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Policy advice for climate resilient economic development based on an E3 model built in Excel

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ABSTRACT

This paper reports on the project "Policy advice for climate resilient economic development (CRED)" on behalf of GIZ (German Corporation for International Cooperation) which aims at (i) improving capacities on building economic models in three pilot countries namely Georgia, Kazakhstan and Vietnam with a focus on climate change, (ii) integrating the results of improved models in economic development strategies and policies as well as adaptation policies and (iii) to strengthen international exchange on these issues between e. g. governments and researchers. In the partner countries, a few environmental models exist but these are not linked to economic models and vice versa. Furthermore, many of these models do not sufficiently reveal their structure ("black box") and thus can hardly be maintained or extended. The major challenge is to provide a state-of-the-art, science-based solution suitable for policy analysis which at the same time is sustainable so that local experts and researchers can cope with maintaining and enhancing the models independently with limited resources. In the project, an easy to learn yet powerful framework based on Visual Basic for Applications in Microsoft Excel is applied and trained in intensive courses. The framework allows for creating a macro-econometric Input-Output model covering economy, energy and environment(so called E3 models) and provides mechanisms for quickly calculating complex climate change and adaptation scenarios which can be developed also by non-model builders and stakeholders. Model builders must get acquainted to only one programming language to populate and enhance the provided model template and can reuse their Excel knowledge. The full data set, framework and model code as well as the scenarios are stored in just one Excel workbook allowing for easy distribution and evaluation.

***Keywords**:* dynamic E3 modelling in Microsoft Excel; climate change; adaptation measures; capacity building; scenario analysis

1 ECONOMIC IMPACTS OF CLIMATE CHANGE IN KAZAKHSTAN

Most experts agree that global warming is inevitable, especially with continued emission of greenhouse gases. Dramatic changes in the climate system lead to severe and irreversible environmental impacts, which in turn will affect the socio-economic system. Climate change becomes more and more important to Kazakhstan as well, mostly in the agricultural, energy and the water sector. In climate projections, increased temperatures, droughts, and heat waves are expected as well as more incidences of heavy precipitation events by 2050.

Climate change adaptation is essential for a climate resilient economic development. As climate risks affect key economic processes, policy makers need to manage adaptation measures which consider both possible costs and benefits. By providing a macro-econometric Input-Output (EIO) model extended by an energy and environment module (E3 model)which helps to quantify the impacts of climate change as well as of adaptation strategies at a sectoral level, the project actively supports policy makers in their climate change and adaptation management.

For an economic model to be climate change aware, it needs to capture the structural economic changes that are directly affected by climate change but also must consider supply chains. Additionally, such an economic model must quantify long-term economic developments.

For the economic analysis of climate change effects, an economic model needs to be linked to a climate model. Different economic model types exist, e. g. Computable General Equilibrium (CGE), IO and macro-econometric models (Lehr et al. forthcoming). For example, Integrated Assessment Models (IAMs) link temperature changes or sea level rises to a CGE model using a loss function. In contrast to the highly aggregated economic analysis in IAMs, Disaster Impact Models (DIMs) assess economic effects of catastrophic events on local economies. Static IO models can be applied for short-term disaster analysis and its sectoral, interdependent economic impacts but they are not suitable for long-term adaptation processes. Macro-econometric (dynamic) IO models can better reflect economic development year by year and they are able to integrate impact chains for individual economic sectors such as energy and agricultural sector.

Based on experiences from previous projects, E3 models are considered appropriate tools in combination with scenario analysis to consider and analyze not only the impacts of climate change and adaptation but also a wide range of other economic and energy-related questions. Two contrasting scenarios are created: one scenario includes climate change without adaptation measures. The other scenario combines both. Comparing the two scenarios shows the impacts (such as adaptation costs and avoided damages) of adaptation activities.

In course of the CRED (Climate-Resilient Economic Development) project for Kazakhstan, the E3 model named e3.kz will be developed from scratch and implemented in Microsoft (MS) Excel Visual Basic for Application (VBA) together with local experts to provide sustainable capacity building. A second group of users will be trained in applying the model for scenario analysis in the fields of climate change and adaptation.

2 AN E3 MODEL FOR KAZAKHSTAN

Since the 1990s, different models have been developed to quantify the economic effects of climate change. While, for example, IAMs focus on the economic impacts at the global level caused by gradual changes of climate, DIMs aim at the effects of extreme weather events at regional level (e. g. Patt et al. 2010, Hallegatte et al. 2011, Ortiz, Markandya 2009).

So far, E3 models are widely used to analyse greenhouse gas emission reduction pathways (e. g. GWS et al. 2014, Barker et al. 2011, Dagoumas, Barker 2010) but not so often for the evaluation of climate change impacts and adaptation measures, although they are suitable to model damages at the level of individual economic sectors. According to Lehr et al. (forthcoming) it is, amongst others, due to climate is changing dynamically and the high uncertainty about climate change effects making it difficult to select appropriate adaptation measures. Furthermore, adaptation modelling data are scarce and subject to greater uncertainty than mitigation modelling data.

Nevertheless, the suitability of this modelling approach for evaluating the economic effects of extreme weather events and adaptation measures has been convincing with projects in Germany and for the EU islands (Lehr et al. 2015, 2016, 2018, Aaheim et al. 2015). The inherent uncertainty in climate change can be addressed with the help of scenario analysis, which is described in chapter 4.

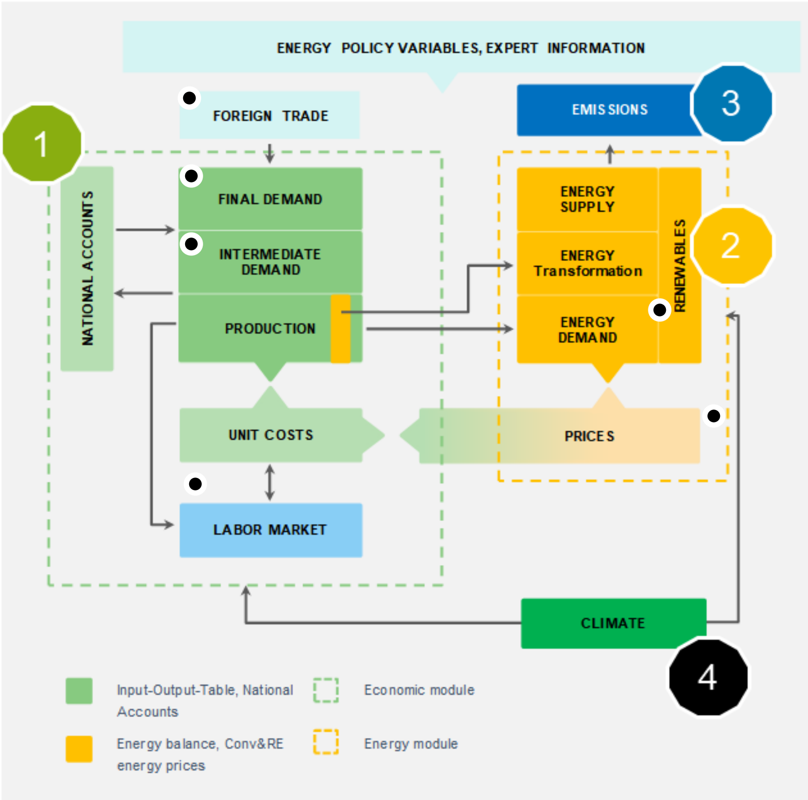

Figure 1. Simplified structure of the model E3.kz.

Figure 1 briefly shows the interrelations of all three model parts. All modelling parts are linked which has the advantage of calculating impacts simultaneously for the 3E's. Each module is based on a rich and up-to-date dataset given as time series which allows for deriving model relationships empirically. However, the data situation for economic impacts of climate change, i. e. extreme weather events, is different. No time series exist so that costs and damages must be derived from single events and serve as a benchmark. Data on costs of adaptation measures stem from cost estimations of selected adaptation projects found in literature. The details of how climate change is illustrated in E3 models is indicated with the black circles and is described in chapter 4.

The core of the **economic** modelling part of the e3.kz model is a dynamic (or macro-econometric) Input-Output (IO) model which is based on the INFORUM approach (Almon 1991, 2014). These models exist in different forms and degrees of complexity (see e. g. Eurostat 2008, pp. 527, Stocker et al. 2011, Lehr et al. 2016, Großmann, Hohmann 2016, Lewney et al. 2019). For example, IO models can be modelled bottom-up or top-down: bottom-up indicates that each industry respectively product group is modelled individually, and macroeconomic variables are calculated through explicit aggregation. Top-down means that first, the final demand components are determined at the macro level and then are disaggregated accordingly, for instance by using the industry or product shares of the respective variable. The model e3.kz is based on the top-down approach.

An IO table depicting the structure of the economy is at the core of each IO model. It shows important growth drivers (e. g. exports, consumer demand, investments) as well as the key industries (e. g. manufacturing industries, service sectors).

E3.kz is demand-side driven and includes supply and price elements to account for supply constraints possibly caused by extreme weather events. First, the components of GDP are determined on the expenditure side. Then, the results are broken down by industries using constant shares for each final demand category (top-down approach). This result in turn serves as input for the Leontief production function to describe the link between demand and supply. For each industry, the IO table shows the cost structure given by demand for intermediate goods and used primary inputs such as compensation for employees, net taxes on production. Prices are derived by using a unit cost approach considering the single cost components. Purchasers' prices are calculated from production prices plus net taxes on goods and determine, in addition to disposable income, the demand of private households.

The economic cycle is completely represented by the national accounts, so that relationships of production, income generation and redistribution to consumption are shown. An important variable in the national accounts is disposable income, which is influenced by both the current labour market situation and the redistributive activities of the government through taxes and subsidies. Disposable income is one important determinant of private consumer demand.

Volume and price reactions in this dynamic IO model are empirically validated, take the passing on of costs into account and thus include the competitive situation on the different product markets and the labour market.

Supplementary data is given by population by age groups, employment and wages by industries. Population at working age determines the work force. Labour demand is determined at industry level based on the most basic assumption that labour productivity remains constant in the future. The macroeconomic wage rate is derived from the Phillips curve approach. Wages per employment at industry level follow the growth rate of the macroeconomic wage rate. Labour income is then calculated from wages per employment and employed persons.

The model contexts shown in Figure 1 are captured both via identities (e. g. in the IO context) and empirically validated behavioural equations. Econometric methods allow for imperfect markets and bounded rationality (Meyer, Ahlert 2016). The specification of the model is not finished with the estimation of single equations, though. For each year, the complete, non-linear, interdependent model equation system is solved iteratively using the Gauss-Seidel algorithm. The iteration process is finished if a given convergence criterion is met. This criterion takes an endogenously calculated model variable, e. g. production, and calculates the deviation between two consecutive iterations. If the difference exceeds a certain threshold, the model performs another iteration. If the model has converged, it proceeds to the next year until the projection horizon is reached (2050 for e3.kz).

Exogenous impulses for the model are, for example, population development and exports which trigger adjustment reactions in the highly interdependent, non-linear model. The modelling approach covers not only quantity effects but also income and price effects and provides further 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 income 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.

The **energy** module describes the relations within the energy sector in greater detail than 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 the energy price development. The energy consumption of private households is particularly based on the living space to be heated and the energy consumption per square meter.

The energy supply is determined by the energy demand of all sectors. Energy is either produced domestically or imported. Primary energy inputs for power generation as well as heat generation are captured.

As with energy system models, the energy module in e3.kz considers different energy sources as well as energy supply, transformation and demand. However, energy system models have a much higher level of detail regarding regional and temporal resolution as well as the represented technological properties. Nevertheless, the modelling approach is sufficient to implement effects of climate change on e. g. hydro power derived from more comprehensive energy system models.

The **environmental** module comprises the energy-related CO_2 emissions. Reductions in the use of fossil fuels caused by deployment of renewable energy or increased energy efficiency can be seen in CO_2 savings. In contrast to the energy module, the environmental module has only reporting characteristics and does not contain feed-back effects into the economic model.

3 A FRAMEWORK FOR DEVELOPING E3 MODELS IN MICROSOFT EXCEL

3.1 FRAMEWORK PROPERTIES

In the last two decades, the application of IO in general and the development of E3 models in particular has increased especially due to the increase in computing power and the general availability of extensive data sets.

Common tasks such as inverting a matrix or solving equation systems which in the past could only be accomplished on expensive workstations or mainframe computers can now be calculated in seconds up to a few minutes by cheap desktop or notebook computers. Model builders can now choose from a wide range of programming languages (e. g. Python) and integrated application frameworks (e. g. GAMS, EViews).

Today’s internet technology greatly simplifies the task of collecting the necessary information to build an E3 model. In the past, the data had to be extracted either from books or later CD-ROMs. A lot of time-consuming, tedious work was necessary to be able to build the database. In recent years, the internet technology greatly simplified the process of data publishing: The number of data sources increased dramatically while the update-cycles became much shorter (e. g. the online version of the Eurostat database (https://ec.europa.eu/eurostat/data/database is updated daily). Furthermore, the number of data formats has been reduced over time which makes data processing less time-consuming. For desktop data processing, most data providers offer either MS Excel, CSV (comma-separated values) or XML (extended mark-up language) files. To be able to use the data in the model, it still must be processed. Most model building tools require data to be arranged in a certain layout (e. g. values in columns). Even more importantly, variable names (and types) must be assigned to the data before it can be accessed in the model.

Even with these powerful technologies at hand, the task of building E3 models is still a challenge. A potential model builder has not only to get acquainted to the underlying theory but must have profound knowledge in information technologies (i. e. data processing, programming, spreadsheet programs). Most of the needed building blocks of an E3 model (i. e. basic algebra, data file format support) are already provided by spreadsheet programs such as MS Excel or OpenOffice Calc.

Due to the increased complexity of E3 models, their implementation usually requires extensive programming tasks. Model builders first must decide on their development environment. They can either build their own development environment by selecting one out of the hundreds of common programming languages (which all have specific strengths and weaknesses) and collecting or implementing programming libraries which carry out specific tasks (e. g. handling of times-series data, matrix algebra). Another option is to get acquainted to a (costly) all-in-one application framework such as GAMS or EViews. With each of these options, model builders will be facing a steep learning curve before they can fully exploit the power of these systems.

Another option to build an E3 model could be the application of MS Excel not only for data preparation but also for implementing a fully-fledged model in the integrated programming language VBA. This approach would offer some important advantages:

1. MS Excel is widely used for data processing and evaluation. Thus, most potential model builders are already familiar with at least the basic functionality.
2. Most computers which are used in a professional environment are equipped with the MS Office program suite and are therefore prepared for model development.
3. A model which is fully built in MS Excel can be easily shared or distributed to other users.
4. There is no need for buying other (expensive) model building tools.

5. By reusing existing knowledge in operating MS Excel, the time needed to build a model is greatly reduced which is important for projects with tight time and/or budget restrictions.

The result of several implementation attempts carried out by the authors is called DIOM-X (a Dynamic Input Output modelling framework in Excel, see Großmann, Hohmann 2019). It provides

- A data set manager to maintain the database variables,
- A template for compiling the historical data,
- A model execution engine to solve the equations system. Modell builders only must provide the core model code (i. e. equations) and a convergence criteria to successfully perform projections.
- A scenario tool to formulate sets of assumptions in order to carry out scenario analysis.

The resulting models perform more than acceptable: The calculation time for one scenario on an average computer is about one minute and proved to be much faster than expected.

One of the biggest advantages is self-containment, though: All data (both historical and projected) and model code (framework and model core) are stored in one single workbook (*.xlsb) and are fully accessible, avoiding the well-known “black box” problem. This architecture allows for extremely simple installation and distribution: The recipient needs nothing more than a computer with MS Excel installed to verify, use, or extend the model.

3.2 MODEL BUILDING STEPS

The DIOM-X framework does not enforce a certain model type: It can be used for simple trend projection of a small set of equations as well as for an elaborated E3 model just as e3.kz.

Different model types share the same basic model development cycle:

1. Database management
2. Regression analysis
3. Model implementation
4. Scenario analysis

(1) Database management: The foundation of every quantitative model is data collected from different sources which needs to be harmonized before it can be processed by the model. This involves i. e. assigning variable names and meta information (e. g. unit) as well as harmonizing the layout of the values (e. g. years in columns). DIOM-X provides the necessary template sheets and data processing routines.

(2) Regression analysis: The availability of historical data is the most important prerequisite for regression analysis which is carried out by econometric models to estimate model

parameters for behavioural equations. Instead of using elasticities from literature, relationships of variables known from e. g. economic theory are econometrically tested against historical data. MS Excel's capabilities are rather limited compared to more specialized software such as EViews. In order to easily share historical data and regression results, DIOM-X will provide import and export routines for the most popular econometric and statistical software packages. An interface to EViews is already available.

(3) Model implementation: The main task of this model building step is to create the model structure by combining the set of equations together. Most equations – both regressions and definitions – are not independent but interrelated. Left-hand-side variables of one equation occur as right-hand-side variables in other equations. One of the biggest problems in this stage is that at the beginning many variables that occur as right-hand-side variables in some equation have not already been specified. Thus, a lot of mathematical problems occur, e. g. division by zero, mainly due to missing data. The minimize such problems, the DIOM-X framework keeps the values of variables constant in the future unless a specification is given. The framework also can protect historical data from being overwritten accidently. The integrated debugging tools of the VBA programming environment further help to track down problems thru runtime-inspection and step-by-step execution.

(4) Scenario analysis: DIOM-X provides a simple to use mechanism for performing scenario analysis. Model users can specify sets of quantified assumptions which will be automatically injected into the model at runtime. The assumptions can vary with respect to time frames, values and type (e. g. growth rate or value overwrite). Once the scenario calculation is finished, the framework automatically copies the full data set (both historic and projected) to a new worksheet for further inspection.

The more complex the model, the more unlikely it is that these steps can be performed in strict sequence. With most models, these steps are carried out iteratively for various reasons – mostly, because missing information or errors are detected in a certain step which induces another loop.

DIOM-X actively supports this iterative approach by logically separating the different kinds of information and combining them in one self-contained package (the workbook).

4 INTEGRATING CLIMATE CHANGE AND ADAPTATION MEASURES INTO E3 MODELS

4.1 GENERAL APPROACH

Integrating climate change into economic or E3 models is a challenge. Usually, economists derive future developments from past observations. Unfortunately, climate change is not directly observable in most data sets because it did not cause any economic damages, was not relevant for the economic performance in the past or the damage could not even be detected as impact from climate change due to the fact that repairs of damages often look like positive GDP effects. Furthermore, climate change may lead to disruptive events, some of which have never been seen before. Extreme weather events and gradual changes (e. g.

temperature increase) impact production processes, affect infrastructure and shift costs which need to be considered in the future.

Another important aspect is that economic and climate models are operating on different temporal and spatial scales. While climate models have usually a high spatial resolution and long-term horizons, economic models are focusing more on the national economy and short- to mid-term projections.

Therefore, the favored approach is not to have an integrated modelling approach which tries to combine climate models and economic / E3 models. Instead, scenario analysis is applied which is based on a four-step approach.

First, a scenario with climate change but without adaptation is created which may be based on conventional climate scenarios and supplemented by frequency, type and extent of extreme events and gradual changes. Extreme weather events and trends in temperature and precipitation patterns observed in the past can give a first indication of future key climate impacts in the respective country. Future occurrence as well as their frequency and intensity are given by climate models such as CORDEX (cordex.org).

Second, the climate change variables must be translated into model parameters. The impact chain concept (Fritzsche et al. 2014) is used to identify relevant interfaces and effect chains. Starting point is the biophysical effect of the extreme weather event (e. g. flooding). The economic sector that is impacted needs to be identified (e. g. transportation) as well as its damages and losses. The translation of physical into monetary variables is based on information taken from literature and e. g. data from insurances and costs for repairing the damages.

Third, adaptation instruments and measures are identified and compiled into a scenario combining both climate change and adaptation. Costs and benefits respectively loss reduction of adaptation measures must be translated into monetary values. In the fourth step, both scenarios are calculated with the E3 model to evaluate and compare resulting effects for the model variables.

4.2 MODELLING CLIMATE CHANGE IN KAZAHSTAN

For the model to consider the future impacts of climate change, climate projections need to be linked to economic damages and losses which have been observed in the past. In other words: Physical terms need to be translated into monetary terms to calculate the economic effects. This information will then be fed into the model e3.kz as part of the scenario analysis. As a result, the model calculates the impacts of such climate change assumptions on each E (energy, economy, environment). As results are calculated very quickly, the model can be used to calculate and compare a wide range of varying climate change scenarios. One example is the occurrence of extreme weather events: These can be varied in intensity, frequency and type (e. g. flooding, drought) even with different combinations. As a result, the bandwidth of impacts induced by climate change can be better understood to take appropriate measures. Economic variables being possibly affected by climate change are shown as black dots in Figure 1.

According to the Ministry of Energy of the Republic of Kazakhstan et al. (2017), to date changes in climate reflect an average annual temperature increase of 0.28°C every ten years. The trend is statistically significant and positive in all regions and seasons but to different extents. In contrast to the air temperature, precipitation presents a heterogenous picture: in some areas, there is a slight increase and in others a decrease. A significant increasing trend is observed in winter and a decreasing trend in other seasons. On national and seasonal average, a weak and insignificant trend of precipitation decrease by 0.2 mm in ten years is observed.

In the past, Kazakhstan was also facing extreme weather events, i. e. heavy rainfall, strong wind, heavy snow and strong blizzards. Since 1990, an increasing trend of extreme weather events could be observed. Furthermore, the number of days with temperatures above 35°C increased from one to five days every ten years. Also, heatwave duration is increasing by one to three days per decade. At the same time, ice days frequency trend is decreasing by five to six days every decade.

Future climate projections expect a further rise in temperature whereas the increase depends on the representative concentration pathways. In case of moderate/intermediate stabilization of radiative forcing (RCP4.5) by 2050 average annual temperature projection will be 2.4°C higher compared to the base period 1980-1999 and 3.1°C for the high emissions pathway (RCP8.5). Precipitation projections expect an insignificant increase in annual precipitation until 2050. As in the past, the developments differ for the regions and seasons. It is also be expected that extreme weather events will occur even more frequently and more intensively.

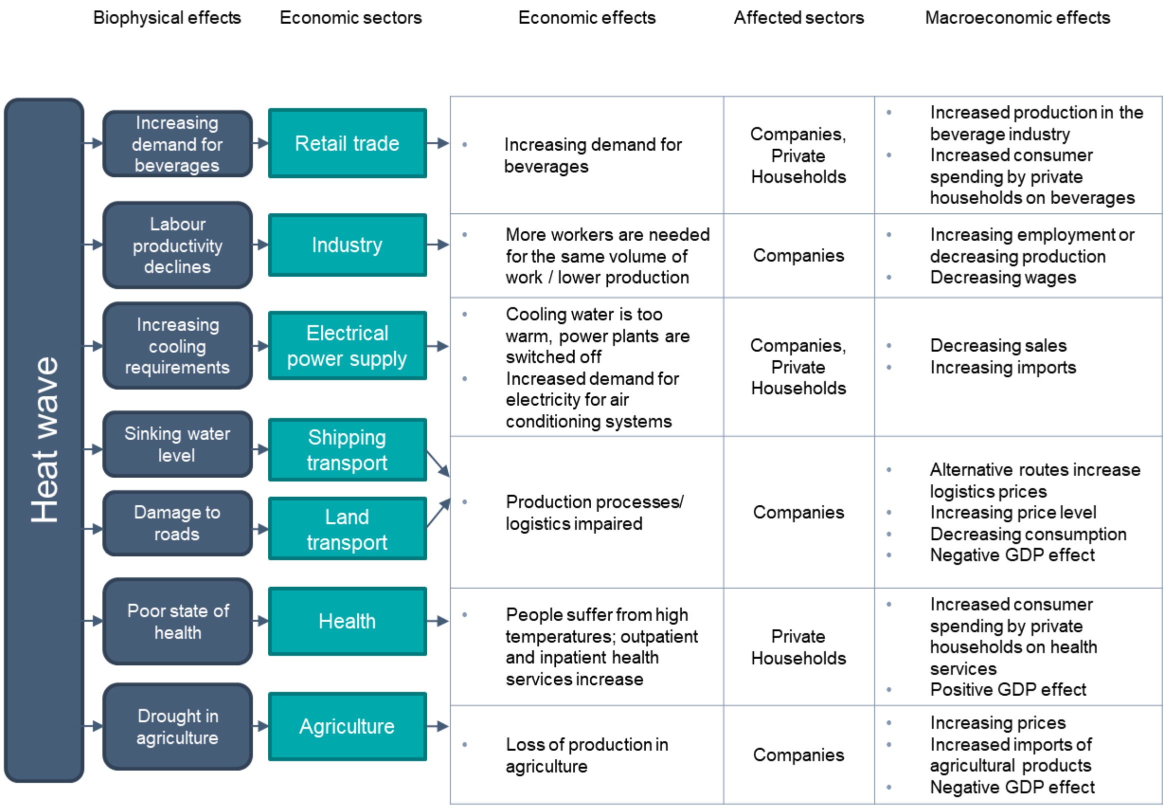

Figure 2. Translation from climate change (here the example of heat waves) into economic model parameters, Flaute et al. 2019.

According to literature, the most vulnerable economic sectors with respect to the identified key climate impacts are agriculture and forestry, water, energy and transport. For past climate events, data on damage is available physically and in monetary terms but usually not for individual economic sectors (e. g. Ministry of Energy of the Republic of Kazakhstan et al. 2017, OECD 2019, World Bank 2016). In the further course of the project, a data set will be created to compile the information for all relevant climate events. This information then serves as a link to the economic model.

Figure 2 shows the translation from climate change (here the example of heat waves) into economic model parameters using the concept of impact chains. Different sectors will be impacted, amongst others the agricultural sector which might be facing a loss of production. The shortage in turn may lead to price increases and possibly the loss needs to be compensated by imports. Also, the transport sector could be affected due to a sinking water level which impairs transport or alternative routes can be taken. Due to increases in travel time and longer routes, logistic prices might increase. Both examples will impact GDP negatively. In contrast, an increasing demand for beverages will positively affect economic growth.

5 FUTURE WORK

Modelling the impacts of climate change on the E's (energy, economy, environment) is already a challenging task. A model is only a sustainable tool if it can be used and adopted by other experts than the initial model builders. This project will not only give insight into the effects of climate change e. g. in Kazakhstan but will be helpful to generate best practices and to improve the model building framework in order to adopt the solution to other countries which will reduce development time considerably.

In the coming months, the implementing partners in each pilot country will be trained in economic modelling and the integration of climate change. The trainings will be adopted to country-specific needs and capacities.

The models will be furthermore used to analyze adaptation strategies and measures. For this, the economic models need to be implemented first and the integration of climate change into the models needs to be finalized. Again, costs and benefits respectively loss reduction of adaptation measures must be translated into monetary values.

As a result, questions such as "How can we adapt? What are costs for single adaptation measures and by how much will the damages be reduced?" become tangible and necessary upfront investments of adaptation measures become more predictable. Modeling results will be available in late 2020 due to ongoing development.

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6 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, 1-7.

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

Barker, T., Lutz, C., Meyer, B., Pollitt, H., Speck, S., 2011. Modelling an ETR for Europe. In: Ekins, P., Speck, S. (Eds.), Environmental Tax Reform (ETR): A Policy for Green Growth, Oxford University Press.

Dagoumas, A., Barker, T., 2010. “Pathways to a Low-Carbon Economy for the UK with the Macro-

Econometric E3MG Model”, Energy Policy, 38 (6), 3067-3077.

Eurostat, 2008. Eurostat manual of Supply, Use and Input-Output Tables. Luxembourg. https://ec.europa.eu/eurostat/documents/3859598/5902113/KS-RA-07-013-EN.PDF/b0b3d71e-3930-4442-94be-70b36cea9b39 (last accessed 15.06.20)

Flaute, M., Lehr, U., Ahmann, L., 2019. Economic modelling and adaptation policies – challenges and results for Germany. Proceedings of the EcoMod 2019. Forthcoming.

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. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, Bonn.

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

Hallegatte, S., Ranger, N., Mestre, O., Dumas, P., Corfee-Morlot, J., Herweijer, C., Wood, R. M., 2011. Assessing climate change impacts, sea level rise and storm surge risk in port cities: a case study on Copenhagen. In Climate Change 104 (1), 113-137.

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 15.06.20)

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. (eds): Climate Change, Adaptation, Resilience and Hazards, 125-141, Springer.

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 15.06.20)

Lehr, U.; Flaute, M.; Ahmann, L.; Nieters, A.; Wolff, C.; Hirschfeld, J.; Welling, M.; Gall, A.; Kersting, J.; Mahlbacher, M.; von Möllendorff, C., forthcoming. 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 XX/20XX, Dessau-Roßlau.

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., Lindenberger, D., Schlesinger, M., Großmann, A., Lehr, U., Knaut, A., Malischek, R., Paulus, S., Tode, C., Wagner, J., Kemmler, A., Ley, A., Piégsa, A., Straßburg, S., Koziel, S., 2014.

Gesamtwirtschaftliche Effekte der Energiewende. (Cited as GWS et al. 2014) Study commissioned for the Federal Ministry for Economic Affairs and Energy, Osnabrück, Köln, Basel.

Meyer, B., Ahlert, G., 2016. Imperfect Markets and the Properties of Macro-Economic-Environmental

Models as Tools for Policy Evaluation. GWS Discussion Paper 2016/9, Osnabrück.

Ministry of Energy of the Republic of Kazakhstan, UNDP, Global Environment Facility, 2017. 7th National Communication and 3rd biennal report of the Republic of Kazakhstan to the UNFCCCC. Astana.

OECD, 2019. Risk Governance Scan of Kazakhstan. https://read.oecd-ilibrary.org/governance/risk-governance-scan-of-kazakhstan_cb82cae9-en#page4 (last accessed 15.06.20)

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.

Patt, A.G., van Vuuren, D.P., Berkhout, F., Aaheim, A., Hof, A.F., Isaac, M., Mechler, R., 2010. Adaptation in integrated assessment modelling: where do we stand? In

Climatic Change 99 (3), 383-402.

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

World Bank, 2016. Kazakhstan – Agricultural sector risk assessment.