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Global Warming Induced Water-Cycle Changes and Industrial Production – A Scenario Analysis for the Upper Danube River Basin

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Abstract

Using the environmental decision support system DANUBIA, we analyze the effects of climate change on industry and compare the effectiveness of different adaptation strategies. The observed area covers Germany and Austria up to 2025. Since the main effects of climate change in this region are expected to be caused through changes in the water-cycle, we place a special focus on the exemplary region of the upper Danube catchment area. Industry is the main regional user of water resources. Water is an essential production factor and is used in almost every production process of a manufactured good. We apply estimates of regional production functions, based on AFiD-panel micro-data for Germany, to calibrate regional industrial production and water usage within DANUBIA. Thus, we are able to simulate region-specific effects of climate change and the impact of social scenarios using an unprecedented model of reciprocal influences of a huge network of interdisciplinary research areas. Simulation results show wide regional differences in production site reactions as well as between differing scenarios. Comparing scenarios of moderate and serious climate change, we are able to illustrate the severe environmental effects in some regions and to determine considerable economic effects on regional economic growth.

JEL Code: D24, R30, Q01, Q25, Q52, Q53.
Keywords: Environmental decision support system, climate change, water-cycle, river basin management.

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1 Introduction

Is the behaviour of human society sustainable? Posing this question inevitably relates to the urgent problems of climate change. Climate change affects all three pillars of sustainability: ecological, social and economic stability. It does so in many ways of which the water-cycle is the most crucial. Besides being exceptionally sensitive to climate change, water is the one scarce good that is without comparison in its necessity for the functioning of nature and society. Less than 3% of the earth's water is fresh-water, of which only ⅓ is accessible for human needs at justifiable costs. Climate change will dramatically worsen this situation and as a consequence the natural and artificial water-cycles have been gaining increasing attention. One of the ten Millennium Development Goals agreed on by the United Nations and world leaders is to cut in half the proportion of people without sustainable access to safe drinking water by 2015. To this aim, in December 2003 the United Nations General Assembly proclaimed the International Decade for Action "Water for Life 2005–2015" (United Nations, 2004). In this article we analyze the social, economic and environmental effects of climate change with respect to sustainable access and use of water by applying the environmental decision support system DANUBIA (EDSS DANUBIA) which is part of the GLOWA-Danube project. Siegfried Demuth states in the GLOWA report of the UNESCO International Hydrological Programme and the WMO Hydrological and Water Resources Programme: *"Water management affects our environment, society and culture. Finding solutions to mitigate impacts and adopt to different geographical conditions and climate regions requires an approach that unites sound and unbiased science with social and policy considerations". (IHP HWRP Report on the GLOWA project 2008: 5).*

In the following analysis we highlight a small portion of the results of DANUBIA. These can help potential stakeholders gain an idea of the capability of the applied web-based environmental decision support system. We investigate the effects of global warming on medium-sized mountainous watersheds as well as on developed societies under temperate climate conditions. By deeply modelling the

Upper Danube catchment within a simulation region covering Germany and Austria we aim on answering the following questions:

- Climate change is one of the main global issues for sustainable development, but is it also an issue for German and Austrian regions?
- What are the regional causes for water scarcity: climate or society?
- How can society compensate for climate change and how can differing policy scenarios be evaluated with respect to sustainability?
- What are the small-scale effects and regional differences? E.g. how do cities perform versus rural areas?
- What are the effects of climate change on economic development given the close interconnection of climate change and the water-cycles?

1.1 Environmental decision support systems focused on climate change and the water-cycle

DANUBIA was the first decision support system of its kind which features a dynamic, simultaneously interconnected simulation model network. Furthermore, the underlying Deep-Actor Framework (see section 1.3) allows an analysis of completely new research issues by applying standardized interfaces to systematically connect scientific models of natural, environmental and socio-economic fields of research. There are also an increasing number of similar projects which will be briefly introduced in this section:

LANDSCAPE LOGIC (LL) is an environmental decision support system that is currently being developed in Australia. It consists of a research hub with 6 regional organisations, 5 research institutions and is supported by several state agencies in Tasmania and Victoria.[1] It focuses on two current gaps of knowledge. It seeks, firstly, to improve the inadequate understanding of how to organize knowledge and assumptions about dynamic interactions between activities in land management and environmental outcomes. Secondly, LL aims to expand this understanding through studying the historical development of water quality and native vegetation conditions.

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[1] For further details see http://www.landscapelogic.org.au/ .

MODSIM is an EDSS that was developed at Colorado State University. Its aim was to create a generic river basin management decision support system and it is based on a system of simulations of river network flows and reservoir operations (Assaf et al., 2008). It has been linked with stream-aquifer models for the analysis of the combined use of groundwater and surface water resources. To control the effectiveness of pollution control strategies, MODSIM has also been used in water quality simulation models. An important feature of MODSIM is that it provides an interface to standard geographic information systems (Labadie, 2005).

The web-based decision support system BodenseeOnline (BO) has been developed for the Lake Constance to support decision-makers in issues such as water protection and hazardous incidents. Since BO has a strong focus on monitoring the current environmental conditions, it uses measurement stations to deliver current data about wind, water quality, temperature profiles and other important parameters. All this information is processed in a nexus of physical, biological and chemical models. Finally the model output is visualized and published for the stakeholders via the internet (Lang et al., 2010).

GLOWA-Elbe is another GLOWA project that is very similar to DANUBIA but focuses on the Elbe catchment area. With the aid of the EDSS Elbe-Expert-Toolbox it is possible to analyze and describe scenarios about future changes in water quality and quantity and to assess the consequences of climate change as well as potential adaptation strategies. Contrary to DANUBIA this toolbox only allows limited feedback between the model components during the simulation process.[2]

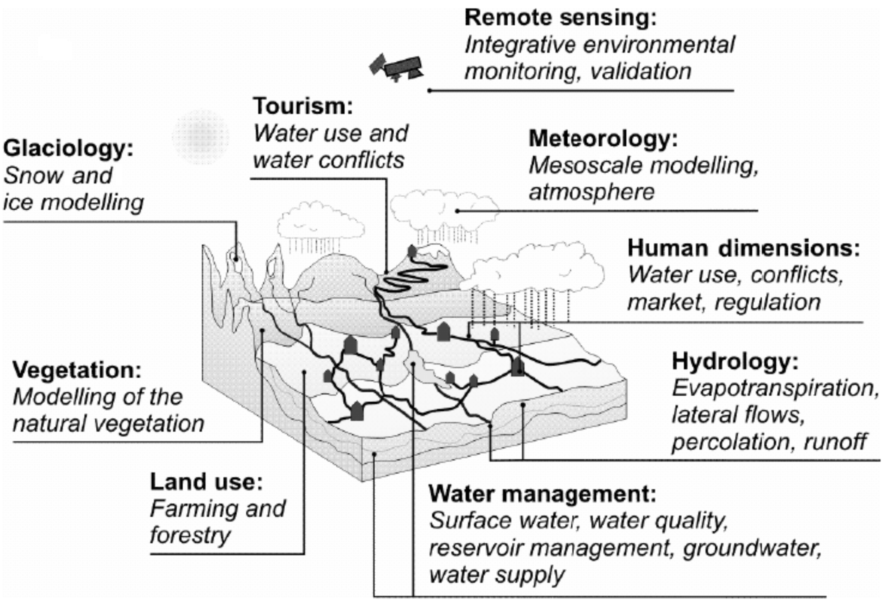
A survey on further water-cycle and climate change related EDSSs can be found in Assaf et al. (2008), but none of the reviewed projects is comparable in depth and scale to DANUBIA.

[2] For further details see http://www.glowa-elbe.de/ .

1.2 GLOWA & DANUBIA – behind the scenes

The GLOWA-project originated from an initiative of the German Federal Ministry of Education and Research. Its goal is to study the effects of global change on the water-cycle and to develop an environmental decision support system for the sustainable management of water resources. In this paper we can only present a small selection of results. Most of the background, theoretical foundations, model mechanics and the model calibration have been discussed in detail in corresponding publications. At present there are more than 700 publications directly related to the GLOWA project, the majority in academic journals. More than 300 of these publications are connected to the EDSS DANUBIA on which this paper is based. There is a separate online search engine available that enables searches within the GLOWA publications for works relevant to the topics and foundations of this paper.[3]

Figure 1: Interactions inside DANUBIA



Source: GLOWA Danube

[3] The online search engine for GLOWA publications is available under: http://www.glowa.org/eng/literaturliste_eng/literaturliste_eng_suchen.php .

1.3 DANUBIA

DANUBIA uses regional climate models to project climate change. Physical and physiological components describe the natural processes (hydrology, hydrogeology, plant physiology, and glaciology). For socio-economic simulations DANUBIA makes use of actor models[4] (farming, economy, water supply, households, and tourism) to model decisions based on the social structure, the respective general conditions, and individual interests. It enables in particular the simulation of different climate change scenarios and socio-economic scenarios in conjunction with diverse social and political action and reaction patterns.[5] The objective of this work is a well-founded simulation of the industrial production under climate change conditions and the development and evaluation of climatic and social scenarios of interest with a special focus on the water-cycle. Figure 1 shows a schematic representation of how a real environment is covered by the different sub-models within the simulated environment in DANUBIA. A more detailed description of the different sub-models and of their interaction can be found in the appendix.

1.4 DANUBIA base data and model calibration

For the calibration of the industrial model within DANUBIA we use micro data provided by the "Forschungsdatenzentren der Statistischen Ämter des Bundes und der Länder" (Data Research Centres of the Federal and Land Statistical Offices) and estimates of regional production functions which are as well based on these micro data. These data are available for research purposes via the AFiD-Panel which can be extended by several modules, e.g. covering environmental statistics. The data contains the economic as well as the environmental characteristics of the companies on the level of the individual firm, of which the industrial water usage

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[4] An actor model simultaneously simulates the actions and activities of many independent actors who are able to interact with and perceive each other and their environment. Given their perception of the environment, the actors decide to execute a specific set of actions out of the possible set of actions. This decision will typically maximize the subjective utility of the actor.

[5] The theoretical foundations for the EDSS-DANUBIA as well as the simulation model itself were developed and implemented within the GLOWA Danube project (www.glowa-danube.de) between 2001 and 2010. All components of DANUBIA can run contemporaneously on a cost-effective LINUX-Cluster.

is of special interest for our analysis.[6] We examine the statistics for the years 1998, 2001 and 2004. To generate plausible, small-scale simulation results in DANUBIA, it is indispensable that data is available in a similar spatial resolution. Due to data privacy protection, it is not possible to calibrate the model on the scale of one square kilometre. Therefore, we estimated representative production technologies on the scale of the NUTS 3 regions. Since the representative production sites are simulated on the scale of one square kilometre and also the conditions and characteristics that are exchanged with other sub-models vary on the scale of one square kilometre, we observe large differences in the behaviour of producers within the same region.[7] For the simulation results shown in this paper we employ the most restrictive specification estimated in Jeßberger and Zimmer (2010), which represents a Cobb-Douglas technology.[8] We explicitly model the industrial production and water usage, while we use the output of the existing DANUBIA sub-models as input to our model and vice-versa. Thus, we are able to include the interactions and feedback mechanisms of industrial producers and, for example, social conditions like the labour market and migration or natural conditions like aquifers or river networks. While DANUBIA in general aims at assessing a broad portfolio of problems it was especially tailored around climate change issues. In addition to similar environmental decision support systems, it also accounts for the interaction of the different natural and man-made water-cycles and the atmospheric conditions. The water-cycle plays a major role in climate change, especially if the effects are analyzed on a small-scale.

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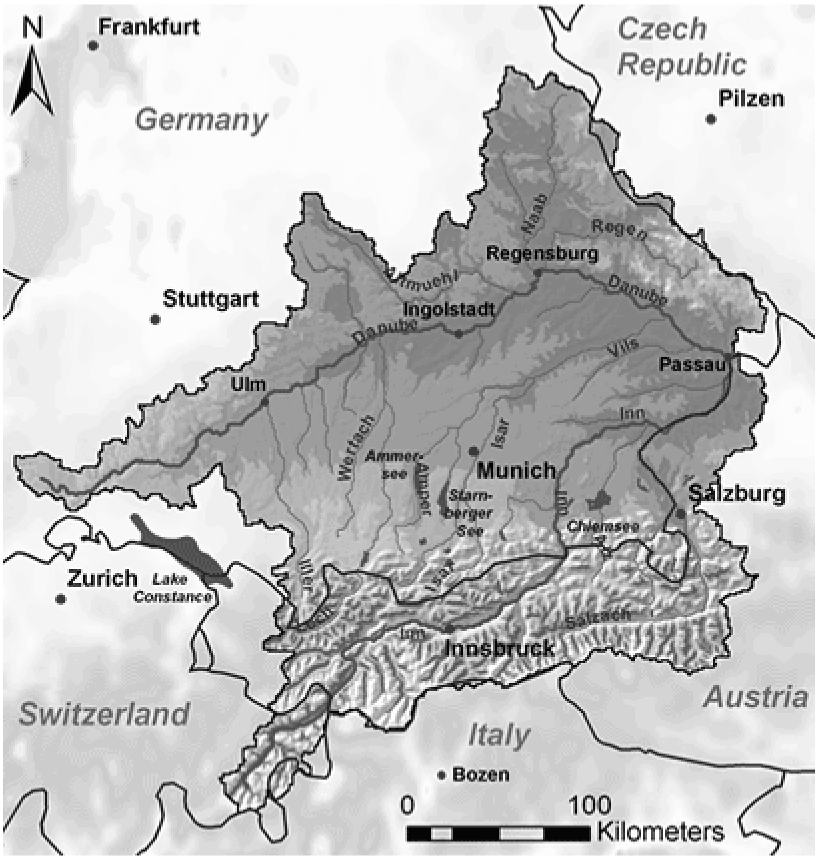
[6] This triennial statistic includes all industrial production sites and mining sites that have an annual water demand of at least 10,000 m^3. Therefore it should be noted that the conclusions made here are only valid for the examined sub-group.

[7] The full set of characteristics and conditions is only available within the Upper-Danube Catchment of the simulation area since that is the only area that is common to all sub-models. For the remaining areas our model employs average characteristics.

[8] The regional differences are captured by region dummies. For the Austrian regions of the simulation area we use also data from Statistik Austria but since we didn't have access to comparable Austrian micro-data we base our production technologies of the Austrian representative regional industrial producers on estimates of similar Bavarian entities. Thus we impose that Austrian producers can be approximated by Bavarian producers with similar characteristics.

Figure 2: The Upper Danube River Basin.



Source: GLOWA-Danube

Figure 2 shows the investigated Upper Danube River Basin which is the focus of the water-cycle effects in this analysis.[9] Within this core region the feedback mechanisms of human activities with the natural environment are modelled and calibrated on the micro scale.[10] The entities on which this paper focuses are the

[9] In the philosophy of EDSSs it is common to observe a natural resource within its natural boundaries rather than its administrative borders, examining in particular natural phenomena occur. Especially when observing the water cycle, it is obvious that the watersheds delimit the dispersion of pollution at least for surface waters. Computer-based EDSSs like DANUBIA take this into account and typically generate their results to be consistent with the natural borders.

[10] In model terms this means on the area of one square kilometre. The remaining regions of the simulation area of this analysis – which covers the remaining parts of Germany and Austria – are mostly based on averages of micro-effects of the core region. Even though the simulations in the remaining regions of the observed area also operate on the area of one square kilometre, the results are much less regionally differentiated for these regions. This further highlights the necessity of small-scale data availability (e.g. the AFiD micro data).

industrial producers. These, together with agriculture and tourism, are expected to be most exposed to climate change.

1.5 Modelling industrial water use

Water is an essential production factor and is used in almost every production process of a manufactured good. The electricity generation, the mining industry and the industries that produce paper products, chemicals and metals require especially large quantities of water. Water is used for cleaning, diluting, transporting products, cooling, heating, generating steam, sanitation and, of course, as a constituent in the final product. In Germany 5.1 billion cubic meters of water were extracted by the public water supply in 2007. Of this only 0.9 billion cubic meters of water were supplied to the industrial sector. This has to be seen in relation to the 27.1 billion cubic meters of water that industry extracts on its own. In the observed area agriculture plays only a very minor role in the water usage, in contrast to regions that are less developed or situated in a warmer climate zone. Agricultural production, forestry and the fishery sector only used a comparably small total amount of 0.2 billion cubic meters of water in 2007 (Federal Statistical Office Germany, 2006). For the self-supplied industrial users in Germany, water is easily available and cheap to extract. Even considering possible discharge costs, water is still a relatively cheap factor of production. Nevertheless, the extraction of water is restricted by contingents. These include the sophisticated extraction permits that are enforced by local environmental authorities. Water is often circulated within the production process or used multiple times in consecutive processes. While multiple employment might follow from economic considerations, cycle use is a reaction to regulatory constraints (Egerer/Zimmer 2006a; Egerer 2005). In industrial production processes, water is typically not consumed in the traditional sense. Instead, it is used for production purposes and afterwards returned to the water-cycle. The equivalent to "consumption" is the reduction of the usable amount of the resource for other natural or artificial utilisations. This might for example result from the reduction of the water quality below a critical threshold. Factors that are closer to the traditional interpretation of consumption, for example, if the water resources are evaporated in a cooling process, might also result in an upstream/downstream riparian conflict.

In the simulation model, the industry sub-model mimics the decisions of the relevant industrial production sites from an economist's perspective. The decision process is focused on the questions of the optimal production output and on how to produce this output with minimal costs given the technical, regulative and resource constraints. In accord with the dominant research question in this work, we spotlight the use of water resources in the production process. We assume that a representative firm behaves rationally given that its information is limited by its perceptive abilities and its imperfect expectations.[11] This means, for example, that rather than incorporating the signal about the sustainability of water-usage directly into the decision process, it is used to determine the amount of regulation imposed on the production site by the local environmental agencies.[12] These also have the means to regulate water usage by extraction or effluent charges or by limiting the amount of water extraction.

1.6 Inside the industrial producer

Depending on the available resources, it is plausible to imagine different approaches for modelling the industrial producer. Typically, the final

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[11] The conditions influencing the firm's decisions can be categorized into three groups: Factors which the firm perceives as exogenous and thus as not influenceable by its actions, factors that it perceives as being influenced by its decisions, and factors which it can directly determine by choice. In our modelling approach examples for exogenous factors are the technological progress and the condition of the water resources. Among the factors the industrial agent perceives as influenceable are the water-related expenditures (including eventual charges). These are indirectly determined by factors of his direct choice, namely his investments in technologies that reduce the pollution discharge or increase the utilisation factor of the water in the production process. Other important factors of direct choice are the labour employed and the production output.

[12] This approach has been identified as preferential since the industrial producers themselves cannot observe the sustainability of their resource usage. While counterintuitive at first glance, this is the consequence of simple information asymmetry. It is indeed true that in reality the production site cannot observe the consequences of its water consumption and that the monitoring of the environmental effects is done by the local environmental authorities. This might not be the case for regions that are less restrictive than Germany and Austria concerning the regulation of environmental pollution. In the observed area production facilities are typically restricted before the environmental effects are obvious to the producer.

implementation is based on anecdotal evidence, theoretical considerations or econometric estimates. To construct a representative industrial producer we explored all three of these options. In the theoretical approach, the production function of the firm is modelled and the derived optimal factor demands are used in the simulation. To simulate the production process it is helpful to gather as much information about it as possible. To achieve this we conducted a questionnaire campaign, did field and telephone interviews and visited actual production sites.[13] The final step was to examine the available data and to draw conclusions on the production technology.

As a result we designed the industrial production sites as profit-maximizing entities in a competitive market environment. It was an essential requirement in the model construction to consider the effects of climate change and conservation of the environment. As discussed earlier it is reasonable to model the resulting consequences for the firm as regulatory constraints. Due to the integrative nature of DANUBIA these characteristics influence the macroeconomic and discipline-specific models, which will in turn create a feedback on the industrial producer. Model results are calculated on the scale of a single representative industrial production site on each industrialized square kilometre within the observed area.[14] The characteristics of the representative production site are determined by the local natural environment, the economic conditions and by the econometric estimates of the production technology. Companies minimize the production costs for a given production output. With p_n being the price vector of the production factors employed, the total expenditures E_n of a production site aggregates the costs for the variable production factors X_n.

$$\min E_n = p_n' X_n \quad s.t. \quad Y_n = f\left[X_n, T\right]$$

[13] This participatory process involving the industrial water users was described in depth in Egerer and Zimmer (2006b).

[14] For the area of Germany and Austria this corresponds to a total of 16,800 representative agents as identified by analyzing the remote sensing data.

The output Y_n of the industrial facility is a function of the vectors of the production factors employed and of the technology used at time T. This black-box, converting multiple inputs in the production output, mirrors the technical production process in a production site. For the simulations featured in this paper we employ estimates of regional Cobb-Douglas production technologies.[15] Details on the estimation procedure and results can be found in Jeßberger and Zimmer (2010).[16]

2 Economic and social scenarios in the context of climate change

Scenario Analysis is a wide field that has been intensively analyzed in many works of different disciplines. A good overview on the theory, guidelines and literature can be found in Alcamo et al. (2008). This book discusses in depth the generation of scenarios for EDSS and also provides many useful examples. The scenarios presented in the following sections have been designed in accordance with the requirements of such a scientifically founded scenario generation process.

[15] Such estimates are based on the known data of factor usage, factor prices and output. A wide range of possible production technologies can be used for estimation. A very good overview of the currently used approaches can be found in Chung (1994). In this work we focus on the Translog production framework. This functional form is especially appealing since it covers many commonly used production functions as special case, including the Cobb-Douglas specification used in the simulations in this paper. A further reason is that the properties of this function are well known and especially the price and the cross-price elasticities – in which we are ultimately interested in for the simulation – are easy to derive from the estimated coefficients. The production technology is assumed to be homothetic and separable from unobserved production factors. Since we have to up- or downscale the technology in various steps of the later simulation it seems sensible to assume constant returns to scale. Further discussion about the theoretical formulation of industrial water usage can be found in Renzetti and Elgar (2002), Gispert (2004) and Dupont and Renzetti (2001).

[16] They use the estimation of the primary form of the production function in order to determine the shadow value of industrial water use, the price elasticities of the production factors and the region-specific dummies which characterize the local production technologies on the scale of the NUTS 3 regions (The NUTS 3 district classification of the European Union is in size equal to a German *Stadtkreis* or *Landkreis*). A comprehensive description of the estimation procedure can be found in Kim (1992) as well as in Eckey et al. (2005) who also describe the calculation procedure for the elasticities of Translog production-functions in detail. Further works focus on assessing the value of water for industrial production include Reynaud (2003), Griffin (2006), Dachraoui and Harcharoui (2004) and Dupont and Renzetti (2003).

Air temperature in Central Europe has already increased by up to 1.5 °C compared to the pre-industrial era, and up to 2025 another temperature rise of 1–1.5°C is expected (IPCC, 2007). In terms of DANUBIA this means that droughts will become more common in the summer and water levels will fall strongly. What consequences this implies for the society, in particular for the industry, is this paper's focus. Regarding the socio-economic perspective, this paper focuses on the comparison of two opposing socio scenarios: A *performance* scenario representing globalization and a society focused on economic growth and a *common public interest* scenario with growing environmentalism in the society. These two scenarios span a plausible corridor of adaptation strategies that can be compared with a *baseline* scenario, which could also been seen as the business-as-usual scenario. Interactions and feedback mechanisms of industrial producers are matched with the storyline of these scenarios. The following sections describe these settings.

2.1 The economy in the baseline scenario

Table 1 shows five adjustable scenario parameters that are on their default levels for the *baseline* scenario. The *baseline* scenario serves as a benchmark for the other scenarios. The adjustment parameter "investment costs for re-using water", represents investments in water recycling technologies and technologies for water circulation usage, for example. Costs for water extraction pumps and extraction related tasks are summarized in "costs for extracting water". The parameters "subsidies for environmental protection", "cost of capital", and "labour costs" represent policy parameters. Typical governmental interventions like subsidies or taxes are translated to the model by varying these parameters. However, the "cost of capital" parameter also represents conditions of the global capital market and, thus, is interpreted as a proxy for globalization (Kuhn et al., 2008). The assumptions about the different trends in the parameters for the *performance* scenario and *common public interest* scenario are summarized in Table 1.[17]

[17] Parameter settings for the different scenarios are listed in appendix A.3.

Table 1: List of scenario parameters for the industrial model

Parameter	Parameter declaration	Performance scenario	Common public interest scenario
ChangeCostOfWaterReuse	investment costs for re-using water	constant	decreasing
ChangeCostOfExtraction	costs for extracting water	constant	increasing
ChangeSubsidies	subsidies for environmental protection	constant	increasing
ChangeCostOfCapital	cost of capital	decreasing	decreasing
ChangeWages	labour costs	constant	increasing

Source: GLOWA Danube scenarios, GLOWA Danube project

2.2 The industrial model in the performance scenario

The parameter setting of the performance scenario is based on an optimistic view on the sustainability of the water resources. This is motivated by the fact that in Germany a long-term mean of 188 billion cubic meters of water is available per year, whereas total water usage only adds up to 35.6 billion cubic meters.[18] In other words: because about 81% of the natural water supply is not used, water resource conditions for industrial water usage in Germany seem to be assured today as well as in the future.

Nevertheless, the available water is distributed very heterogeneously over space and time. Therefore local water scarcity – especially in the increasingly hot and dry summers – will become more common. This will result in periods of tighter local water usage regulation when conditions become severe. This scenario assumes stable and continual economic growth, and due to limited regulation under regular conditions it assumes that the costs for extracting water stay moderate. Accordingly low investments in water re-usage technologies are expected. Investment costs for re-using water stay at a high level as only few subsidies for environmental protection are assumed. As a theoretical background we use the development of public drinking water prices as a benchmark for future costs for extracting water.[19] As public water supply operations are cost-covering,

[18] 35.6 billion m³ water are composed of 22.5 billion m³ water for thermal power plants, 7.7 billion m³ water for mining, and 5.4 billion m³ water for the public water supply (cf. Federal Statistical Office Germany, 2006)

[19] An overview on the current development of drinking water prices and sewage charges can be found in appendix A.4.

we assume the costs for industrial water consumption to be similar. Additionally we assume moderate development of labour costs. The only parameter that is adjusted is the "cost of capital", representing the reaction to a further globalizing world with decreasing prices on the global capital markets.

2.3 The industrial model in the common public interest scenario

In this scenario, increasing environmental consciousness in the society affects governmental policy as well as the behaviour of the industrial sector. Subsidies for environmental investments increase. This is expressed in this scenario as a decrease in the cost of capital for environmental investments. To ensure a balanced national budget, these subsidies are partially financed by higher ancillary labour costs. Moreover, statutory requirements of water usage will become stricter and the costs of water usage will increase. For example, an increase of 5 cents per cubic meter is plausible, assuming that the same extraction fee as in Baden-Wuerttemberg (the so called "water cent") will be established in Bavaria.[20] In this scenario the revenues of the water fees are used to subsidize investments in projects that aim at reducing water intensity.

3 Simulation results

The topic of the following section is the impact of climate change as well as the impact of the socio-economic scenarios. In this paper we present the consequences for the gross regional product and the industrial water demand for the period from 2012 to 2025. Results of the socio-economic scenarios – *baseline*, *performance*, and *common public interest* – are based on the baseline climate trend *REMO regional* and the *baseline* climate variant (see Figure 3).

The following simulations include the feedback of the majority of the interdisciplinary sub-models, in particular the models *Demography*, *Economy*, *GroundwaterFlow*, *Ground-waterTransport*, *Household*, *Tourism*, and *Water-Supply*. Exceptions are the models *Atmosphere*, *Farming*, *Landsurface*, *Rivernetwork*, and *Traffic,* which are included as pre-calculated scenarios for the corresponding time horizon. The climate trends are assumed to be exogenous. The

[20] Appendix A.5 lists the regional differences in water fees in Germany.

parameters that influence the industrial model the most are the conditions of the local water resources, water prices (including fees and other regulations), labour market conditions (wages, ancillary labour costs, …), capital market conditions (interest rates, subsidies, …) and the climate. The full set of feedback and spillover effects between all the sub-models is only implemented inside the upper Danube river basin. Since domestic migration of workers (which serves as an input factor for industrial production) does not stop at this geographic border, we use our best guesses for the remaining areas in Germany and Austria. For this purpose we compute in every simulation step the average value of a parameter inside the upper Danube area which we then use as a proxy for missing parameters outside the upper Danube catchment area. For this reason we observe much more fluctuation and regional distinctions inside this core area.

For visual interpretation in a map it is not recommendable to show the results on the micro-scale of the simulated square kilometres. The areas are simply too small and the industrial regions too scattered to allow a sensible interpretation when printed. Therefore we choose to display the NUTS 3 district averages in the following maps. To illustrate the underlying simulation on square kilometres, Figure 4 shows a cut-out with the micro results of the regions surrounding Munich (München).

Figure 3: GLOWA Danube scenario matrix

1st Selection: Climate trend	2nd Selection: Climate variant	3rd Selection: Social scenario	4th Selection: Policy measure
IPCC regional	Baseline	Baseline	Policy measure 1
REMO regional	5 warm winter	Performance	Policy measure 2
MM5 regional	5 hot summer	common public interest	Policy measure …
Foreward projection	5 dry years		
	REMO scaled & bias corrected		
	MM5 scaled & bias corrected		

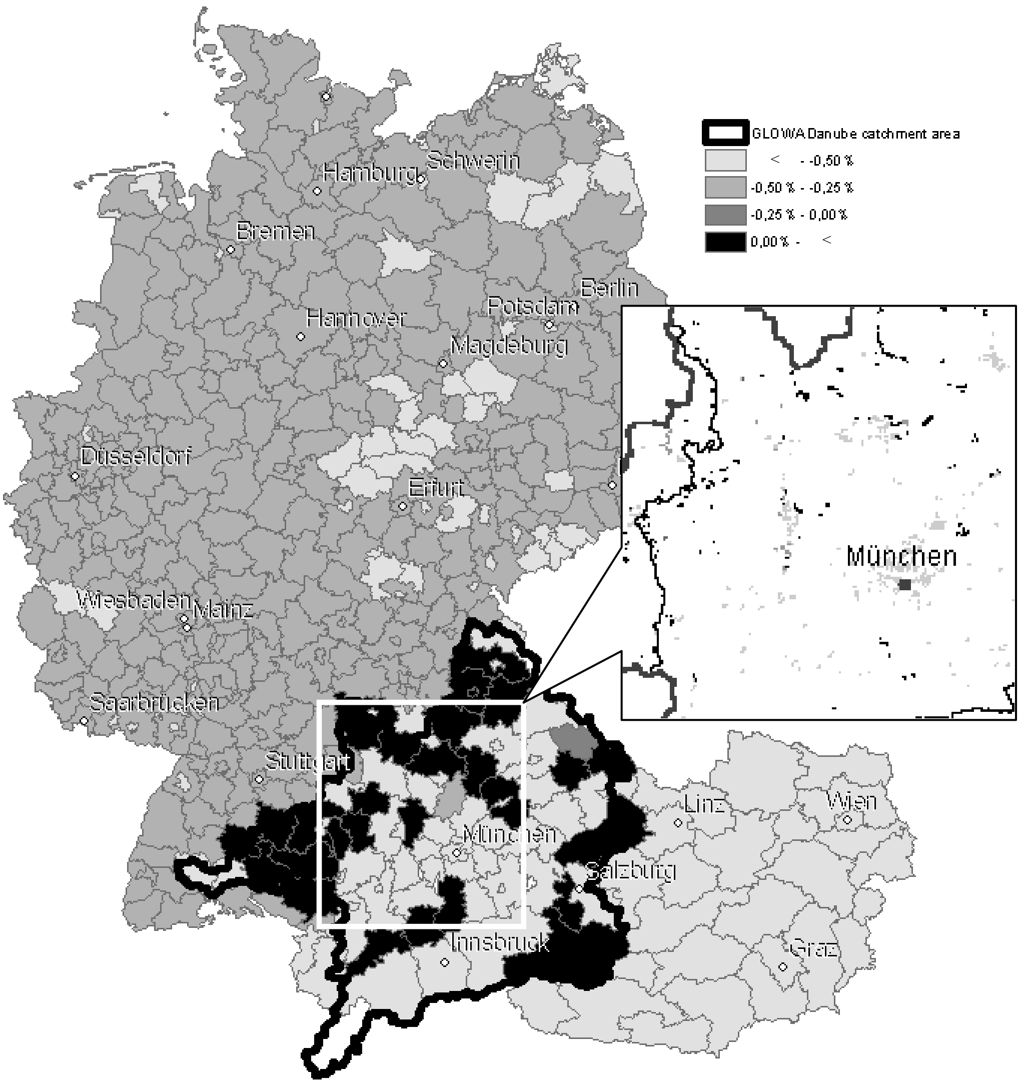
Description of the climate scenarios in Mauser, W. / GLOWA Danube Project (2010).

Source: GLOWA Danube

3.1 Development of the gross regional product

The following results are based on the climate trend *REMO regional*, the climate variant *baseline*, and the *baseline* social scenario. They are compared to a simulation based on an artificial *zero climate change* climate trend, which is defined by simply conserving today's climate and water-cycle conditions.

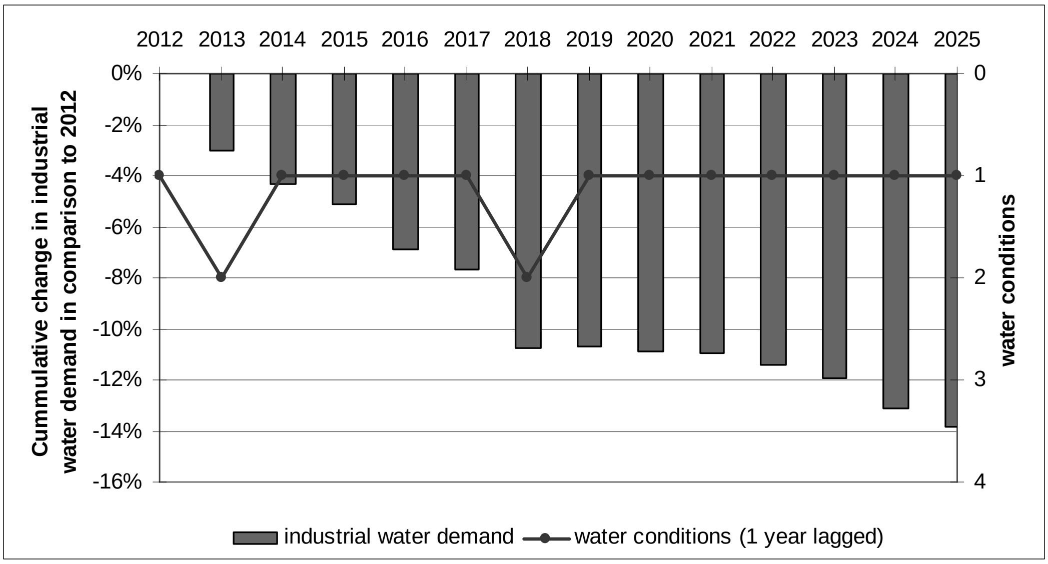
Figure 4: Gross regional product 2012–2025,
zero climate change, *baseline* scenario vs. *REMO regional* climate change, *baseline* scenario
(Values in percent)



Source: Ifo Institute

To assess the consequences of climate change, we use this scenario in order to illustrate the hypothetical case that no further climate change would occur from today onwards. The simulation of this *zero climate change* scenario includes the dynamic interaction between the economic models and the *Demography* model and uses pre-calculated scenarios for the input of all other GLOWA sub-models. Figure 4 displays the relative percentage growth rates of the gross regional product (GRP) between 2012 and 2025 on each representative industrial square kilometre. Thus, negative values indicate less GRP growth in the simulation with the *REMO regional* climate trend. On average we can observe that climate change causes a reduction in the growth of industrial production. However, some producers inside the Upper Danube Catchment profit from global warming. The reason is simple. Since the impacts of climate change on water supply differ regionally, the water conditions can vary substantially between production sites. As a result an industrial producer may have a comparative advantage over a nearby producer who faces worse water conditions.

Figure 5: Change in industrial water demand in comparison to 2012 and 1 year lagged ground water conditions in Weiden/Oberpfalz

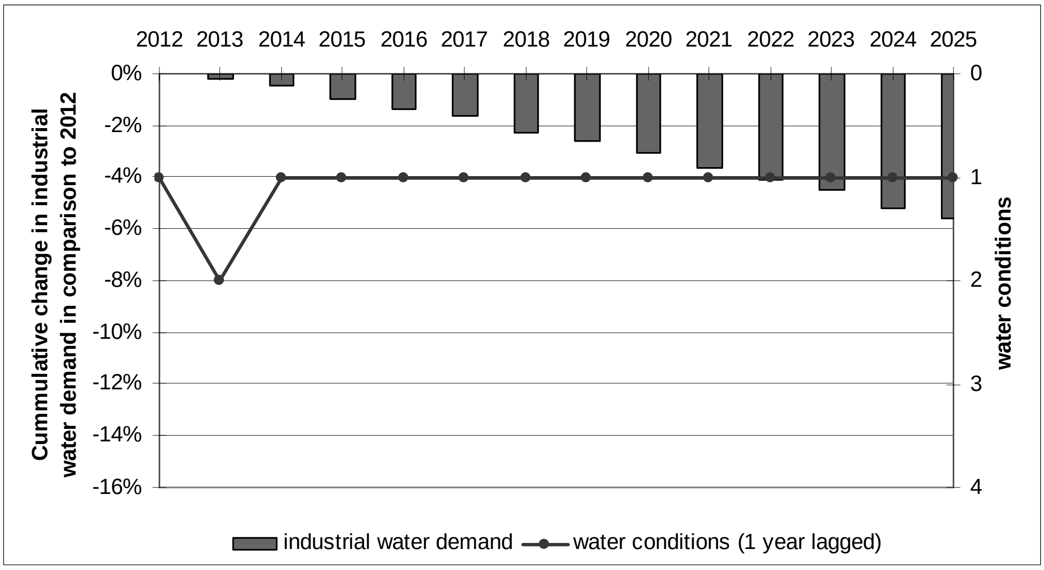


Source: Ifo Institute

3.2 Trends in industrial water demand

To illustrate the responsiveness of our industrial model in conjunction with the regionally diverse climate conditions, we exemplarily discuss two locations inside the Upper Danube Catchment area: Weiden in der Oberpfalz in Germany and Salzburg in Austria. Water conditions are characterized by so-called water flags (Barthel et al., 2008). These flags signal the condition of the source of water supply, with a value of 1 indicating a good condition and a value of 4 indicating extreme water scarcity. Due to worsening conditions in the water quantity that is available for sustainable use in Weiden (located near the northern end of the Upper Danube Catchment area), in particular in the years 2013 and 2018, a clear shift in industrial water usage is apparent in 2018 (see Figure 5). In total, Weiden displays a reduction in industrial water usage of 14% in 2025 relative to the base year 2012. It should be mentioned that this reaction is not only the result of the worsening water conditions but rather caused by all the factors in the simulation, foremost the demographic development and the trend in the gross regional product.

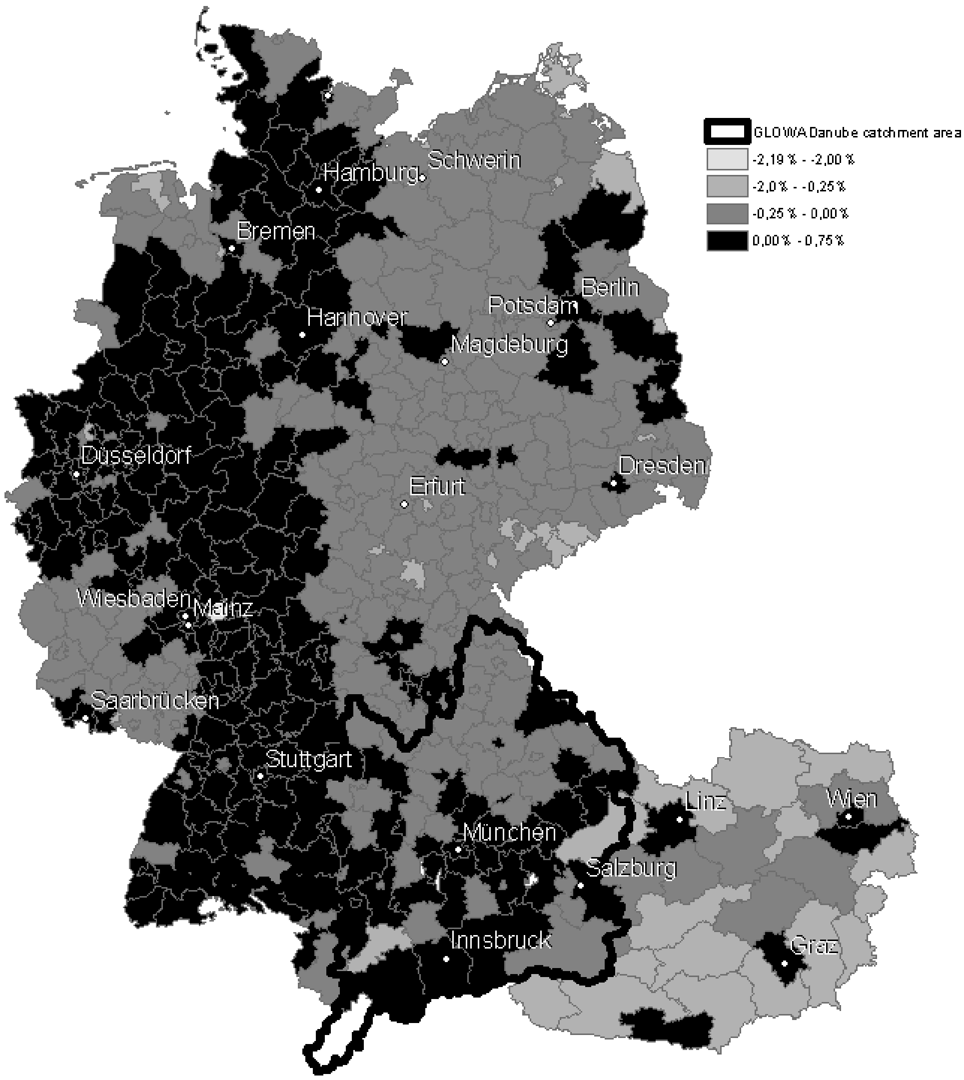
Figure 6: Change in industrial water demand in comparison to 2012 and 1 year lagged ground water conditions in Salzburg.



Source: Ifo Institute

For Salzburg the situation stays rather moderate. In the simulation the water quantity conditions worsen once in 2013, but improve again in the following year and remain good in the following years. Consequently the industry reduces the water demand only slowly and does not even reach a 5% reduction in 2025 relative to 2012 (see figure 6), one reason also being a local increase in the population contrary to a decreasing population in Weiden.

Figure 7: Industrial water demand 2012–2025,
baseline scenario vs. performance scenario
(values in percent)



Source: Ifo Institute

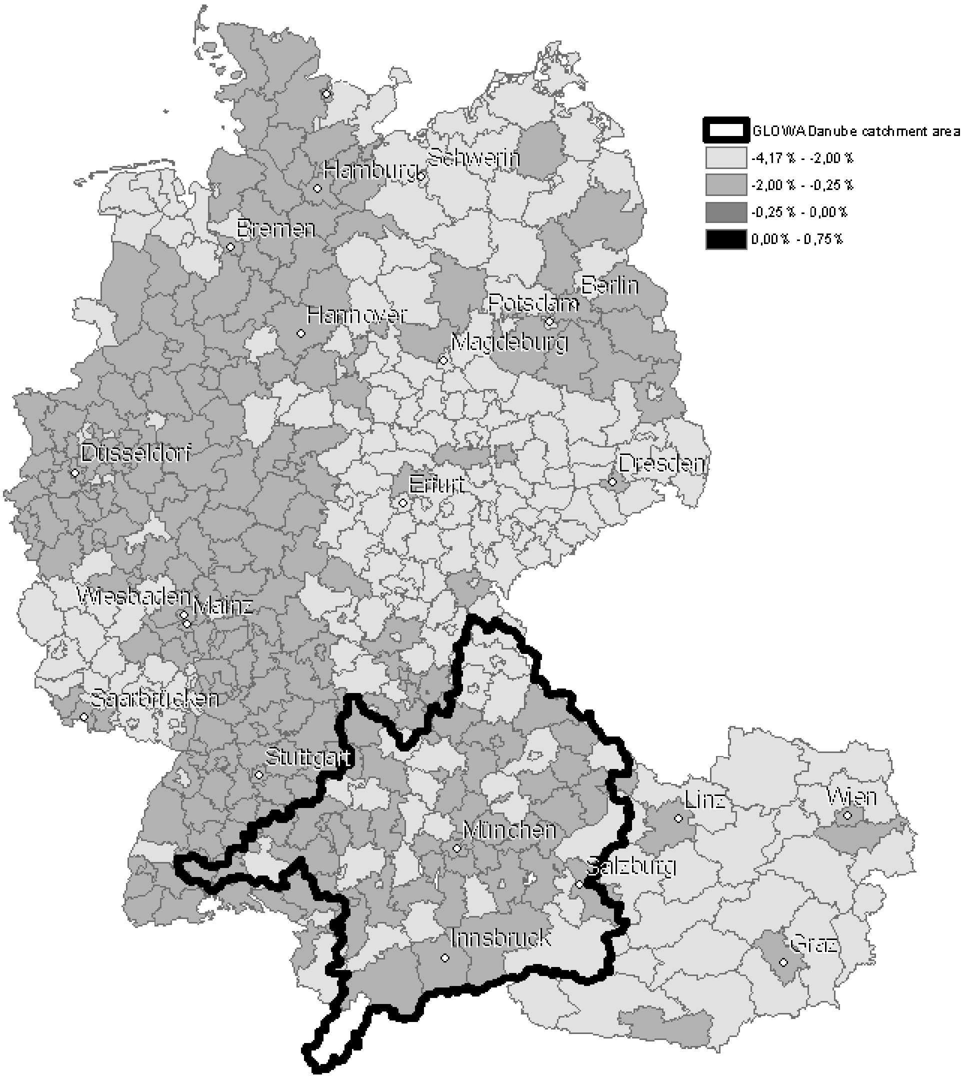
3.3 Comparison of the scenarios for industrial water demand

Figure 7 and Figure 8 show the difference in the relative changes of industrial water demand between the socio-economic scenarios *performance* or *common public interest* in relation to the *baseline* scenario for each industrial active square kilometre in 2025 relative to 2012. In other words, we compare one simulation driven by the *performance* scenario or *common public interest* scenario with one simulation driven by the *baseline* scenario and compute the difference of the percentage values for each square kilometre. For this reason, positive values indicate higher industrial water demand in the *performance* or *common public interest* scenario than in the *baseline* scenario.

In the *performance* scenario the changes in water demand range between 2.19 percentage points reduction and 0.75 percentage points increase compared to the *baseline* scenario (see Figure 7) or between 4.17 percentage points reduction and 0.75 percentage points increase in the *common public interest* scenario compared to the *baseline* scenario (see Figure 8). This effect is less negative in areas of high population density like Munich, Innsbruck and Salzburg. Thus, in comparison to rural areas, the relative water demand increases in the cities. Different small-scale effects like higher migration movements into cities reinforce these regional differences.

The observed regional differences can be explained partially by regionally highly divergent water conditions. Water scarcity in Germany and Austria worsens due to climate change. This in conjunction with the social adaptation strategy leads to a reduction in water demand, which is reflected in the light gray and gray districts. Moreover, higher subsidies for investments in sustainable water usage in the *common public interest* scenario encourage higher water demand reductions of industry when water conditions worsen.

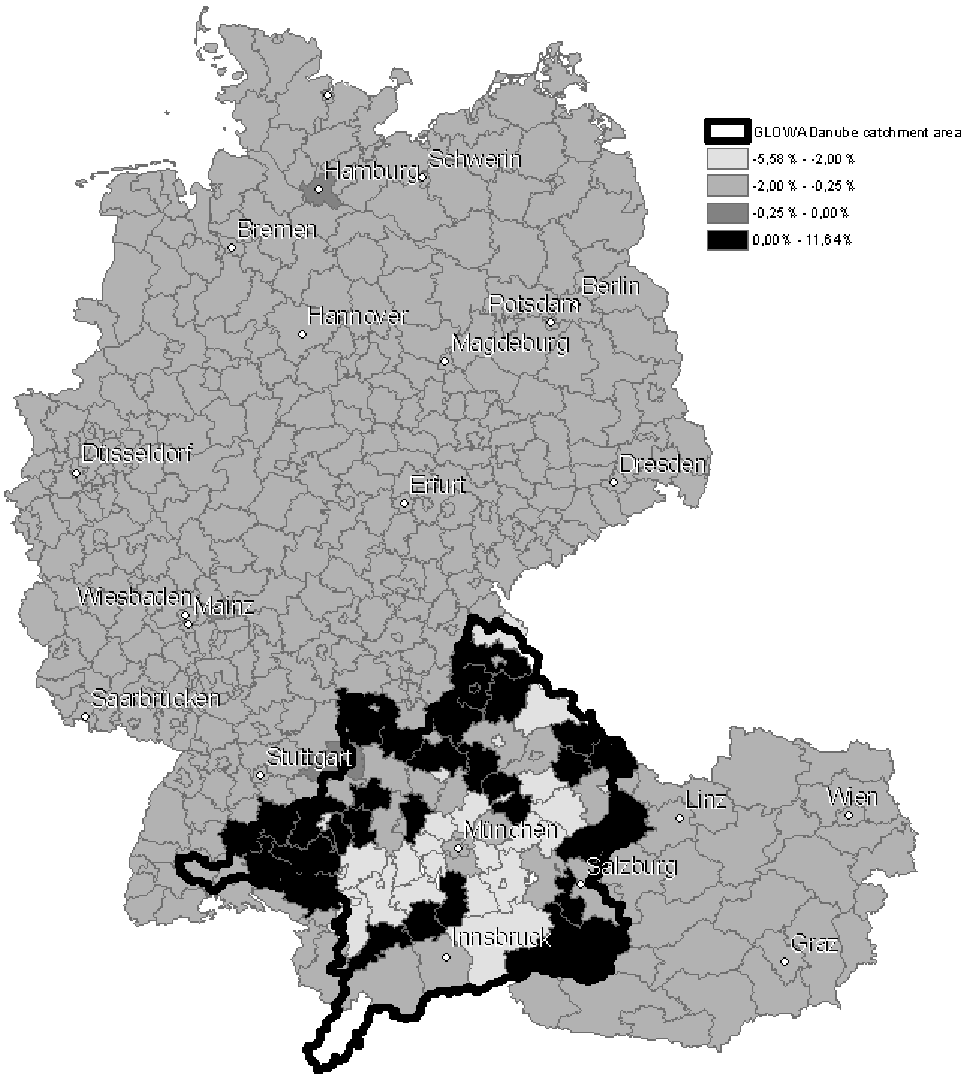
Figure 8: Industrial water demand 2012–2025,
baseline scenario vs. *common public interest* scenario
(values in percent)



Source: Ifo Institute

To isolate the effect of climate change up to 2025, we again compare results of a local simulation with the *zero climate change* setting with the results of a local simulation with the "REMO regional" climate trend (the similar setting as for the GRP results above). The changes in industrial water range between 5.58 percentage points reduction and 11.64 percentage points increase up to 2025 relative to 2012 (see Figure 9). The results again show the necessity of regional small-scale simulation and interaction as we can observe large regional differences inside the upper Danube catchment area. These differences reflect the regional divergent effects of climate change due to water condition developments explicitly modelled in the river basin. An important message that we can derive from these results is the fact that the effects of the socio-economic scenarios (*performance* or in the *common public interest*) is minor compared to the consequences of climate change.

Figure 9: Industrial water demand 2012–2025,
zero climate change, baseline scenario vs. *REMO regional* climate change, *baseline* scenario
(values in percent)



Source: Ifo Institute

4 Conclusions

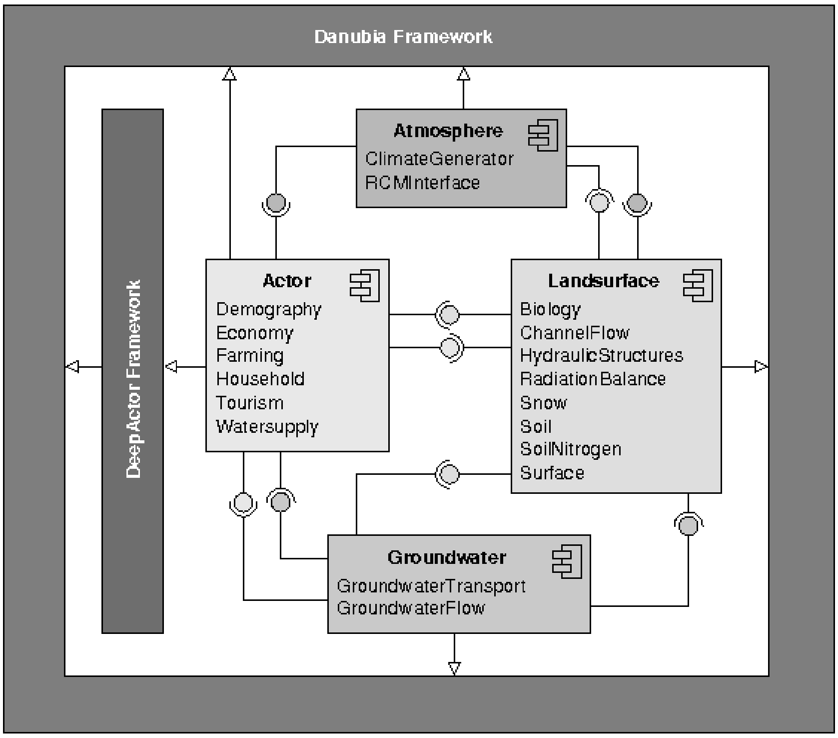
Using the AFiD Panel we calibrated the environmental decision support system DANUBIA and simulated the effects of different climate change and socio-economic scenarios up to 2025. The results show a general decline in water usage accompanied by worsening conditions in natural water-cycles. Thus, climate change is an issue for the sustainable development in German and Austrian regions although it is comparatively moderate. We observe large regional disparities in the extensively analyzed upper Danube river basin. These are mainly caused by climate change but also by society. We further show that cities are economically less affected by climate change than rural areas. The results allow the identification of regional hot spots and a quantification of the effects of various policy measures that aim at compensating society for climate change with respect to economic and environmental sustainability. However, the potential improvements in the observed socio-economic scenarios are limited since their effect is minor compared to the impact of climate change.

Appendix

A.1 Sub-model interaction in DANUBIA

The UML diagram in Figure A.1 presents an overview of the structure of the DANUBIA framework.[21]

Figure A.1: Interaction of the models in DANUBIA



Source: GLOWA Danube

Detailed descriptions of the framework can be found in Barthel et al. (2010), Barthel et al (2008), Hennicker and Ludwig (2006), Hennicker and Ludwig (2005) and Barth et al. (2004).

[21] UML refers to unified modelling language, a notation convention common to computer science applications. Since the general intuition of the illustration is assessable without deeper knowledge of the terminology, we will abstract from a detailed introduction into object-oriented programming. In general it is sufficient to know that the boxes labelled with the respective superordniated type serve as a container of conformable models representing its classes. The arrows with blank heads mean “extend” such that a class or model at the tail of an arrow extends the one at the head (or in other words: the model at the head of the arrow is the base of the extending model and its abilities are inherited to the extension). An outgoing line with a circle means “provide” and a semicircle with an incoming line means “require”.

A.1 Estimation results used for the calibration of the simulation

Table A.1: Coefficients used for the calibration of the simulation

Model	(1) OLS	(2) OLS	(3) OLS	Below prices derived from model (3)
year	0.010**	0.012**	0.010**	
employees	0.549**	0.533**	0.490**	€27,698 per year and employee
capital	0.406**	0.315**	0.380**	6.0% interest rate
extracted water	0.056**	0.054**	0.040**	€3.07 per cubic meter
region dummies	no	yes	yes	
constant	-13.751*	-16.012**	-15.142**	
R^2	0.9850	0.9996	0.9933	
observations	160	160	160	

Model specification (3) used for the simulations in this paper. Source: Ifo Institute

The coefficients in Table A.1 for the calibration of the model were estimated in Jessberger, Zimmer (2010). Due to the log-log specification, the coefficients can be directly interpreted as elasticities. The implicit prices for the production factors that follow from the Cobb-Douglas specification of the production function are listed in the last column of Table 1. As seen in Table 2 in the scenario chapter the German average effluent charges in 2005 were about € 2.28for each cubic meter of water. Since public water suppliers in Germany charge their water on a non-profit base according to their extraction and supply costs, we can use their prices as an indicator for the extraction cost of the self-supplied industrial producers. The average costs for public water in 2007 were €1.85, as indicated in Table 3. As expected, the estimated costs of €3.07 per cubic meter lie well below the roughly four euros of the public water supply.

A.2 Components of the interdisciplinary global change decision support system DANUBIA

<u>**Atmosphere:**</u>

Mesoscale modelling of the atmosphere

The mesoscaled atmosphere model MM5 has been integrated in DANUBIA and interconnected with the land surface modelling of the group "Hyd-Fern" by the sub-project group "Meterology/MM5". They use a downscaling method, which has been developed within the project by the former project partners "Wirth", to downscale the 45 km grid of MM5 to the 1 km grid of DANUBIA. Meterology/MM5 also employed, processed, and downscaled data of the A1B scenario of the global climate model ECHAM5 for the years 2001 to 2100.

<u>**Land surface:**</u>

a) Plant growth

The model *Biological* simulates plant growth in the context of the DANUBIA decision support system. *Biological* was designed to assess the role of the vegetation in the cycles of, water, nitrogen, and carbon under climate change conditions using a process based approach (Lenz-Wiedemann et al., 2010). It simulates plant growth, taking into account the influences of radiation as well as the availability of water, nitrogen, and CO_2. In the case of agricultural vegetation, *Biological* interacts dynamically with the farming component.

b) Soil Nitrogen Transformation (SNT)

The model SNT simulates soil nitrogen transformation in the context of the DANUBIA decision support system. SNT was designed to assess the role of nitrogen transformation processes in the soil in the context of changing cycles of water, nitrogen, and carbon under climate change conditions using a process based approach (Klar et al., 2008). Distinguishing between humus and fresh organic matter, it simulates all relevant turnover processes of ammonia and nitrate pools including nitrate leaching into the groundwater.

c) Natural environment

Further components modelling soil, land surface and radiation balance.

<u>**Actors:**</u>

The actor component consists of a rich set of models, which are strongly interacted with each other (An interaction is typically an exchange data, e.g. the household model generates the households' water demand, which is used by the water supply model as input in order to decide on the development of additional infrastructure). An overview of the strongest direct interaction paths between the models is given in Figure A.2. The models themselves typically consist of several sub-models.

a) Ground water management and supply

In the water supply model, which is implemented as an actor model (Barthel et al. 2008, Barthel et al. 2010), the *WaterSupplyCompany* actors behave differently in different socio-economic scenarios (see section "Economic and societal scenarios in frames of climate change").

b) Household

The sub-project "environmental psychology" developed an agent based model of lifestyles in the context of the environment and water usage behaviour. Main issues here are drinking water consumption, risk awareness and risk valuation with respect to water, and investments of households in water saving innovations.

c) Farming

The aim of the sub-project "agricultural economy" is to detect possible changes in agricultural incomes, land and water use and crop management, due to different climate change and socio economic scenarios. Accordingly, a two-step model was developed. At first the process-orientated agricultural sector model ACRE makes plans for farming for the next year on a county level. In a second step the agent model *DeepFarming* models the daily management decisions per square kilometre based on these agricultural plans.

d) Demography

The demography model determines the domestic migration movements depending on the socio-economic conditions and amenities of potential destinations and given national demographic trends. It accounts not only for conditions at the specific destination but also for network effects and the conditions in neighbouring regions.

d) River network

Surface water is modelled with direct interfaces to the atmosphere, ground water, and plant growth. This sub-project illustrates energy and water fluxes inside the upper Danube catchment area and models the water quantities for every square kilometre of a river channel. Thus, it serves as the basis of our industrial model's river water demands.

e) Snow cover and glaciers

Snow and ice components have been developed from the sub-project "Glaciology" to the needs of other DANUBIA partners like water management, tourism, and other socio economic issues. As DANUBIA processes are standardized on a 1x1 km scale (one DANUBIA Proxel), they had to model snow accumulation and snow melt as the development of glacier area and the resulting ice melt by use of subscale parameterization.

<u>Groundwater:</u>

Ground water balance

This sub-project group implemented models to simulate ground water flow and ground water quality (Barthel et al. 2005a, Barthel et al. 2005b, Wolf et al. 2008) as well as the water supply for the upper Danube catchment area.

e) Tourism

The sub-project "Tourism" simulates the water demand of the tourism sector. Therefore several sub-models have been developed for: the operating state of tourism infrastructure (golf courses, ski areas, swimming pools, hotels and gastronomy) and the tourism location attractiveness – measured in the number of bed nights and same day visitors. The model simulates various possible changes in the tourism industry – supply and demand – as conditioned by climate change, e.g. movement of winter guests to more snow-reliable ski areas or the increase of guests during the summer season.

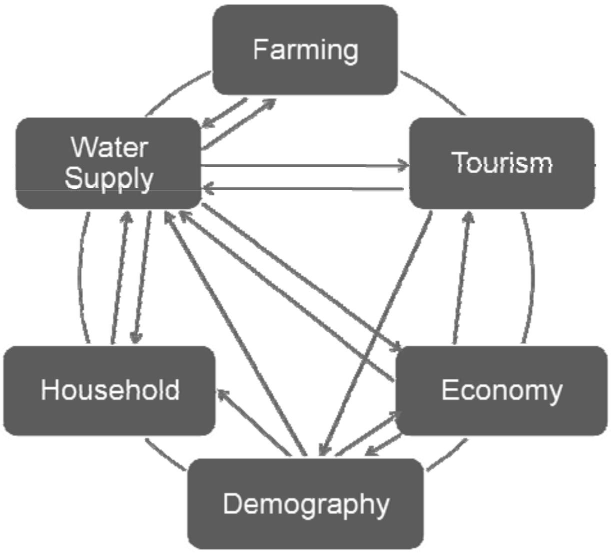
f) Economy

The "RIWU" sub-model captures macroeconomic developments and delivers the price levels, wage rates and interest rates that are employed by other sub-models (Langmantel/Wackerbauer 2003).

g) Industry

The sub-model which simulates the industrial producers with a spotlight on their usage of water resources is the focus of this paper.

Figure A.2: Main paths of interaction in the actor network of DANUBIA



Source: GLOWA Danube

A.3 Trend values of the scenario parameters

Table A.2: List of adjustable scenario parameters for the industrial model

Adjustable parameter	Declaration	Performance scenario	Common public interest scenario
ChangeCostOfWaterReuse	investment costs for re-using water	-	-0.48 % p.a.
ChangeCostOfExtraction	costs for extracting water	-	+0.15 % p.a.
ChangeSubsidies	subsidies for environmental protection	-	+0.48 % p.a.
ChangeCostOfCapital	cost of capital	-0.48 % p.a.	-0.48 % p.a.
ChangeWages	labour costs	-	+0.48 % p.a.

Source: GLOWA Danube scenarios

A.4 Development of water prices and sewage charges in Germany

Table A.3: Sewage charge prices conform to the fresh water benchmark weighted by habitants

	€/m^3 2002	€/m^3 2005	Change	p.a.
Old West German states	2,05	2,16	5,4%	1,8%
Newly-formed German states	2,47	2,87	16,2%	5,1%
Germany	2,11	2,28	8,1%	2,6%

Source: BDEW (Federal Association of Energy and Water Management)

Table A.4: Mean water prices in Germany in 2007

	€/m^3 2001	€/m^3 2007	Change	p.a.
Old West German states	1,64	1,79	9,1%	1,5%
Newly-formed German states	2,05	2,15	4,9%	0,8%
Germany	1,70	1,85	8,8%	1,4%

Source: BDEW (Federal Association of Energy and Water Management)

A.5 Water extraction fees in Germany

Table A.5: "water-cent" per each m^3 of extracted water in German states

State	Water-cent	Explanations	Yearly payments	Designated use of funds
Baden-Württemberg	5.1	since 1988		No label
Bayern	–			
Berlin	31		ca. €55 million	Protection of ground water
Brandenburg	10.2	With two times of increase since 1994	ca. €20.2 million	Realization of WRRL, maintenance of dikes , etc.
Bremen	5	since 1993, confirmed in 4/2004	ca. €0.7 million of WVU	
Hamburg	7 – 8	For about. 12 years, increased in 12/2005	€3.0 million of WVU	
Hessen	–	Abolished in 1 / 03		
Mecklenburg-Western Pomerania	1.8	Updating the water-pfennig of the DDR, confirmed in 1/2003	ca. €1.7 million	For ground water saving arrangements
Niedersachsen	5.1	Confirmed in 12/2004	Ca. €20 million of the public water supply	For ground water saving arrangements
Nordrhein-Westfalen	4.5	Since 1.2.2004	€72 million for drinking water and process water (2005)	Realization of WRRL 2)
Rheinland-Pfalz	–			
Schleswig-Holstein	5 – 11 1)	since 1.1.2004	ca. €24.5 million	50 % labelled for different purposes
Saarland	6 – 7	Proposed To introduce by state-government in 2007	(up to €3 million)	(partially labelled)
Sachsen	1.5		ca. €3.4 million	Labelled for different purposes
Sachsen-Anhalt	–			
Thüringen	–			

1) 5 cents for business enterprises as end-consumers if they consume more than 1,500 m^3 of water in time period, 11 cents for all other end-consumers. 2) Possible to apply against expenditures within the farming cooperation. Source: BDEW (Federal Association of Energy and Water Management)

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