Global-scale vs. regional-scale scenario assumptions: implications for estimating future water withdrawals in the Elbe River basin

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Abstract In this paper, we explore how scenarios of future water withdrawals in a river basin are influenced by scale-dependent quantifications of the driving forces for two global-scale storylines. Either global-scale information or region-specific information is used to do the quantifications. In addition, we analyze the impact of including or not some restricted regional-scale information in the employed water use model. To develop scenarios of water withdrawals in the German part of the Elbe River basin, we applied the modules for domestic, thermoelectric power and manufacturing water use of the global water model WaterGAP, using scale-dependent driving forces scenarios and other scale-dependent model input. In the global-scale quantitative interpretations of the storylines of the IPCC SRES scenarios A1 and B2, all major driving forces of water withdrawals in the basin—population, thermoelectric power production and industrial gross domestic product—show vigorous increases between 2000 and 2025, while from the regional perspective, smaller increases but mostly decreases appear to be plausible. These discrepancies are partly due to the fact that for the global-scale interpretations only the historic developments until 1990 were taken into account, and not until 2000 as in the regional case. The resulting scenarios of sectoral water withdrawals in 2025 differ strongly between the two scale-dependent interpretations of the storylines, with the global one leading to much higher absolute water withdrawals and much lower withdrawal decreases between 2000 and 2025. Therefore, for regional assessments of water withdrawals, we recommend to embed the scenario analysis in global-scale storylines by performing regional-scale quantifications of the global qualitative driving forces scenarios, based on a limited amount of region-specific information.

Keywords Regional scale · Global scale · Scenarios · Water demand · Water withdrawals · Water management · Regional planning

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Introduction

Scenarios of the future ideally combine qualitative and quantitative elements, i.e. storylines that tell about alternative plausible futures with selected quantitative interpretations of these storylines. These quantitative interpretations can be a combination of numerical estimates of the driving forces and the output of models for which these estimates are used as input. Now, when deriving scenarios for certain regions of the globe, e.g. river basins, it is, in many cases, recommended to make these consistent with global-scale scenarios, as there are many global-scale processes which affect the development in the region. Thus, the development of regional-scale scenarios requires regional interpretations of global-scale storylines. The regional interpretations can be done by first developing regional-scale storylines which are consistent with the global-scale one and then quantifying these regional-scale storylines. Another possibility is to directly interpret the global-scale storylines for the region of interest by quantifying them using specific information about the region. In the latter case, the derived quantitative scenarios will differ from the quantitative scenarios that are obtained if the quantification of the global-scale storylines, for the region of interest, is done by merely using global-scale information.

In this paper, we explore how scenarios of water withdrawals in a river basin are influenced by **scale-dependent quantifications of the driving forces** for two global-scale storylines. In addition, we analyze the impact of including or not some restricted regional-scale information in the applied water use model. Our tool for quantification is the global model of water resources and water use WaterGAP (Döll et al. 2001, 2003; Alcamo et al. 2003; Vassolo and Döll 2003), which is applied, on the one hand, in its standard configuration and with global-scale driving-force scenarios and, on the other hand, with some regional-scale modifications and regional-scale driving force scenarios. This comparison helps

1. To recognize to what extent the assumptions behind a regional scenario might differ from those of the global-scale scenario (for the region of interest), even though the regional scenario assumptions are consistent with the global-scale storyline, and;
2. To analyze the implications of this scale-dependency for the modeled water withdrawal scenarios.

Water withdrawal scenarios are a useful tool for supporting a sustainable river basin management as freshwater is a renewable, but mostly scarce resource. Any significant human water use affects the natural environment, either because water availability for humans is artificially increased by reservoir construction or groundwater development, or because water availability for freshwater ecosystems is reduced by human water withdrawals and water consumption. Generally, the part of the withdrawn water that is returned to the environment has a lower quality, and consumptive use (the part of the withdrawn water that evapotranspirates) leads to a reduction of water flows. Thus, it is generally acknowledged that water demand management (which includes the management of water withdrawals) must play a prominent role in water management. However, much less scientific effort has been spent on the analysis of water demand than on the analysis of water resources.

Our study area is the German part of the Elbe River basin upstream of Geesthacht (a few kilometers upstream of Hamburg, Fig. 1). It is located mainly within the New Laender of Germany, i.e. former East Germany (Fig. 2 shows the outlines of the Laender). The spatial resolution of the applied global water model WaterGAP, 0.5 degree latitude by 0.5 degree longitude, is also shown in Fig. 1. In this paper, only household, manufacturing and thermoelectric power water withdrawals are considered, as irrigation and livestock water withdrawals are relatively small in the Elbe River basin. The presented work was performed in the framework of a regional-scale evaluation of the impact of global change on the water situation in the Elbe River basin, GLOWA-Elbe (http://www.glowa-elbe.de), where WaterGAP was applied to provide a first rough assessment of current and future water resources and water use in the basin.

In the next section, we shortly describe the water use module of WaterGAP and introduce the applied scenario method. Then, we present the different scenarios of water withdrawals in 2025 that result from scale-dependent scenario assumptions and explain why scale-dependent differences occur. We discuss the implications of scale-dependent quantitative interpretations of storylines and draw conclusions with respect to regional interpretations of global scenarios.

Fig. 1
Elbe River basin with its German and Czech parts, overlain by the WaterGAP 0.5 degree by 0.5 degree computational grid

Methods

Global water use model

The global water use model of WaterGAP simulates water use in individual grid cells of 0.5 degree by 0.5 degree, which may be aggregated to larger spatial units like river basins or countries. Five water use sectors are distinguished: households, thermoelectric power plants, manufacturing, irrigation and livestock. Both water withdrawal and water consumption are computed (water consumption is the part of the withdrawn water that is lost by evapotranspiration). An earlier version of the water use model is described in Alcamo et al. (2003) and Döll et al. (2001). In the current version, water use for thermoelectric power and manufacturing are computed separately (Vassolo and Döll 2003). A detailed description of the global irrigation water use model is provided in Döll and Siebert (2002). In-situ water use (e.g. for navigation) is not taken into account in WaterGAP. Water use in each sector is computed as a function of a sector-specific water use intensity (e.g. per-capita domestic water use of population with access to safe drinking water) and a driving force of water use (e.g. population). Sectoral water use intensities depend on a number of model parameters that, for example, describe the impact of technological change. In the

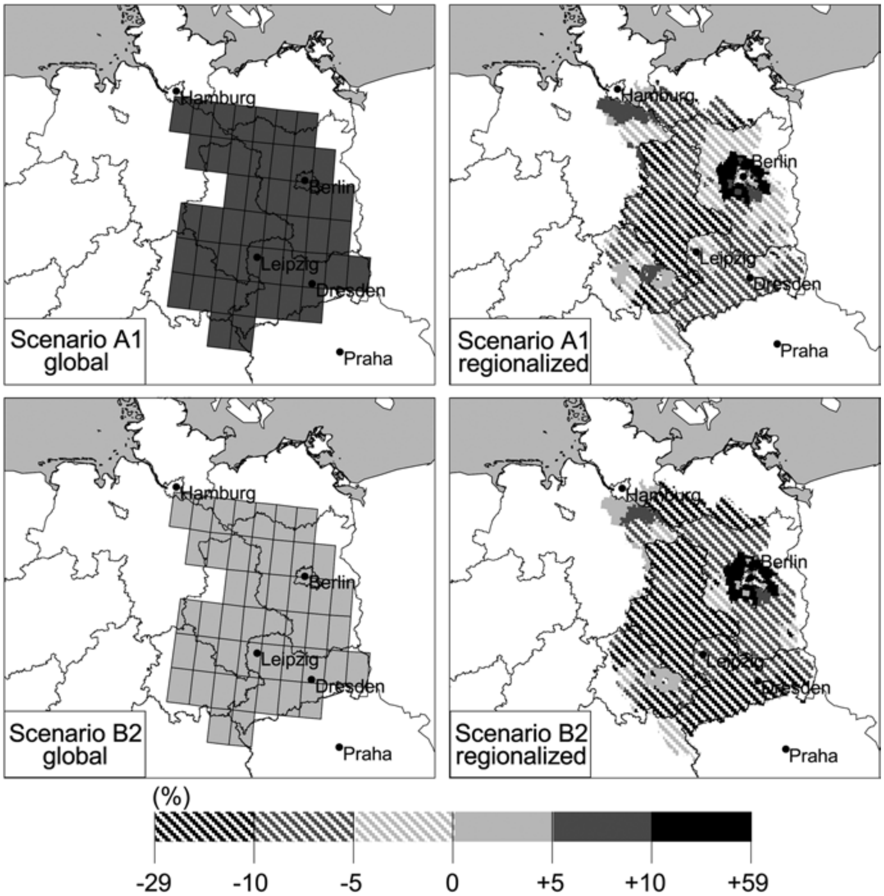

Fig. 2
Change in population in the German Elbe Basin upstream of Geesthacht between 2000 and 2025: scenarios A1 and B2 in the global and the regionalized approach. The resolution of the population scenario is 0.5 degree by 0.5 degree in the global approach and 2.5 minute by 2.5 minute in the regionalized approach. The outlines of the German Laender are indicated

following paragraphs, only the methods to compute water use in the domestic, thermoelectric power and manufacturing sectors are described, as these are the three sectors included in our study.

Domestic sector

Domestic water use is computed as a function of domestic water use intensity [m^3/(cap yr)] and population. It is determined based on country-specific estimates of domestic withdrawal and consumptive water use in 1995 (Shiklomanov 2000). The country values are allocated to the WaterGAP grid cells based on population density (CIESIN 2001), urban and rural population in each country (WRI 1998) and the fraction of inhabitants with access to safe drinking water in rural and urban areas (World Bank 1996; WRI 1998).

Two main concepts are used for modeling the future change in water intensity in the domestic sector, structural change and technological change. Structural change means that households in poorer countries first acquire more and more water-using appliances as their income increases. Eventually, the average household becomes saturated with water-using appliances and water use stabilizes. The consequence of these structural changes is that average water intensity of households first grows with per capita gross domestic product GDP, and stabilizes as per capita GDP continues to grow. In WaterGAP, this process is represented by a sigmoid curve:

$$DSWI = DSWI_{\min} + DSWI_{\max} \cdot \left(1 - \exp\left(-\gamma_d \cdot GDP^2\right)\right) \tag{1}$$

where $DSWI$ = domestic structural water intensity [m^3/cap], GDP = per capita annual GDP and γ_d = curve parameter. Values of $DSWI_{\min}$, $DSWI_{\max}$, and $_d$ are calibrated for each of 26 World regions (grouping of countries) based on the trend of historic data up to 1990 as published by Shiklomanov (2000) or to country data in the case of Germany, Japan, USA and Canada. Technological change is assumed to decrease water intensity by a certain annual rate resulting in a domestic water intensity that is a function of per capita GDP and time.

Thermoelectric power sector

Thermoelectric power water use is based on the geographical location of 63,590 thermal power stations worldwide that were connected to the net around 1995 (UDI 2000). Unfortunately, the cooling system type, which determines both withdrawal and consumption intensity (water withdrawal or consumption per unit electricity production) is not known for 89% of the stations. In these cases, it was estimated as a function of the construction year of the station or the cell-specific energy production and river discharge. Total water withdrawal and consumption of a station are computed as the product of the electricity production and the withdrawal (or consumption) intensity [m^3/MWh produced thermal energy].

Annual electricity production of each power station is estimated from the total electricity production in each country, fuel type-dependent typical working hours and the station-specific installed capacity. The computed data set was compared to data of state-specific thermoelectric power withdrawals and consumption in the USA (Vassolo and Döll 2003); modeling efficiency is high, 0.77 for total withdrawals, in million m^3/yr and 0.76 for area-specific withdrawals, in $m^3/(km^3$ yr).
Thermoelectric power water intensity is assumed to decrease in the future due to technological change that only affects newly constructed stations. Station-specific water intensity remains constant during the whole life span of a station.

Manufacturing sector

Manufacturing water use is modeled by first estimating country-specific water withdrawal values, which are then distributed to the grid cells as a function of city nighttime lights (Vassolo and Döll 2003). Country-specific withdrawals are calculated based on the production volumes of eight manufacturing sectors and the respective specific withdrawal intensity, taking into account estimates of country-specific values of total industrial water withdrawals. A comparison to published industrial water use in the 50 states of the USA and 89 administrative regions in Russia shows that grid cell values cannot be properly modeled without additional subnational statistical information on manufacturing water withdrawals. However, the spatial distribution proportional to the city nighttime lights effectively prevents WaterGAP from erroneously distributing total country withdrawals to (almost) uninhabited areas (e.g. Northern Canada).
To develop scenarios of future manufacturing water use, an overall manufacturing water withdrawal intensity is defined as total water withdrawal per Industrial Gross Domestic Product (IGDP) at constant (i.e. inflation corrected) prices. Manufacturing water intensity is assumed to decrease in the future at a certain annual rate, due to technological change.

Scenario development

Applying the water use module of WaterGAP, four scenarios of water withdrawals in the German Elbe River basin upstream of Geesthacht between 2000 and 2025 were developed. These scenarios reflect two different global-scale storylines (IPCC SRES, Nakicenovic and Swart 2000), each of which is translated into quantitative scenarios by either

1. Using purely global-scale information as available for deriving scenarios for the whole globe (here “global approach”), or;
2. Supplementing a limited amount of easily available basin-specific information (here “regionalized approach”).

Thus, different scenarios for the Elbe River basin result for the same global storyline, depending on the scale of the information used to quantify both the driving forces and the model parameters. Table 1 lists, for each of the three considered water use sectors, the different information used in the global and the regionalized approach for current and future conditions. For the domestic and manufacturing water use sectors, mainly the assumptions about the future development of the driving forces and model parameters differ. For the thermoelectric power water use sector, the regionalized and global approaches differ, in addition, significantly with respect to the modeling of the current water use. Any driving forces or parameters not mentioned in Table 1 are the same in the global and the regionalized approach.

Table 1
Differences between the purely global–scale water use modeling and scenario approach and the regionalized global-scale approach for the German Elbe River basin. The base year for the scenarios is 1995 in the global approach and 2000 in the regionalized one

Water use sector	Global approach		Regionalized approach	
	Present-day (1995)	Scenario (2000, 2025)	Present-day (2000)	Scenario (2025)
Domestic	D: Total population in Germany in 1995 P. Domestic water intensity in Germany in 1995	D: Population changes based on country (UN 1998) and (scenario-specific) World region projections (IMAGE)	D: Total population in Germany in 2000 P: Domestic water intensity in Germany in 2000	D: Population changes based on projections for Laender and smaller administrative units of Germany*
Thermoelectric power	D: Electricity production in Germany (VD)	D: Change in electricity production in world regions (IMAGE)	D: Electricity production in Laender (FZJ)	D: Change in fuel-type specific electricity production in Laender (FZJ)
	P: Cooling type and water intensity (global analysis, VD)	P: Technological change and life span (global analysis)*	P: Cooling type of large power stations in Laender water intensity (FZJ)	P: Technological change, life span (FZJ)
Manufacturing	D, P: global analysis (VD)	D: Change in industrial GDP in world regions (IMAGE)	D: global analysis plus change in industrial GDP in Germany*	D: Change in industrial GDP in Germany*
		P: Technological change (global analysis)*	P: global analysis plus techn. change in Germany*	P: Technological change in Germany*

D, Driving force; P, model parameter; *, this paper; IMAGE, IMAGE Team (2001); VD, Vassolo and Döll (2003); FZJ, Vögele and Markewitz (2001)

With respect to the scenario storylines, all scenarios developed in the framework of the GLOWA-Elbe project were supposed to follow either the global-scale IPCC SRES storyline A1 or B2 (Nakicenovic and Swart 2000). In their section 4.2.1, Nakicenovic and Swart summarize the two storylines as follows:

- "The A1 storyline and scenario family describes a future World of very rapid economic growth, low population growth, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. (...)
- The B2 storyline and scenario family describes a World in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a World with moderate population growth, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels."

In scenarios of future water use, both the changes of water use intensities and driving forces are quantified to reflect the two storylines. The main driving forces of water use are population (domestic sector), electricity production (thermoelectric power sector) and industrial gross domestic product IGDP (manufacturing sector). In the global approach, the changes of the driving forces are provided by the global integrated model IMAGE model (IMAGE Team 2001), which served to quantify the SRES storylines and to downscale them to 17 World regions. Cell-specific changes of the driving forces are obtained by assuming that the changes in driving forces (and parameters) are the same in each cell within the IMAGE World region, or, in the case of population, in each cell within a country. For population, the country-specific population changes as projected by the medium-fertility projection of UN (1998) are scaled with World-region specific scenarios of IMAGE, such that different scenarios like A1 and B2 can be simulated while taking into account the different population developments in the individual countries within a World region. The population of a country in scenario x is computed as

$$P_{\mathrm{country},x}(2025) = P_{\mathrm{UN,country}}(2025)\frac{P_{\mathrm{IMAGE,world\ region},2025,x}}{P_{\mathrm{UN,world\ region},2025}} \quad (2)$$

In the regionalized approach, the driving forces are prescribed with a much finer resolution, i.e. for districts, federal states or the whole of Germany, depending on the water use sector (Table 1). Regional-scale scenarios of technological change were derived for the thermoelectric power and manufacturing sectors. Additionally, specific information on cooling system type, water intensity, life span and replacement of thermal power stations was used for the thermoelectric power sector.

Results

Table 2 lists basin-wide averages of sectoral water withdrawals in the German Elbe River basin upstream of Geesthacht, for the years 1995 (base year of global approach), 2000 (base year of regionalized approach) and 2025. As the base year in the global approach is 1995, the global approach water withdrawal values in 2000 already depend on the scenario. In both the regionalized and the global approach, manufacturing is the most important water use sector in 2000 and 2025, followed by the domestic sector, or, in 2025 with the global approach, by the thermoelectric power sector. For both approaches, water withdrawals in scenario A1 are larger than in scenario B2, which is consistent with the storylines. The

Table 2
Current and future water withdrawals in the German Elbe River basin upstream of Geesthacht as computed with the global and the regionalized approach

	Water withdrawals (km^3/yr) (change between 2025 and 2000)						
	1995	2000		2025 Scenario A1		2025 Scenario B2	
Water use sector	Global	Global (A1/B2)	Regionalized	Global	Regionalized	Global	Regionalized
Domestic	1.00	0.98/0.93	0.94	0.93 (−5%)	0.76 (−19%)	0.31 (−67%)	0.32 (−66%)
Thermoelectric power	0.89	0.82/0.81	0.31	1.11 (+35%)	0.30 (−3%)	0.91 (+12%)	0.22 (−29%)
Manufacturing	1.96	1.95/1.85	1.71	1.85 (−5%)	1.08 (−37%)	1.14 (−38%)	0.68 (−60%)
*Total**	*3.85*	*3.75/3.59*	*2.96*	*3.89 (+4%)*	*2.14 (−28%)*	*2.36 (−20%)*	*1.22 (−59%)*

*Without irrigation and livestock water use regionalized approach leads to significantly smaller water withdrawals than the global approach for both 2000 and 2025, and to a much larger overall decrease of water withdrawal. In scenario A1, total water withdrawals increase by 4% between 2000 and 2025 in the global approach, but decrease by 28% in the regionalized approach. In scenario B2, they decrease in both approaches, by 20% and 59%, respectively. Combined with the higher estimate of withdrawals in 2000, much higher values of water withdrawals in 2025 are computed with the global approach than with the regionalized one (Table 2). In the latter, water withdrawals in the main water use sectors (households, thermoelectric power and manufacturing) decrease between 2000 and 2025 both in scenario A1 and B2. In the global approach, the reductions in the household and manufacturing sectors are relatively small and thermoelectric power water use even increases in A1 and B2. The discrepancies between the two approaches are mainly due to the assumed future developments of the main driving forces population, thermoelectric power production and IGDP, which increase strongly in the global approach, while in the regionalized approach they either decrease or increase only weakly (Table 3).

In the following sections, the differences between the withdrawals computed with the global and the regionalized approach are explained by presenting, for each sector, which additional information was included in the regionalized approach and how this changed the assumed development of the driving forces and the model parameters as well as the water withdrawal computations itself.

Domestic sector

For the domestic sector, the differences between the water withdrawals as computed by the global and the regionalized approach mainly result from the different scenarios of the driving force population. In the global approach, population in all grid cells of the study region is assumed to increase with the same rate as OECD Europe according to IMAGE (Table 1). The regionalized approach combines German population projections for the 16 Laender (federal states) and for smaller administrative units of Germany (Vassolo and Döll, unpublished report "Population Scenarios for Germany and the Czech Republic with focus on the Elbe River basin" Center for Environmental Systems Research, University of Kassel, Germany, 10 pp, December 2002). Two alternative population projections for the time period 2000–2050 for the Laender (Statistisches Bundesamt 2000) were assumed to be consistent with scenarios A1 and B2, respectively, and short-term, but inconsistent projections for smaller spatial units (without alternative scenarios) were used to represent migration within the individual Laender. Thus, the spatial distribution of population within the Laender does not differ between the two scenarios. The population distribution in 1995 on the 0.5-degree grid is obtained by aggregating the 2.5' × 2.5' global population data set for 1995 of CIESIN (2001), which, for Germany, is based on the population in the 447 districts of the country (global approach). For the regionalized approach, population distribution in 2000 is obtained as a combination of the CIESIN data set for 1995, total population in Germany in 2000, and projections of migration within Germany.

Figure 2 shows the derived changes in population in the German Elbe Basin between 2000 and 2025 for scenarios A1 and B2. In the regionalized approach, the total population within the German Elbe Basin decreases by 5% in scenario A1 and by 8% in scenario B2 (Table 3). The strong decreases occur in spite of significant net immigration because birth rates are assumed to remain at only 1,400 children per 1,000 women. In some regions, however, population increases are expected due to the continuing process of suburbanization. In the global approach, population increases by 6% in A1 and by 2% in B2 (Table 3), and population change is constant in all cells (Fig. 2). Why do the global scenarios result in a population increase, while the regional scenarios show a population decrease? The main reason is that according to the IMAGE implementation of the SRES scenarios, population increases in the World region OECD Europe, to which Germany belongs, by 7% in A1 (to 421 million people) and by 3% in B2 (to 402 million people), while according to UN (1998) it decreases by 1.9% (to 381 million people). Using the population scaling equation (Eq. 2), these IMAGE

Table 3
Change of driving forces of water use in the global-scale and the regionalized approach

Driving force	Change of driving force between 2000 and 2025, in percent, within the German part of the Elbe river basin upstream of Geesthacht			
	Scenario A1		Scenario B2	
	Global	Regionalized	Global	Regionalized
Population (domestic)	+6[a]	−5[b]	+2[a]	−8[b]
Electricity production by thermal power stations (thermoelectric power)	+78[c]	+11[d]	+48[c]	−20[d]
Industrial Gross Domestic Product (manufacturing)	+57[c]	+10[e]	+32[c]	−10[e]

[a]UN(1998), IMAGE Team (2001); [b]Statistisches Bundesamt (2000), as downscaled by the authors of this paper; [c]IMAGE Team (2001); [d]Vögele and Markewitz (2001); [e]this paper

scenarios lead to the very high assumed population increases in the study region, even though according to UN (1998) population in Germany will decrease by 2.4%. Figure 3 show the differences in the domestic water withdrawals that are computed with the global and the regionalized approach for the 46 cells that make up the German Elbe River basin upstream of Geesthacht. The maps of domestic water withdrawals in 2000 (Fig. 3 top) are rather similar. In the regionalized approach, water withdrawal intensity in 2000 is set to 59 m^3/yr, a figure that is equal to the average German value in 2001 (Statistisches Bundesamt 2003a). The differences between the global A1 and B2 estimates are due to the higher total population and water intensity in A1, and the regionalized approach map reflects the migration between 1995 and 2000, which is not taken into account in the global approach. While in the global approach, the percentage change in domestic water withdrawal between 2000 and 2025 is the same within the whole basin, the regionalized approach distinguishes areas with large decreases from areas with small decreases due to the spatially distributed changes of the driving force population (Fig. 3 bottom). The development of domestic water intensity is the same in both the global and the regionalized approach.

The different decreases of domestic water intensity, 0.6%/yr in A1 and 4.0%/yr in B2, are the main reason for the different water uses in the two scenarios (Table 2). The different base years in the two approaches have the effect that the global approach estimate for water withdrawals in 2025 for B2 is lower than that in the regionalized approach, as the very strong water intensity decrease already starts in 1995 in the global approach, but only in 2000 in the regional approach.

Thermoelectric power sector

The regionalized quantification of thermoelectric power water use is based on a study of Vögele and Markewitz (2001) on the electricity production market and its future in the five New Laender of Germany, which also considered thermoelectric power water use. However, no specific regional information was available for the power stations within the basin that are located in Berlin, Schleswig-Holstein and Niedersachsen. Following Vögele and Markewitz, all power stations in the German Elbe Basin upstream of Geesthacht had already turned to cooling towers in 2000, and water withdrawal intensity was 3.23 m^3/MWh. This figure is lower than the 4.5 m^3/MWh adopted in the global approach. In total, the water withdrawals for thermoelectric power production in 2000 are strongly overestimated in the global approach (Table 2). This is mainly due to only a few power plants that, in the global approach, are assumed to still have one-through flow cooling systems. As the water withdrawal intensity of one-through-flow cooling systems is approximately 40 times higher than that of cooling tower systems, a small number of cooling system conversions makes a big difference in water withdrawals. In Fig. 4 (top), which shows the maps of thermoelectric power water withdrawals in 2000, the locations of the one-through-flow stations that are assumed to still exist in the global approach, but are known to have been retired in the regionalized approach, are quite obvious.

Vögele and Markewitz (2001) presented two alternative scenarios of fuel-type specific electricity production in each of the New Laender. For their scenarios, they considered the large thermal power stations individually and defined life span and replacement of certain power plants depending on the scenario. In one of the scenarios, which is assumed to represent scenario A1, climate protection policies are rather weak, while in the other scenario (B2), a strong orientation towards climate protection leads to a lower energy demand, a more significant use of renewable energy and combined heat and power production, and the replacement of lignite by natural gas (resulting in smaller power stations). In the regionalized approach, electricity production by thermal power plants increases by 11% between 2000 and 2025 in A1, and decreases by 20% in B2 (Table 3). In the global approach, production increases by 78% and 47% respectively, representing average conditions in OECD Europe (Table 2). Mainly due to the very strong increase of electricity production in the global approach, thermoelectric power water withdrawal increases, while it decreases according to the regionalized approach (Table 2). The increase is slightly lowered by a technological change rate of 1%/yr in both scenario A1 and B2, which is somewhat higher than the rate in the regionalized scenario, 0.8%/yr (Table 4). This regional rate was derived from information on water withdrawal intensity of a large lignite power station and that of its replacement in 2000, as provided in Vögele and Markewitz (2001).

The computed changes of thermoelectric power use between 2000 and 2025 are rather homogeneous in the global approach, and the few cells with decreasing withdrawals are due to the replacement of one-through-flow cooling systems by cooling towers (left-hand side of Fig. 4 bottom). The spatial distribution of change in water withdrawal in the regionalized approach is very heterogeneous (right-hand side of Fig. 4 bottom). A strong decrease between 2000 and 2025 reflects the retirement of power stations (more in scenario B2 than in A1). A strong increase (from a small value in 2000) indicates the switch from oil-fuelled to gas-fuelled power plants that typically have longer working hours (although both are peak load stations). Neither a retirement of plants nor a switch of fuels can be simulated in the global approach.

Manufacturing sector

In order to derive scenarios of manufacturing water use, an analysis of the historic development of water withdrawals for manufacturing (Statistisches Bundesamt 1998) and IGDP (Statistisches Bundesamt 2003b) in the Old Laender of Germany was performed. This provided the basis for deriving regionalized estimates of IGDP and water withdrawal intensity in the manufacturing sector (Table 1). The analysis was not done for the New Laender, which essentially make up the German Elbe River basin, because the abrupt changes due to re-unification do not allow for an extrapolation of the past and because the

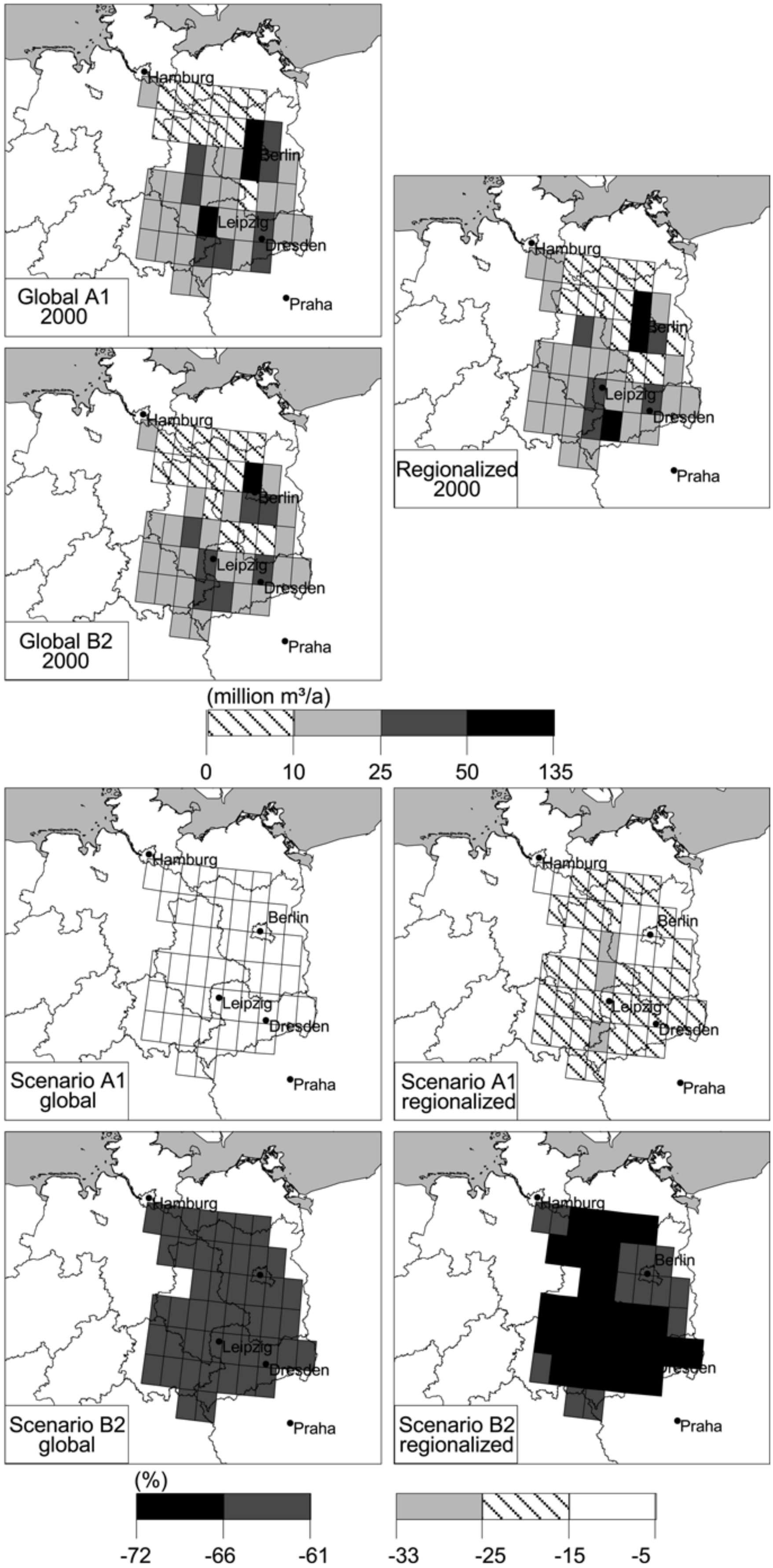

Fig. 3
Domestic water withdrawals in the German Elbe Basin upstream of Geesthacht in the year 2000 in the global and the regionalized approach (*top*), and change in domestic water withdrawals between 2000 and 2025: scenarios A1 and B2 in the global and the regionalized approach (*bottom*)

Table 4
Annual decrease of water withdrawal intensity of thermoelectric and manufacturing water use in the global and the regionalized approach

	Annual decrease of water withdrawal intensity of thermoelectric and manufacturing water use until 2025, in percent per year			
	Scenario A1		Scenario B2	
Water use sector	Global	Regionalized	Global	Regionalized
Thermoelectric power	1.0	0.8	1.0	0.8
Manufacturing	2.0	2.2	3.0	3.2

economic and technological development in the New Laender is expected to continue to become more similar to development in the Old Laender. Figure 5 shows the development of IGDP between 1960 and 1998, at constant prices of 1991, i.e. subtracting the effect of inflation. Total GDP is shown for comparison. IGDP, as a fraction of GDP, decreased steadily with time, from 45% in 1960 to 38% in 1990 and 33% in 1998 (while the service sector concurrently expanded). In the 1990s, IGDP in the Old Laender did not increase anymore, a tendency that is confirmed by the almost constant IGDP values for Germany as a whole from 2000 to 2002 (while GDP increased, Statistisches Bundesamt 2003b). Thus, in the regionalized approach, we foresee only weak changes of IGDP. In the economically oriented scenario A1, we assume that IGDP in Germany and thus also in the German Elbe River basin increases by 10% between 2000 and 2025, and that it decreases by 10% in the environmentally oriented scenario B2 (Table 3 and Fig. 5). This bifurcation with respect to approximately 0%-change since 1990 reflects the idea that German policies were oriented in the past towards economic growth but also discouraged industrial polluters to continue operating in Germany. Very different from the regionalized scenarios, the global scale scenarios of IGDP in OECD Europe and thus the German Elbe River basin imply a very strong increase of IGDP, by 57% in the case of A1 and by 32% in the case of B2 (Table 3 and Fig. 5). They seem to follow the long-term trend for West Germany until 1990, and do not take into account the more recent development.

According to the regional information, water withdrawal intensity for manufacturing in the Old Laender of Germany decreased at a rate of 2.7%/yr between 1975 and 1995 (Fig. 6) and continued decreasing approximately at that rate in more recent years. This strong decrease, which represents technological change, is due to an increased recycling of water inside the production process, but also due to the shift away from water-intensive industries like steel. Similar rates are deemed feasible for the time period up to 2025, in particular because internal recycling can still be improved. According to Lallana et al. (2001), work in closed circuits can reduce water withdrawals by about 90%. In the regionalized approach, we assume a constant technological change rate of only 2.2%/yr for scenario A1, while with an increased emphasis on environmental protection in B2, a value of 3.2%/yr appears feasible (Table 4 and Fig. 6). Similar technological change rates are assumed in the global approach, 2.0%/yr for A1 and 3.0%/yr for B2 (Table 4).

The slightly lower regional approach estimate of manufacturing withdrawal in 2000 as compared to the global approach value (Table 2) is mainly due to setting IGDP in 2000 equal to its value in 1995, while it increases significantly in the global approach. For both the regional and the global approaches, water withdrawals in 2025 are computed to be lower than 2000, but the decreases in the global approach are much weaker due to the very strong increases of IGDP in both scenarios.

Discussion

We discuss the implications of scale-dependent quantitative interpretations of storylines for estimating water use in the German Elbe River basin by answering the following two questions.

Does the inclusion of regional-scale information lead to significantly different water use scenarios?

Scenarios are not predictions of the future but should help to understand the range of alternative futures that we might have to face. In the case of the developed water use scenarios for the German Elbe River basin, the two scenarios derived using the purely global-scale approach show a quite different range of alternative futures than those scenarios that resulted when a limited amount of regional information was included to quantify the storylines. The global approach leads to total water withdrawals in 2025 of 3.89 and 2.36 km^3/yr in scenarios A1 and B2, respectively, and the regionalized approach to only 2.14 and 1.22 km^3/yr. Thus, the regional-scale interpretation of the storylines results in a range of alternative water withdrawals that is completely outside the range of the values derived with the global approach. In case of scenario A1, water withdrawals increase by 4% between 2000 and 2025 with the global-scale assumptions, but decrease by 28% with the regional-scale assumptions. In the case of B2, the respective changes are minus 20% (global) and minus 59% (regional). In addition, the regional-scale approach leads to more detailed spatial patterns of current and future water withdrawals. This is particularly true for the domestic and the thermoelectric power sectors.

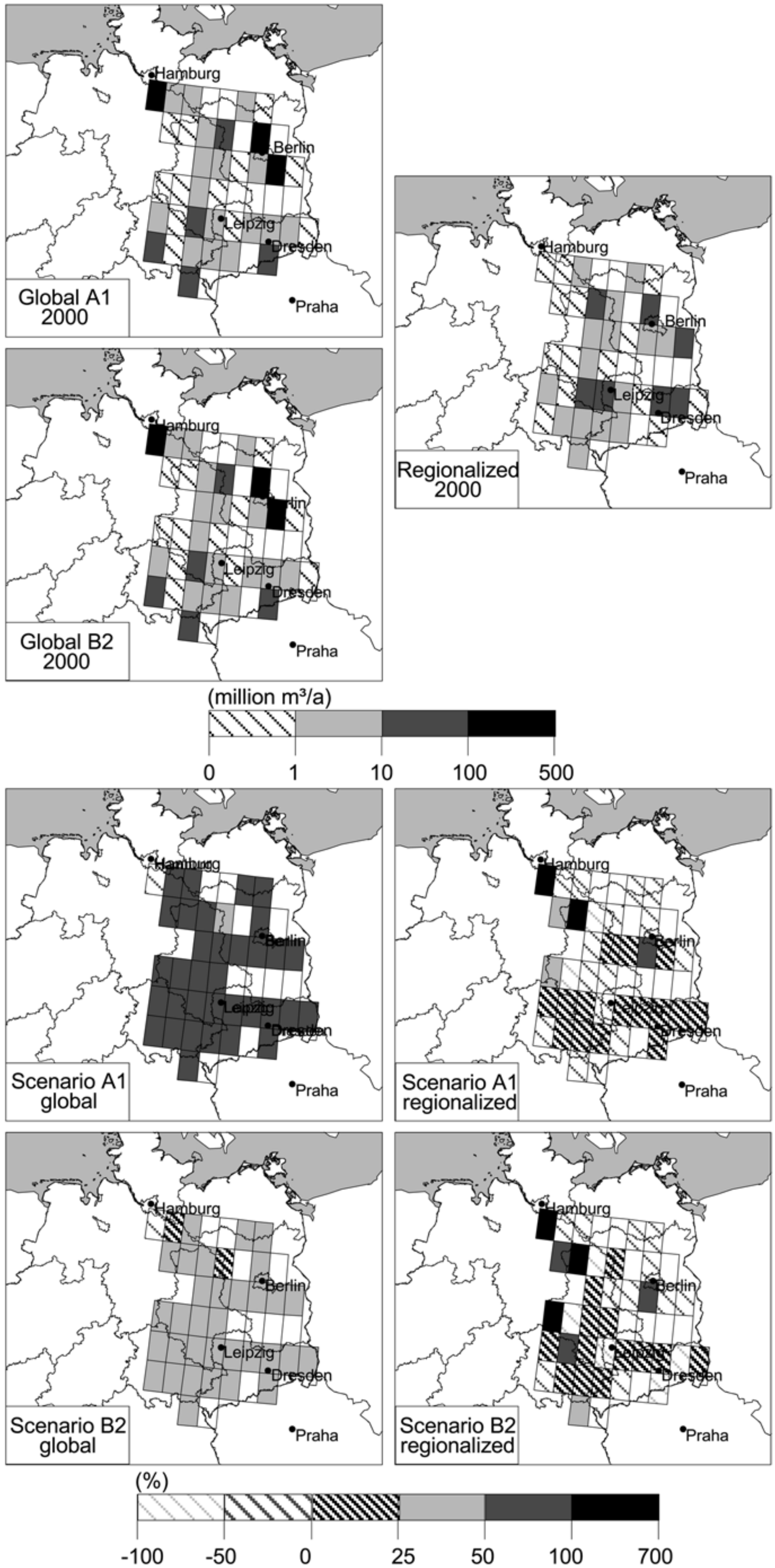

Fig. 4
Thermoelectric power water withdrawals 2000 in the German Elbe Basin upstream of Geesthacht in the global and the regionalized approach (*top*), and change in thermoelectric power water withdrawals in between 2000 and 2025: scenarios A1 and B2 in the global and the regionalized approach (*bottom*)

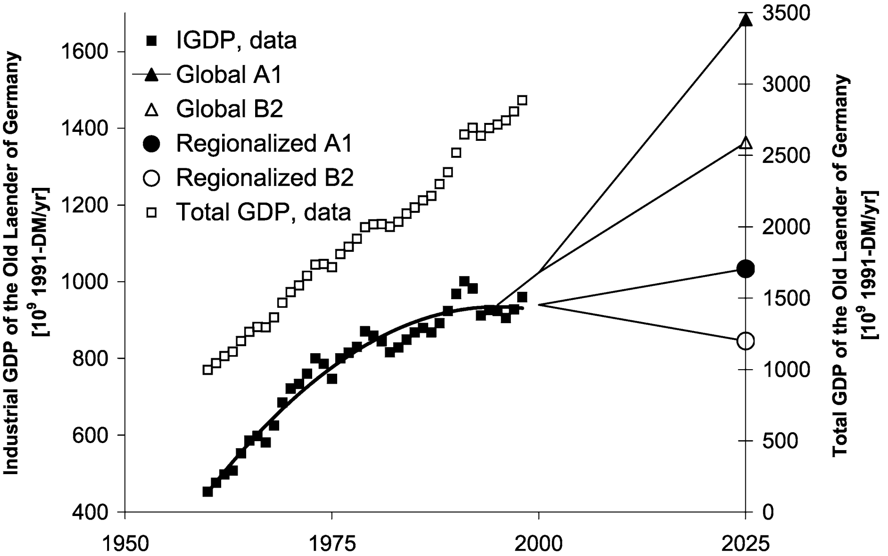

Fig. 5
Historic development of industrial IGDP in the Old Laender of Germany (former West Germany) and assumed changes until 2025: scenarios A1 and B2 in the global and the regionalized approach

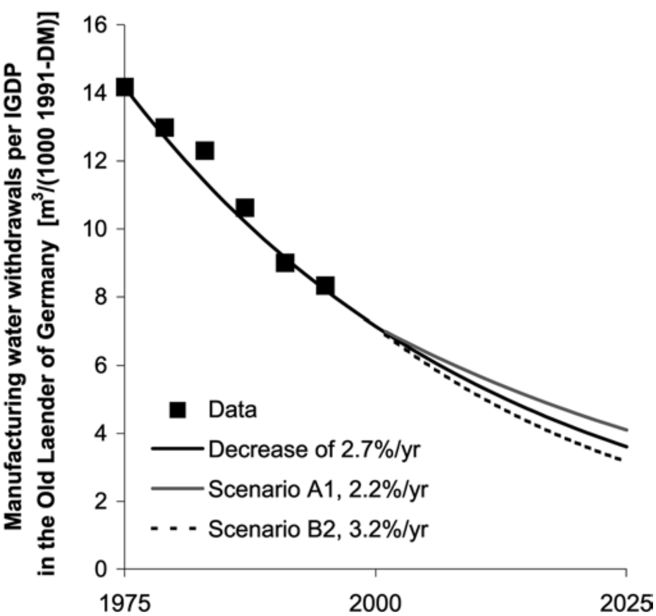

Fig. 6
Historic development of manufacturing water withdrawal intensity in the Old Laender of Germany (former West Germany) and assumed changes until 2025; scenarios A1 and B2 in the global and the regionalized approach

Why does the regional-scale quantitative interpretation of the global-scale storylines lead to more plausible and relevant scenarios of water withdrawals?

We will discuss if and why the regionalized approach leads to more plausible and relevant scenarios than the global approach, based on the type of regional information included and a general discussion of the global SRES scenarios as implemented by the IMAGE Team (2001). The developments of the driving forces and the other inputs of the water use model that determine the future changes of water withdrawals are, for each approach, a quantitative interpretation of the same storylines of future societal development. Certainly, this interpretation depends on both the spatial and temporal scale but also on the subjective thinking of those who performed the quantification. In the global approach, the quantification of the driving forces was done for 17 World regions originally (IMAGE Team 2001), and was downscaled within WaterGAP in very simple ways to the country and the grid cell level. The other model inputs, i.e. technological change rates, were set at a similar or even lower spatial resolution. In the regionalized approach, the driving forces are quantified for much smaller spatial units: population in administrative units that are similar to districts, thermoelectric power production in Laender, and IGDP in the whole of Germany. Technological change rates in the thermoelectric power and manufacturing sectors were set for the whole of Germany, too.

The different spatial scales alone, however, cannot explain why the World region scenarios of IMAGE always show much stronger positive changes in the driving forces than the regionalized approach. The strongly expansive tendencies in the global IMAGE scenarios may be due to the following:

- The SRES scenarios do not take into account the historic development in the 1990s, when a general economic slow down occurred as compared to the decades before (The Economist 2003), and population increases slowed down. However, the SRES scenarios have a time horizon up to the year 2100 (while their application here only considers the time period up to 2025) such that one might argue that decadal-scale developments should not be taken into account in the SRES scenarios. This argument, however, is only correct if the decadal-scale developments are only fluctuations around a mean trend, but not if they are a sign of a structural, long-term change in trend.
- The World region OECD Europe, which includes Germany, is certainly a heterogeneous region that encompasses a lot of dierent countries. The trends in the individual countries or in subunits of countries like the German Elbe Basin might often be dierent from the

overall trend in the World region. Without a detailed study for e.g. all the countries of OECD Europe, we cannot judge if the world region scenarios would be a good aggregation of plausible country scenarios. With respect to thermal energy production, however, it appears likely that the increases as foreseen for OECD Europe are too high for Germany, where an overcapacity for electricity production exists due to energy savings, and where there is a relatively strong tendency for using alternative energies that do not require cooling.
– With respect to population development in B2, the quantification of the SRES scenarios for the World regions in IMAGE does not follow the original SRES B2 quantification, as it is stated in Nakicenovic and Swart (2000, p 194) that the population in B2 follows the medium-fertility projection of UN (1998). This means that the B2 population of Germany in 2025 (global approach) should be equal to the UN (1998) value for 2025 (Eq. 1), which is 2.4% below the UN value for 2000. However, the population of OECD Europe decreases by 2% between 2000 and 2025 according the UN (1998), but increases by 3% according to the IMAGE quantification of B2.

In the regional-scale quantifications of the storylines, regional-specific information (at the scale of Germany, the Laender and smaller subregions) on the historic development of the driving forces up to the year 2000 was considered. On the contrary, in the global approach, mainly the developments in OECD Europe as a whole up to around 1990 were taken into account. This is the major reason why the water withdrawal scenarios of the regionalized approach appear to be more plausible and relevant than those of the global approach.

Conclusions

When global-scale storylines are quantified for a river basin based on either global-scale information or with some additional regional information, different quantitative interpretations with respect to the model parameters and the development of the driving forces result. This is mainly due to different analyses of the historic developments related to the different spatial units for which the analyses are done. In our case, another major reason for the discrepancies are the different time windows for the historic analyses (up to either 1990 or 2000).

In the global-scale quantification of the storylines, the driving forces of water withdrawals, which are based on a quantification of the IPCC SRES scenarios by the IMAGE Team, are assumed to increase much more strongly than appears to be plausible from the regional perspective. This is equally true for population, electricity production and IGDP, the major driving forces of domestic, thermoelectric power and manufacturing water withdrawals, respectively. Note, however, that in our case, the regional-scale quantifications take into account historic developments until 2000, and not only until 1990 (as for the global-scale quantifications), which has an important impact on the plausible future developments of the driving forces. Consequently, the regional-scale quantifications of the storylines lead to much stronger decreases in water withdrawals in the German Elbe River basin up to the year 2025 in (almost) all sectors and scenarios as compared to the global-scale quantifications.

For regional assessments of water use, we recommend to embed the scenario analysis in global storylines like those of the IPCC SRES scenarios. However, we caution against directly applying the quantitative changes of the driving forces, as for example provided by the IMAGE model, to the region of interest. It is preferable to collect some limited additional regional information and then perform regional-scale quantifications of the driving forces (and other model input) that are consistent with the global storylines.

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