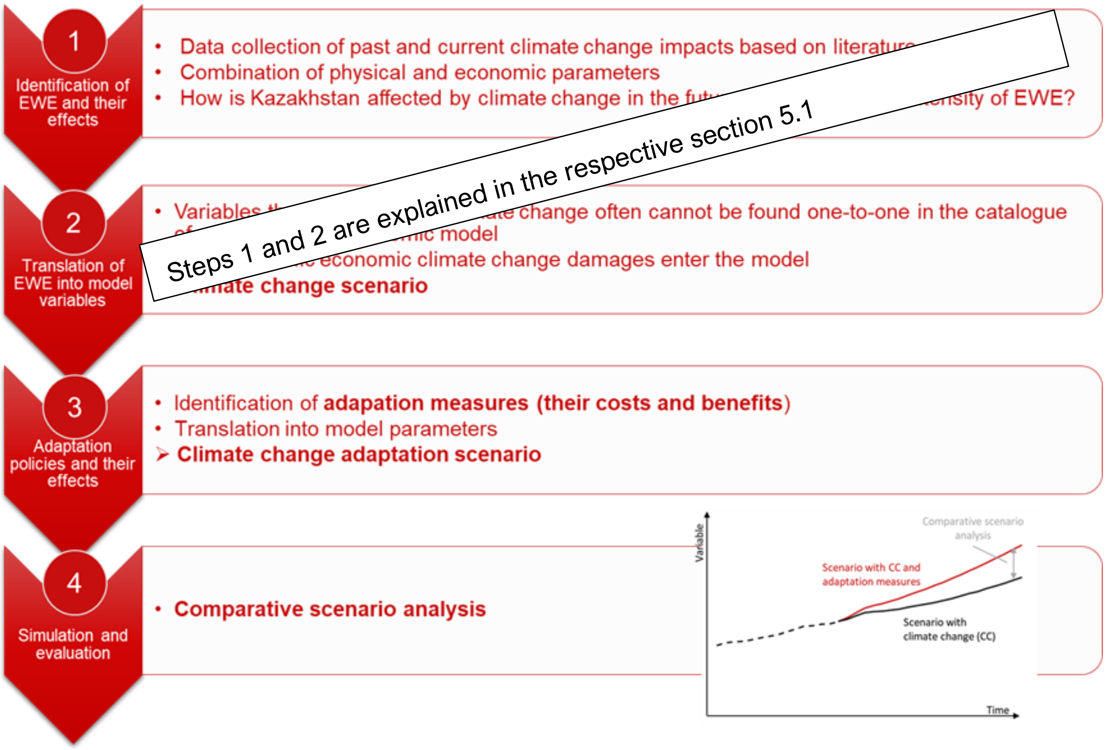


Figure 53: Four-step approach to implement climate change and adaptation in an economic model

Source: Own illustration based on Lehr et al. 2020

(3.) Possible adaptation options are identified by screening national and international literature as well as by discussions with Kazakh experts to prevent or minimize the damages or taking advantage of the opportunities that may arise. Costs and benefits (in terms of damage reduction) of the measures need to be quantified and then fed into the e3.kz model. The CBAs are based on analyses and studies by third parties which are ideally country-specific such as the EBRD et al. (2018) study on adaptation options in agriculture. While the benefits are implemented into e3.kz as the reverse impacts of climate change damages, costs are usually integrated as investments of various products.

(4.) For evaluating the impacts of adaptation measures, a climate change scenario and the adaptation scenario must be compared. Usually, there is more than one adaptation option (e. g. irrigation systems or drought-resistant crops). The model helps to identify the option(s) with high effectiveness and positive effects on the economy and the environment. Selection criteria might be the biggest avoided damages, employment effects or synergies with other strategies such as mitigation which needs to be prioritized by policymakers.

6.2 ECONOMY-WIDE EFFECTS OF ADAPTATION MEASURES – SECTOR STUDIES

In the subsequent sections, for Kazakhstan's priority sectors namely agriculture, energy and infrastructure the following adaptation measures are analyzed regarding their economy-wide impacts:

Table 16: Overview of adaptation scenarios analyzed with the model e3.kz

Climate threat	Economic sector affected	Adaptation measures
Droughts	Agriculture	Irrigation systems (reconstruction of water canals and installation of drip irrigation)
Droughts	Agriculture	Precision agriculture: parallel driving
Extreme precipitation and floods	Energy	Expansion of underground powerlines
Heat wave	Energy	Deployment of wind power and energy efficiency in buildings
Extreme precipitation and floods	Road infrastructure	(Re-)construction of climate resilient roads
Extreme wind	Building infrastructure	"Green Belt" mass afforestation
Extreme wind	Building infrastructure	(Re-)construction of storm-proofed buildings

Source: Own illustration.

For the purpose of analysis, each scenario is dedicated to a certain adaptation measure. However, it is also possible to combine different adaptation measures to further reduce the adverse impacts of climate change. For example, the energy sector faces various impacts of climate change. While floods are damaging the energy infrastructure, heat waves are impacting energy demand and energy supply. Thus, suitable adaptation options can be combined into one scenario including the economic impacts of both hazards and respective adaptation measures with their costs and benefits.

6.2.1 ADAPTATION IN AGRICULTURE

Current Situation

Agriculture plays an essential role in Kazakhstan's economic and social development. In 2019, around 5% of GDP was related to agriculture and about 13% of the workforce or 1.2 million people are employed in this sector. Although this share has declined since 2010 from originally 28%[30], the sector is still important for income generation (Bureau of National statistics of the Republic of Kazakhstan 2021).

According to the strategy document "Kazakhstan 2050", agriculture is one of the key sectors to develop and diversify the national economy (OECD 2020a, ADB 2018). Current agricultural policies are oriented towards boosting domestic production to substitute imports and promote exports. Kazakhstan is already

[30] It is important to take into account that the methodology for statistical data collection on employment was changed in 2014: from then onwards certain categories of self-employed people in agriculture are no longer included in the statistics (see Center for Research and Consulting, 2020).

one of the leading wheat exporters (UNDP 2019). However, wheat production is also an important segment in agriculture contributing to food security within the country.

A major challenge is the high wheat yield variability in the mainly rain-fed northern area which is likely to amplify due to rising temperatures, changes in precipitation patterns and increased pest and disease outbreaks (USAID 2017, World Bank 2016). Due to lower precipitation in the south and southeast, large areas of arable land are artificially irrigated.

Due to a lack of maintenance and investments in irrigation and drainage systems after the end of the Soviet Union, the irrigation infrastructure is not in a good condition. Furthermore, the share of irrigated land is low and accounts for 0.9% of total agricultural land. Water demand in agriculture is high with a share of around two-thirds of total water consumption. About 11-15% is lost during transport mostly due to the obsolete irrigation infrastructure and to the low cost of water supply (OECD 2020b).

Increasingly noticeable climate change is likely to exacerbate the already volatile production and thus food security and income risks. The government addressed agricultural productivity and environmental issues in its “Green Economy Transition Concept”[31]. Nevertheless, the concept falls short of formulating climate resilient strategies to be better prepared for EWEs and gradual changes in the agriculture sector.

Options for building climate resilience in agriculture

According to the New Environmental Code[32] adopted in 2021, agriculture is one of the priority areas for climate change adaptation (Article 313). Several options exist for farmers to adapt to climate change partly also known from the “Green Economy Concept” adopted in 2013, such as the introduction of water-saving technologies, cultivation of water-efficient crops and restoring of water infrastructure and leakage control. Additionally, the use of moisture saving technologies (conservation agriculture, no-till farming) can contribute to soil conservation (UNDP 2020a, World Bank 2016, see Table 17). Precision agriculture optimizes return on inputs while preserving resources (EBRD et al. 2018). Amongst them are yield monitoring, remote sensing and GPS and GIS technologies. The system of parallel driving guided by GPS is a key element of precision agriculture. Other options include fertilization and improved crop protection to limit pests and diseases. Selective breeding and pasture improvement through rotational grazing aims at avoiding overgrazing and increasing livestock productivity. Improved weather forecasting and early warning systems for EWEs can also help to limit the economic losses caused by climate change (FAO and EBRD 2017). Each of these individual techniques can at least partially offset yield losses in drought years. In contrast, insurance against crop failures compensates farmers at least partly, but cannot prevent losses. The techniques require investment in new machinery and equipment, knowledge, and training.

Crop farming and livestock technologies are already analyzed regarding their cost and benefits in terms of mitigation and adaptation potential (EBRD et al., 2018). Cost-benefit-analyses of investments into particular adaptation measures already indicate the value of adaptation benefits derived from them (Table 17). Additional macroeconomic analyses which are currently missing to assess the economy-wide impacts of single measures would greatly enable decision-makers to adopt the most effective adaptation measures that also have positive effects on the economy and job creation (win-win measures).

[31] https://policy.asiapacificenergy.org/sites/default/files/Concept%20on%20Transition%20towards%20Green%20Economy%20until%202050%20%28EN%29.pdf

[32] https://unece.org/sites/default/files/2021-07/frPartyVI.8g_30.06.2021_annex1_rus.pdf

Table 17: Cost-benefit-analysis of adaptation measures in agriculture

Adaptation measures	Investment (million USD)	Adaptation benefit per year (million USD)
Drip irrigation of arable lands	83	112
Precision agriculture (parallel driving)	80	10
Investment in field machinery (tractors, harvesters)	1,000	63
Conservation agriculture (no-till farming): investing in modified and direct seeders	263	250
Improved greenhouses	4	1
Pasture improvement through rotational grazing (investment	144	70
Fattening units	290	72

Source: EBRD et al. (2018)

The macroeconomic effects of the adaptation measures "rehabilitation and expansion of irrigation systems" and "precision agriculture: parallel driving" are presented as examples in the next sections. Irrigation systems are well suited to limit drought damages but due to poor maintenance in the past and the need for additional irrigated land, high investments are needed. Parallel driving as one aspect of precision agriculture requires lower investment which is favorable for small scale farmers who do not have huge financial resources.

6.2.1.1 Investing in rehabilitating and expanding irrigation systems

The rehabilitation, modernization, and expansion of irrigation and drainage systems is a key to prevent water scarcity and to improve agricultural productivity under climate change scenarios. Droughts are expected to occur more frequently and more severely causing increasingly higher economic losses in agriculture, affecting jobs and food security (section 5.1.1).

Scenario assumptions and implementation

Investments in the reconstruction and expansion of water infrastructure (e. g. canals, drainage, reservoirs) as well as water-saving technologies are the main pillars to increase agricultural productivity. With this, the irrigated area can be increased by one million hectares without a significant increase in water consumption (Kazakh Government 2020). Related costs amount to almost one trillion KZT (Astana Times 2019). Including expected replacement investments to maintain the water infrastructure, overall investments amount to 100 billion KZT on average per year. Without financial incentives from the government, farmers pay the investments themselves and try to pass on the costs to the consumers. In this scenario, the government subsidizes the investments which lead to expenditure cuts in other areas.

Table 18: Investing in rehabilitating and expanding irrigation systems – key assumptions

Adaptation measures	Cumulated investment (2022 – 2050)	Adaptation benefits per year (in terms of higher agricultural output)
Investment in reconstruction of canals and reservoirs	2,894 billion KZT	537 billion KZT
Investment in drip irrigation	105 billion KZT	47 billion KZT

Source: Based on Astana Times (2019), EBRD et al. (2018), Kazakh Government (2020)

Most of the drip irrigation systems must be imported either from Europe, Israel or China. Only a few local producers exist (EBRD et al. 2018). The rehabilitation and extension of the irrigation and drainage systems involves mainly local construction works.

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

Model results

The economy-wide effects of the investments in water infrastructure in agriculture are positive as Figure 54 illustrates. Both the intensified construction activity and higher crop yields due to the additional irrigation facilities have a positive impact on GDP which is at max. 1.2% (resp. 833 bn. KZT) higher compared to a situation without adaptation and droughts. Foregone export chances and increases in agriculture imports to compensate for yield losses during drought years can now be partly prevented. The import of drip irrigation systems has per se a negative effect but does not prevail. Total exports increase by max. 0.24% (resp. 30 bn. KZT) whereas total import growth is 1.1% (resp. 133 bn. KZT) lower than without adaptation.

As the government subsidizes the investments in irrigation systems, government consumption expenditures in other areas are assumed to be cut. At the beginning of the simulation period, investments in irrigation systems are highest and thus, impacts on government consumption. Afterwards, the investment stimuli become smaller as well as the impact on government consumption.

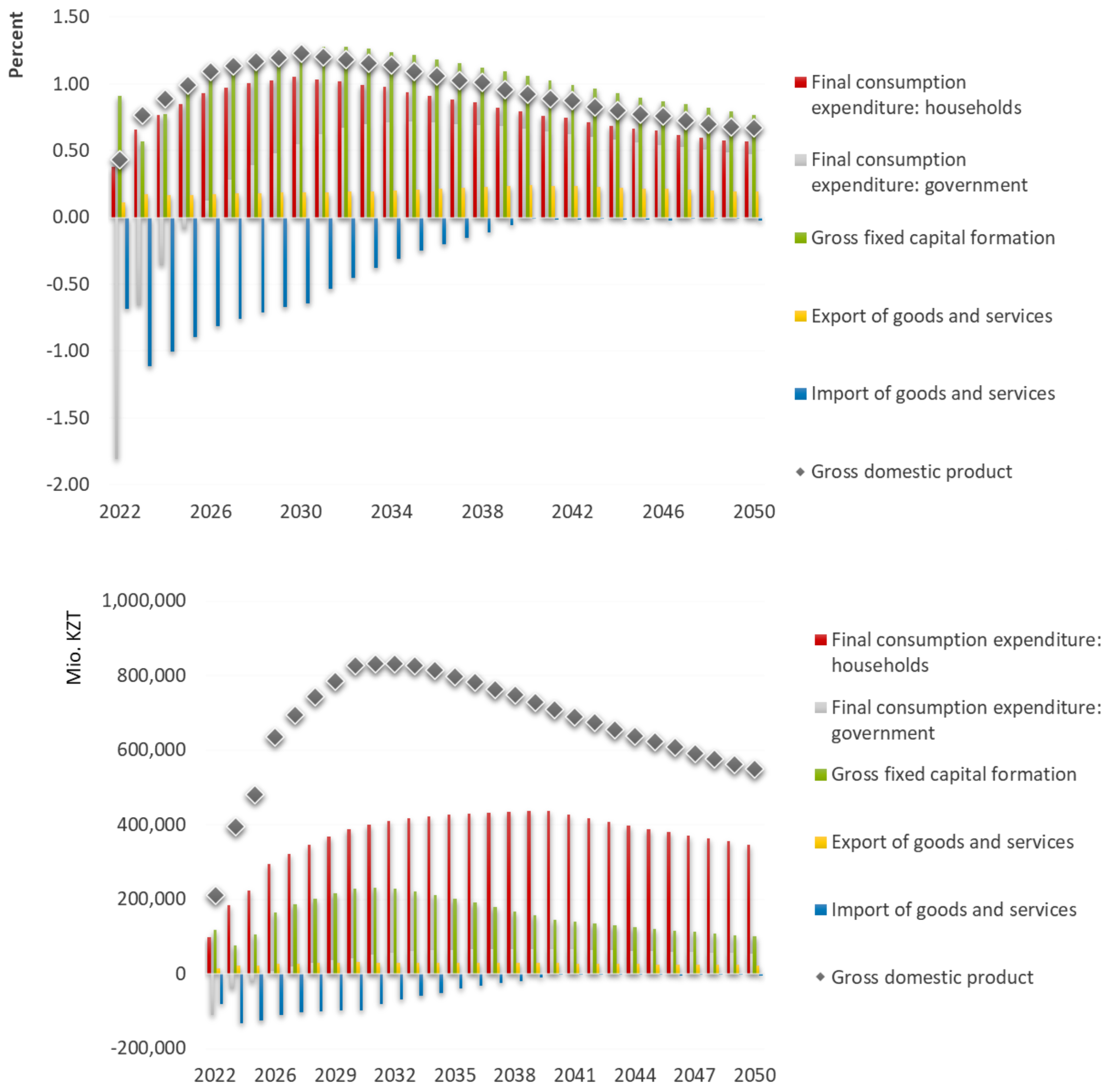


Figure 54: Macroeconomic effects of the "Irrigation" scenario , 2022-2050, deviations from a "Drought" scenario in percent (top figure) and Mio. KZT (bottom figure)

Source: Own illustration based on e3.kz scenario results

The restored irrigated land helps to significantly reduce the drought damage which results in higher agricultural output (7.2% resp. 338 Bn. KZT in 2030) in drought years but also in years without a drought (Figure 55). Furthermore, the intensified construction activity (1.5% resp. 130 KZT in 2030) increases the demand for building materials such as concrete (1.3% resp. 11 Bn. KZT in 20230; shown in the sector manufacturing of other non-metallic mineral products). Also other sectors along the value chain are indirectly, positively affected such as food producers and chemical industry.

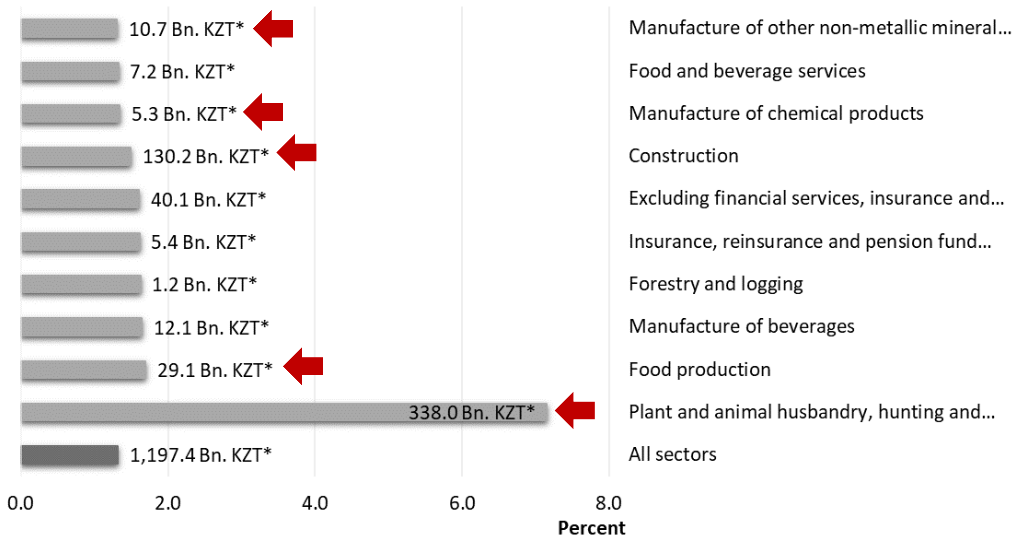


Figure 55: Effects of the "Irrigation" scenario on real production by economic sectors, 2030, deviations from the "Drought" scenario in percent (x-axis) and respective bn. KZT (*)

Source: Own illustration based on e3.kz scenario results

During the construction period additional jobs in the construction sector are created (Figure 56). Thereafter, regular maintenance and replacement investments are necessary and preserve jobs. Permanent jobs are created in agriculture by restored and additional irrigated land. Farmers can generate additional income from selling their products either to the world market or domestically. Supplying (e. g. fertilizer manufacturer which is part of manufacturing in Figure 56) and purchasing industries (e. g. flour producers which is part of manufacturing in Figure 56) profit as well – in terms of additional turnover and jobs – from the higher agricultural productivity not only in drought years. According to the e3.kz model results, building irrigation measures will in total create at max. 78,000 additional jobs (respectively 0.8%) per year compared to a situation where no adaptation is done and droughts occur (Figure 57).

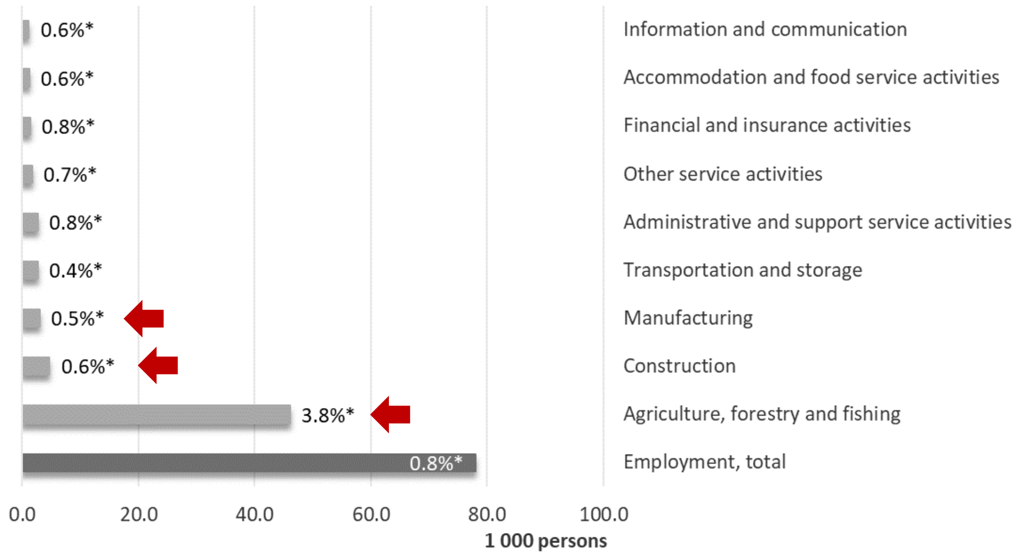


Figure 56: Effects of the "Irrigation" scenario on employment by economic sectors, 2030, deviations from the "Drought" scenario in 1,000 persons (x-axis) and respective percentage changes (*)

Source: Own illustration based on e3.kz results

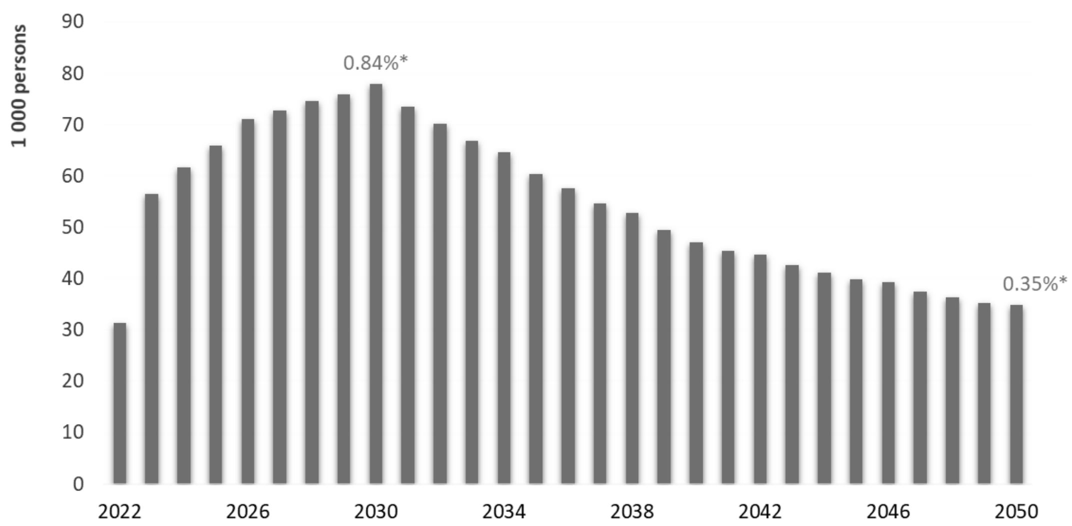


Figure 57: Effects of the "irrigation" scenario given as deviations from the "drought" scenario in 1,000 persons and percent (*)

Source: Own illustration based on e3.kz results

As the government is assumed to bear the investment costs which limits the public expenditures in other areas, fewer jobs will be created in the public sector compared to a situation without adaptation.

The higher economic activity shows on the one hand positive impacts on income and thus spending opportunities of households and investment plans of companies. On the other hand, energy demand and CO_2 emissions increase as long as additional mitigation options are not considered. In 2030, the GDP has the highest increase compared to the "drought" scenario without adaptation and thus, total final energy consumption in this year also shows the largest deviation with 237 ktoe resp. 0.5% (Figure

58). In other years the deviations in energy demand and CO_2 emissions from the "drought" scenario without adaptation are smaller.

The changes for the various energy carriers are dependent on the fuel-specific energy consumption in the economic sectors. Agriculture and construction as well as up- and downstream industries are mainly benefitting from this adaptation measure (c.f. Figure 55) causing in particular a higher demand for oil products (80 ktoe resp. 0.6%), heat (62 ktoe resp. 0.8%) and coal (41 ktoe resp. 0.3%).

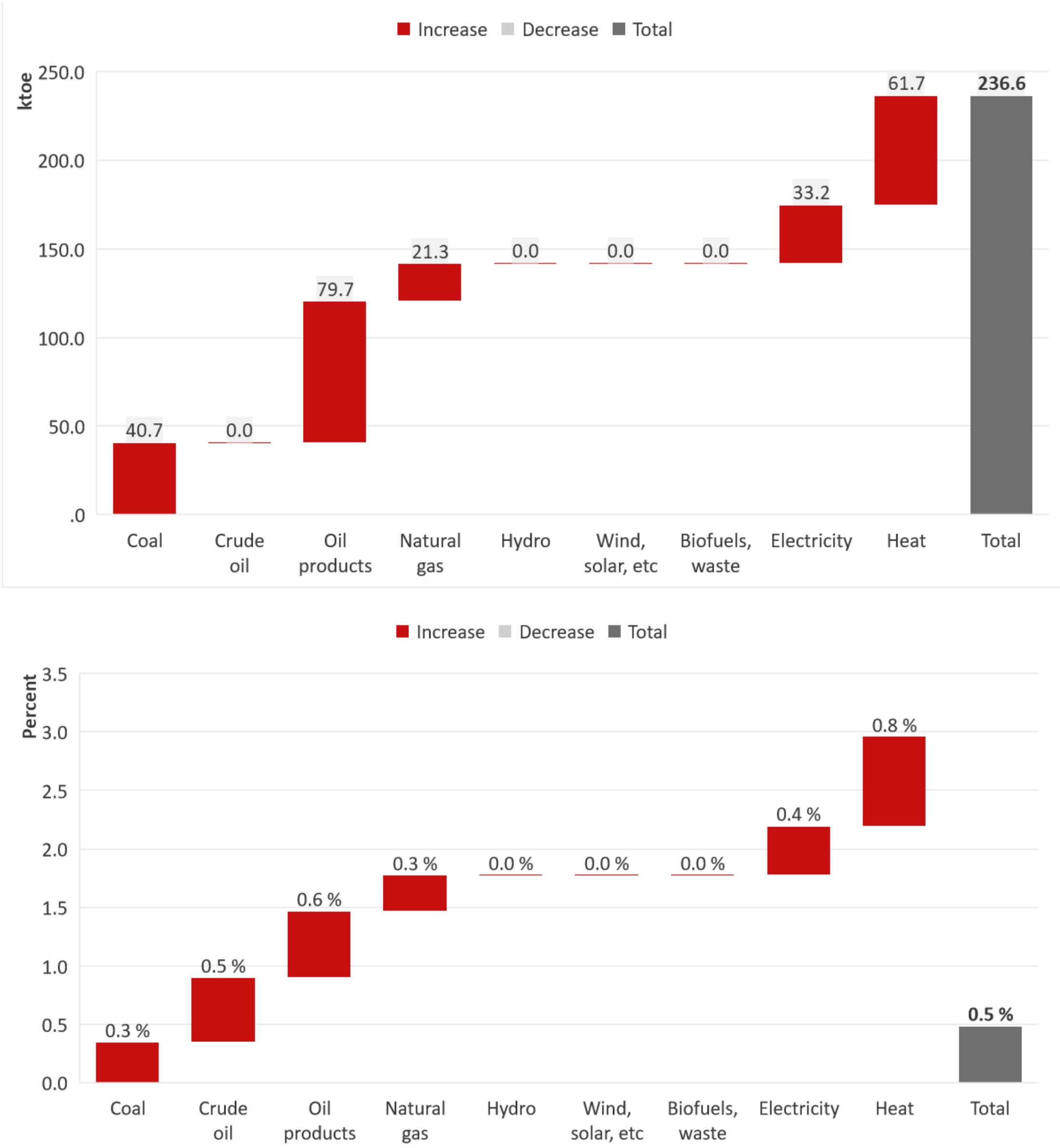
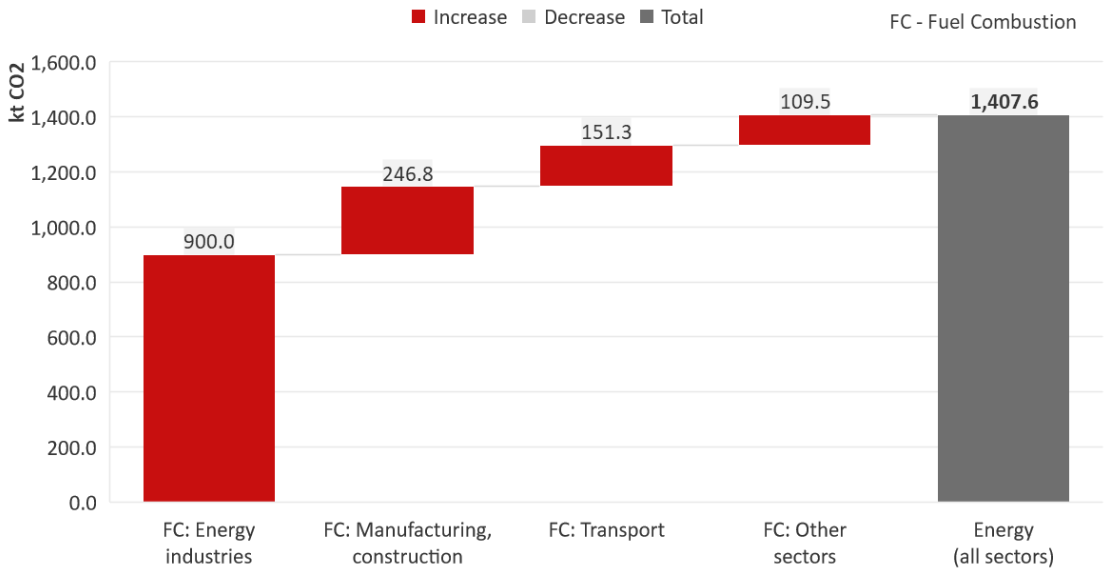


Figure 58: Effects of the "Irrigation" scenario on TFEC, 2030, deviations from the "Drought" scenario in ktoe (top figure) and percent (bottom figure)

Source: Own illustration based on e3.kz results

The impact on CO_2 emissions follows the use of fossil fuels in the respective sectors as shown in Figure 59. Combustion-related CO_2 emissions are at max. (in 2030) 1.4 Mt (resp. 0.4%) higher than in the "drought" scenario without adaptation. Energy industries are mainly contributing 0.9 Mt CO_2 resp. 0.6% because the demand for oil products, heat and power is increasing and the use of fossil fuels in refineries and CHP plants remains high without additional mitigation measures.



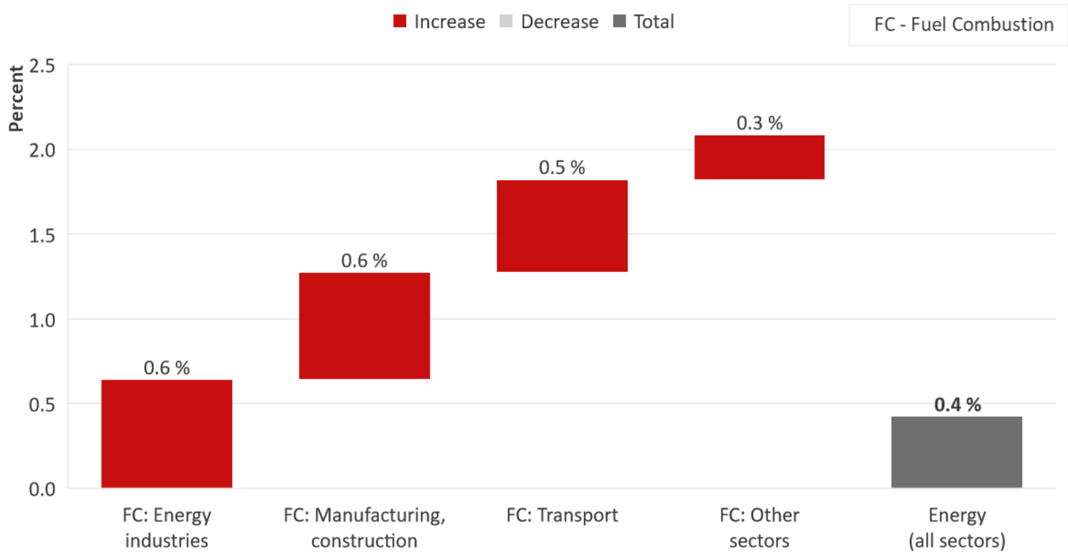


Figure 59: Effects of the “Irrigation” scenario on CO_2 emissions, 2030, deviations from the "Drought" scenario in kt CO_2 (top figure) and percent (bottom figure)

Source: Own illustration based on e3.kz results

Figure 60 summarizes the key impacts of the “Rehabilitation and expanding irrigation systems” scenario.

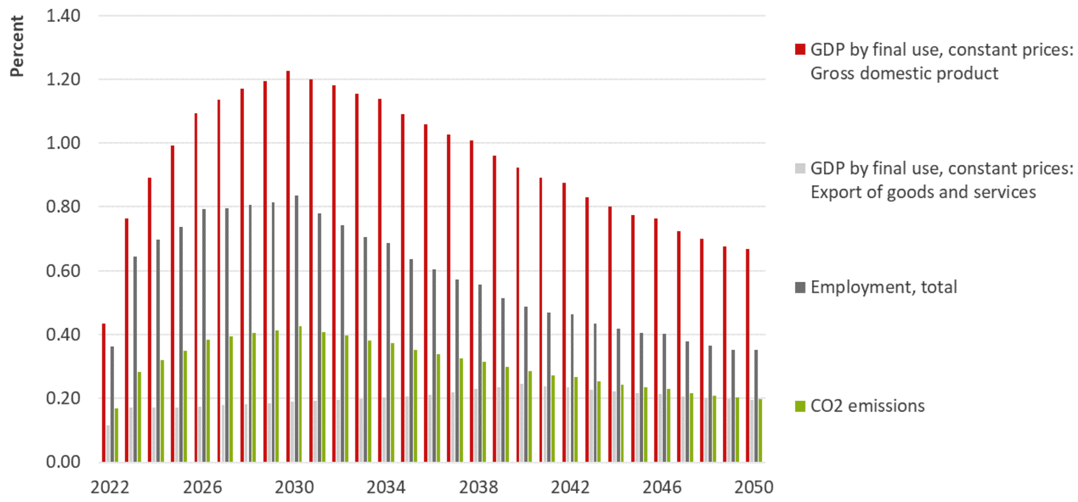


Figure 60: “Irrigation” scenario: key impacts, 2022-2050, deviations from a " drought" scenario in percent

Source: Own illustration based on e3.kz results

6.2.1.2 Investing in precision agriculture: parallel driving

Various technologies for agriculture management are available to support farm management in optimizing yields while preserving resources. Amongst them are yield monitoring, remote sensing and GPS and GIS technologies. The system of parallel driving is a key element of precision agriculture (EBRD et al., 2018).

Existing machinery can be upgraded with GPS and computer systems. The costs can be kept low compared to the purchase of new machines which are usually equipped with GPS by default. Farmers benefit from reduced outgoings and repeated passes. Thus, yields increase, and fuel consumption can be reduced (Table 19).

Table 19: Investing in precision agriculture: parallel driving – key assumptions

Adaptation measures	Cumulated investment (2022 – 2050)	Adaptation benefits per year (in terms of higher agricultural output)
Investment in precision agriculture: parallel driving	100 billion KZT	4 billion KZT

Source: Based EBRD et al. (2018),

The equipment of the machines with GPS takes place gradually. It is assumed that the government supports the investments which limits other public spending but does not affect prices for agricultural goods. The more machines are upgraded, the greater the benefits. This is reflected in declining agricultural imports as well as increasing exports. Since GPS and computer systems are mainly imported (EBRD et al., 2018), total imports are increasing.

Model results

The impacts of this measure for the national economy are rather small (Figure 61). As long as the benefits from the adaptation measure cannot be fully exploited, the economic growth is at a lower level. Afterwards, GDP is slightly higher compared to a situation without this measure. Employment, food, and energy security can by improved within a limited scope. According to EBRD et al. (2018) this adaptation measure helps to save up to 122,000 tons of CO_2 equivalents per year.

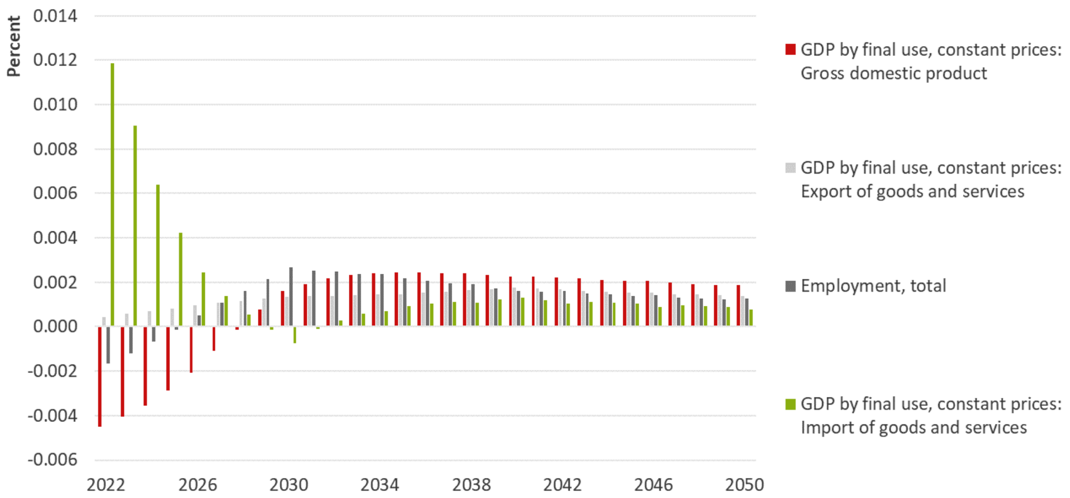


Figure 61: Macroeconomic effects of the "Precision agriculture: parallel driving" scenario, 2022-2050, deviations from the "Drought" scenario in percent

Source: Own illustration based on e3.kz scenario results

6.2.1.3 Key messages

The government of the Republic of Kazakhstan adopted the Ecological Code in January 2021 which shows ambitions to mainstream climate change adaptation into policies and development plans at the national and sub-national levels. Modelling results helps to understand which planned adaptation measures (or a combination thereof) are better suited in terms of the impacts for the economic sector and the whole economy. Thus, adaptation options which are supposed to be beneficial for the agriculture sector should be examined regarding their impacts for the whole economy before implementation.

The consequences of climate change are already noticeable and will occur more frequently and become more severe in the future. Food security might be at risk. Jobs and income are endangered not only in agriculture. Policymakers should be aware of what could happen to manage adaptation strategies and to initiate a climate resilient economic development.

Many adaptation measures exist for agriculture. Cost-benefit analysis helps to rank the individual technologies following techno-economic assessments (FAO and EBRD, 2017). Additionally, macroeconomic analyses should be conducted to detect the economy-wide impacts of single measures and enable decision-makers to adopt win-win options.

Investments in adaptation provide co-benefits, as the two adaptation measures analyzed with the e3.kz model exemplarily demonstrate (c.f. section 6.2.1.1 and 6.2.1.2). Economic losses in agriculture can be reduced also in up- and downstream industries. **Measures that primarily support the domestic economy as the case of the rehabilitation of water canals are even more beneficial**. The associated construction activities create jobs in Kazakhstan. **Products such as drip irrigation systems are mainly imported and curtail the advantages**. Nevertheless, in both cases permanent jobs can be created in agriculture and related industries.

Other adaptation measures such as pasture improvement through rotational grazing, the cultivation of drought-resistant species, an improved soil coverage, the adaptation of crop rotations and the use conservation agriculture technologies can further enhance these positive effects. **Combining selected adaptation measures may help to exploit existing opportunities to further reduce the impacts of climate change**.

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

Combating climate change requires a holistic approach including both mitigation and adaptation action: The e3.kz model results show that higher economic activity in particular in cement production and chemical industry cause more CO_2 emissions. Other GHG emissions not covered by the e3.kz model so far are likely to increase as well with higher agricultural production. The GHG mitigation potential may be leveraged with efficiency improvements, the use of renewables and other sustainable practices methods (e. g. organic agriculture). The currently elaborated Kazakhstan's Low-Emission Development Strategy recognizes sustainable development as the overarching context for climate policy and indicates close links between adaptation and mitigation, their co-benefits and adverse side effects. Thus, additional adaptation measures fulfilling the selection criteria mentioned in section 6.1 are recommended to be analyzed with the e3.kz model.

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

Although the financial and economic impacts are relevant for policymakers to decide which adaptation measure is "most effective", other criteria must be considered as well such as health aspects and ecosystem services (biodiversity, regulation of the water balance).

Adaptation measures providing small(er) benefits at low(er) costs also have smaller macroeconomic effects and vice versa.

Adaptation measures (partially) **financially supported by international donors are even more beneficial** for the macroeconomy.

In addition to macroeconomic effects, **contributions to CO_2 mitigation should be included in the evaluation** of adaptation measures.

Furthermore, the example of parallel driving as one element of precision agriculture demonstrates that although the macroeconomic impacts are small, **such a "low-cost" measure offers (limited) potential for reducing emissions**.

When comparing macroeconomic impacts of adaptation measures, scenario assumptions (e. g. underlying costs and benefits, investment period, who takes the financial burden?) must be considered as well to properly interpret the results.

6.2.2 ADAPTATION IN ENERGY

Current Situation

Energy plays an essential role for Kazakhstan's economic and social development. In 2019, around 16% of the GDP was related to the energy sector (incl. mining and energy supply) and about 5% of the workforce were employed in this sector, which equals 0.4 million people (COMSTAT, 2020).

The energy sector is the backbone of the whole economy and assures energy security, economic growth and jobs. Kazakhstan is a major producer and exporter of all kinds of fossil fuels. Domestic energy demand is also high, especially in the industry (15 Mtoe in 2018) and the residential sector (11 Mtoe in 2018; IEA, 2021).

Coal, oil and gas are the dominant fuels in Kazakhstan's energy mix. So far, renewable energy plays a minor role. In 2018, the share of renewable energy accounted for 10.4% (mainly hydro, IEA, 2021). Thus, Kazakhstan emitted 364 Mt CO_2e in 2019 of which 73% accounts for fuel combustion. Energy industries have the largest share (47%), followed by manufacturing and construction (10%), transport (10%) and other sectors incl. the commercial, residential and agriculture sector (16%, UNFCCC, 2021).

The need for investment in energy infrastructure is high due to ageing and inefficient power generating facilities as well as transmitting infrastructure. Kazakhstan's Electricity Grid Operating Company plans to modernize and construct new power transmission lines and substations by 2025. Furthermore, the Green Economy Concept aims at 50% alternative and renewable energy in the energy mix by 2050 which is supported by the deployment of renewable energy and energy efficiency improvements (Green Economy Concept, 2013). Even more ambitious and challenging is Kazakhstan's commitment to achieve carbon neutrality by 2060, which was announced in December 2020.[33]

Kazakhstan's current energy mix requires a lot of water for hydropower generation, for cooling in thermoelectric power plants and during fuel extraction (Rivotti et al. 2019). Due to expected rising demand for electricity, the water use in the energy sector would presumably increase, if the energy mix, power plant locations and water-cooling technologies remain unchanged. Additionally, climate change is likely to amplify energy security concerns as described below.

Options for building climate resilience in the energy sector

The energy sector is required to respond to climate change in two ways: On the one hand, Kazakhstan is committed to undertake climate mitigation activities and, on the other hand, adaptation measures are needed to reduce the previously mentioned climate change impacts. Due to the long-lived nature of infrastructure assets, decisions made now will lock-in vulnerability if they fail to consider climate change impacts (OECD, 2018). Thus, it is important to coordinate and plan mitigation and adaptation activities accordingly to create co-benefits and avoid adverse side effects.

According to the World Bank (2011), several adaptation options exist to reduce the impacts of climate change in the energy system by 40% to 68%. Structural adaptation measures such as investments in protective infrastructures (e. g. dams), improvement of design standards (e. g. climate-proofed power plants, underground or insulated power lines) and refurbishment provide physical protection and increase robustness (OECD 2018). Efficiency improvements provide win-win solutions for mitigation and

---

33 https://www.kz.undp.org/content/kazakhstan/en/home/presscenter/news/2021/october/kazakhstan_s-vision-to-achieve-carbon-neutrality-presented-at-hi.html (last accessed December 1st, 2021)

adaptation in the context of rising energy demand and respective supply constraints due to climate change.

The development of alternative renewable energy sources reduces the vulnerability of the energy system to various climate impacts as a whole (MNE et al. 2017, World Bank 2011). Wind and solar power are not water demanding but reliant on wind speed and solar radiation. They are often available when water is scarce or not usable for cooling purposes. Moreover, the deployment of renewable energy sources supports a decentralized energy structure, and thus, reduces the risk of suffering from large-scale outages compared to a centralized energy system. Management (or non-structural) adaptation measures such as the relocation of energy infrastructure, regular inspections and repair plans as well as improved meteorological forecasting tools also help to be better prepared (OECD 2018, World Bank 2011).

The macroeconomic effects of the adaptation measures "Expansion of underground powerlines" and "Deployment of wind power and energy efficiency improvements in the housing sector", which is a mitigation measure in the first place, are presented as examples in the next sections. Underground powerlines are better suited to prevent damages from extreme precipitation and storms. Investment in wind power has the advantage of not being water demanding. In combination with energy efficiency measures, these two mitigation actions can contribute to balancing out the effects of heatwaves with regard to even higher energy consumption and impaired power production.

6.2.2.1 Expansion of underground powerlines

The rehabilitation and modernization of the energy infrastructure are key to prevent climate change damages and to limit production failures in other sectors due to power outages. Extreme precipitation and floods are expected to occur more frequently (every two years) and more severely. This will cause increasingly higher economic losses in the energy sector, negatively affecting jobs and energy security.

Scenario assumptions and implementation

The modernization of power transmission lines is a prerequisite to maintain the energy security of the economy and people. To increase the climate resilience of the grid and to reduce power outages, a proactive replacement of uninsulated overhead lines with underground power lines is assumed until about half of the total 25,000 km of long-distance high voltage transmission lines have been renewed in 2050. The costs for one kilometer of underground cable are specified with 100 million KZT and thus total investments amount to 1,250 billion KZT over a 30-year-period. It is anticipated that the investment sum is divided into equal shares for construction work and electrical equipment. Investments are financed by the energy sector which pass the costs on to the consumers.

Table 20: Investment in underground power lines – key assumptions

Cumulated investment (2022-2050)	Adaptation benefits (by 2050)
1,250 billion KZT (50:50 construction works and electrical equipment)	• Up to 50% reduction of power loss and outages • Up to 50% reduction of the additional (involuntary) electricity production to compensate the power loss due to joule heating and corona discharge • Up to 50% reduction of production losses in various economic sectors due to power outages • Up to 50% reduction of (involuntary) reconstruction costs in the energy sector

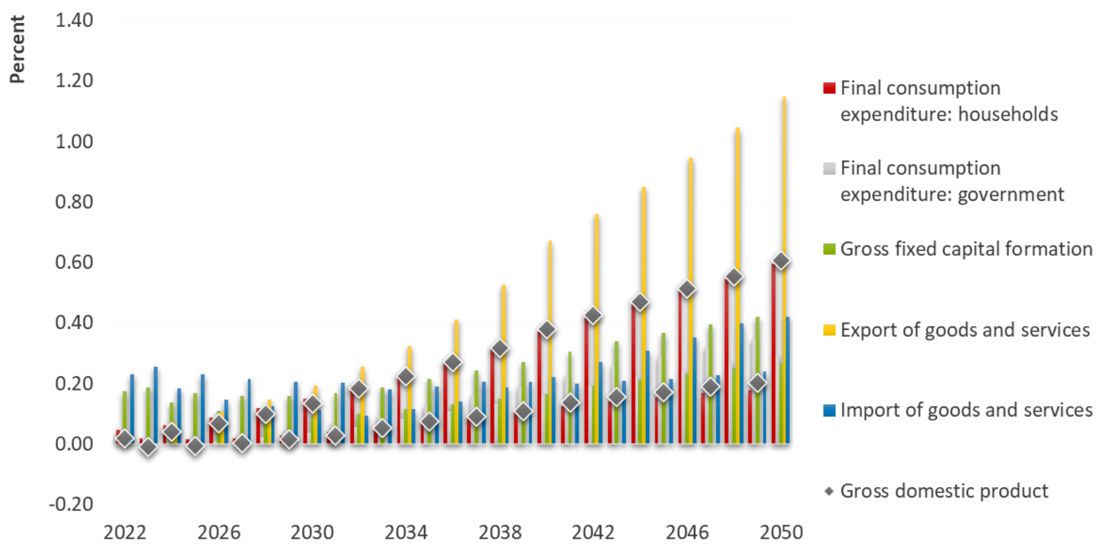
Source: Own assumptions and KEGOC 2018.

As the modernization of power lines progresses over time, the climate resilience of the energy system increases. Power losses and outages as well as triggered production losses in other economic sectors are assumed to be reduced by up to 50% by 2050. Thus, both export losses in export-oriented industries (e. g. manufacturers of metal products) and the imports of various manufacturing industries to compensate production failures can be reduced. Furthermore, the additional (involuntary) electricity production to compensate the power loss due to joule heating and corona discharge is assumed to be reduced by 50% by 2050.

In addition to the direct effects (construction works, imports of electrical equipment, higher output in economic sectors), these effects account for further indirect and induced effects, e. g., an increase of production in upstream and downstream sectors of construction as well as for price and income effects, which in turn influence consumption expenditures.

Model results

The economy-wide effects of the gradual replacement of overhead by underground powerlines in the energy sector are positive. GDP growth is supported by higher exports, investment and consumption expenditures by households. Both the intensified construction activity and production in various economic sectors due to prevented power outages have a positive impact on GDP which is up to approx. 0.6% (resp. 503 Bn. KZT) higher compared to a situation with no adaptation and extreme precipitation and floods (Figure 62). In the years without extreme precipitation and floods, the economy grows also faster initiated by the gradual replacement of overhead by underground powerlines.



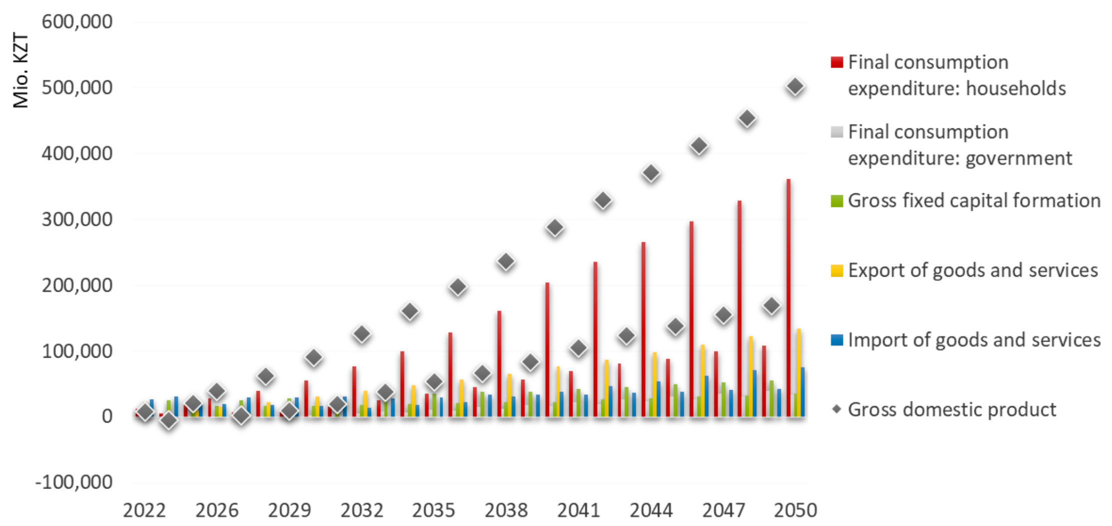


Figure 62: Macroeconomic effects of the “underground powerlines” scenario, 2022-2050, deviations from the "extreme precipitation" scenario in percent (top figure) and mio. KZT (bottom figure)

Source: Own illustration based on e3.kz scenario results

Lost export chances due to climate change and increases in imports in various manufacturing industries to compensate for production losses can now be partly prevented. The import of electrical equipment has per se a negative effect but does not prevail. Total exports increase by 1.2% (resp. 134 Bn. KZT) by 2050 while total imports increase by 0.4% (resp. 75 Bn. KZT) compared to an “extreme precipitation” scenario without adaptation due to the high import-dependency of the economy.

Various manufacturing industries have lower production losses (Figure 63). The higher construction activity increases demand for intermediate goods (e. g. concrete which is part of non-metallic mineral products) and thus positively affects production in several other sectors.

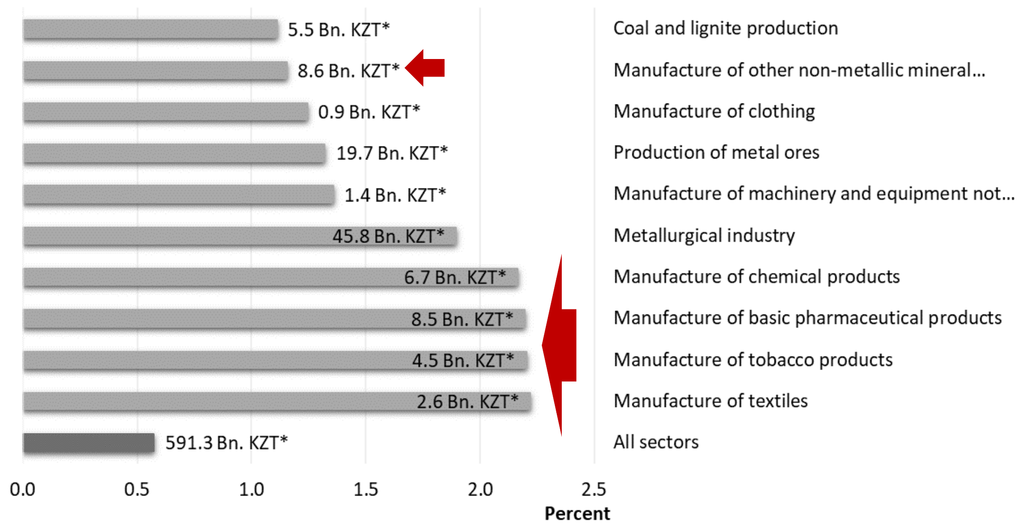


Figure 63: Effects of the "underground powerlines" on real production by economic sectors, 2050, deviations from the "extreme precipitation" scenario in percent (x-axis) and % (*)

Source: Own illustration based on e3.kz scenario results

The increased construction activity associated with the adaptation measure generates more jobs in the construction sector and avoids job losses in manufacturing sectors. The number of additional jobs is increasing over time and reaches the maximum in 2050 which results in 17,000 (resp. 0.2%) employed persons more compared to a scenario without adaptation to extreme precipitation and floods (Figure 64).

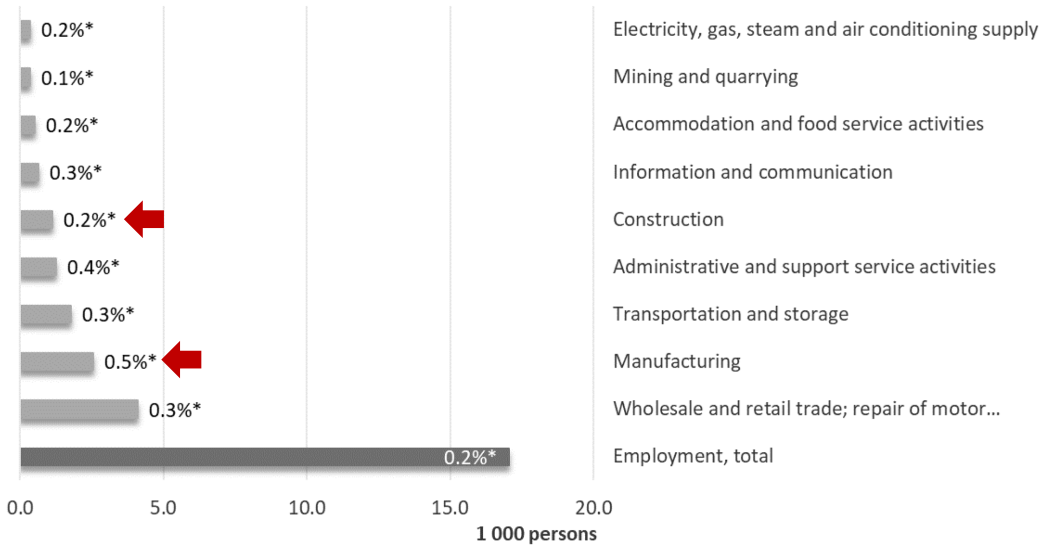


Figure 64: Effects of the "underground powerlines" scenario on employment by economic sectors, 2050, deviations from the "extreme precipitation" scenario in 1,000 persons (x-axis) and respective percentage changes (*)

Source: Own illustration based on e3.kz results

Greater economic activity induces an increase in energy demand (Figure 65). CO_2 emissions in manufacturing sectors and construction increase. Lower additional (involuntary) energy production – needed before due to energy losses from corona discharge and joule heating – reduces input for coal and gas which in turn decrease CO_2 emission in energy industries. In total, CO_2 emissions decrease max. by 0.4% (resp. 1.3 Mt CO_2, Figure 66).

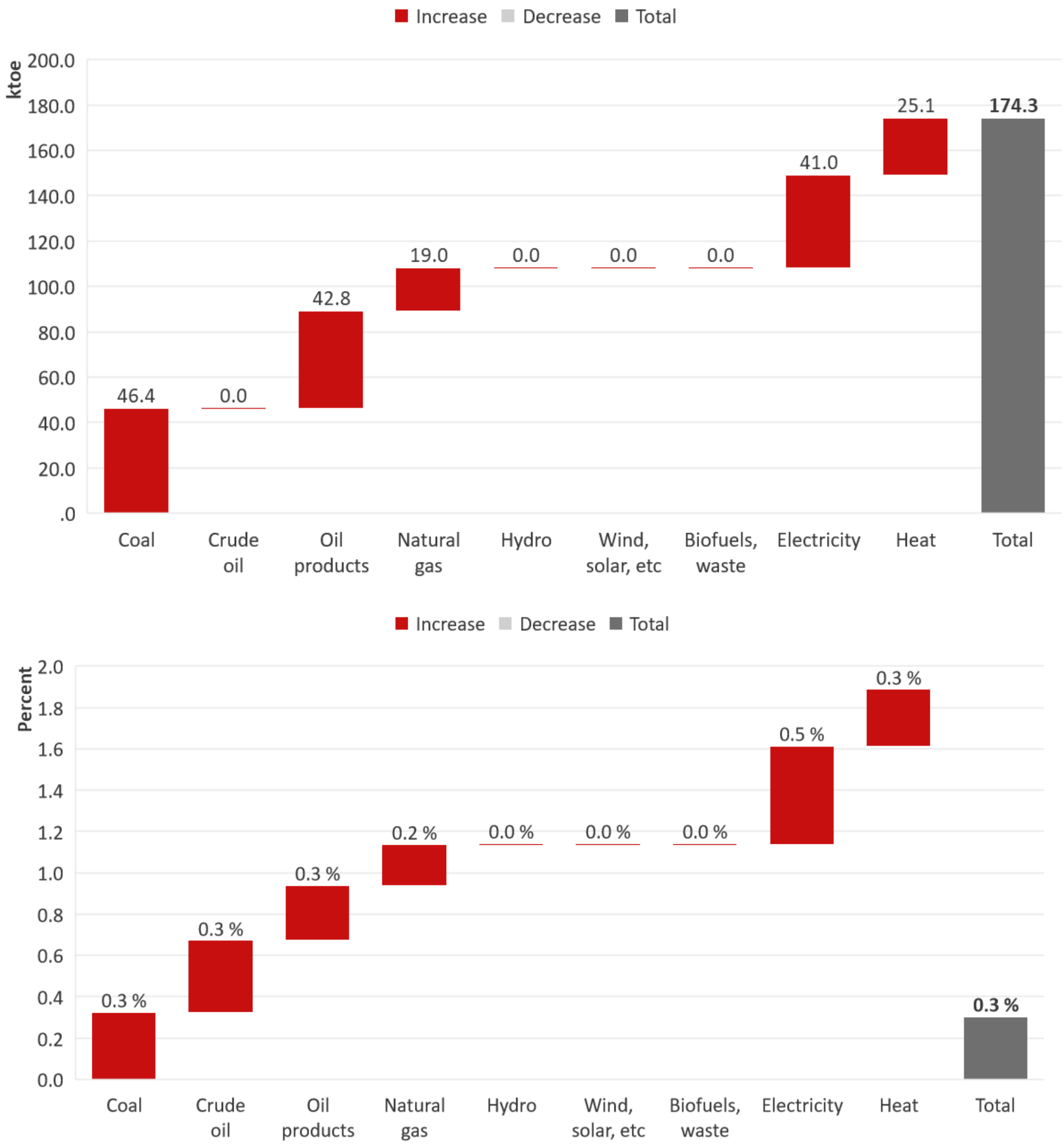


Figure 65: Effects of the “underground powerlines” scenario on TFEC, 2050, deviations from the "extreme precipitation" scenario in ktoe (top figure) and percent (bottom figure)

Source: Own illustration based on e3.kz results

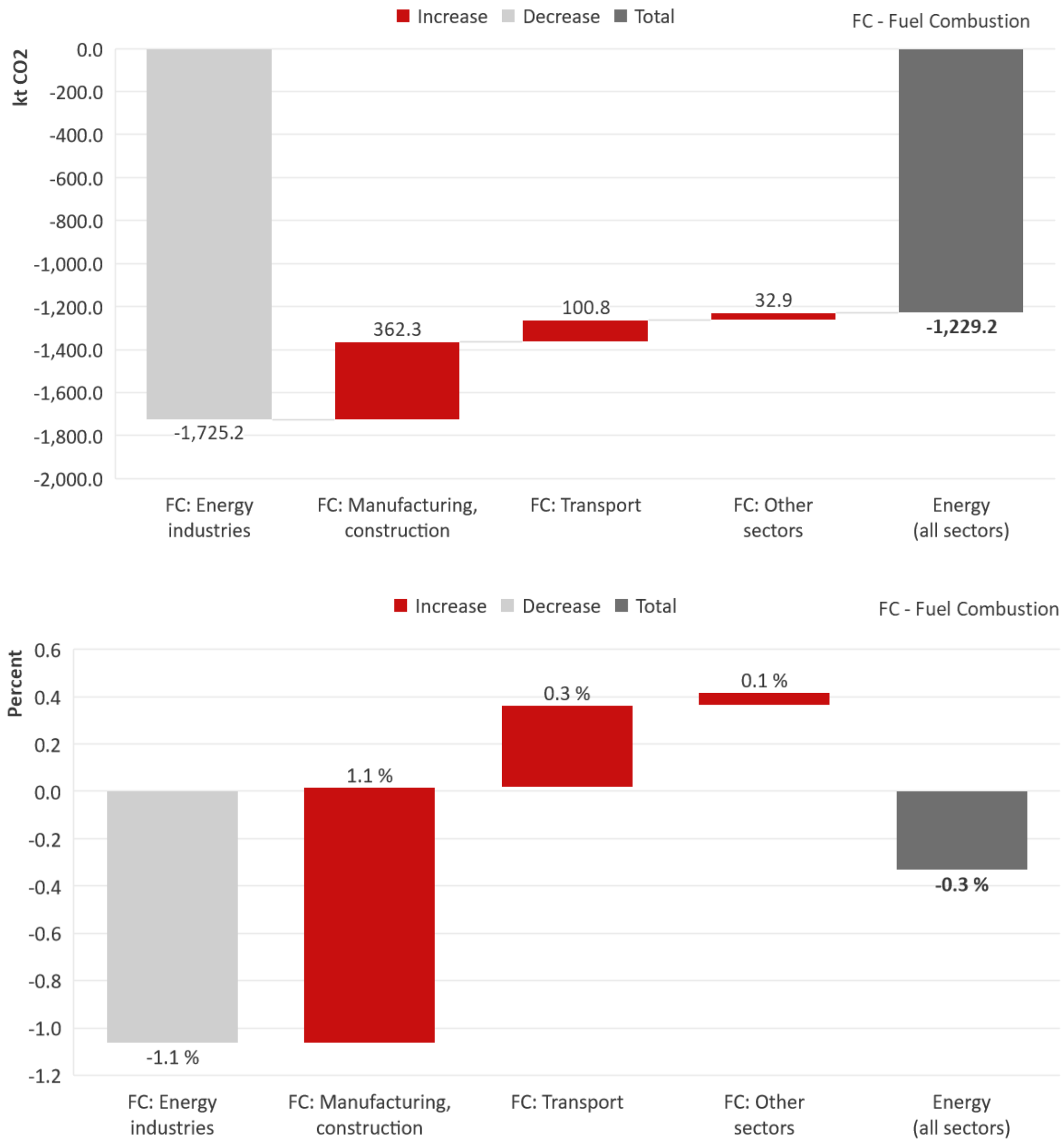


Figure 66: Effects of the “underground powerlines” scenario on CO_2 emissions, 2050, deviations from the "extreme precipitation" scenario in kt CO_2 (top figure) and percent (bottom figure)

Source: Own illustration based on e3.kz results

Figure 67 summarizes the key impacts of the “underground powerlines” scenario.

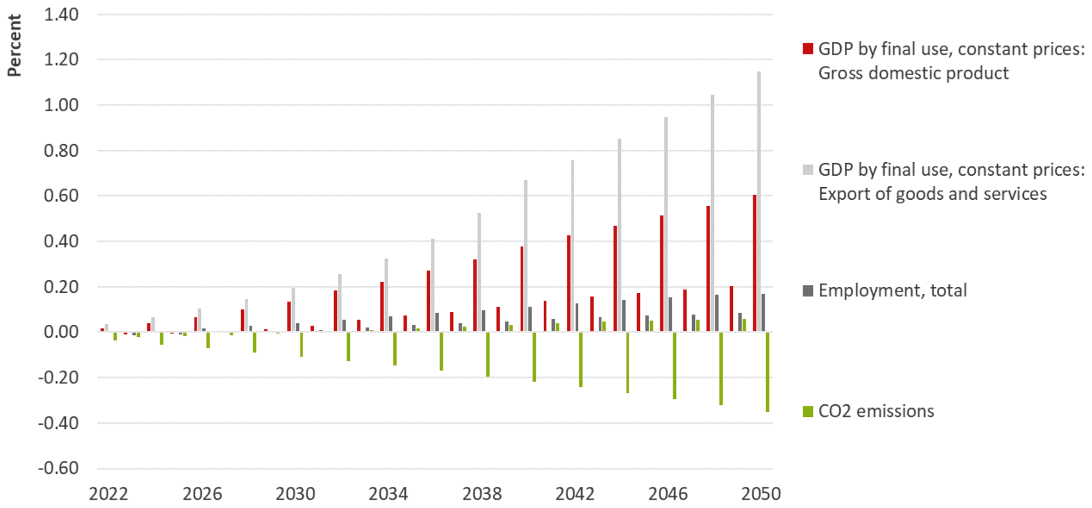


Figure 67: “Underground powerlines” scenario: key impacts, 2022-2050, deviations from a "extreme precipitation" scenario in percent

Source: Own illustration based on e3.kz results

6.2.2.2 Deployment of wind power and energy efficiency improvements in the housing sector

Both the expansion of water-independent energy technologies such as wind power and the reduction of energy consumption are important elements to prepare for heat waves and possible imbalances of energy supply and demand. At the same time, synergies between climate protection and climate adaptation measures are exploited.

Scenario assumptions and implementation

According to IRENA (2021), the wind power capacity in Kazakhstan can be increased by 2.8 GW. Until 2050, 2.9 trillion KZT must be invested assuming costs of USD 2,472 per installed capacity in kW. Further cost reduction due to learning curve effects is not assumed. With this expansion and expected 3,154 full load hours per year, additional 8,831 GWh of electricity can be generated from wind power. Investments are financed by the energy sector which pass the costs on to the consumers. Wind power serves as reserve power source during heat waves and may support – depending on the wind situation – the energy supply and reduces electricity imports.

Table 21: Deployment of wind power and energy efficiency improvements in housing – key assumptions

Adaptation measures	Cumulated investment (2022-2050)	Adaptation benefits (by 2050)
Deployment of wind power[1]	• 2.9 trillion KZT* (2.8 GW additional installed capacity at 2,472 USD / kW) • Capacity factor: 36 % à 8,831 GWh	• Preservation of power generating capacity during heat waves
Energy efficiency improvements in housing[2, 3]	• 9 billion USD	• Reduced energy demand by -11% for housing compared to BAU in 2050

Source: [1]IRENA., 2021; [2]World Bank, 2018b; [3]LEDS table 13 and table 20

* Based on an exchange rate of 425 KZT / USD.

The efficiency improvements in the building sector are adopted from the LEDS project (DIW Econ, 2021), which assumes an energy savings potential of 11% compared to a BAU scenario. Investments are assumed to be a quarter of the total investments of all efficiency measures specified in World Bank (2018b) which amounts to nine billion KZT over the entire period. Residential buildings are about half owned by the real estate sector and half by private owners. Thus, both sectors must bear the investment costs. Private households are assumed to spend less on other consumption options and to finance it from savings. The real estate sector passes on the costs to the consumers. This measure helps to reduce both cooling demand during heat waves and heating demand in winter.

Model results

The economy-wide effects of the yearly investments in wind power and in energy efficiency improvements in buildings are positive. GDP is increasing and is 0.7% resp. 558 bn. KZT higher compared to a situation with no adaptation and heat waves by 2050 (Figure 68). Additional imports of wind turbines have a negative impact on the GDP. Over time, total imports grow less rapidly as more and more electricity imports can be replaced by domestic, climate resilient electricity production.

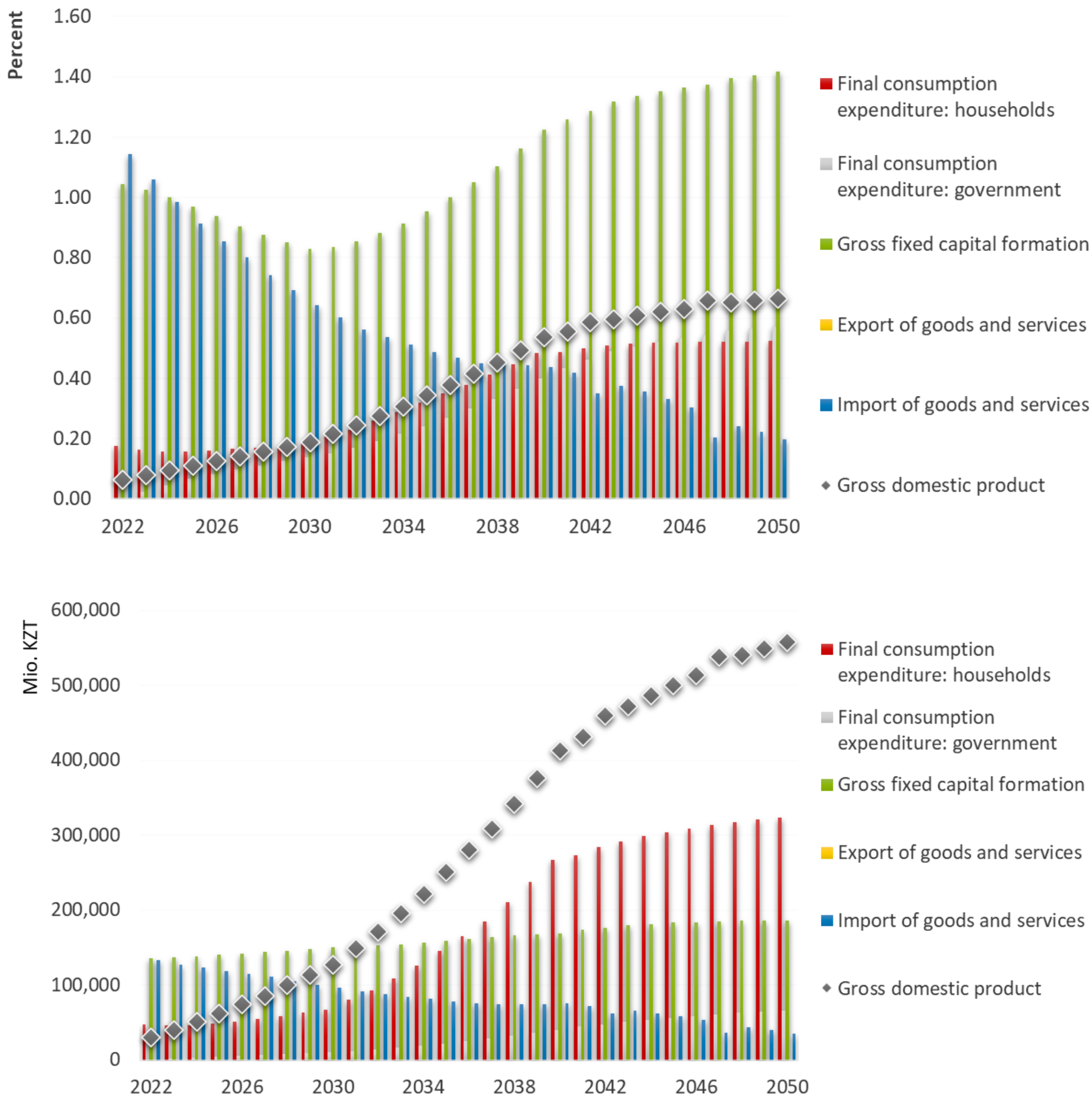


Figure 68: Macroeconomic effects of the "wind power deployment and housing energy efficiency improvement" scenario, 2022-2050, deviations from the "heat wave" scenario in percent (top figure) and mio. KZT (bottom figure)

Source: Own illustration based on e3.kz scenario results

GDP effects are dampened by an increasingly lower energy demand. The latter was intended to be achieved. Additionally, expenditure on refurbishment activities by private households can increasingly be offset by lower energy expenditure, leaving also financial scope for additional non-essential activities which are supporting GDP growth. Also, spending opportunities of private households increase due to more jobs and income. Overall, private household expenditures are up to 0.5% resp. 323 bn. KZT per year higher compared to a "heat wave" scenario without adaptation.

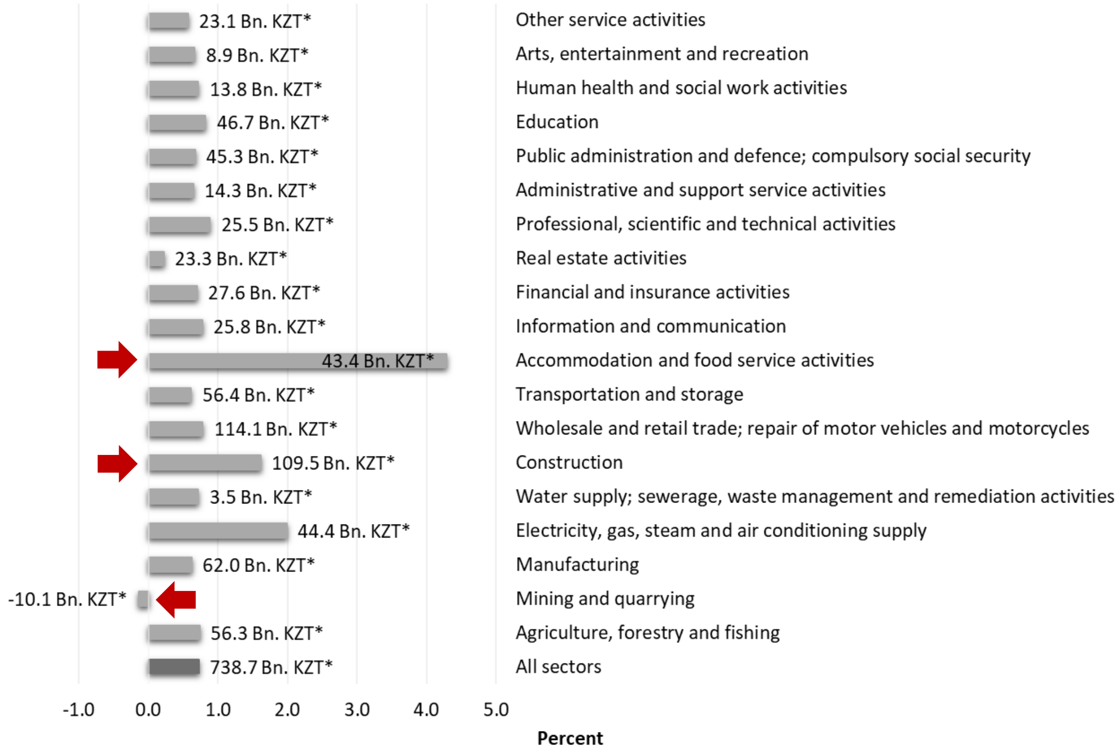


Figure 69: Effects of the "wind power deployment and housing energy efficiency improvement" scenario on real production by economic sectors, in 2047, deviations from the "heat wave" scenario in percent

Source: Own illustration based on e3.kz scenario results

The refurbishment of houses increases the construction activity and thus the demand for building materials such as concrete and insulating material (Figure 69). Furthermore, the energy sector profits not only from higher renewable power production but also from the greater economic activity although demand in the residential sector is growing more slowly compared to a heat wave scenario without adaptation. The sector accommodation and food service activities are expected to benefit from the energy expenditures saved. Refurbishment of houses increases both the savings of electricity for air conditioning in summer and savings for heat demand in winter. Thus, demand for e. g. coal and gas is at a lower level and also mining and quarrying activities compared to a heat wave scenario without adaptation.

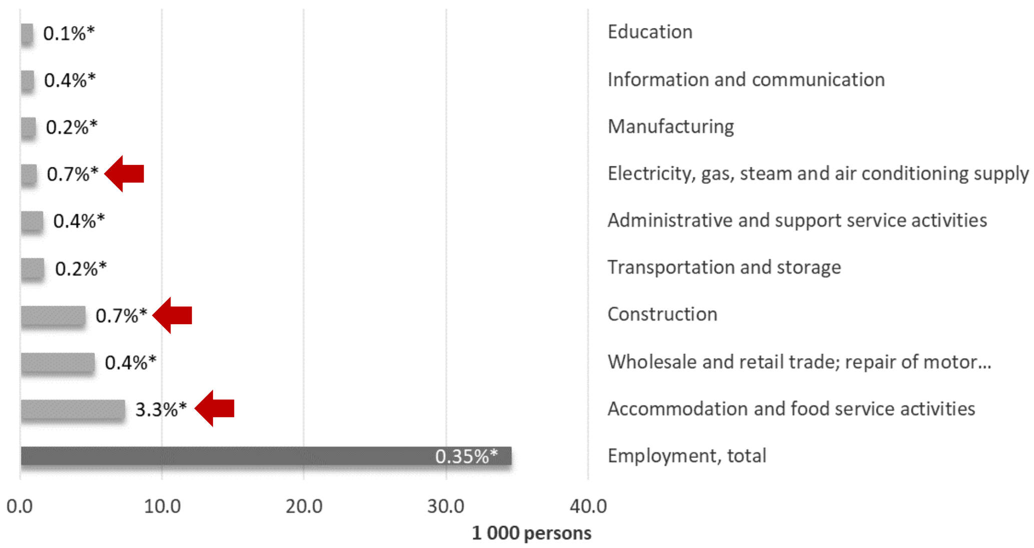


Figure 70: Employment effects of "wind power deployment and housing energy efficiency improvement" scenario, 2047, deviations from the "Heat wave" scenario in 1,000 persons (x-axis) and percent (*)

Source: Own illustration based on e3.kz results

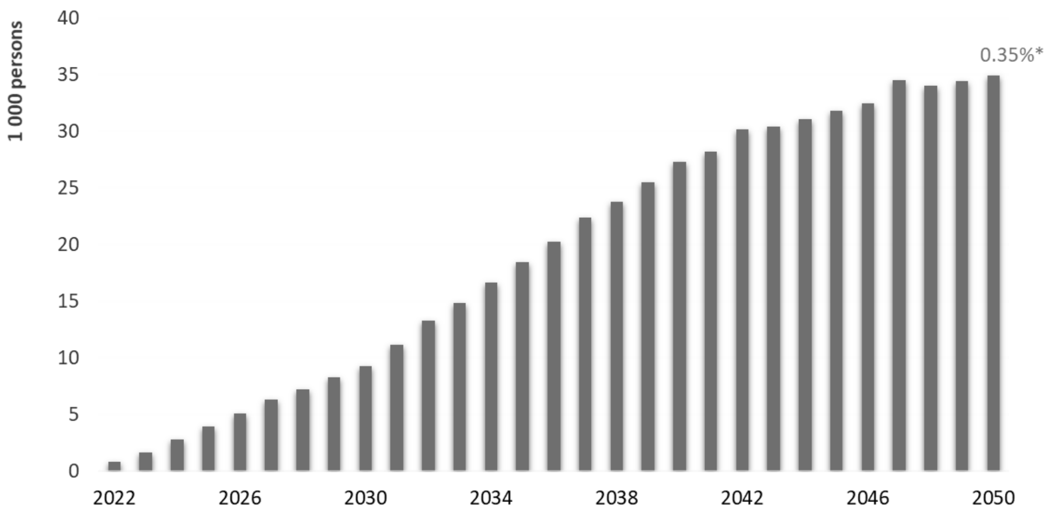


Figure 71: Effects of the "wind power & housing energy efficiency improvement" scenario given as deviations from the "heat wave" scenario in 1,000 persons and percent (*)

Source: Own illustration based on e3.kz results

In total, employment increases up to 0.35 % (35 thousand persons) compared to a situation without adaptation and heatwaves (Figure 71). Figure 70 shows that positive employment effects for the accommodation and food service activities as well as construction and energy sector will arise with increasing efficiency gains and renewable energy expansion. The steady expansion of renewable energies and refurbishment activities secure permanent jobs in the construction sector.

Furthermore, it can be expected that additional jobs for operation and maintenance of the wind turbines will also be created. The total employment effects would then be even higher.

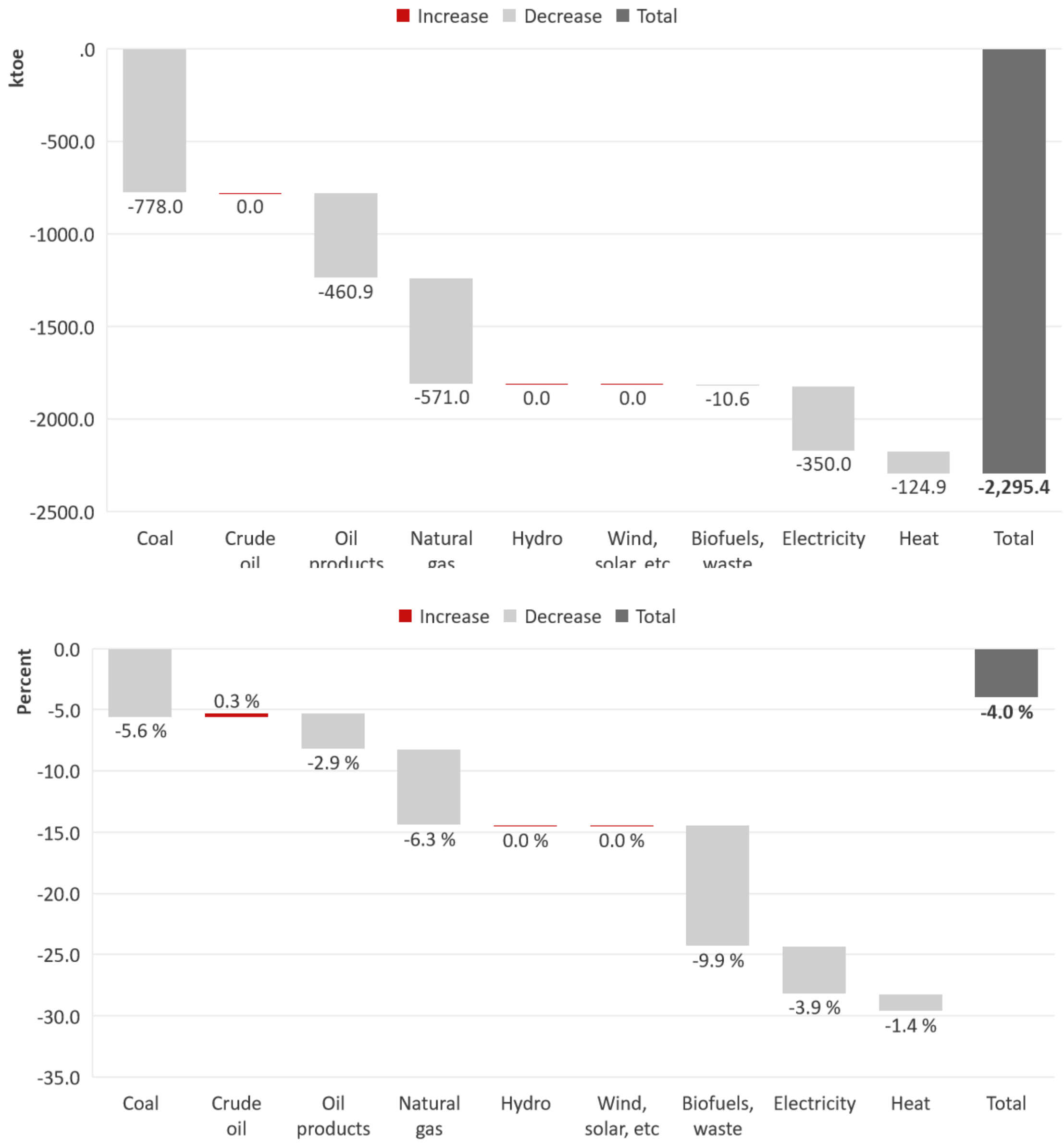


Figure 72: Effects of the "wind power deployment and housing energy efficiency improvement" scenario on TFEC, 2047, deviations from the "heat wave" scenario in ktoe (top figure) and percent (bottom figure)

Source: Own illustration based on e3.kz results

Refurbishing the residential sector helps to avoid higher electricity consumption from air conditioning in particular during heat waves and reduces also heat demand in winter. Until 2050, the residential sector is expected to save up to 11% of its energy demand. For the total final energy consumption that means 2.3 Mtoe resp. 4% less compared to a “heat wave” scenario without adaptation in 2047 (Figure 72). However, stronger economic activity increases final energy consumption in other sectors (in particular the manufacturing industries and construction), since no further sector-specific climate protection measures were adopted.

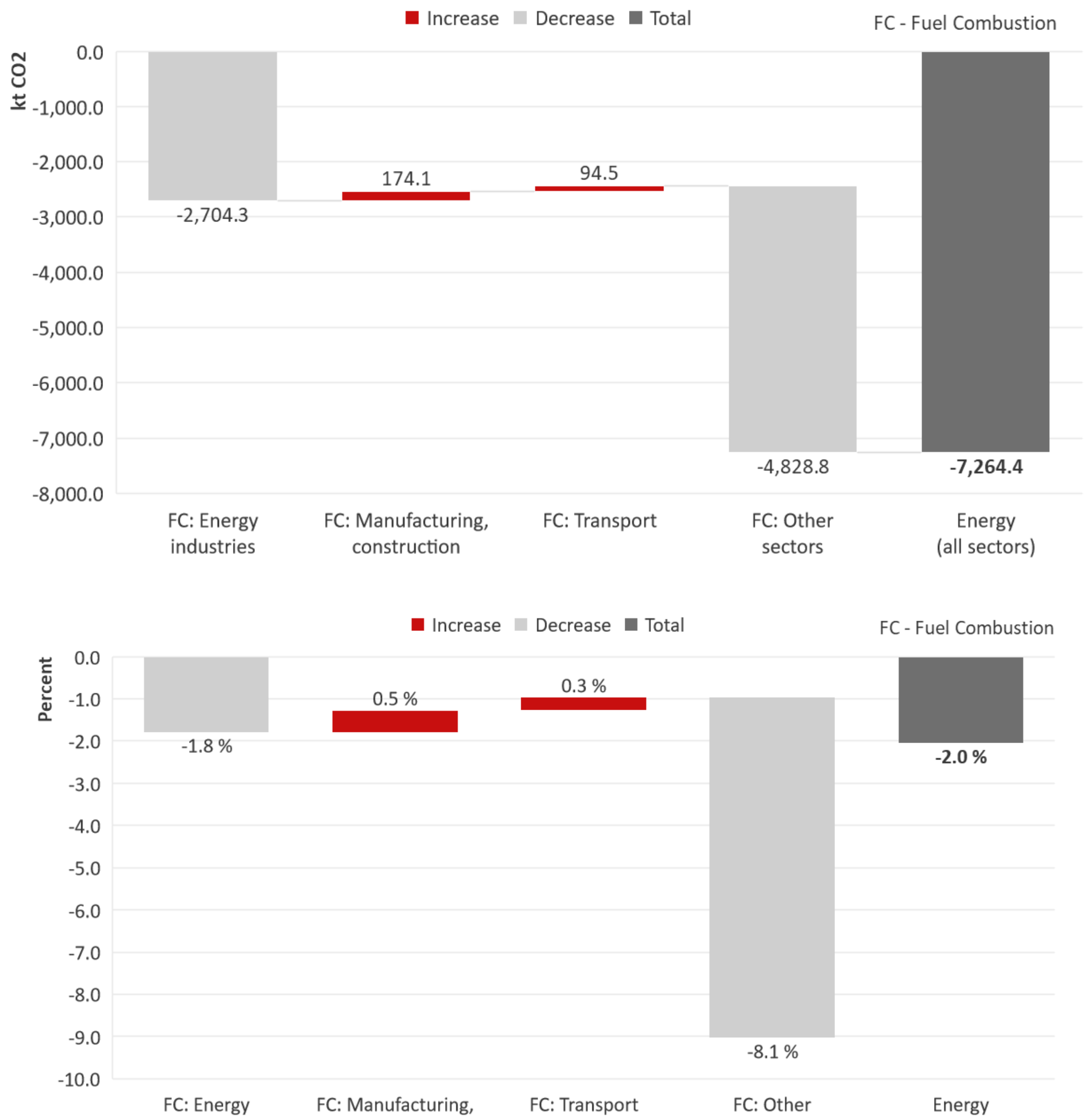


Figure 73: Effects of the “wind power deployment and housing energy efficiency improvement” scenario on CO_2 emissions, 2047, deviations from the "heat wave" scenario in kt CO_2 (top figure) and percent (bottom figure)

Source: Own illustration based on e3.kz results

Nevertheless, CO_2 emissions are rising slower than without mitigation measures (-7.3 Mt CO_2 resp. -2%, Figure 73) compared to a heat wave scenario without adaptation. CO_2 emissions in the energy sector are slowed down by the increased use of wind power (-2.7 Mt CO_2 resp. -1.8% in 2047). The relative decoupling of economic growth and emissions can be achieved by exploiting synergies between adaptation and climate protection measures. Efficiency improvements combined with the use of more renewable energy to protect from climate change impacts in the energy sector creates co-benefits.

Figure 74 summarizes the key impacts of the “wind power deployment and housing energy efficiency improvement” scenario.

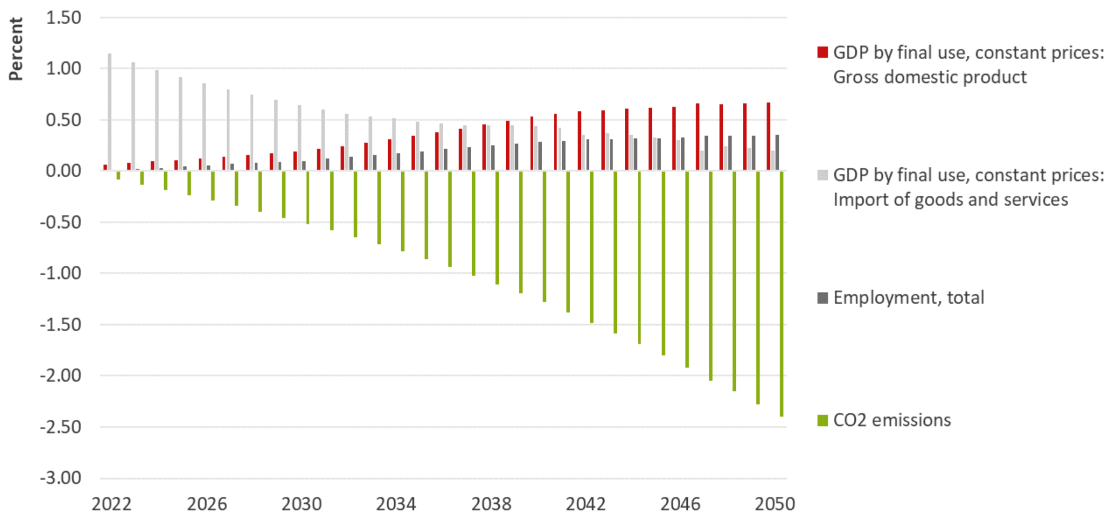


Figure 74: “Wind power deployment and housing energy efficiency improvement” scenario: key impacts, 2022-2050, deviations from a "heat wave" scenario in percent

Source: Own illustration based on e3.kz results

6.2.2.3 Key messages

The energy sector faces already the consequences of climate change which will occur more frequently and become more severe. Energy security might be at risk. Jobs and income are endangered not only in the energy sector. Policymakers should be aware of what could happen to manage adaptation strategies and to initiate a climate resilient economic development.

Many adaptation measures exist for the energy sector to protect the energy infrastructure or to reduce the negative impacts on energy supply and energy demand. Cost-benefit analysis should be done first to identify the most suitable individual technologies following techno-economic assessments. Then, macroeconomic analyses should be conducted to detect the economy-wide impacts of single measures and enable decision-makers to adopt win-win options.

Investments in adaptation provide co-benefits, as the two adaptation measures analyzed with the e3.kz model exemplarily demonstrate. Economic losses in the energy sector and in downstream industries can be reduced. **Measures that primarily support the domestic economy are even more beneficial**. For example, construction activities create jobs in Kazakhstan. **Products such as electrical equipment and wind turbines are mainly imported and curtail the advantages**. Nevertheless, in both cases economic growth and jobs can be created in the energy sector and related industries.

Other adaptation measures can be complementary measures to further reduce the impacts of climate change in the energy sector or might be other (less costly and / or climate-compatible “green”) opportunities such as building dams or installing drainage systems to protect critical energy infrastructure from being flooded, improving robustness of installations to withstand EWEs or installing nature-based solutions like “green” roofs and buildings which helps to reduce cooling demand during heat waves and simultaneously provides environmental benefits.

The protection of the energy infrastructure is very important due to their key role within economic processes. Even minor damages to energy infrastructure can lead to major losses in other industries due to the disruption of energy supply (OECD 2018). In particular, failures in large, centralized power generation plants can significantly affect the power supply. Renewable energy such as wind power entails a greater decentralization of energy supply and protects from major impacts of local climate hazards. Furthermore, wind power and photovoltaics are not water-dependent like hydro power or CHP plants. On the other hand, without wind and sun, power generation from wind turbines and photovoltaic is impossible.

Both presented examples need investment and are assumed to be paid by the investing energy sector which in turn passes the costs on to the energy consumers. To a large extent, these investments are likely to be "anyway" costs that Kazakhstan will have to spend on replacing outdated energy infrastructure. In that sense, it is recommended when **investing in replacement and / or enhancement of energy infrastructure, likely climate change impacts should be considered to improve climate resilience.**

Regarding the two adaptation scenarios exemplarily calculated with e3.kz, there is no "better" or "best" adaptation solution because both measures focus on different climate change impacts. Instead, both measures must be considered to protect the energy system from various climate change impacts as best it can be.

Part of the costs can possibly be supported by financing commitments from the industrialized nations. Given the promises of the industrialized countries to support climate protection measures such as adaptation measures, the macroeconomic effects of the measures would be even better. **Thus, international funding opportunities should be explored to allow for even better macroeconomic impacts.**

Combating climate change requires a holistic approach including both mitigation and adaptation action: Beyond the pure objective of ensuring adaptation to climate change, the e3.kz model results show that the decoupling of economic growth and CO_2 emissions can be enhanced**. Combining climate protection and adaptation measures can create co-benefits.** Also, the currently elaborated Kazakhstan's Low-Emission Development Strategy indicates the close links between adaptation and mitigation, their co-benefits but likewise adverse side effects (DIW Econ 2021).

6.2.3 ADAPTATION IN INFRASTRUCTURE

Current Situation

Well-functioning infrastructures are an important foundation for economic and social development. Trade and the transport sector heavily depend upon it. In 2019, around 17% of Kazakhstan's GDP was related to the trade and 8% to the transportation and storage sector (COMSTAT 2020). About 16% of the workforce (respectively 1.4 million people) were employed in the trade sector. The transportation and storage sector accounted for 7% of the workforce (respectively 0.6 million employed people) (COMSTAT 2021d).

Due to its central location between Asia and Europe, Kazakhstan holds a strategic position as a transit country. Apart from the gas and oil pipeline network, road and rail infrastructure are the most dominant transport infrastructures regarding freights carried and cargo turnover (UNECE 2019a). The development of the transport infrastructure is one goal in the Kazakhstan 2050 strategy. The Belt and Road Initiative (BRI[34]) , also known as the New Silk Road, is an important cornerstone. According to a World Bank (2019) analysis, this initiative and its transport corridors has the potential to substantially improve

[34] The BRI is an initiative of China seeking to connect Asia with Europe to improve regional integration, increase trade and foster economic growth.

trade, foreign investment, and living conditions for Kazakh citizens. However, the potential as a transit country has not yet been fully exploited (ADB 2019a).

The state of infrastructure is identified as a bottleneck for Kazakhstan's economic development. About 75% of existing infrastructure needs to be replaced or rehabilitated – of which the transport infrastructure is particularly affected (OECD 2019b). Due to the size of the country and the extensive transport network, construction and maintenance of the transport infrastructure is costly (ADB 2019a, ITF 2019). In recent years, however, efforts have been made to re-establish and further expand national and international transport corridors e. g. through the infrastructure programs Nurly Zhol and Central Asian Regional Economic Cooperation (CAREC) (ITF 2019).

The need for investments in building infrastructure is also high: this is due to ageing and energy-inefficient buildings but also because of a growing population und urbanization in Kazakhstan (UNECE 2019b). The domestic energy demand in the residential sector accounted for 11 Mtoe in 2018 (IEA 2021). Considering the expected growth in housing stock and living space, energy efficiency improvements are a strategic national priority for Kazakhstan which is anchored in the Green Economy concept (2013).

Despite progress, the current state of the physical infrastructure requires large investments which offers the opportunity to make the infrastructure climate resilient. Due to the long-lived nature of infrastructure assets, decisions made now will lock-in vulnerability if they fail to consider climate change impacts (OECD 2018). Thus, it is important to coordinate and align infrastructure and climate (adaptation and mitigation) policies to create co-benefits and avoid adverse side effects (OECD 2018, UNECE 2019b).

Options for building climate resilience in the transport and building sector

Climate resilient infrastructure is a key to reduce or even prevent from adverse climate change impacts. Several options exist for adapting the infrastructure to climate change. Basically, adaptation options can be proactive or reactive. While proactive adaptation anticipates likely future impacts of climate change, reactive adaptation implements "build back better"[35] measures to increase climate resilience after experiencing the negative impacts of climate change.

The construction and maintenance of road and building infrastructure offers the opportunity for adapting to climate change. Climate resilient measures can thus be directly incorporated into the planning and implemented at relatively low additional costs. According to ADB (2019b) and the World Bank (2012), additional 7% to 9% of total investments are needed to make roads climate resilient. Costs for climate-proofed buildings depend on "how" it is achieved ("green" nature-based solutions vs. "non-green" solutions) and against "what" climate impact (heat waves, floods, storms). The policy brief "Economy-wide Effects of Adaptation in the Energy Sector" presents energy efficiency improvements in the housing sectors as an option to minimize impacts of heat waves.

Structural adaptation measures such as investments into protective infrastructures (e. g. dams), improvement of design standards and mandatory building codes (climate-proofed transport and building infrastructure) as well as refurbishment provide physical protection and increase robustness (OECD 2018). Adaptation measures for transport infrastructure are, for example, new pavement structures to reduce the risk of increased diurnal temperature range. The creation of drainage structures may help to prevent erosion and protect the embankment (ADB 2019a, b). Efficiency improvements in buildings

---

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

and nature-based solutions (e. g. the “green belt” mass afforestation in Astana, “green” buildings or solar-system based air conditioning) provide win-win solutions for mitigation and adaptation (adelphi and Development Alternatives 2019, Brolsma et al. 2021). Restoring natural wetlands and floodplains may also help to retain excess water.

Management (or non-structural) adaptation measures such as the relocation of infrastructure from e. g. flood-prone to flood-safe areas, regular inspections and repair plans as well as improved meteorological forecasting tools and early warning systems also help to be better prepared (OECD 2018, World Bank 2011).

The macroeconomic effects of the adaptation measures "(re-)construction of storm-proofed buildings" and “’Green Belt’ mass afforestation” are presented as adaptation options to extreme winds. Both options help to reduce damages caused by extreme wind while the latter also contributes to carbon absorption as part of the long-term strategy to achieve carbon neutrality by 2060. "(Re-) construction of climate resilient roads" is presented as an example for reducing flood impacts on roads.

The macroeconomic effects of the adaptation measures "(re-)construction of storm-proofed buildings" and “’Green Belt’ mass afforestation” are presented as adaptation options to extreme winds in the next sections. Both options help to reduce damages caused by extreme wind while the later also contributes to carbon absorption as part of the long-term strategy to achieve carbon neutrality by 2060. "(Re-) construction of climate resilient roads" is presented as an example for reducing flood impacts on roads.

6.2.3.1 (Re-)construction of storm-proofed buildings

Extreme wind events are expected to occur every four years with a similar intensity as today according to Navarro and Jordà (2021). The rehabilitation and modernization of the building infrastructure is key to prevent storm damages and to reduce (involuntary) reconstruction costs. The extent of damage ranges from a few million KZT to 2.5 billion KZT per event. Damage is mainly caused to buildings, cars and energy infrastructure. Typically, extreme wind events blow off roofs and flying objects cause damage to windows, cars and power transmission lines.

Production losses in various economic sectors resulting from power outages and impaired production sites can be quite severe depending on the damage and duration of power loss. According to the World Bank enterprise survey in Kazakhstan, power outages caused losses in sales of 1.7% on average and sector specific losses ranging from 0.5% (fabricated metal products) to 7.7% (other manufacturing) (World Bank 2019b).

Scenario assumptions and implementation

Involuntary replacement investments must be undertaken to repair the damage each time when such an event occurs. Thus, instead of repeatedly bearing the costs and losses, investments in storm-resistant buildings are reasonable.

One option is to strengthen the connection between roof batten and roof truss which increases the costs by 1-2% of the houses' value and at the same time reduces the risk of the roof being destroyed by wind by 50-65% (Stewart and Deng 2014). Exemplarily, in this scenario it is assumed that 10% of the existing and new buildings are made stormproof until 2050, especially in regions that have already been affected by extreme wind events, such as Astana. Necessary investments account for maximum 87 bn. KZT.

Assuming that about half of the residential buildings are owned by the real estate sector and the other half by private owners, both sectors must bear the investment costs. Private households are assumed to spend less for non-essential consumption and to finance it from savings. The real estate sector passes the costs on to the consumers.

As the modernization of buildings progresses over time, damages caused by storms are expected to be reduced by up to 65% including less reconstruction costs for damaged buildings, cars and power-lines as well as reduced losses in service sectors due to power outages. At the same time construction activities are increasing which leads to positive impacts also in several other sectors such as manufacturing of non-metallic mineral products producing concrete.

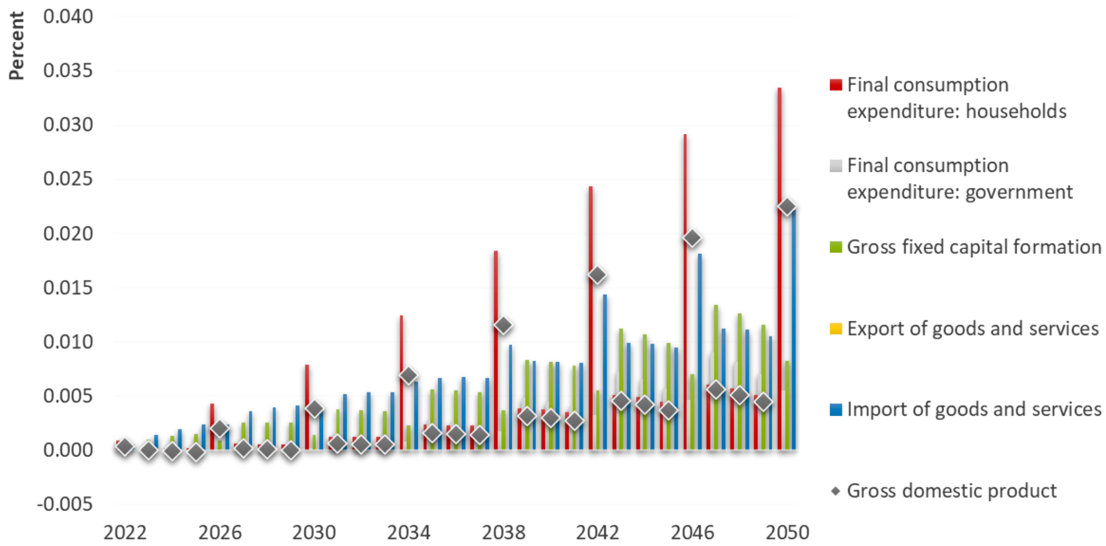
Table 22: Investment in (Re-)construction of storm-proofed buildings – key assumptions

Cumulated investment (2022-2050)	Adaptation benefits (by 2050)
87 bn. KZT	• Up to 65% reduction in (involuntary) reconstruction costs to repair the damage in buildings and power lines • Up to 65% reduction in (involuntary) replacement costs for cars • Up to 65% reduction of losses in service sectors due to power outages

Source: Stewart and Deng 2014.

Model results

The economy-wide effects of the (re-)construction of storm-proofed buildings are small but positive. GDP increases by up to 0.02% respectively 19 bn. KZT per year compared to a situation with extreme wind and absence of adaptation measures (Figure 75).



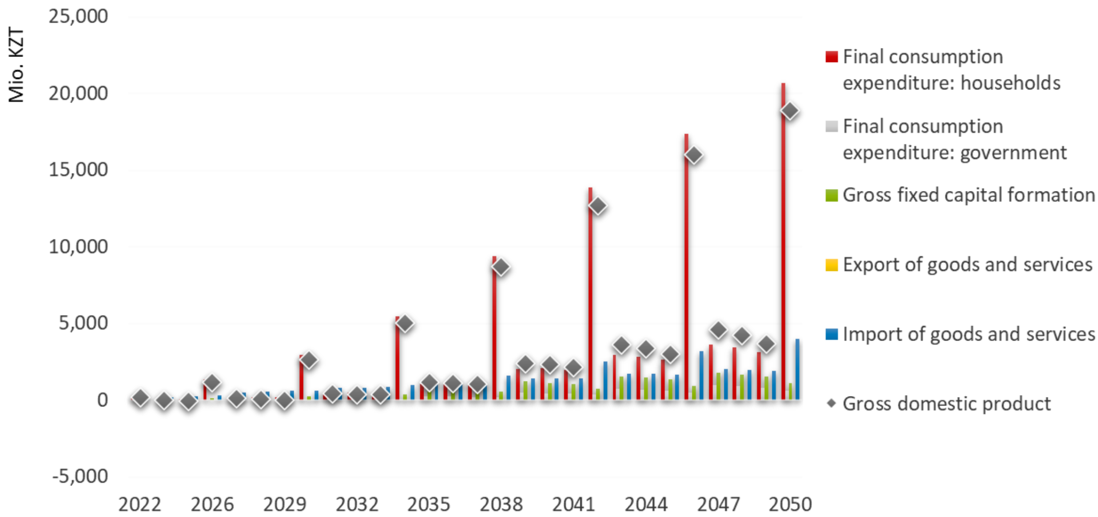


Figure 75: Macroeconomic effects of the "(Re-)construction of storm-proofed buildings" scenario, 2022-2050, deviations from the "extreme wind" scenario in percent (top figure) and Mio. KZT (bottom figure)

Source: Own illustration based on e3.kz scenario results

GDP is positively impacted by higher consumption expenditures of private households and investments in storm-proofed buildings of the real estate sector. Investment increase over time by max. 0.01% (resp. 2 bn. KZT).

Household consumption increases by up to 0.03% respectively 21 bn. KZT per year compared to a situation with no adaptation and extreme wind. Closure of service sectors caused by power outages in extreme wind years can be partly prevented due to adaptation and thus consumer demand can be satisfied. Furthermore, the construction works on private houses increases the expenditures of private households.

Rising imports (0.02% resp.4 Bn. KZT in 2050) as a result of higher economic activity and thus increasing production induced imports have a dampening effect on GDP.

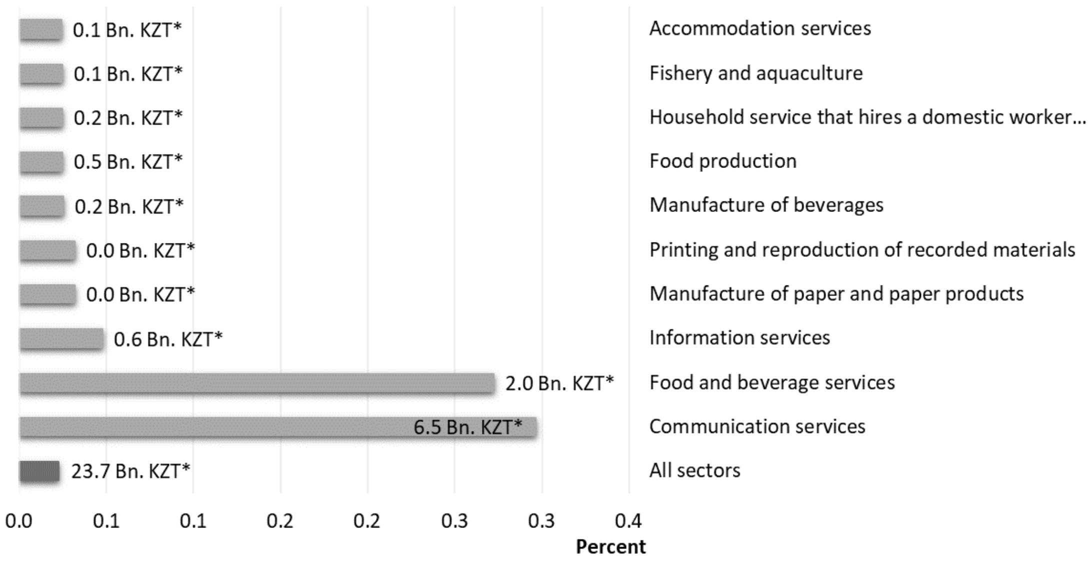


Figure 76: Effects of the "(Re-)construction of storm-proofed buildings" scenario on real production by economic sectors, in 2050, deviations from the "extreme wind" scenario in percent (x-axis) and Bn. KZT (*)

Source: Own illustration based on e3.kz scenario results

Construction works to make the buildings storm-resilient and reduced losses for communication, information (+0.2% resp. 7 Bn. KZT) as well as food and beverage services (+0,2% resp. 2 Bn. KZT compared to an "extreme wind" scenario without adaptation) during extreme wind events support economic growth (Figure 76). The success of storm-resilient buildings lowers the (involuntary) defensive spending to repair the damages resulting in reduced reconstruction activities. However, the overall impact on construction is positive (+0.02% resp. 1.3 Bn. KZT).

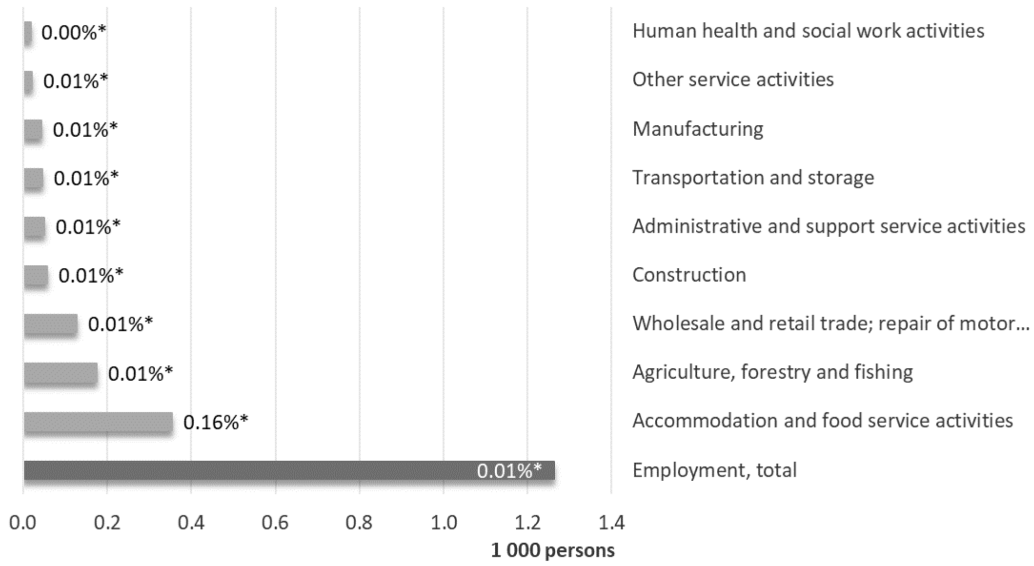


Figure 77: Employment effects of "(Re-)construction of storm-proofed building" scenario, 2022-2050, deviations from the "extreme wind" scenario in 1,000 persons (x-axis) and percent (*)

Source: Own illustration based on e3.kz results

Employment is increasing in the service sectors such as accommodation and food service activities and construction resulting in total by up to 0.01% (1,300 persons per year, Figure 77).

With a slightly higher GDP compared to a situation with no adaptation measures taken and extreme wind occurring, energy demand and CO_2 emissions are increasing within a limited scope (+0.01% resp. 22 kt CO_2, Figure 78). If no additional mitigation measures are considered, economic growth and CO_2 emission cannot be decoupled.

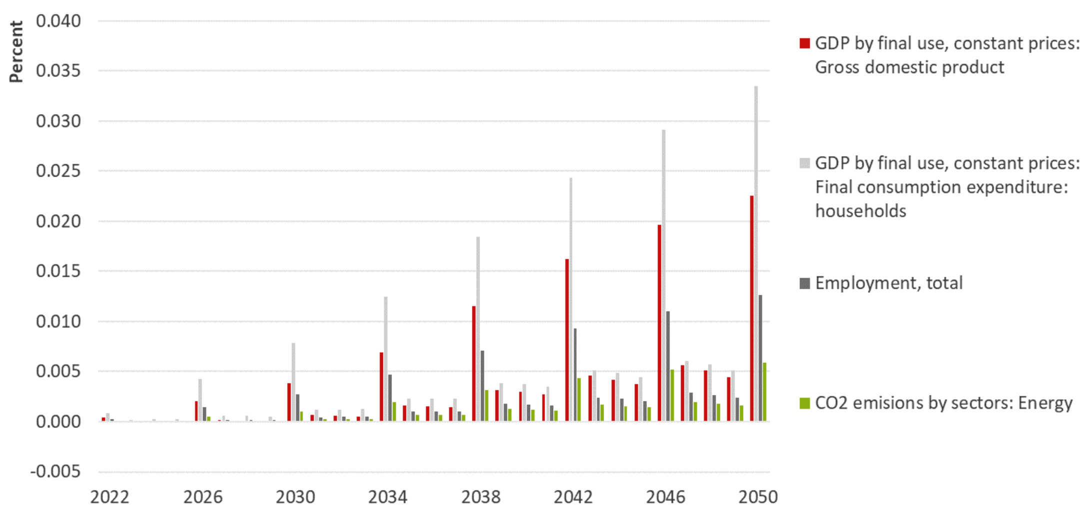


Figure 78: "(Re-)construction of storm-proofed building" scenario: key impacts, 2022-2050, deviations from a hypothetical "extreme wind" scenario in percent

Source: Own illustration based on e3.kz results

6.2.3.2 "Green Belt" mass afforestation

"Green Belt" mass afforestation is a nature-based solution which contributes to damage reduction caused by extreme wind and to carbon absorption. The "Green Belt" of Nur-Sultan which consists of approximately 12 million trees around the city is a prominent example of how to reduce wind speed, improve soil moisture and reduce soil emissions. The number of storms could be reduced from 15 to 5 in summer and from 37 to 22 in winter (Table 23) and thus damages caused by extreme wind such as blown off roofs can be reduced. It should be noted that mass afforestation may have negative impact on biodiversity if monocultures are planted.

Scenario assumptions and implementation

According to the Prime Minister of the Republic of Kazakhstan, 15 million trees are going to be planted in settlements helping to reduce damages from extreme wind and to absorb approximately 360 kt of CO2 per year. The "Green Belt" of Nur-Sultan may serve as an example on how to implement this adaptation measure and what the costs and benefits are. Damage reduction is assumed to be on average -55% and thus proportionally to the lower number of storms.

The total costs account for 6,000 bn. KZT which is assumed to be paid by the government but at the expense of other government expenditures such as for arts and entertainment.

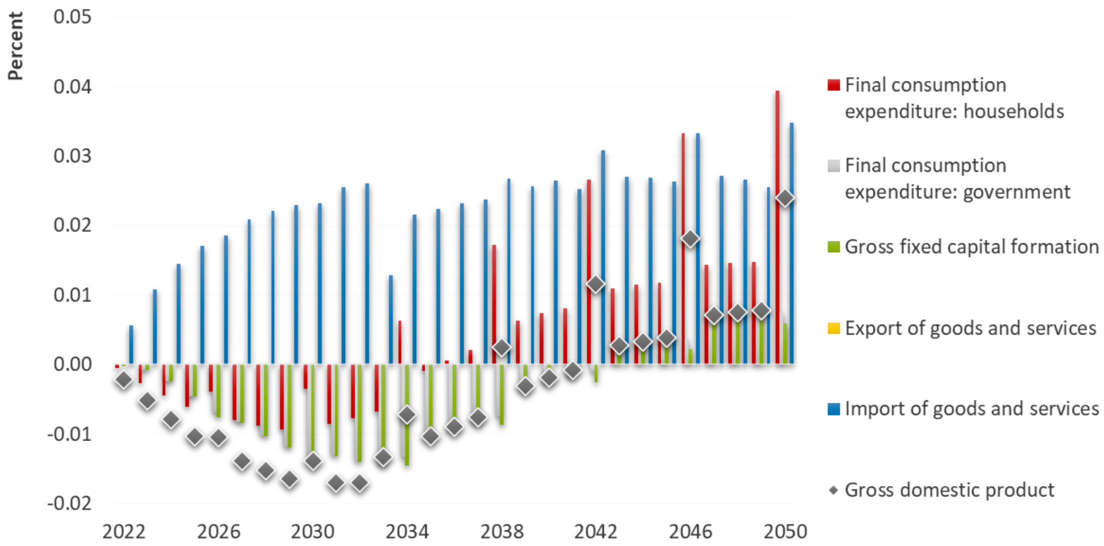
Table 23: "Green Belt" mass afforestation – key assumptions

Cumulated investment (2022-2050)	Adaptation benefits (by 2050)
6,000 bn. KZT (15 mio. trees are planted in settlements[2]; on average a tree cost 400,000 KZT[3])	• Number of storms reduced from 15 to 5 (-67%) in summer and 37 to 22 (-41%) in winter[4] • Damages are expected to be reduced proportionally to the lower number of storms (on average by -55%) • 15 mio. trees absorb 360 kt CO2 p.a.[5]

Sources: [2] Prime Minister of the RK 2020a; [3] The Guardian 2017; [4] Tulepov 2019; [5] The Environmentor

Model results

The macroeconomic impacts of the "green belt" mass afforestation are rather small. However, for the region benefiting from the measure, the impacts are much higher. As long as the benefits from the adaptation measure cannot be fully exploited, GDP is increasing more slowly compared to a situation without adaptation to climate change and extreme wind events. Subsequently, GDP is slightly higher (0.024% resp. 20 bn. KZT, Figure 79).



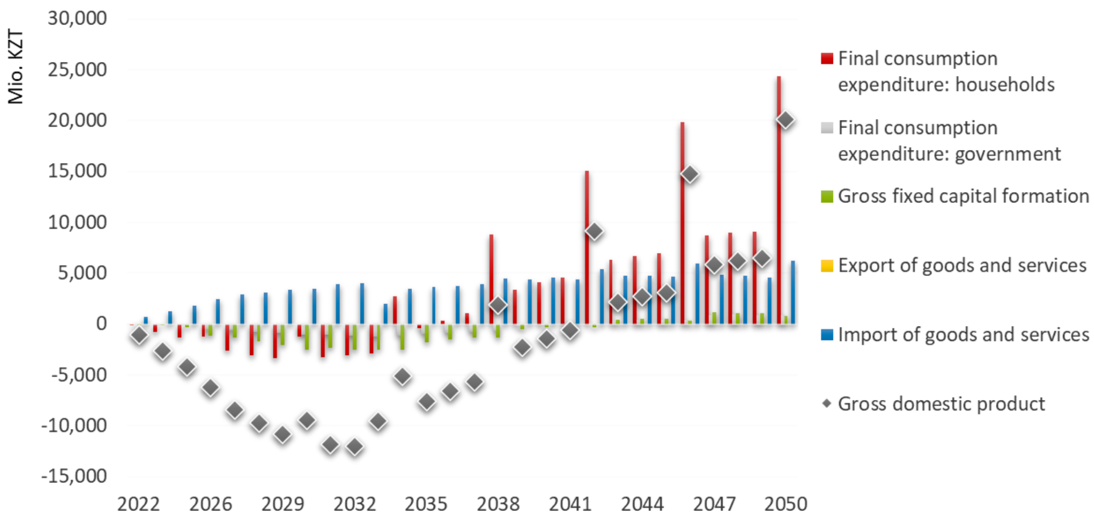


Figure 79: Macroeconomic effects of the “Green belt mass afforestation” scenario, 2022-2050, deviations from the "extreme wind" scenario in percent (top figure) and Mio. KZT (bottom figure)

Source: Own illustration based on e3.kz scenario results

In the years with “extreme wind” events which is assumed to be every four years starting in 2022, the economic impacts are better (less negative or more positive) than in the years without “extreme wind” events because the negative climate change impacts can be prevented (Figure 79).

GDP growth is supported by increased household expenditures (+0.04% resp. 25 bn. KZT in 2050) but is slowed down by higher imports (+0.03% resp. 6 bn. KZT in 2050 compared to an “extreme wind” scenario without adaptation) related to the imported intermediate demand of the forestry sector in particular machinery, trailers and semitrailers as well as chemical products.

Private households profit from less repair expenses which frees up money for other consumption purposes. Additionally, as with the previously discussed scenario, household consumption increases by up to 0.04% respectively 24 bn. KZT per year compared to a situation without adaptation measures and extreme wind because losses due to power outages in extreme wind years can be partly prevented and thus consumer demand (in particular in information, communication was well as accommodation and food service activities) can be satisfied.

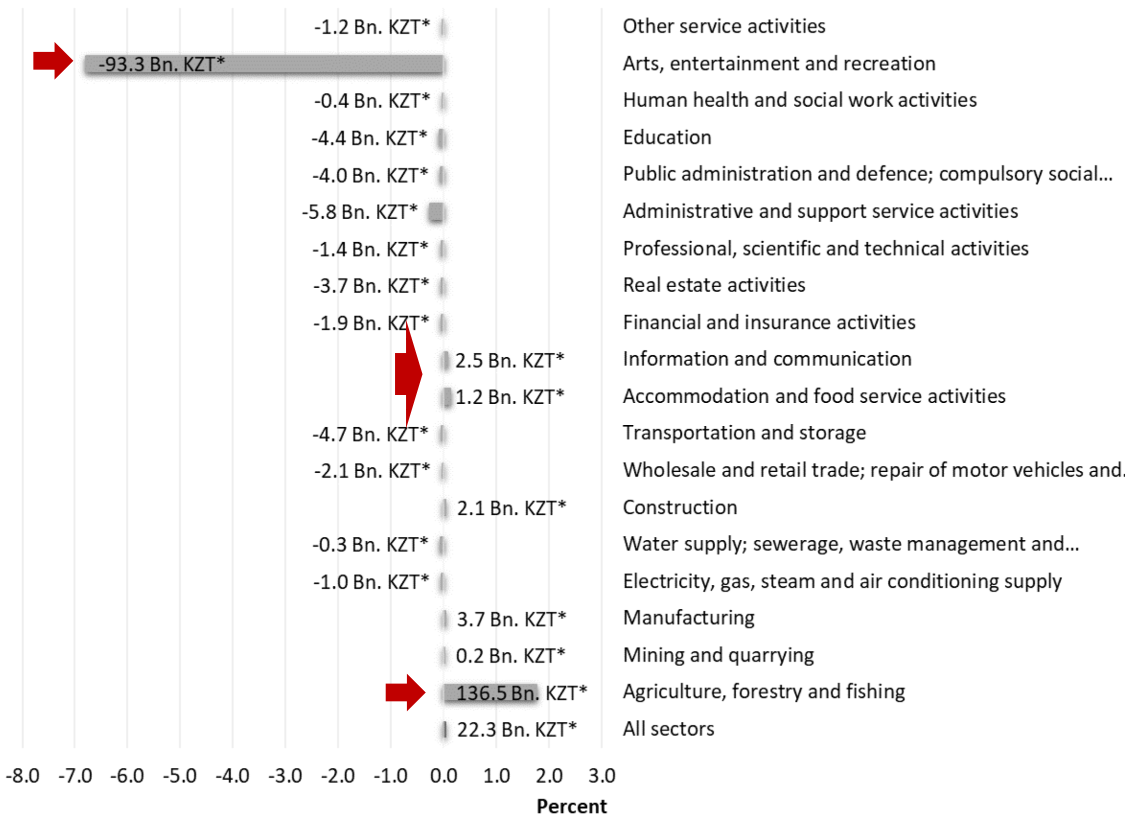


Figure 80: Effects of the “green belt mass afforestation” scenario on real production by economic sectors, in 2050, deviations from the "extreme wind" scenario in percent (x-axis) and Bn. KZT (*)

Source: Own illustration based on e3.kz scenario results

Government consumption is more or less on the same development path because the higher expenditures for afforestation are compensated by lower governmental support for arts, entertainment and recreation activity. That impacts production and employment in the aforementioned economic sectors (Figure 80 and Figure 81).

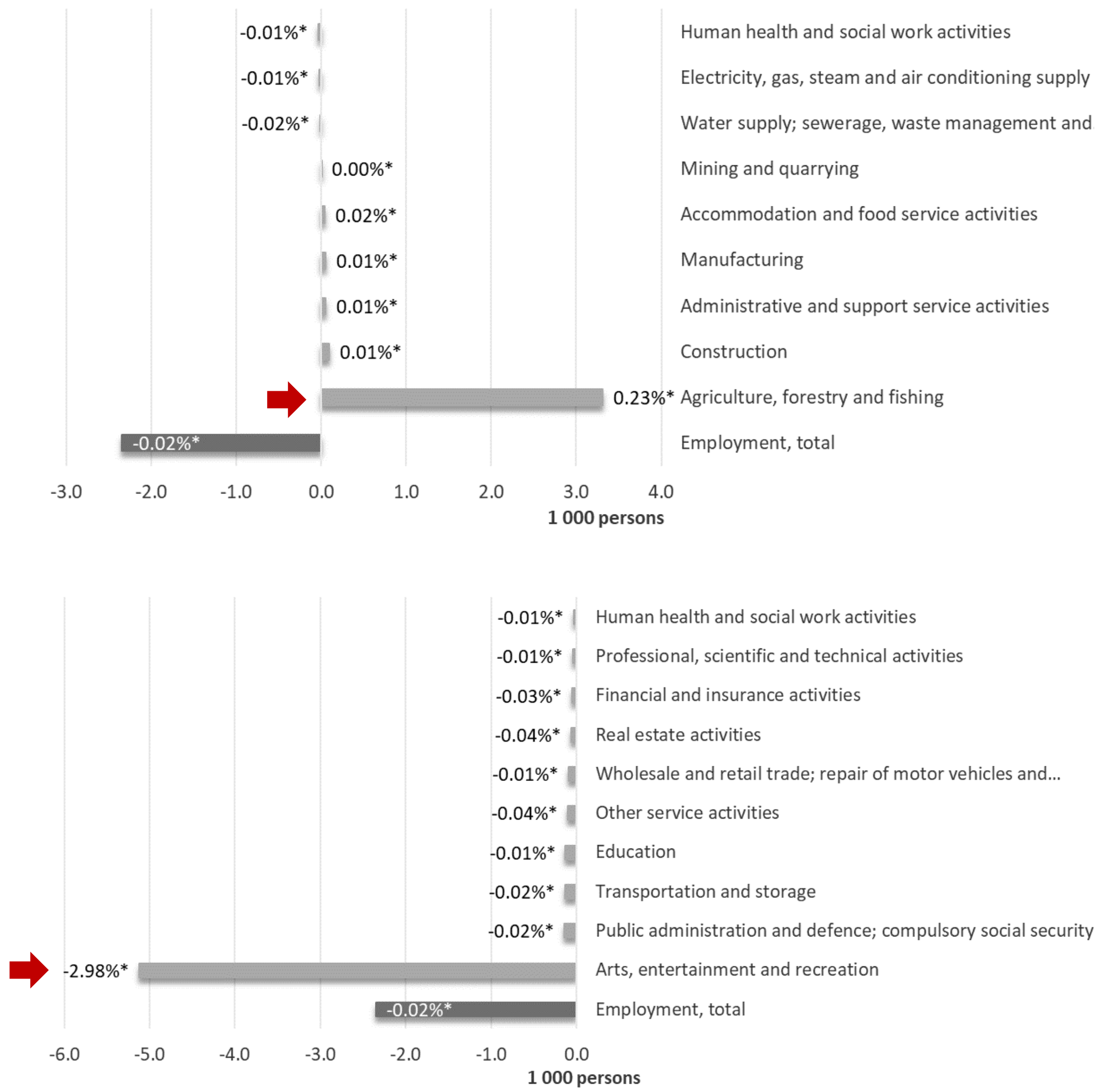


Figure 81: Employment effects of the "green belt mass afforestation" scenario, 2022-2050, deviations from the "extreme wind" scenario in 1,000 persons

Source: Own illustration based on e3.kz results

While the forestry sector profits in terms of employment (max. additional 3,300 jobs resp. 0.2% per year) and production (max. +105 bn. KZT resp. 85% per year compared to an "extreme win" scenario without adaptation), "Arts, entertainment, and recreation" sector suffers with max. 5,100 persons (resp. 3%) less and a lower production level of max. -93 bn. KZT (resp. 6.8%) per year. However, both employment and production in arts, entertainment and recreation are increasing over time but at a slower pace compared to a scenario without additional afforestation.

Total employment is at a lower growth path (-0.02%, respectively -2,350 jobs in 2050) compared to a situation with no adaptation and extreme wind but still increasing over time (Figure 82).

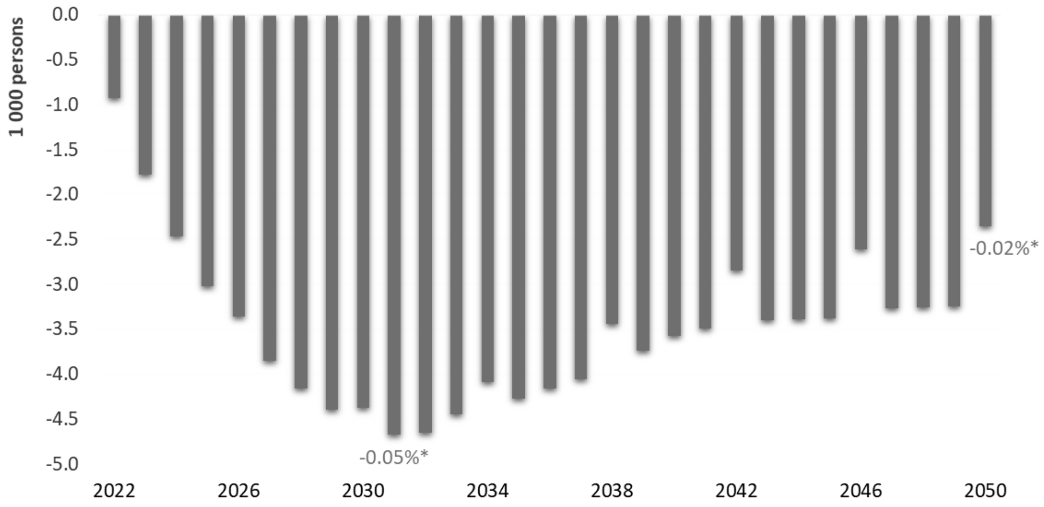


Figure 82: Effects of the "green belt mass afforestation" scenario given as deviations from the "extreme wind" scenario in 1,000 persons and percent (*)

Source: Own illustration based on e3.kz results

While energy-related CO_2 emissions are increasing slightly (max. +0.02% resp. 61 kt CO_2, Figure 83) with higher GDP, the afforestation measure allows for absorbing approximately 360 kt CO_2 per year once all 15 million trees have been planted. Considering carbon sinks as well, overall CO_2 emissions are decreasing compared to an "extreme wind" scenario without adaptation.

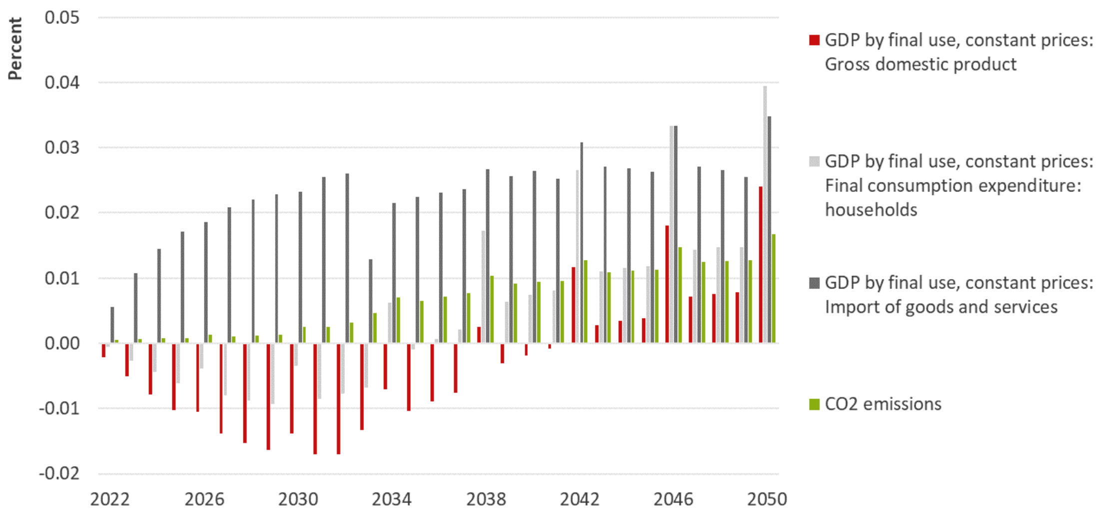


Figure 83: "Green belt mass afforestation" scenario: key impacts, 2022-2050, deviations from a hypothetical "extreme wind" scenario in percent

Source: Own illustration based on e3.kz results

6.2.3.3 (Re-)construction of climate resilient roads

The modernization of the transport infrastructure is key to prevent climate change damages. Extreme precipitation and floods are expected to occur more frequently and cause increasingly higher costs in the transport sector, negatively affecting jobs and economic growth.

The extent of damage in Kazakhstan ranges from one billion KZT to 19 billion KZT per event depending on the location where the event occurs. Non-climatic factors such as population density, degree of surface sealing in urban versus rural areas, land use, and infrastructure endowment influence the extent of damage. Typical recorded damages are destroyed and flooded roads, bridges, cars and buildings. Economic losses due to impaired production as a result of disrupted and delayed transport is not quantified and thus underestimates the costs of climate change and the benefits of adaptation.

The average direct damage per major extreme precipitation and flood event is estimated with 15,000 Mio. KZT and is expected to occur every five years.

Scenario assumptions and implementation

Construction and regular maintenance of road infrastructure offers the opportunity to adapt to climate change in a proactive manner. For example, the Nurly Zhol budget 2020-2025 amounts to 5.5 trillion KZT for approximately 20,000 km of roads to be built, reconstructed, and repaired. Climate-proofing (e. g. drainage structures, new pavement structure) of these roads increase costs by 7-9% of regular road investments which accounts for 64 to 82.5 bn KZT per year. According to road adaptation projects in Kazakhstan, international donors are financing 100% of the adaptation costs. It is assumed that each year until 2050 such road investment programs including climate- proofing measures are implemented.

With increasing investments in climate-proofed roads, the damages caused by extreme precipitation are assumed to be reduced by up to 50%. It must be noted that there is a high degree of uncertainty associated with the estimated benefits.

Table 24: Investment in (re-)construction of climate resilient roads – key assumptions

Cumulated investment (2022-2050)	Adaptation benefits (by 2050)
• 2,117 bn. KZT[a, b] • Adaptation costs are financed by international donors[c]	• Up to 50% reduction of damages is assumed • Up to 1% lower trade costs[c]

Sources: [a] Prime Minister of the RK 2020b; [b] World Bank 2012, ADB 2019b; [c] World Bank 2020a estimate lower trade costs of 2.5% which includes completion of BRI transport projects (incl. road and railways).

Model results

The economy-wide effects of the investments in climate-proofed roads are positive. The higher road investments have a positive impact on GDP which is at max. up to 0.46% respectively 389 bn. KZT higher per year compared to a situation with no adaptation measures in place and extreme precipitation occurring (Figure 84). The avoided damages due to adaptation, which reduce the (involuntary) defensive investment spending in flood years, is overlaid by regular adaptation investments. Investments are at max. 0.5% (resp. 66 bn. KZT in 2050) higher than in the “extreme precipitation” scenario without adaptation.

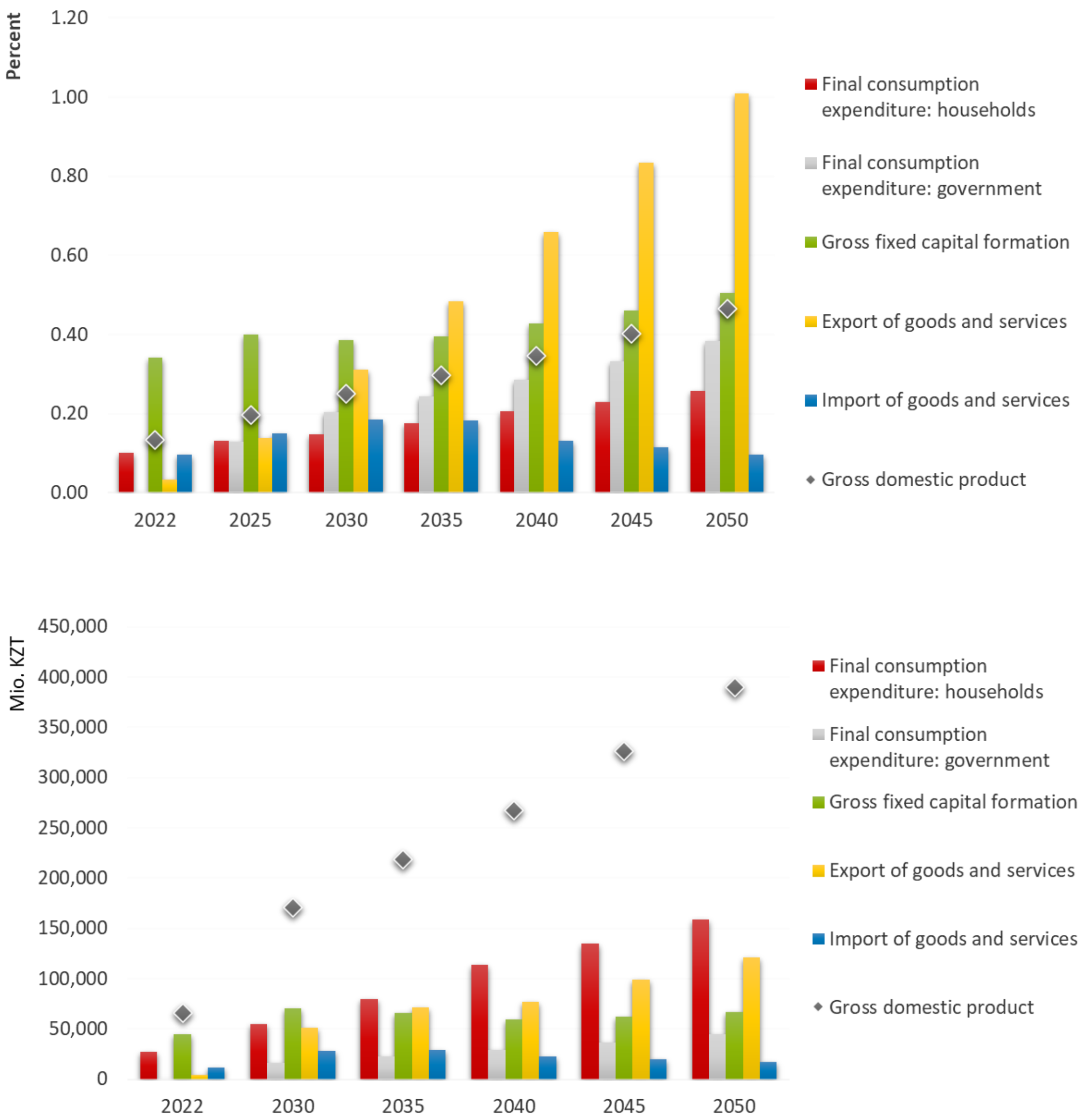


Figure 84: Macroeconomic effects of the “(re-)construction of climate resilient roads” scenario, 2022-2050, deviations from the "extreme precipitation" scenario in percent (top figure) and Mio. KZT (bottom figure)

Source: Own illustration based on e3.kz scenario results

With ongoing road improvements, travel time and thus transport costs are decreasing by up to 1%. Exports are expected to increase by 1% and respectively by 121 bn. KZT.

Higher economic activity positively impacts income and spending opportunities of households which increase by 0.26% respectively 159 bn. KZT compared to an “extreme precipitation” scenario without adaptation.

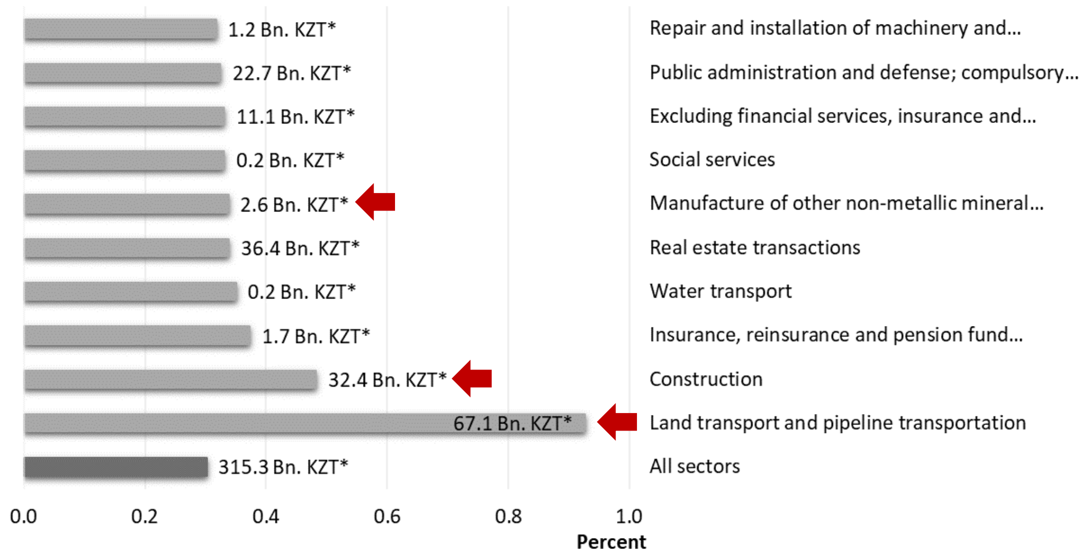


Figure 85: Effects of the "(Re-)construction of climate resilient roads" scenario on real production by economic sectors, in 2050, deviations from the "extreme precipitation " scenario in percent (x-axis) and bn. KZT (*)

Source: Own illustration based on e3.kz scenario results

The intensified construction activity (+0.5% resp. 32 bn. KZT) positively affects production in several other sectors such as manufacturers of non-metallic mineral products (+0.3% resp. 2.6 bn. KZT). Due to higher exports, land transport can profit (+0.9% resp. 67 bn. KZT) as well compared to an "extreme precipitation" scenario without adaptation.

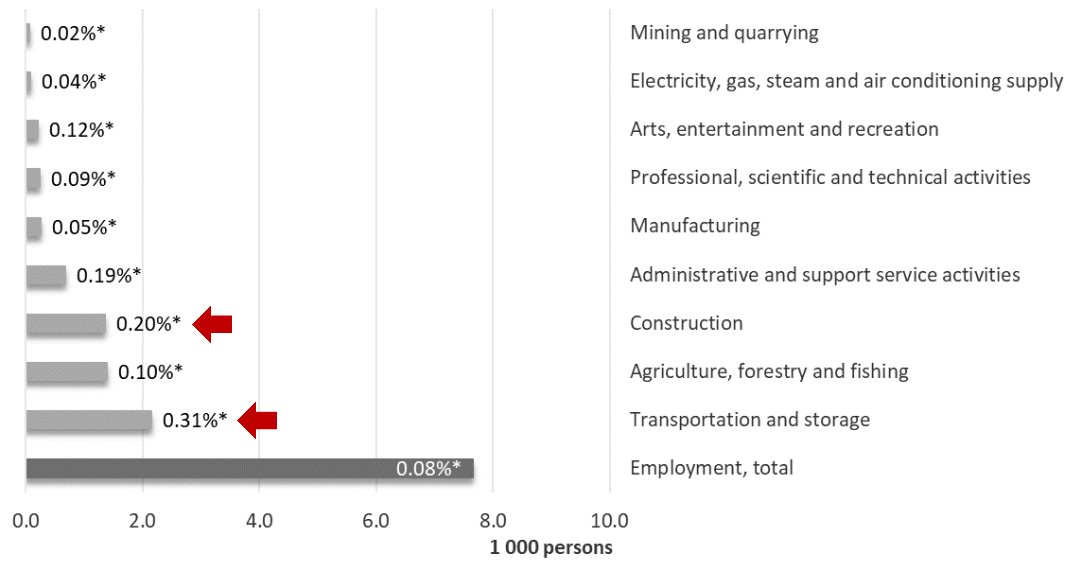


Figure 86: Employment effects of "(Re-)construction of climate resilient roads" scenario, 2050, deviations from the "extreme precipitation" scenario in 1,000 persons (x-axis) and percent (*)

Source: Own illustration based on e3.kz results

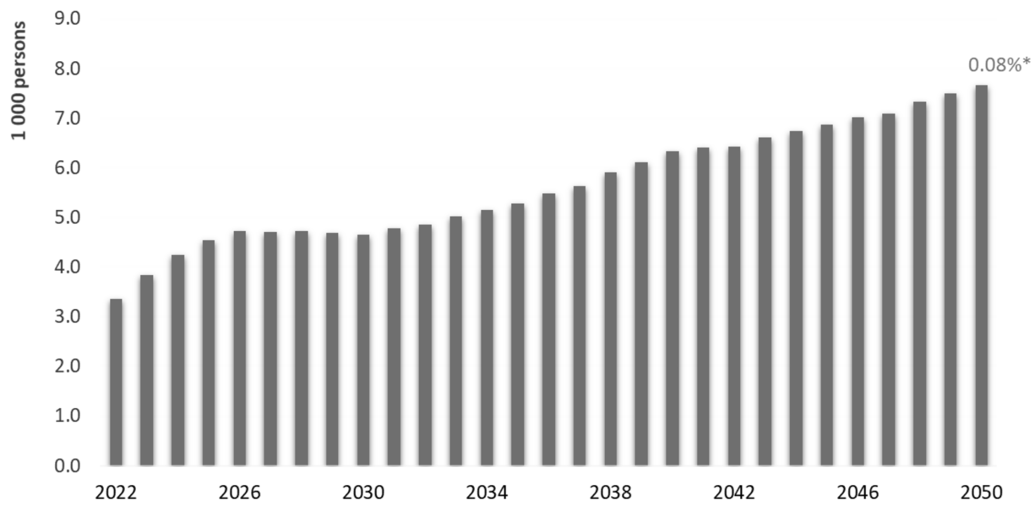
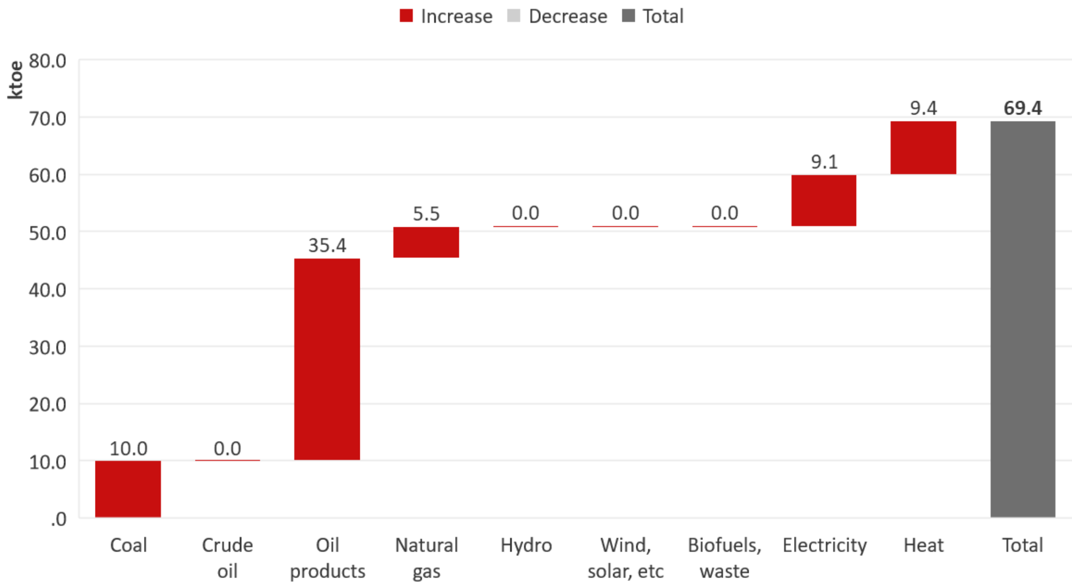


Figure 87: Effects of the "(re-)construction of climate resilient roads" scenario given as deviations from the "extreme precipitation" scenario in 1,000 persons and percent (*)

Source: Own illustration based on e3.kz results

During the reconstruction period additional jobs are created which leads to an increase of max. 1,400 persons resp. 0.2% per year in the construction sector (Figure 86). Employed persons in the transport sector profit as well (+2,200 persons resp. +0.3% in 2050). In total, employment is increasing by up to 0.08% and respectively 7,700 persons per year compared to a situation without adaptation to climate change and extreme precipitation events (Figure 87).



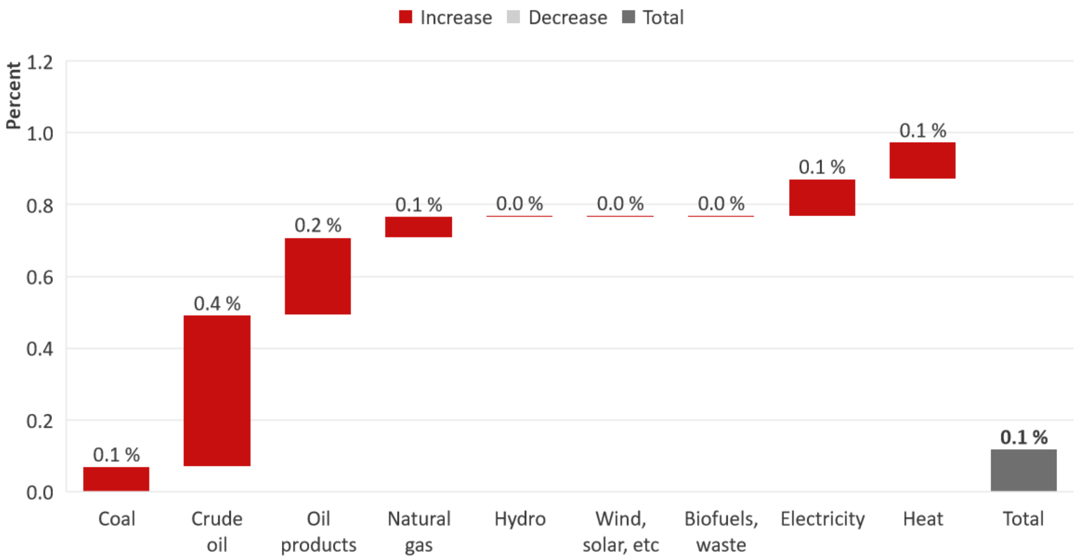


Figure 88: Effects of the “(re-)construction of climate resilient roads” scenario on TFEC, 2050, deviations from the "extreme precipitation" scenario in ktoe (top figure) and percent (bottom figure)

Source: Own illustration based on e3.kz results

Due to the higher economic activity, total final energy consumption is up to 69 ktoe (resp. 0.1%) per year higher compared to an “extreme precipitation” scenario without adaptation where GDP growth is less (Figure 88). In particular, demand for oil products (35 ktoe resp. 0.2% in 2050) increases due to the higher transport activity (c.f. Figure 85).

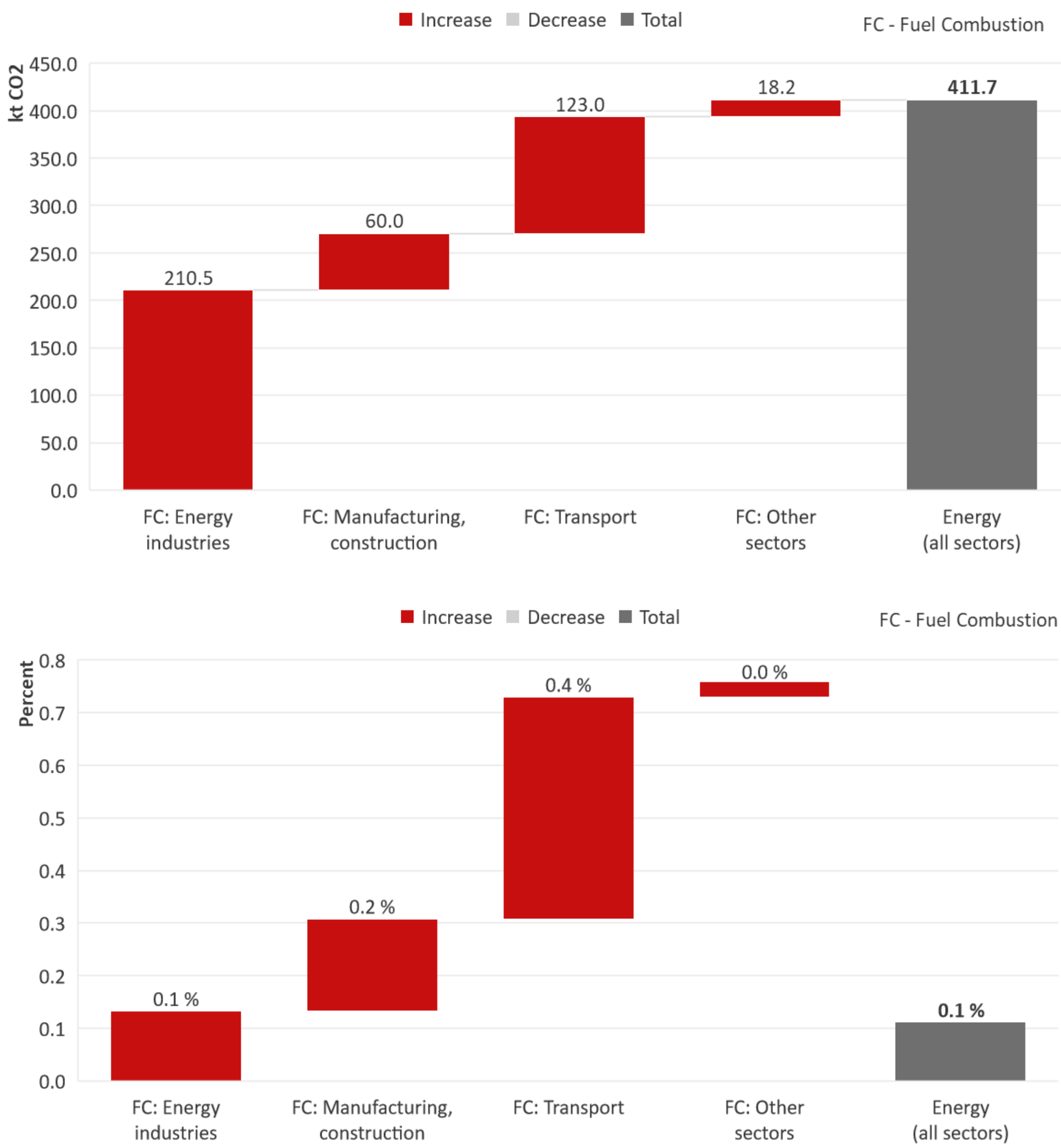


Figure 89: Effects of the "(Re-)construction of climate resilient roads" scenario on CO_2 emissions, 2050, deviations from the "extreme precipitation" scenario in kt CO_2 (top figure) and percent (bottom figure)

Source: Own illustration based on e3.kz results

With higher energy demand for fossil fuels, CO_2 emissions are increasing as well by 0.1% (respectively 412 kt), especially in the transport (+123 ktoe resp. 0.4%) and energy industries (+211 ktoe resp. 0.1%) which is related to oil refineries. As long as no additional mitigation measures are realized such as an improve energy efficiency of vehicles and / or a switch to renewable energy, economic growth and CO_2 emissions cannot be decoupled further.

Figure 90 summarizes the key impacts of the "(Re-)construction of climate resilient roads" scenario.

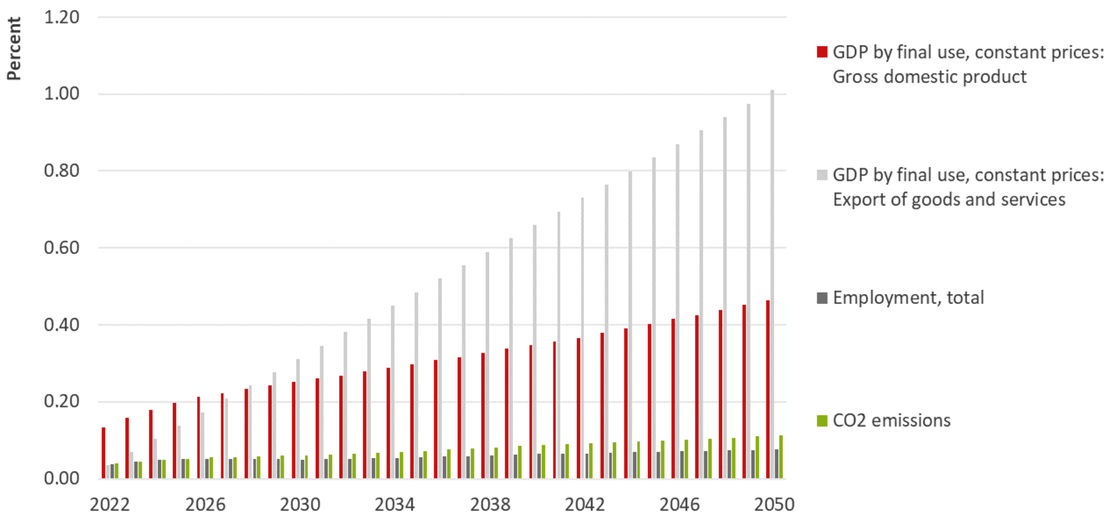


Figure 90: "(Re-)construction of climate resilient roads" scenario: key impacts, 2022-2050, deviations from a hypothetical "extreme precipitation" scenario in percent

Source: Own illustration based on e3.kz results

6.2.3.4 Key messages

Transport and building infrastructure is already impacted by climate hazards which will become more frequent and more severe. Jobs and income are endangered along the value chain. Policymakers should increase their knowledge on possible impacts of climate change and opportunities to increase the climate resilience of infrastructures.

Various adaptation options exist for the infrastructure to reduce the damages and losses from different climate change impacts. Cost-benefit analyses are important to identify the most suitable individual technologies based on techno-economic assessments. However, the quantification especially of the benefits is not easily assessable and is associated with a high degree of uncertainty. The model e3.kz helps to detect the economy-wide impacts of single measures and enable decision-makers to adopt win-win options. These results are subject to several uncertainties due to the nature of climate change and the current limited knowledge. However, the results serve as a starting point for the development of an adaptation strategy.

Suitable adaptation options provide co-benefits, as the adaptation measures analyzed with the e3.kz model exemplarily demonstrate. Reduced damages to the infrastructure and losses in economic sectors support economic growth and trade. **Measures that involve for example construction works primarily support the growth and wealth in Kazakhstan**. However, **improvements of road infrastructure are expected to increase driving performance and thus CO_2 emissions if no countermeasures** (e. g. CO_2 limits for vehicles or a switch to railways) **are taken**.

Combating climate change requires a holistic approach including both mitigation and adaptation actions: The e3.kz model results show that economic growth and CO_2 emissions can be decoupled. **Combining climate protection and adaptation measures can create co-benefits as the example of the nature-based solution demonstrates.** Without mitigation measures, economic growth is usually associated with greater CO_2 emissions.

Adaptation measures with more extensive investments show greater economic impacts in terms of e. g. GDP and jobs compared to minor investments. If the investment costs are covered by international donors, macroeconomic effects would be even better as exemplary shown with the “(re-)construction of climate resilient roads”. If infrastructure development is more linked to the SDGs, additional financing modalities such as global climate finance could be acquired (UNESCAP 2021b).

As long as investment costs are at the expense of other government expenditures, as shown at the example of “green belt mass afforestation”, **or result in higher prices** – exemplary shown in the “(re-)construction of storm-proofed buildings”, **then certain sectors are strained by these effects**. In both scenarios, GDP is higher compared to a “heavy wind” scenario without adaptation but employment is at a lower level in the “green belt mass afforestation” scenario because more jobs are lost in “arts and entertainment” than won in the forestry sector.

7 INTEGRATING SCENARIO RESULTS IN THE POLICY PROCESS

7.1 ENTRY POINTS FOR MACROECONOMIC MODELLING RESULTS IN POLICY PROCESSES

In 2016, the government of the Republic of Kazakhstan initiated the process of developing a National Adaptation Plan (NAP) that seeks to provide sector-specific guidance for the greater integration of adaptation considerations into policies and programs[36]. In January 2021, the Ecological Code which shows ambitions to mainstream climate change adaptation into policies and development plans at the national and sub-national levels was adopted. So far, climate change adaptation and mitigation actions have not been aligned although there is evidence that both are closely linked providing synergies but also creating trade-offs (OECD 2021, DIW Econ 2021).

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

Implementing adaptation strategies can be described as a multi-stage process involving experts from different fields. Figure 91 shows how and when macroeconomic modelling may enter the policy cycle of either NAP processes, sectoral planning, or other medium and long-term strategies on climate policy. The key role of the e3.kz model application is the analysis of the economy-wide impacts of key policy questions, in particular climate change and adaptation. Model results support the selection of measures for adaptation and sectoral planning. Thus, mainstreaming and finally the implementation of adaptation measures in economic development strategies and financial decisions is supported.

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

(1) **Preparation**: During the preparatory phase, key policy questions are formulated. These may relate, for example, to climate impacts and adaptation options. The consultation of key experts and policy makers is important to obtain high-level support for the intended economic evaluation of adaptation options.

(2) **Modelling and evaluation**: In this phase, the model e3.kz, developed jointly with the implementing partners is applied to analyze the economy-wide impacts of the key policy questions, e. g. climate change and adaptation. Comparing relevant indicators resulting from the model analysis of different adaptation option supports prioritizing of adaptation measures or finding complementary measures. As mentioned earlier, economic criteria should not be used exclusively as a basis for

[36] https://www.globalsupportprogramme.org/projects/supporting-kazakhstan-advance-their-nap-process

decision-making. Other criteria must be considered as well such as health aspects and ecosystem services (biodiversity, regulation of the water balance) to get a more comprehensive evaluation.

(3) **Implementation**: In the final phase, the implementation of adaptation measures is further supported by CRED activities. Macroeconomic modelling provides an important basis for prioritization and selection of viable adaptation measures. Adaptation strategies and their financing need to be discussed at high level workshops in the respective ministries at all governance levels (see also Dekens and Hammill 2021). The vertical integration of climate action ensures successful implementation of adaptation measures (Bierkandt et al. 2019). Furthermore, a process of and framework of monitoring and evaluation needs to be initiated.

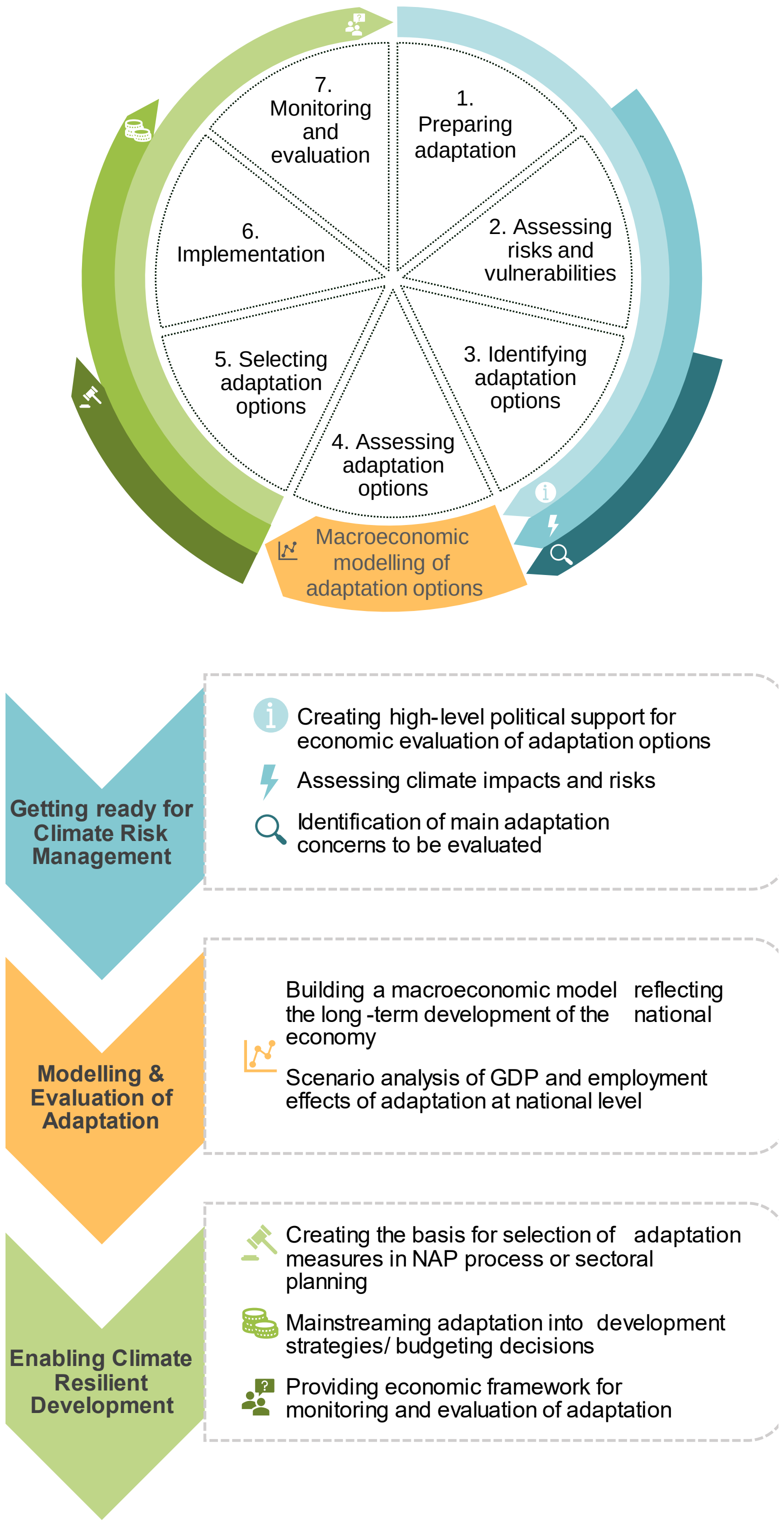


Figure 91: CRED approach: Integration and support of macroeconomic modeling in policy processes

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

7.2 ANCHORAGE AND INSTITUTIONALIZATION

In section 7.1, adaptation strategies were described as the outcome of a multi-stage process involving actors from different fields of expertise. Another visualization of this process with respect to participating authorities is given in the following figure:

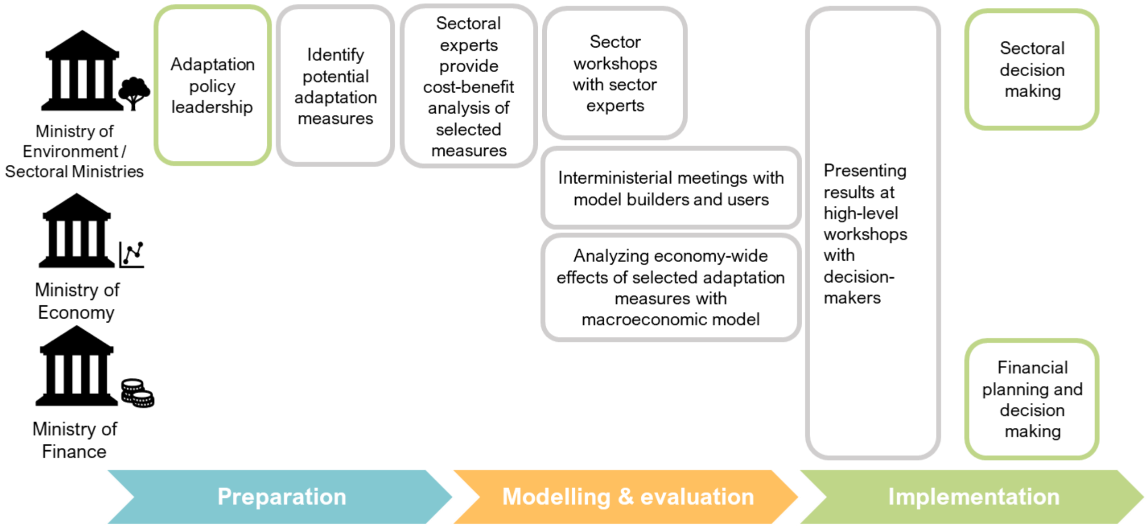


Figure 92: Actor involvement in adaptation policy processes

Source: GIZ

The visualization clearly shows that interdependencies exist between the different authorities which require established communication channels, coordination mechanism and responsibilities. This is necessary to avoid duplication of efforts and to ensure timely distribution of information.

While the ministry of environment primarily focused on climate policy, the ministry of economy is particularly interested in the economic implications of climate policy whereas the ministry of finance has to address financing issues. It is important to bring all involved policy makers to the table and to promote interaction and close coordination. Since participation in the process binds resources, participants need to know about their benefits. There are different options, e. g.

- Joint meetings with other experts to discuss adaptation options from different points of view. This is primarily to gather knowledge that can then be used for model-based scenario analysis. The scope of the contribution is limited.
- Capacity building on model application, i.e. scenario analysis. This is much more time consuming and usually limited to selected modeling experts. It is a necessary prerequisite for independent future use and ownership of the model.
- Distribution of information, e. g. in form of policy briefs which can be widely disseminated.
- Access to the model and/or model results. While the access to the model e3.kz might be restricted by the model owner Economic Research Institute (ERI)[37], model results can be widely disseminated.

Another important aspect – partly related to contributions – is the clarification of responsibilities and rights. Once vulnerabilities and adaptation options have been identified, the corresponding sector

[37] Access to the model and further conditions of model application must be clarified with ERI.

experts need to provide CBA which give detailed sector-specific information about adaptation actions and measures. For the agriculture sector, there is a selection of CBAs for different adaptation options specific to Kazakhstan. Country-specific adaptation options for e. g. road and building infrastructure are less comprehensive and often only identify costs, while benefits (in terms of damage reduction) are not quantified. If country-specific information is scarce or not available at all, international studies may serve as initial benchmarks. Discussions with country experts help to verify if these benchmarks are applicable for Kazakhstan as well.

CBAs not only serve as an input for further discussion regarding financing requirements (financial support from government, investing sector or international donors) but also as an input for the e3.kz model.

The e3.kz model then analyzes the economy-wide effects and provides economic arguments. The results are condensed into policy briefs, and will be presented at high-level workshops and discussed

The future application of the e3.kz model requires **regular contact between e3.kz model owner(s) and ministries** to be **informed about** current and future **key policy questions**. For being able to provide evidence-based support, model owner(s) should **regularly update the model database** and if necessary **upgrade the model**.

While economic data are provided in a comprehensive and systematic manner by statistical offices, this is not true for damage data caused by climate change and CBAs for adaptation options. **Systematic data collection would facilitate the model application to climate change and adaptation issues**.

To avoid the negative impacts of brain-drain within the modeling institution, **internal trainings** on model update, upgrade and use **in particular for new members are recommended**.

with decision-makers. These workshops generate valuable information for subsequent sector strategies and financial planning. This information may also be used to connect with international institutions and donors.

To assure the future use of the e3.kz model, the responsibility for the maintenance, possible extensions and regular application of the e3.kz model need to be clarified, which is not necessarily limited to climate change adaptation. This includes the question, who will be in charge of covering the necessary expenses in the future.

ERI, the responsible institution which holds the ownership of the model should be in regular contact with ministries who need support with macroeconomic modeling to answer key policy questions and inform them about model updates and upgrades. Furthermore, contact to field experts should be initiated and maintained to assure knowledge transfer about the most recent developments, issues and data.

7.3 BENEFITS OF MODEL APPLICATION

Evidence-based policy making is an important cornerstone in the policy making process which is supported by modelling tools. For example, the European Commission[38] applies models extensively for ex

[38] https://knowledge4policy.ec.europa.eu/node/10748_de

ante assessment of socio-economic and environmental impacts of policies as well as ex post evaluation of policies to create knowledge and thus design “better” policies.

Climate change is one of the most pressing challenges that need to be solved. Policymakers are in charge of developing strategies that can mitigate climate change and effectively reduce the unavoidable impacts of climate change while not jeopardizing the nation's welfare.

The use of the e3.kz model contributes to strengthening the knowledge base for climate change impacts and evaluating and prioritizing adaptation options for the respective sector in Kazakhstan. Scientific knowledge is condensed in the form of key outcomes of climate scenarios and physical effects in different sectors of the national economy. Sector-specific, regionalized and monetized impacts from climate change are summarized in a damage database which comprises regionalized damages from past climate hazards in Kazakhstan and damage projections from detailed country- and sector-specific models. CBAs of sector-specific adaptation options provide the necessary information for a macroeconomic evaluation of the measure.

Macroeconomic models such as the e3.kz model contribute to **evidence-based policy making**. In combination with **scenario analysis** ("what-if”), the model **helps to reduce uncertainty and raises awareness** regarding possible economy-wide impacts of climate change.

Model users can independently adjust model variables and parameters, enabling them to test their own assumptions instead of relying on predefined scenarios on the expertise of external consultants.

Macroeconomic analyses of adaptation options shows feedback and inter-sectoral effects of a sector-specific adaptation measure **and long-term developments**.

Comparing adaptation options and their macroeconomic impacts shows which option is highly effective and has positive impacts on the economy and environment. Thus, model results **offer one opportunity to prioritize adaptation options for the respective sector**.

Combating climate change requires a holistic approach enabling policymakers **to detect synergies and trade-offs of policy measures.** The e3.kz model covers the linkages between the economy, energy sector and emissions and thus helps in identifying sustainable policies.

The use of the model e3.kz allows for the quantification of economy-wide and environmental impacts of climate change as well as of sector-specific adaptation options based on the information mentioned previously. The model also allows for a macroeconomic evaluation of a combination of several adaptation measures together.

Furthermore, economic impacts of different financing options can be made visible. For the implementation of adaptation measures financial resources are needed which can be either be paid by the government, the investing sector (e. g. agriculture) or international donors such as the ADB. If international funds finance adaptation measures, the macroeconomic effects of the measures would be even better. The use of the model e3.kz in combination with scenario analysis helps to deal with the inherent uncertainty of climate change and the future in general. In scenarios, different assumptions on the frequency, intensity and occurrence of climate hazards can be examined. Various adaptation options can be analyzed with respect to their impacts on the 3E’s. The E3 modeling approach has the advantage of identifying the direct, indirect and induced socio-economic consequences as well as the implications for energy consumption and CO_2 emissions. Thus, with the e3.kz model, synergies or contradictions with other strategies, e. g. the LEDS, or long-term development strategies such as “Kazakhstan 2050”[39] can be explored to a certain extent. For example, nature-based adaptation solutions such as the “Green Belt mass afforestation” exemplary described in section 6.2.3.2 (e. g. Brolsma et al. 2021) have the potential to contribute to both nationally determined contributions (NDC) and NAP planning.

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

Thus, the use of the e3.kz model supports decisionmakers in evidence-based development of adaptation strategies that are described by the European Commission (2021b) as:

- **Smarter adaptation** meaning improving the knowledge and managing uncertainty and
- **More systematic adaptation** including the support of policy development at all levels and sectors

The climate change simulations conducted with the model e3.kz so far could be expanded by integrating other EWEs such as wildfires and extreme temperatures as well as gradual changes in temperature and precipitation. Furthermore, the impacts of other climate scenarios e. g. RCP 2.6 can be evaluated with the model. Re-assessments of climate impacts and adaptation options should be conducted when updated CBAs, novel adaptation actions or new studies on climate change impacts become available for Kazakhstan. In this regard, it is important to stay in close exchange with international and national partner institutions such as ADB, World Bank and UNDP.

Climate change adaptation must be understood as an ongoing process, which takes into account the most recent developments. For example, at EU level, the adaptation strategy of 2013 has been revised. After impact assessments to deepen the analyses and efforts to mainstream options as for example, nature-based adaptation options and to consider transboundary effects of climate impacts, a new adaptation strategy has been adopted in 2021 (European Commission 2021b). Revisioning and further developing a national adaptation strategy is advisable. In the case of Kazakhstan, the e3.kz model could also contribute to such a revisioning process by conducting scenario analyses using the most recent knowledge with regard to promising adaptation measures.

The model e3.kz is not limited to the macroeconomic analysis of climate change and adaptation. Due to its “white box” approach and intensive capacity building of model builders and users, the model can be enhanced and applied to analyze other pressing questions such as climate protection measures as well. Furthermore, the model is capable to integrate results from more detailed, technology-oriented bottom-up models. A region-specific expansion of the e3.kz model is also conceivable. Policy measures could then be further examined with regard to their regional impacts.

[39] https://kazakhstan2050.com/

8 LESSONS LEARNED

Quantitative economic models in combination with scenario analysis are powerful tools to effectively support policy makers in the assessment and evaluation of different climate change adaptation options.

The e3.kz model which uses the Excel-based DIOM-X framework in conjunction with intensive capacity building reduce the typical technical hurdles of model building and application tremendously. The "white box" approach not only ensures that each and every aspect of the model (data, model code and equations, results) are accessible and customizable but also increases confidence and the awareness of possible applications as well as limits of the model. Transferring full ownership of the model to the respective partners in the country not only allows for evaluating but also for continuous monitoring of current and future adaptation options.

However, the successful integration of the e3.kz model into strategic planning processes is linked to various preconditions.

For a data-driven model such as e3.kz, the quality of results greatly depends on the quality and timely availability of the underlying historic data. Frictions can only be avoided if data sources and responsibilities are identified at the beginning of the project.

Since each model represents a simplified view of the underlying economy and the increase in the level of detail inevitably also increases the model complexity, the modeling should initially only take into account the interrelationships relevant to the problem in order to ensure that the necessary capacities can be successfully built up among the respective partners. This is the only way to ensure continuous use and expansion of the model. Once the necessary capacities have been established, the model can be safely adopted to evolving requirements. An example regarding the e3.kz model is the expansion towards regional aspects which should be one of the first steps to be taken after the initial model has been finalized.

A critical success factor is related to the availability of local project partners. First, the availability of project members depends on approval and exemption by higher levels. A second common problem stems from the regular workload of employees at the partner institutions, which often does not allow for continuous participation in the model building and application process. As a consequence, it is highly challenging to build the necessary local capacities to successfully maintain and apply the model to pressing questions. Another aspect is brain-drain caused by project members leaving the partner institutions. Given time and budget restrictions usually there is not much room for training new team members. Furthermore, successful model application requires the assignment of responsibility as well as planning of financial and personal resources beyond the initial release.

The CRED approach and process with its three main pillars – model development, capacity building and policy support regarding adaptation planning – is on the one hand challenging with respect to coordination and planning as well as time-consuming for all partners involved. On the other hand, the approach is very successful in terms of collaboration with partners, intensive exchange with experts, dialog between decisionmakers from different fields and evidence-based policymaking with country-specific economic models for climate change adaptation planning. The highly participatory approach is suitable to foster an exchange between field experts and thus, increase the acceptance of methods, tools and results.

REFERENCES

Aaheim, A., Ahlert, G., Meyer, M., Meyer, B., Orlov, A., Heyndrickx, C. (2015). Integration of top-down and bottom-up analyses of adaptation to climate change in Europe – the cases of energy, transport and health. European Community's 7th Framework Programme under Grant Agreement No. 308620 (Project ToPDAd), Deliverable D3.4, Oslo.

Almon, C. (1991). The INFORUM Approach to Interindustry Modeling. Economic System Research 3/1, pp. 1–7.

Almon, C. (2014). The Craft of economic modelling – Part 1. Fifth Edition. January 2014. Department of Economics, University of Maryland.

Asian Development Bank (ADB) (2018). Kazakhstan. Accelerating economic diversification. Edited by Anderson, K., Capannelli, G., Ginting, E., Taniguchi, K. August 2018. https://www.adb.org/sites/default/files/publication/445446/kazakhstan-economic-diversification.pdf (last accessed October 4, 2021).

ADB (2019a): Kazakhstan: Central Asia Regional Economic Cooperation Corridors 1 and 6 Connector Road (Aktobe–Kandyagash) Reconstruction Project (RRP KAZ 52286). Project Data Sheet. https://www.adb.org/projects/52286-001/main#project-pds (last accessed November 26, 2021).

ADB (2019b). Proposed Loan KazAvtoZhol National Joint Stock Company Central Asia Regional Economic Cooperation Corridors 1 and 6 Connector Road (Aktobe–Kandyagash) Reconstruction Project (Guaranteed by the Republic of Kazakhstan). Report and Recommendation of the President to the Board of Directors, Sept. 2019.

Adelphi and Development Alternatives (2019): Sustainable Housing – Addressing SCP in the Housing Sector –Scoping Study, prepared on behalf of the EU SWITCH- Asia Sustainable Consumption and Production Facility (SCPF).

Astana Times (2019). Kazakh government to increase irrigated land area to 3.5 million hectares. https://astanatimes.com/2019/01/kazakh-government-to-increase-irrigated-land-area-to-3-5-millionhectares/ (January 3, 2019, last accessed October 4, 2021).

Batsaikhan U. and Dabrowski, M. (2017). Central Asia – twenty-five years after the breakup of the UDSSR. Russian Journal of Economics 3 (2017) 296–320. https://www.sciencedirect.com/science/article/pii/S2405473917300429 (last accessed November 26, 2021).

Bertelsmann Stiftung (2020). BTI 2020 Country Report – Kazakhstan. Gütersloh: Bertelsmann Stiftung. https://www.bti-project.org/content/en/downloads/reports/country_report_2020_KAZ.pdf (last accessed October 4, 2021).

Bierkandt, R., Medebayeva, A., Yermolyonok, D., Oshakbayev, D. (2019). Entry Points for Vertical Integration of Climate Action in Kazakhstan. Government of Kazakhstan: Nur-Sultan, Kazakhstan. https://www.weadapt.org/system/files_force/napgn-en-2019-entry-points-for-vertical-integration-of-climate-action-in-kazakhstan.pdf?download=1 (last accessed October 4, 2021).

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

Botzen, W. J. W., Deschenes, O., Sanders, M. (2019). The economic impacts of natural disasters: A review of models and empirical studies. Review of Environmental Economics and Policy, volume 13, issue 2, summer 2019, pp. 167–188.

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

Broka, S., Giertz, Å., Christensen, G., Rasmussen, D., Morgounov, A., Fileccia, T., Rubaiza, R. (2016). Kazakhstan. Agricultural sector risk assessment. World Bank Group Report Number 103076-KZ. February 2016. https://documents1.worldbank.org/curated/en/422491467991944802/pdf/103076-WP-KZ-P154004-Box394863B-PUBLIC-ASRA.pdf (last accessed October 4, 2021).

Brolsma, R., van de Ven, F., Hulsman, H., Mondeel, H., Joling, A. (2021). Pre-feasibility study Ecosystem-based Adaptation Nur-Sultan.

Bureau of National statistics of the Republic of Kazakhstan (2021). Statistics of Labor and Employment. https://stat.gov.kz/official/industry/25/statistic/7 (last accessed October 4, 2021)

Cambridge Econometrics (2019). Committee on Climate Change. A consistent set of socioeconomic dimensions for the CCRA3 Evidence Report research projects. Final report, June 2019.

CAREC Program (2021). Central Asia Regional Economic Cooperation. https://www.carecprogram.org/

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

Ciscar, J.-C., Lásló, S., Van Regemorter, D., Soria, A. (2011). The integration of PESETA sectoral economic impacts into the GEM-E3 Europe model: Methodology and results. Climate Change 112 (1), pp. 127–142. DOI: 10.1007/s10584-011-0343-y.

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

Climate Service Center Germany (GERICS) (2018). Climate-Fact-Sheets. Updated Version 2015; Country Kazakhstan; Helmholtz-Zentrum Geesthacht Zentrum für Material- und Küstenforschung GmbH, May 2018.

COMSTAT (2020). Gross domestic product by the production method for 2019. Express-information 3rd August of 2020. https://stat.gov.kz/api/getFile/?docId=ESTAT389479 (last accessed October 4, 2021).

COMSTAT (2021a). Statistics of National Accounts. https://stat.gov.kz/official/industry/11/statistic/8 (last accessed October 4, 2021).

COMSTAT (2021b). Structure of GDP https://stat.gov.kz/api/getFile/?docId=ESTAT101338 (last accessed October 4, 2021).

COMSTAT (2021c). https://stat.gov.kz/official/industry/25/statistic/7 (last accessed October 4, 2021).

COMSTAT (2021d). https://taldau.stat.gov.kz/ru/NewIndex/GetIndex/702840?keyword= (last accessed October 4, 2021).

Dekens, J. and Hammill, A. (2021). Climate Economic Modelling. Using Climate Economic Modelling for Sustainable Economic Development. A Practitioner's Guide. Published by GIZ on behalf of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety. https://www.giz.de/de/downloads/giz2021-en-climate-economic-modelling-practitioners-guide.pdf (last accessed November 26, 2021)

Deutsches Institut für Wirtschaftsforschung (DIW) Econ (2021). Kazakhstan: Towards Net Zero by 2060. Opportunities and challenges. Project: Long-term Low Greenhouse Gas Emission Development Strategy (LEDS) of Kazakhstan. Second draft. Implemented by GIZ on behalf of Federal Ministry for the Environment, Nature Conversation and Nuclear Safety, Germany.

Dochshanova, A. (2016). Legal responsibility for mudflow consequences in Kazakhstan. International Journal of Sciences and Research. Vol. 72, No. 12, Dec 2016.

DWD (2021): Urban climate - urban heat islands. https://www.dwd.de/EN/climate_environment/climateresearch/climate_impact/urbanism/urban_heat_island/urbanheatisland_node.html (last accessed November 10, 2021).

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

European Bank for Reconstruction and Development (EBRD) (2015–2020).

European Bank for Reconstruction and Development (EBRD), Finance and Technology Transfer Centre for Climate Change (FINTECC), Food and Agriculture Organization of the United Nations (FAO) (2018). Adoption of climate technologies in Kazakhstan's agrifood sector. http://www.eastagri.org/docs/group/512/KAZ_ACT_25.10.18.pdf (last accessed October 4, 2021).

European Bank for Reconstruction and Development (EBRD), Finance and Technology Transfer Centre for Climate Change (FINTECC), Food and Agriculture Organization of the United Nations (FAO) (2018a). Accelerating adoption of climate technologies in Kazakhstan's agrifood sector. http://www.eastagri.org/docs/group/499/4.2.KAZ_Session2_Project_results_ENG.pdf (last accessed October 4, 2021).

European Commission (2020): Study on Adaptation Modelling. Comprehensive Desk Review: Concise Summary. CLIMA/A.3/ETU/2018/0010 4th December 2020. https://www.adaptecca.es/sites/default/files/documentos/study_on_adaptation_modelling._concise_summary.pdf (last accessed October 4, 2021)

European Commission (2021a). Impact Assessment Report. Forging a climate-resilient Europe – The new EU Strategy on Adaptation to Climate Change, Brussels, 24.02.2021. https://ec.europa.eu/clima/sites/clima/files/adaptation/what/docs/swd_2021_25_en.pdf (last accessed October 4, 2021).

European Commission (2021b). Forging a climate-resilient Europe – The new EU Strategy on Adaptation to Climate Change, Brussels, 24.02.2021. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52021DC0082&from=EN (last accessed October 4, 2021).

European Environment Agency (EEA) (2019). Adaptation challenges and opportunities for the European energy system – building a climate-resilient low-carbon energy system. EEA Report 01/2019.

European Statistical Office (Eurostat) (2008). Eurostat Manual of Supply, Use and Input-Output Tables. Luxembourg.

Feyen L., Ciscar, J. C., Gosling, S., Ibarreta, D., Soria, A. (ed.) (2020). Climate change impacts and adaptation in Europe. JRC PESETA IV final report. EUR 30180EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-76-18123-1, DOI: 10.2760/171121, JRC119178. https://ec.europa.eu/jrc/sites/jrcsh/files/pesetaiv_summary_final_report.pdf (last accessed October 4, 2021).

Food and Agriculture Organization of the United Nations (FAO) (2017). Drought characteristics and management in Central Asia and Turkey. FAO Water Reports 44. https://www.droughtmanagement.info/literature/FAO_Drought_characteristics_and_Management_in_CAsia_Turkey_2017.pdf (last accessed October 4, 2021).

Food and Agriculture Organization of the United Nations (FAO), European Bank for Reconstruction and Development (EBRD) (2017). Adoption of climate technologies in the agrifood sector. Methodology, Rome.

Food and Agriculture Organization of the United Nations (FAO), World Bank (2019). Understanding the drought impact of El Niño/La Niña in the grain production areas in Eastern Europe and Central Asia: Russia, Ukraine and Kazakhstan. Rome. 132 pp. http://www.fao.org/3/ca3758en/ca3758en.pdf (last accessed October 4, 2021).

Friedrich Ebert Stiftung (FES) (2015). The Eurasian Economic Union – Analyses and Perspectives from Belarus, Kazakhstan and Russia. https://library.fes.de/pdf-files/id-moe/11181.pdf (last accessed October 4, 2021).

Fritzsche, K., Schneiderbauer, S., Bubeck, P., Kienberger, S., Buth, M., Zebisch, M., Kahlenborn, W. (2014). The Vulnerability Sourcebook Concept and guidelines for standardised vulnerability assessments. Published by GIZ. https://www.adaptationcommunity.net/download/va/vulnerability-guides-manuals-reports/vuln_source_2017_EN.pdf (last accessed October 4, 2021).

Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ) (2013). Economic approaches for assessing climate change adaptation options under uncertainty. Excel tools for Cost-Benefit and Multi-Criteria Analysis. Competence Center for Climate Change. https://www.adaptationcommunity.net/download/ms/mainstreaming-guides-manuals-reports/Economic_assessment_of_CC_adaptation_options_-_GIZ_2013.pdf (last accessed November 21, 2021).

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

Global Facility for Disaster Reduction and Recovery (GFDRR), Government of Georgia, UN Development Programme, World Bank (2015). Tbilisi Disaster Needs Assessment 2015. Tbilisi.

Green Economy Concept (2013). https://policy.asiapacificenergy.org/sites/default/files/Concept%20on%20Transition%20towards%20Green%20Economy%20until%202050%20%28EN%29.pdf (last accessed October 4, 2021).

Großmann, A., Hohmann, F. (2019). Static and Dynamic Input-Output Modelling with Microsoft Excel. SHAIO Conference Paper 2019, Osnabrück.

Großmann, A., Lehr, U., Lutz, C., Mönnig, A., Kleissl, S. (2016). Planning Policy Impact Assessments and Choosing the Right Methods: Manual for Development Practitioners. Published by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), Eschborn.

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

Hübler, M. (2014). Sozio-ökonomische Bewertung von Gesundheitseffekten des Klimawandels in Deutschland. In: Lozán, J. L., Grassl, H., Karbe, L., G. Jendritzky (ed.). Warnsignal Klima: Gefahren für Pflanzen, Tiere und Menschen. 2. Auflage. Electronic publication. Chapter 4.13. https://www.klima-warnsignale.uni-hamburg.de/wp-content/uploads/pdf/de/gesundheitsrisiken/warnsignal_klima-gesundheitsrisiken-kapitel-4_13.pdf (last accessed October 4, 2021).

Intergovernmental Panel on Climate Change (IPCC) (2012). Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, UK, and New York, NY, USA, 582 pphttps://ane4bf-datap1.s3-eu-west-1.amazonaws.com/wmocms/s3fs-public/news/related_docs/SREX-All_FINAL.pdf (last accessed October 4, 2021).

Intergovernmental Panel on Climate Change (IPCC) (2014). Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Field, C. B., Barros, V. R., Dokken, D. J., Mach, K. J., Mastrandrea, M. D., Bilir, T. E., Chatterjee, M., Ebi, K. L., Estrada, Y. O., Genova, R. C., Girma, B., Kissel, E. S., Levy, A. N., MacCracken, S., Mastrandrea, P. R., White, L. L. (ed.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1132 pp. https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-PartA_FINAL.pdf (last accessed October 4, 2021).

Internationale Arbeitsorganisation (ILO) (2019). Working on a warmer planet. The impact of heat stress on labour productivity and decent work. International Labour Organization. Geneva, 2019. https://www.ilo.org/wcmsp5/groups/public/---dgreports/---dcomm/---publ/documents/publication/wcms_711919.pdf (last accessed October 4, 2021).

International Energy Agency (IEA) (2020). World Energy Outlook 2020.

International Energy Agency (IEA) (2021). Kazakhstan's energy profile. https://www.iea.org/reports/kazakhstan-energy-profile (last accessed October 4, 2021).

International Federation of Red Cross and Red Crescent Societies (IFRC) (2021). Emergency Plan of Action (EPoA). Kazakhstan: Drought. https://reliefweb.int/sites/reliefweb.int/files/resources/MDRKZ010do.pdf (last accessed October 4, 2021).

International Renewable Energy Agency (IRENA) (2021). Renewable Power Generation Costs in 2020. https://www.irena.org/publications/2021/Jun/Renewable-Power-Costs-in-2020 (last accessed October 4, 2021).

International Transport Forum (ITF) (2019): Enhancing Connectivity and Freight in Central Asia, International Transport Forum Policy Papers, No. 71, OECD Publishing, Paris.

Karatayev et al. (2017). https://www.sciencedirect.com/science/article/pii/S1876610217335464 (last accessed October 4, 2021).

Kazakh Government (2020). Eighty-eight thousand jobs to be created during modernization of irrigation infrastructure in Kazakhstan. https://www.primeminister.kz/en/news/v-hode-modernizacii-irrigacionnoyinfrastruktury-kazahstana-budet-sozdano-88-tys-rabochih-mest-73818 (last accessed April 7, 2021).

Kazakhstan Electricity Grid Operating Company (KEGOC) (2018). Keen. S. (2021). The appallingly bad neoclassical economics of climate change, Globalizations. DOI: 10.1080/14747731.2020.1807856. https://www.kegoc.kz/ru/2018 (last accessed October 4, 2021).

Keppo, I., Butnar, I., Bauer, N., Caspani, M., Edelenbosch, O., Emmerling, J., Fragkos, P., Guivarch, C., Harmsen, M., Lefèvre, J., Le Gallic, T., Leimbach, M., McDowall, W., Mercure, J.-F., Schaeffer, R., Trutnevyte, E., Wagner, F. (2021). Exploring the possibility space: taking stock of the diverse capabilities and gaps in integrated assessment models. Environmental Research Letters 16, 053006.

Kozhakhmetov, P. Zh., Nikiforova, L. N. (2016). Weather elements of Kazakhstan in the context of global climate change. Astana, 36 p.

Lehr, U., Flaute, M., Ahmann, L., Nieters, A., Wolff, C., Hirschfeld, J., Welling, M., Gall, A., Kersting, J., Mahlbacher, M., von Möllendorff, C. (2020). Vertiefte ökonomische Analyse einzelner Politikinstrumente und Maßnahmen zur Anpassung an den Klimawandel – Abschlussbericht / In-depth economic analysis of individual policy instruments and adaptation measures to climate change – final report. Climate Change 43/2020, Dessau-Roßlau.

Lehr, U., Meyer, M., Figini, P., Ahrends, B. (2018). Work package 3: Climate change vulnerability assessment framework and complex impact chains. Deliverable 3.4. Specifications for climate, climate impacts and economic modelling – report on modelling chains. This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No776661. https://soclimpact.net/ (last accessed June 15, 2021).

Lehr, U., Nieters, A., Drosdowski, T. (2015). Climate change adaptation and the German economy. GWS Discussion Paper 2015/10, Osnabrück. http://papers.gws-os.com/gws-paper15-10.pdf (last accessed June 15, 2021).

Lehr, U., Nieters, A., Drosdowski, T. (2016). Extreme Weather Events and the German Economy: The Potential for Climate Change Adaptation. In: Leal Filho, W., Musa, H., Cavan, G., O'Hare, P., Seixas, J. (ed.): Climate Change, Adaptation, Resilience and Hazards, Springer, pp. 125–141.

Leontief, W. (1986). Input-Output Economics. 2nd ed., New York, Oxford University Press.

Lewney, R., Pollitt, H., Mercure, J.-F. (2019). From input-output to macro-econometric model. Paper presented to the 27th International Input-Output Association Conference, 30th June to 5th July 2019, Glasgow, Scotland.

Lutz, C., Lehr, U., Ulrich, P. (2014). Economic evaluation of climate protection measures in Germany, Abstract for the 22nd International Input-Output Conference, 15th–18th July 2014, Lisbon.

Máñez Costa, M., Rechid, D., Bieritz, L., Lutz, C., Nieters, A., Stöver, B., Jahn, M., Rische, M.-C., Schulze, S., Yadegar, E., Hirschfeld, J., Schröder, A., Hirte, G., Langer, S., Tscharaktschiew, S. (2016). Synthesis of existing regional and sectoral economic modelling and its possible integration with regional earth system models in the context of climate modelling. Report 27. Climate Service Center, Hamburg. https://epub.sub.uni-hamburg.de/epub/volltexte/2017/69272/pdf/report27.pdf (last accessed October 4, 2021).

Mercure, J.-F., Knobloch, F., Pollitt, H., Paroussos, L., Scrieciu, S. S., Lewney, R. (2019). Modelling innovation and the macroeconomics of low carbon transitions: theory, perspectives and practical use, Climate Policy 19:8, 1019–1037, DOI: 10.1080/14693062.2019.1617665.

Meyer, B., Ahlert, G. (2019). Imperfect Markets and the Properties of Macro-economic-environmental Models as Tools for Policy Evaluation. Ecological Economics, Vol. 155, pp. 809–87, DOI: http://dx.doi.org/10.1016/j.ecolecon.2017.06.017.

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

Ministry of Energy of the Republic of Kazakhstan (GOV), Global Environment Facility (GEF), United Nations Development Programme (UNDP) (2017). Seventh National Communication and Third Biennial Report of the Republic of Kazakhstan to the UN Framework Convention on Climate Change. Astana. https://unfccc.int/sites/default/files/resource/20963851_Kazakhstan-NC7-BR3-1-ENG_Saulet_Report_12-2017_ENG.pdf (last accessed October 4, 2021).

Ministry of National Economy of the Republic of Kazakhstan, Committee on Statistics (2020a). Demographic Yearbook of Kazakhstan. Nur-Sultan 2020. https://stat.gov.kz/api/getFile/?docId=ESTAT379492 (last accessed October 4, 2021).

Ministry of National Economy (2020b). https://stat.gov.kz/official/industry/61/statistic/5 (last accessed October 4, 2021).

Mirasgedis, S., Georgopoulou, E., Sarafidis, Y., Papagiannaki, K., La-las, D. (2014). The Impact of Climate Change on the Pattern of Demand for Bottled Water and Non-Alcoholic Beverages. Business Strategy and the Environment 23. 10.1002/bse.1782.

Muzbay, A. (2020). Policy Advice for Climate Resilient Economic Development Data collection support in Kazakhstan on climate change effect damages. August 2020. Implemented by Aibat Muzbay. Financed and supported by Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.

Navarro, J. S., Jordà, G. (2021). Climatic hazards evolution in the 21stcentury in the frame of the CRED project. Mediterranean Institute for Advanced Studies (IMEDEA, UIB-CSIC), University of the Balearic Islands (UIB)

Network for Greening the Financial System (NGFS) (2020). Technical document. Guide to climate scenario analysis for central banks and supervisors.

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

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

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

Organisation for Economic Co-operation and Development (OECD) (2015). The Economic Consequences of Climate Change, OECD Publishing, Paris. DOI: http://dx.doi.org/10.1787/9789264235410-en.

Organisation for Economic Co-operation and Development (OECD) (2018). Climate-resilient Infrastructure. OECD Environment policy paper No. 14, https://www.oecd.org/environment/cc/policy-perspectives-climate-resilient-infrastructure.pdf (last accessed October 4, 2021).

Organisation for Economic Co-operation and Development (OECD) (2019a). Risk Governance Scan of Kazakhstan, OECD Reviews of Risk Management Policies, OECD Publishing, Paris, DOI: https://doi.org/10.1787/cb82cae9-en.

Organisation for Economic Co-operation and Development (OECD) (2019b): Sustainable Infrastructure for Low-Carbon Development in Central Asia and the Caucasus: Hotspot Analysis and Needs Assessment, Green Finance and Investment, OECD Publishing, Paris, https://doi.org/10.1787/d1aa6ae9-en.

Organisation for Economic Co-operation and Development (OECD) (2020a). “Kazakhstan”, in Agricultural Policy Monitoring and Evaluation 2020, OECD Publishing, Paris. DOI: https://doi.org/10.1787/d3c7bdcf-en

Organisation for Economic Co-operation and Development (OECD) (2020b). Kazakhstan. Agricultural Policy Monitoring and Evaluation 2020, OECD Publishing, Paris. DOI: https://doi.org/10.1787/d3c7bdcf-en.

Organisation for Economic Co-operation and Development (OECD) (2021). Strengthening Adaptation-Mitigation Linkages for a Low-Carbon, Climate Resilient Future. Policy Perspectives. OECD Environment Policy Paper No. 23. https://www.oecd-ilibrary.org/docserver/6d79ff6a-en.pdf?expires=1633339374&id=id&accname=guest&checksum=E476AACB2E0CC35FB51FFEE2742DFDCC (last accessed October 4, 2021).

Ortiz, R. A., Markandya, A. (2009). Integrated Impact Assessment Models of Climate Change with an Emphasis on Damage Functions: a Literature Review. BC3 Working Paper Series 2009-06.

Pannier, B. (2021). Kyrgyzstan's Hydropower Problems Causing Concern In Neighboring Nations. Radio Free Europe / Radio Liberty, April 15, 2021. https://www.rferl.org/a/kyrgyzstan-hydropower-reduction/31205779.html (last accessed October 1, 2021).

Pollitt, H., Mercure, J-F., M. (2018). The role of money and the financial sector in energy-economy models used for assessing climate and energy policy. Climate Policy 18:2, pp. 184–197, DOI: 10.1080/14693062.2016.1277685.

Prime Minister of the RK (2020a). “Two billion trees in forests and 15 million trees in settlements to be planted in Kazakhstan — Minister of Ecology, Geology and Natural Resources“ https://www.primeminister.kz/en/news/v-rk-budet-posazheno-2-mlrd-derevev-v-lesnyh-massivah-i-15-mln-derevev-v-naselennyh-punktah-megpr-24101017 (last accessed November 21, 2021)

Prime Minister of the RK (2020b). “Under Nurly Zhol State Program, it is planned to implement 112 infrastructure projects by 2025. (https://primeminister.kz/en/news/v-ramkah-gosprogrammy-nurly-zhol-do-2025-goda-planiruetsya-realizovat-112-infrastrukturnyh-proektov-213248 (last accessed November 21, 2021)

Republic of Kazakhstan (1998). Initial National Communication of the Republic of Kazakhstan under the United Nations Framework Convention on Climate Change. Almaty. https://unfccc.int/sites/default/files/resource/Kazakstan%20INC.pdf last accessed October 1, 2021).

Rivotti, P., Karatayev, M., Sobral Mourao, Z., Shah, N., Clarke, M. L., Konadu, D. D. (2019). Impact of future energy policy on water resources in Kazakhstan, Energy Strategy Reviews 24, pp. 261–-267.

Steininger, K.W., König, M., Bednar-Friedl, B., Kranzl, L., Loibl, W., Prettenthaler, F. (Eds.) (2015): Economic Evaluation of Climate Change Impacts – Development of a Cross-Sectoral Framework and Results for Austria. 2015, Springer.

Stewart and Deng (2014). Climate Impact Risks and Climate Adaptation Engineering for Built Infrastructure. ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering American Society of Civil Engineers. DOI: 10.1061/AJRUA6.0000809.

Stocker, A., Großmann, A., Madlener, R., Wolter, M. I. (2011). Sustainable energy development in Austria until 2020: Insights from applying the integrated model "e3.at". Energy Policy 39 (10), 6082–6099, DOI: 10.1016/j.enpol.2011.07.2009.

TALAP (2019). Assessment of Economic and Environmental Modeling Capacity in Kazakhstan. Working Draft 4. Nur-Sultan, July 2019.

The Environmentor (n.d.) https://blog.tentree.com/this-is-the-impact-of-1-million-trees/ (last accessed November 21, 2021)

The Guardian (2017). Astana's plan to stay warm in the winter? Build a ring of one million trees https://www.theguardian.com/cities/2017/oct/18/astana-plan-warm-winter-ring-one-million-trees (last accessed November 21, 2021)

Tulepov (2019). Climate change: the capital's experience https://vechastana.kz/izmenenie-klimata-opyt-stolicy/ (last accessed November 21, 2021)

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

UN Economic Commission for Asia and the Pacific (UNESCAP) (2020). Kazakhstan COVID Country Responses. Last update: July 15, 2020. https://www.unescap.org/sites/default/files/Kazakhstan_COVID%20Country%20Responses_updated.pdf (last accessed October 4, 2021).

United Nations Development Programme (UNDP) (2019). Building the Climate Resilience of Grain Farming in the Northern Kazakhstan.

United Nations Development Programme (UNDPa) (2020a). Summary analytical report on the assessment of economic losses in the agricultural sectors. UNDP project "Development of the Eighth National Communication of the Republic of Kazakhstan under the UNFCCC and preparation of two (fourth and fifth) biennial reports".

United Nations Development Programme (UNDP) (2020b). Human Development Reports. http://hdr.undp.org/en/countries/profiles/KAZ (last accessed October 4, 2021).

United Nations Development Programme (UNDP) (2011). Transboundary Diagnostic Analysis for the Caspian Sea. Natural Disaster Risks in Central Asia: A Synthesis. https://www1.undp.org/content/dam/rbec/docs/Natural-disaster-risks-in-Central-Asia-A-synthesis.pdf (last accessed October 4, 2021).

United Nations Development Programme (UNDP), UN Environment Programme (UNEP), Technical Assistance to the Commonwealth of Independent States (Tacis), World Bank, Global Environment Facility (GEF), United Nations Office for Project Services (UNOPS) (2002). Transboundary Diagnostic Analysis for the Caspian Sea. Volume Two. The Caspian Environment Programme. Baku, Azerbaijan. September 2002 https://wedocs.unep.org/bitstream/handle/20.500.11822/9726/-Transboundary_Diagnostic_Analysis_for_the_Caspian_Sea-2002Caspian_TDAVolumeTwo_2002.pdf.pdf?sequence=3&isAllowed=y (last accessed October 4, 2021).

UNECE (2019a): Logistics and Transport Competitiveness in Kazakhstan. Geneva. https://unece.org/DAM/trans/publications/Report_-_Kazakhstan_as_a_transport_logistics_centre_Europe-Asia.pdf

UNECE (2019b): Kazakhstan – Environmental Performance Reviews Series No. 50, Third Review, United Nations, Geneva.

United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) (2021a). Kazakhstan – Climate Change and Disaster Risk Profile. https://www.unescap.org/sites/default/d8files/event-documents/Kazakhstan%20-%20Climate%20Change%20and%20Disaster%20Risk%20Profile.pdf (last accessed November 14, 2021)

United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) (2021b). Infrastructure Financing in Kazakhstan. A study commissioned by the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP)

United Nations Framework Convention on Climate Change (UNFCCC) (1992). https://unfccc.int/files/essential_background/background_publications_htmlpdf/application/pdf/conveng.pdf (last accessed November 21, 2021).

United Nations Framework Convention on Climate Change (UNFCCC) (2011). Assessing the costs and benefits of adaptation options. An overview of approaches. The Nairobi work programme on impacts, vulnerability and adaptation to climate change. https://unfccc.int/resource/docs/publications/pub_nwp_costs_benefits_adaptation.pdf (last accessed November 21, 2021).

United Nations Framework Convention on Climate Change (UNFCCC) (2013). Glossary of climate change acronyms. http://unfccc.int/essential_background/glossary/items/3666.php#A (last accessed October 4, 2021).

United Nations Framework Convention on Climate Change (UNFCCC) (2021). Common Reporting Format (CRF) Table https://unfccc.int/sites/default/files/resource/kaz-2021-crf-16apr21.zip (last accessed October 4, 2021).

United Nations General Assembly (UNGA) (2020). Statement by President of Kazakhstan Kassym-Jomart Tokayev at the General Debate of the 75th session of the UNGA. The Future We Want, The UN We Need: Reaffirming our collective commitment to multilateralism" (23 September 2020). https://www.akorda.kz/en/speeches/external_political_affairs/ext_speeches_and_addresses/statement-by-president-of-kazakhstan-kassym-jomart-tokayev-at-the-general-debate-of-the-75th-session-of-the-unga (last accessed November 21, 2021).

United States Agency for International Development (USAID) (2012). Transportation Addressing Climate Change Impacts on Infrastructure: Preparing for Change. https://www.climatelinks.org/sites/default/files/asset/document/Infrastructure_Transportation.pdf (last accessed October 4, 2021).

United States Agency for International Development (USAID) (2017). Climate Risk Profile Kazakhstan. https://www.climatelinks.org/sites/default/files/asset/document/2017_USAID%20ATLAS_Climate%20Risk%20Profile%20-%20Kazakhstan.pdf (last accessed October 4, 2021).

United States Agency for International Development (USAID) (2018). Climate Risk Profile Central Asia. https://reliefweb.int/sites/reliefweb.int/files/resources/2018-April-30_USAID_CadmusCISF_Climate-Risk-Profile-Central-Asia.pdf (last accessed October 4, 2021).

Van Vliet, M. T. H., Sheffiled, J., Wiberg, D., Wood, E. F. (2016). Impacts of recent drought and warm years on water resources and electricity supply worldwide. Environmental Research Letters 11. 124021. DOI: 10.1088/1748-9326/11/12/124021.

Wang, Y., Li, H., Sun, B., Chen, H., Li, H., Luo, Y. (2020). Drought Impacts on Hydropower Capacity Over the Yangtze River Basin and Their Future Projections under 1.5/2°C Warming Scenarios. Frontiers in Earth Science, September 16, 2020. https://www.frontiersin.org/articles/10.3389/feart.2020.578132/full (last accessed October 4, 2021).

West, G. R. (1995). Comparison of Input-Output, IO-Econometric and CGE impact models at the regional level. Economic Systems Research 7–2, pp. 209–227.

World Bank (2005). Drought. Management and Mitigation Assessment for Central Asia and the Caucasus. Report No: 31998-ECA. March 11, 2005. http://documents1.worldbank.org/curated/en/135721468036310201/pdf/319980ENGLISH01ver0p08014801PUBLIC1.pdf (last accessed October 4, 2021).

World Bank (2011). Climate Impacts on Energy Systems. Key issues for energy sector adaptation. https://www.esmap.org/sites/esmap.org/files/E-Book_Climate%20Impacts%20on%20Energy%20Systems_BOOK_resized.pdf (last accessed October 4, 2021)

World Bank (2012). East-West Roads Project (Almaty-Korgos Section): Western Europe - Western China International Transit Corridor (CAREC - 1b) (P128050).

World Bank (2015). Kazakhstan: Nationwide assessment of climate-change related risks and formulation of mitigation strategy. Policy and Institutional Directions for Bolstering Climate Resilience in the Agriculture, Forestry and Energy Sectors. Joint Economic Research Program (JERP). https://openknowledge.worldbank.org/bitstream/handle/10986/22488/Kazakhstan000N0mitigation0strategy.pdf?sequence=1 (last accessed October 4, 2021)

World Bank (2018a). Kazakhstan: The Quest for a New Growth Model: The Urgency of Economic Transformation. Country Economic Update. Spring 2018. Washington, D.C.

World Bank (2018b). Green Economy: Realities & Prospects in Kazakhstan. August 2018. https://www.sk.kz/upload/iblock/8d9/8d97878e7ec2466e04ab62e5d8f4c3a3.pdf (last accessed October 4, 2021).

World Bank (2019a). Belt and Road Economics: Opportunities and Risks of Transport Corridors. Washington, D. C.

World Bank (2019b). Enterprise Surveys. www.enterprisesurveys.org (last accessed October 4, 2021).

World Bank, Food and Agriculture Organization (FAO) (2019). Understanding the drought impact in the grain production areas in Eastern Europe and Central Asia (ECA): Russia, Ukraine, and Kazakhstan (RUK). https://reliefweb.int/sites/reliefweb.int/files/resources/ca3758en.pdf (last accessed October 4, 2021).

World Bank (2011). Climate Impacts on Energy Systems – Key Issues for Energy Sector Adaptation. Washington.

World Bank (2020a). South Caucasus and Central Asia Belt and Road Initiative – Kazakhstan Country Case Study. June 2020.

World Bank (2020b): Adaptation Principles: A Guide for Designing Strategies for Climate Change Adaptation and Resilience. World Bank, Washington, DC. https://openknowledge.worldbank.org/bitstream/handle/10986/34780/AdaptationPrinciples.pdf?sequence=1&isAllowed=y (last accessed November 21, 2021).

World Bank (2021). Climate Risk Country Profile: Kazakhstan. https://climateknowledgeportal.worldbank.org/sites/default/files/2021-06/15834-WB_Kazakhstan%20Country%20Profile-WEB.pdf (last accessed October 4, 2021).

APPENDIX

Appendix 1: Data collection in Kazakhstan on climate change effect damages 1991-2012 (excerpt)

Type of extreme event	Region	Date	Number of people suffered	Injured	incl. People who	Material damage and recovery costs, thousand tenge
High water levels (flooding)	South KZ	20.02.2008		9,869		11,478,388
Heavy rain (downpour)	Mangystau	28.07.1998				3,000,000
High water levels (flooding)	South KZ	20.02.2008		1,727		2,447,870
Forest fire	Jambyl	26.07.2009				1,793,500
High water levels (flooding)	South KZ	20.02.2008		1,209		1,358,172
Heavy rain (downpour)	Almaty	18.07.1995				1,200,000
Wind storm	Atyrau	27.05.2008				900,173
High water levels (flooding)	Almaty	20.05.1998				448,800
Seasonal flood	Akmola	30.06.1994				444,603
High water levels (flooding)	South KZ	21.02.2012				439,920
Wind storm	East KZ	18.04.1998	4			360,000
Forest fire	Pavlodar	08.09.2010		7	6	258,341
High water levels (flooding)	Atyrau	31.05.1998				248,854
Wind storm	Jambyl	18.07.1998		6	1	235,182
High water levels (flooding)	Kostanay	08.04.2000		1,095		187,690
Seasonal flood	Akmola	10.04.1995	2,835	2		180,307
High water levels (flooding)	Jambyl	25.04.2002				174,571
High water levels (flooding)	North KZ	01.04.1994		3,060		167,000
Inundation	Atyrau	29.03.1997				166,800
Inundation	Jambyl	16.05.2002				160,000
Forest fire	Almaty	15.10.1994				150,300
Forest fire	Kostanay	14.07.1995				139,900
Wind storm	Jambyl	21.02.2003				135,890
Rainfall flood	Jambyl	10.02.1996				130,000
High water levels (flooding)	Almaty	14.07.1999				120,000
High water levels (flooding)	West KZ	09.04.2003				113,000
Heavy rain (downpour)	South KZ	26.05.1998	2,700	2,700		112,100
Wind storm	Kostanay	18.05.2004		10		109,000
Rainfall flood	South KZ	30.04.1997				108,315
Forest fire	Almaty	18.10.1994				99,720
Inundation	East KZ	27.03.1997				96,000
Wind storm	Jambyl	18.07.1998				91,392
Inundation	Jambyl	16.05.2002				84,000
High water levels (flooding)	Kostanay	26.04.1994				80,000
High water levels (flooding)	Almaty	19.07.1999				80,000
Seasonal flood	Karaganda	30.04.1995				78,000
Heavy snowfall	South KZ	17.01.1994				72,400
Large hailstorm	South KZ	15.05.2003				70,000
Heavy snowstorm	North KZ	30.12.1995		17	16	65,000
Wind storm	East KZ	31.05.2005		6		64,281
Seasonal flood	Akmola	30.06.1994				63,167
Large hailstorm	South KZ	30.05.1997				58,788
Wind storm	South KZ	21.02.2003				58,522

Source: Kazhydromet

Appendix 2: Data collection in Kazakhstan on climate change effect damages (excerpt)

Year / Date	Affected region	Physical damages / description	Economic damages [in KZT million]	Economic losses [in KZT million]	Recovery needs [in KZT million]	Economic Sectors affected	Source of data
Extreme weather events							
Heavy rain							
2002 May	East Kazakhstan	Heavy rain (NO information on physical damage or description)	22.0				Kazhydromet
2002 June	East Kazakhstan	1 person injured	0.5				Kazhydromet
2004 July	Almaty and Zhambyl	As a result of a heavy rain, several dozen houses were flooded and some crops were destroyed. So, in the Panfilov district of Almaty region, a dam burst on a reservoir in the village of Maly Chagan, which led to about 100 houses and 200 hectares of farmland were flooded. In the Korday district of Zhambyl region, due to the abundance of a heavy rain, a leash was passed along the Rgayty river. Mudflow washed away about 500 hectares of grain crops, and about 30-40 residential buildings were flooded.	12.0			Agriculture and infrastructure	https://www.caravan.kz/news/ushherb-ot-livnevykh-dozhdejj-proshedshikh-v-nachale-nedeli-na-yuge-kazakhstana-sostavil-svyshe-12-mln-tenge-achs-rk-199252/
2007 April	Aktobe	150 person affected	4.1				Kazhydromet
2007 May	Shymkent	As a result of the rain, 2 houses were partially flooded and restored by the mayor's office.				Housing Infrastructure	Akimat of Shymkent city
2008 February	South Kazakhstan and Kyzylorda	Heavy rain led to riverine flooding. 2383 houses were inundated, while 198 houses, 8 schools, 2 primary medical centers were destroyed and 2 bridges washed away; more than 13000 people evacuated	15.6			Housing; transport	https://read.oecd-ilibrary.org/governance/risk-governance-scan-of-kazakhstan_cb82cae9-en#page28; p. 29
2008 June	Mangystau	As a result of a heavy raintorm that took place on the territory of the Karakiyan district on 19.06.2008 from 7:00 till 11:30 on the 69-70 km section of the national significant highway "Aktau-Kuryk", the roadbed was partially washed out with a length of about 100 m. At 8:30 on the section between the 14 and 15 railway sidings of the Mangistau district, there was a derailment of railway cars.				infrastructure Transport	Committee of emergency situations of the Ministry of Internal Affairs
2009 March	Shymkent	Due to heavy rains, 18 residential areas and 2 highways were flooded. There is no material damage.				Housing Transport	Akimat of Shymkent city
2009 May	Almaty	As a result of a heavy rain in the upper reaches of the river Lepsi, there was a sharp jump in water to 120.0 m3 / s, which led to the erosion of the dam on the river Lepsi, Sarkan district.				infrastructure	Committee of emergency situations of the Ministry of Internal Affairs
2009 May	South Kazakhstan	Due to heavy rain which lasted for 2 weeks around 1000 houses were flooded (including hospital and school) in Kazakhstan			KZT 12 mln (for agriculture)	Housing Agriculture	https://www.ktk.kz/ru/news/video/2009/05/19/4168/

ReadMe | Data

Source: Muzbay 2020