FINAL REPORT

1 October 2004

# European Outlook on Water Use


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# ACKNOWLEDGEMENTS

This project was supported by EEA Contract 3241/B2003.EEA.51592, Stéphane Isoard was the responsible Project Manager at the EEA. Data were provided by the RIVM (climate scenarios), Stéphane Isoard (data on water quantity), EUROSTAT (data on water quantity), and all national Statistical Offices who gave their contribution by sending national data on water uses.

The authors wish to thank their colleagues at the Center for Environmental Systems Research, University of Kassel, for assistance of the WaterGAP calculations and preparation of results; in particular, Ellen Teichert and Kerstin Schulze. We are also thankful to Barbara Lübkert for her editorial assistance.

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# EXECUTIVE SUMMARY

This report presents quantitative scenarios of future water use up to 2030 in 30 European countries (the EU plus 5 EEA member countries). Estimates are also presented for future water availability and water stress. Two scenarios were developed – a baseline scenario reflecting a continuation of current trends and a climate policy scenario assuming drastic policies to limit greenhouse gas emissions. The scenarios account for a wide range of driving forces of water use including changing population, economic growth, technological changes, changes in electricity production, transition to new types of power station cooling, structural changes in domestic water use, extent and exploitation of irrigated areas, and climate change.

The WaterGAP model was the tool used to compute the scenarios. After calibration, model estimates compared well to historical trends or base year data on the country level. Nevertheless, scenario estimates have major uncertainties such as the trend in per capita water use in some of the countries undergoing a major economic transition, the emergence of new water-intensive industries, the useful lifetime of different power stations requiring water withdrawals, and the future extent of irrigated areas. Future water outlooks should try to reduce these and other uncertainties.

In a number of ways this study advanced the state-of-the-art of European water use outlooks. First, it used newly available historical data to improve calculations of domestic water use. Second, it employed a new data base on the cooling systems of power stations to improve calculations of water use in the electricity production sector. Third, for the first time detailed calculations of water use in several manufacturing sectors were performed. Finally, calculations of water use in agriculture were tested against independent national estimates.

Some of the study's major findings are:

- *The trend of total European water withdrawals is downward*. Under the two scenarios, total water withdrawals in the Europe-30 countries decrease by approximately 11% between 2000 and 2030. 18 of 30 European countries have a decreasing trend. These results are intermediate compared to previously published estimates.
- *The profile of water use in Europe is changing.* In *Northern Europe* the most important water-using sector is now the electricity production sector but in the future it will be the manufacturing and domestic sectors (with low to medium certainty)[1]. In the *New EU Member States,* the most important sector is the electricity production sector but this will be replaced by the domestic sector (with low certainty). Water withdrawals in *Southern Europe* and in the *EU Candidate States* are currently dominated by agricultural water use and this will remain so (with medium to high certainty).
- *A multi-sector approach is needed*. Since no single sector will dominate water use in Europe, it is not advisable to focus water conservation efforts in Europe on any individual sector. Therefore, the European Water Framework Directive offers a good instrument by setting environmental quality goals and requiring countries to implement integrated water management strategies to attain these goals. These strategies allow different countries to address different water use sectors that are dominant in these countries.
- *A river basin approach is also needed*. For administrative and technical reasons it makes sense to carry out water conservation programs on the country-scale. However, the river basin approach required by the Water Framework Directive makes it also necessary to address water use issues (including the reduction of water use and treatment of runoff from water use) on the river basin scale.

[1] This and other certainty statements presented in the text are expert judgments.

- *A major unknown is future domestic water use in new EU Member States*. Since per capita water use is now relatively low in many of these states, an intervention now to encourage water conservation could avoid large increases in the domestic water use in these countries (low to medium certainty), and thereby help countries to meet the goals set forth in the Water Framework Directive.
- *Water use in the electricity production sector is expected (with medium certainty) to significantly decrease during the scenario period.* It is apparent (with medium certainty) that requiring the use of tower cooling in all new power stations is an effective strategy for reducing overall water withdrawals.
- *Technological development lowers water use*. We expect (with medium certainty) that technological improvements in water use sectors will continue to lead to significant improvements in the efficiency of water use.
- *Irrigation water withdrawals may increase in the South.* A combination of drier/warmer climate and expanding irrigated area may increase water withdrawals for agriculture in the South (low to medium uncertainty). However, this increasing tendency will be dampened somewhat by continuing improvements in the water use efficiency of irrigation.
- *Increase in irrigated areas and/or irrigation water withdrawals may deteriorate the ecological and chemical status of freshwater bodies.* The increase of irrigation withdrawals in the South may lead (with medium certainty) to an increase of contaminated agricultural runoff to surface and groundwater. Countries will have to take this into account when implementing the Water Framework Directive.
- *Climate policies will lead to lower water use in the electricity production sector (medium to high certainty).* The emission reductions assumed in the climate policy scenario do not dampen climate change very much in the coming decades (because of inertia in the climate system). However, climate policies could have a more noticeable effect on the future magnitude and profile of energy production and thereby on the volume of water used in the electricity production sector. Since more non-thermal renewable energy will be used, the capacity of thermal power plants will decline and less cooling water will be needed in the electricity sector.

# 1. INTRODUCTION

A key responsibility of the European Environment Agency (EEA) is to periodically assess the current and future state of the environment in Europe. This assessment is contained in a comprehensive 'State of the Environment and Outlook' report published every five years. It is obvious that such a comprehensive assessment of Europe's environment should also assess the state of Europe's freshwater resources. Of particular concern to society is the use of these water resources. Besides satisfying basic needs for drinking water and sanitation, water in the household also supports other needs such as housecleaning, dishwashing, clothes washing, and landscaping, Water plays a vital role in Europe's economy. It is needed to produce steam and to cool turbines in thermal power stations, and is a necessary input for the manufacturing industry where it is used to produce power, as input to various industrial processes, or as a basic raw material. Much of Europe's agricultural production comes from irrigated fields, and irrigation requires extensive withdrawals of freshwater. Not only is water use critical from the standpoint of society, but the use of water is also an important determinant of water availability and quality in Europe's freshwater system. For that reason the future of water use will have an important influence of the future state of the continent's inland fisheries and freshwater ecosystems.

Because of the importance of water use in Europe, the EEA plans to include an 'outlook' of future water use in Europe in their next State of the Environment and Outlook report to be published in 2005.

## 1.1 Objectives

This report is prepared on behalf of the EEA as a contribution to the next State of the Environment and Outlook Report 2005 (SoEOR2005). In addition, it can also provide valuable information when implementing the European Water Framework Directive. In particular this report provides background information for the outlook on water use in Europe up to 2030. The objectives of the study are to:

(a) **Produce quantitative estimates of water use in Europe up to 2030.** In this study, we use the WaterGAP model (Water – Global Assessment and Prognosis) for modeling European water use and water availability. This model provides a framework for taking into account the impact of major driving forces on future water use and availability in Europe.

(b) **Explain the effects of changes in driving forces on future water use.** In this report, we analyse and explain the impact of key economic, demographic, technological and other driving forces on the future of water use in Europe. This includes the impact of climate change on irrigated agriculture.

(c) **Assess the impact of climate change and changing water use on future water availability and water stress.** Although the emphasis of this study is on future water use, we also analyse the possible effects of climate change and future water use on water availability and water stress.

(d) **Contribute to the development of a medium-term systematic approach to water use outlooks.** The methodology presented in this study can be a major component of a systematic approach for periodically assessing Europe's water use.

## 1.2 Scope

Scenarios in this report cover a 'medium' time horizon, from 2000 (base year) to 2030. Year 2000 is used as a base year because of the availability of data from that year. Most scenario assumptions and results are given in 5-year intervals.

Data are produced for 30 European countries which we refer to in this report as the 'Europe-30'. These countries are listed in Table 1 and shown in Figure 1.

For reporting purposes we sometimes summarize scenario results into four regions (Table 1). These regions are based on a pragmatic combination of geographic and political factors. Due to lack of data Iceland and Liechtenstein are not included in the study.

Table 1. European countries and reporting regions included in this report.

| Reporting region | Countries |
|---|---|
| Northern Europe | Austria, Belgium, Denmark, Finland, Germany, Ireland, Luxembourg, The Netherlands, Sweden, United Kingdom, Norway, Switzerland |
| Southern Europe | France, Greece, Italy, Portugal, Spain |
| New EU Member States | Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovak Republic, Slovenia |
| EU Candidate States | Bulgaria, Romania, Turkey |
| Europe-30 | all countries listed above |

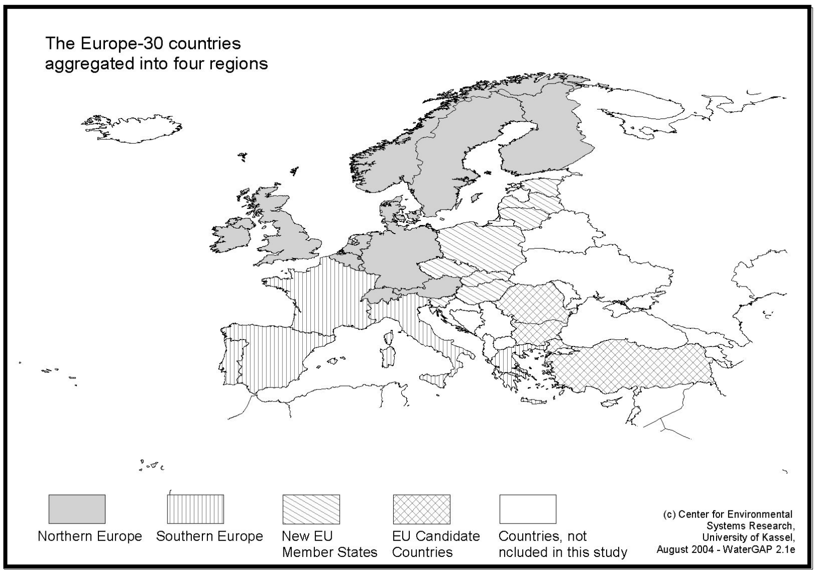


Figure 1. 'Europe-30' region covered in this report.

Estimates of future water use are presented on both the regional, country and sectoral level. In this report we use the following conventions for water sectors:

- *Domestic* – Water use of households and small businesses.
- *Manufacturing* – Water use in all facilities producing industrial products.
- *Electricity power production* – Water use in all facilities producing electrical power except for the power producing facilities of the manufacturing water sector.
- *Agriculture* – Water consumed by irrigation and used by livestock.

As noted above, we analyse not only changes in water use but also changes in water availability and water stress. 'Water availability' is used here to mean the total river discharge in a river basin which is made up of surface runoff and groundwater recharge.

Water stress is taken here as a measure of the amount of pressure put on water resources and aquatic ecosystems by the users of these resources, including municipalities, industries, power plants and agricultural users (see, for example, Alcamo et al., 2000; Vörösmarty et al., 2000; Cosgrove and Rijsberman, 2000). Here we use a conventional measure of water stress, the withdrawal-to-availability ratio. This is the ratio of total annual water withdrawals devided by the total water availability.

Because water availability and water stress vary so strongly spatially, it is not meaningful to compute them on the country or sectoral level as we do for water use. Instead we compute them on the grid and river basin level.

# 2. DRIVING FORCES AND OTHER FACTORS OF WATER USE

Water use in Europe is divided between four important sectors: domestic, electricity, manufacturing, and agriculture (Figure 2). A wide range of factors influence water use in these sectors as we describe in the following paragraphs.

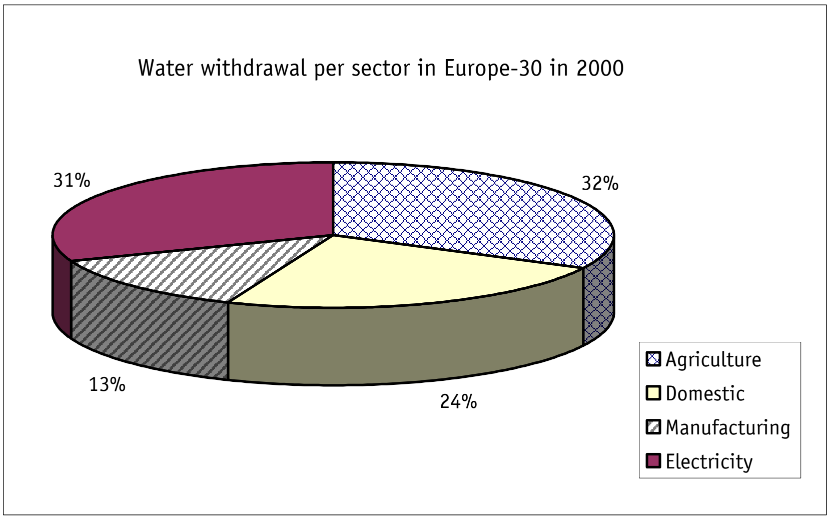


Figure 2. Percentage share of sectoral-specific water use in the Europe-30 region for the year 2000. Sources: EUROSTAT[2] and national Statistical Offices.

## 2.1 Domestic Sector

The domestic sector accounts for about 24 percent of total water withdrawn in the Europe-30 in 2000 (Figure 2). This sector usually includes households and businesses but not manufacturing or electrical production facilities.

The intensity of water use in households [$m^3$/(cap·year)] depends on many factors including the amount of household income which is related to the amount of water-using appliances in a household (Höglund, 1999; Dalhuisen et al., 2003). Another factor is the size of the household since it is usually observed that there are economies of scale in water usage per person in larger households (Björnsen, 1993; Höglund, 1999). Other demographic factors such as the age distribution of the population also apparently affect the amount of water use since some age groups tend to have higher per capita water usage than others. There is also an observed difference between water consumption patterns in urban versus rural areas.

Higher water prices are also known to dampen the demand for water in households and businesses (Hansen, 1994; Dalhuisen et al., 2003). Hence changing water prices are a driving force of water use in this sector. On the other hand the relationship between prices and demand are highly variable because household and business outlays for water are normally only a very small fraction of their total income, and because prices and price structures vary tremendously across Europe. Figure 3 vividly illustrates the wide variability between average domestic water prices and water use across Europe. Currently countries with roughly the same per capita water use have a factor of six difference in water prices.

[2] EUROSTAT. Statistical Office of the European Communities.

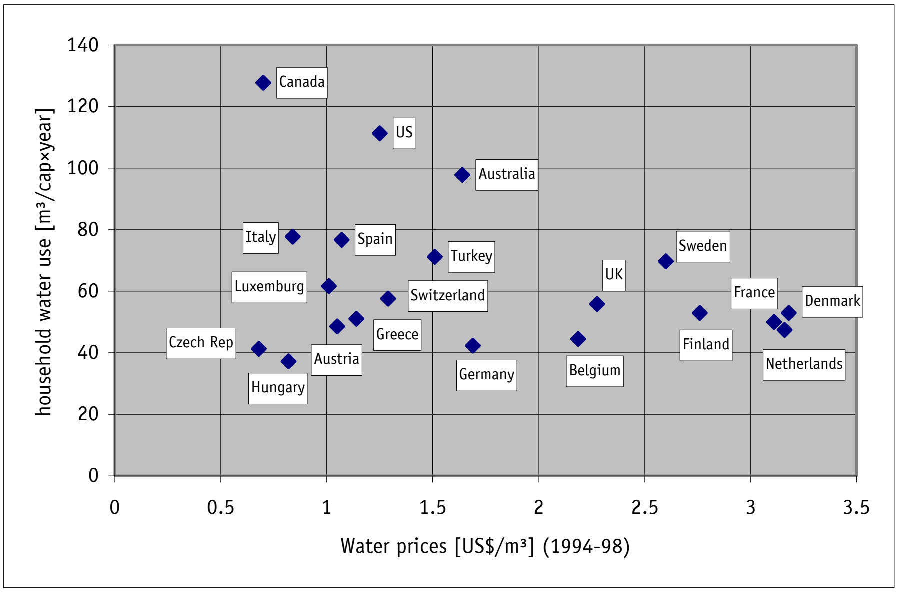


Figure 3. Household water use and water prices in OECD countries. Source: OECD (1999).

Moreover the paucity of data makes it impossible to generalize about the relationship of price and demand for all of Europe. Of course a decisive factor in the domestic sector is not only how much water is used per capita but the size of the population using water. The amount of water withdrawn for domestic water supply will also depend on the amount of losses in the water distribution system. These losses vary considerably between European countries; they range from less than 5% in Germany to 50% in Bulgaria in 1999 (EEA, 2003). Such high percentages of water lost can be effectively reduced with new piping systems.

## 2.2 Electricity Production Sector

This sector accounts for about 31 percent of total water withdrawn in the Europe-30 in 2000 (Figure 2). Within the electricity production sector thermal power plants account for most of the water withdrawn while the amount of water required by wind, solar, and hydroelectric power stations is relatively small. (Sometimes the water evaporated in reservoirs of hydroelectric power stations are reckoned as water requirements of electricity production, but we do not take this into account in our study). In this context, a thermal power plant is a power-generating plant which uses heat to produce energy. Such plants may burn fossil fuels, biomass or use nuclear energy to produce the necessary thermal energy (GEMET, 2000).

The rate of water withdrawals per unit electricity generated is much higher in power stations using traditional once-through flow cooling than in the more contemporary tower cooled plants. Hence one of the principal driving forces of water use in the electricity production is the rate at which plants with once-through flow cooling are being replaced by tower cooled plants. Obviously, another crucial driving force is the magnitude of electricity produced at thermal power plants and how this will change in the future.

## 2.3 Manufacturing Sector

Manufacturing activity accounts for about 13 percent of the total water withdrawn in the Europe-30 in 2000 (Figure 2). The intensity of water use [$m^3$/(1000 € gross value added)] varies tremendously from industry to industry. For example it is around 138 $m^3$/(1000 € gross value added) in the paper industry and only 1 $m^3$/(1000 € gross value added) in the textile industry (values with respect to

Finland). Indeed some industries are clearly much more water-intensive than others. These include not only the paper industry, but also the food industry, the chemical industry and the production of mineral products.

As in the domestic sector, the price of water is known to influence water use in industry. But normally only a small fraction of the operating costs of a firm goes to water costs. Moreover, data are inadequate to generalize about the relationship between water price and water usage in the entire manufacturing sector of Europe.

The main driving force of water use in the manufacturing sector is the change in the output of water-intensive industries (measured, for example, in units of the gross value added of products generated in a particular industry). Hence structural changes in the profile of industrial production – what will be produced and how much – will profoundly affect the total water use in this sector. For example, the increasing influence of water-intensive industries such as electronics, will affect overall water use by manufacturing.

## 2.4 Agriculture Sector

Agriculture accounts for about 32 percent of the total water withdrawn in the Europe-30 in 2000 whereas 1 percent accounts for livestock water use and 31 percent account for irrigation (Figure 2). The two main needs for water use in this sector are irrigation, which accounts for most of the water used in this sector, followed by livestock water use.

The amount of water required for irrigating a hectare of a particular crop depends especially on the water retention characteristics of crops and soil, and local precipitation, temperature, wind, and other climatic conditions. To estimate the country scale water withdrawn for irrigation, we must multiply the per hectare crop requirements for water by the actual area irrigated and then divide this by the irrigation 'field' efficiency. Hence changes in the extent of irrigated land and in the improvement of irrigation efficiency will also drive changes in the amount of water withdrawn for irrigation. Figure 4 presents the increase of area equipped for irrigation in Turkey, an example of rapidly expanding irrigated land. Here the extent of irrigated land increased three-fold between the 1960s and the end of the century. In general the expansion of irrigated area in Europe shows a clear upward trend between 1960 and 1990 (Baldock et al. 2000) and declined or stabilized in the 1990s.

The 'area equipped for irrigation' as a percent of local arable land is depicted on a European grid (base year 1995) in Figure 5. The density of irrigated land is particularly high in southeast Romania and northern Italy. High concentrations of irrigated land are also found in Turkey, Bulgaria, Greece, and Spain.

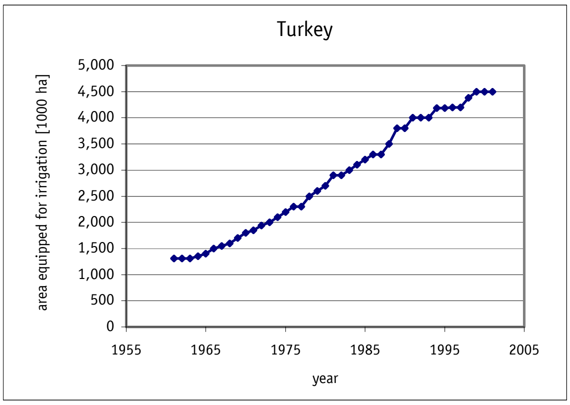


Figure 4. Extent of irrigated land in Turkey between 1961 and 2001. These data depict the surface area equipped for irrigation but not necessarily irrigated every year. Source: FAO (2004).

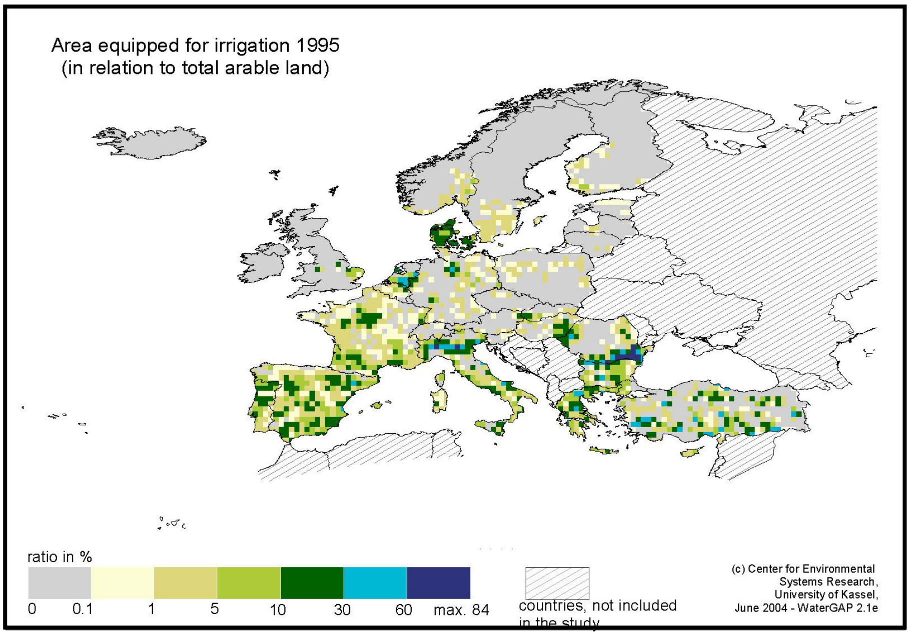


Figure 5. Area equipped for irrigation versus total arable land by country as used in the WaterGAP model. Source: Döll and Siebert (2000).

Livestock also are major users of water in many countries and in Northern Europe the amount of water used for livestock is almost as high as the amount of water used for irrigation. The main driving forces of water use by livestock in a particular area are the type and number of livestock in a given area.

## 2.5 Driving Forces Included in this Study

While Sections 2.1 to 2.4 give an overview of most of the important factors that drive changes in water use, here we review the driving forces that are taken into account in this report.

Although it would be desirable to include all of the driving forces described in Sections 2.1 through 2.4 in a study of future European water use, it is not feasible here for three reasons. First of all, while some Europe-30 countries have detailed data on driving forces, most do not. Second, the short time available for this study (11 months) made it infeasible to identify and analyse large amounts of new data (although some new data were used as we describe in Section 3.3) In Chapter 8 we recommend specific data that should be collected to improved future water use outlooks. Third, even if more driving force data were available for estimating future water use, current models do not reliably describe the relationship between all driving forces and water use. For example, it is currently not possible to model the relationship between future household age structure and future water use on the European scale. More fundamental work is needed in developing comprehensive and realistic water use models that apply to all European countries.

Although not all important driving forces could be taken into account, this study does take into account a very wide range of important driving forces. These driving forces are incorporated in the calculations of the WaterGAP model which is used here to compute quantitative scenarios. The WaterGAP model is described in Section 3.2. Here, we list some of the more important driving forces incorporated into WaterGAP:

**(a) Population:** The number of future water users will obviously determine the magnitude of water use in the domestic sector. Population assumptions are used in the WaterGAP model to compute water use in the domestic sector. (Other variables are also important as explained in Section 3.2.3). Population is also taken into account as an indirect driving force of water use in other sectors. For example, the assumptions for future electricity use (used to compute future water use by power plants) are based on future population estimates among other factors. Likewise, changing population is indirectly included in estimates of future irrigated land and emissions of greenhouse gases (which drives future climate change).

**(b) Per Capita Income (GDP/cap):** From historical trends of water use in Europe it has been observed that water use tends to increase as a country becomes wealthier and then it levels off and in some cases declines. Hence changing income is an important driving force of future water use. Per capita income is used in the WaterGAP model to compute per capita water use in the domestic sector. (Other variables are also important as described in Section 3.2.3). Income is an indirect driver of water use in the electricity production sector because assumptions for future electricity use (used to compute future water use by power plants) are based on assumptions about future income, population, and other factors.

**(c) Thermal electricity production:** The volume of water needed at thermal power plants is driven by the production of electricity at these facilities. The WaterGAP model uses assumptions about future thermal electricity production (and other variables as explained in Section 3.2.4) to drive calculations of water use in the electricity production sector. In this context, thermal power plants may burn fossil fuels, biomass or use nuclear energy to produce the necessary thermal energy.

**(d) Type of cooling system:** Previously we have mentioned that the type of cooling system in a power station (once-through or tower) is an important determinant of the station's water use. This driving force (and others as explained in Section 3.2.4) is taken into account by the WaterGAP model to compute water use in the electricity production sector.

**(e) Gross value added:** The magnitude of manufacturing output in a particular industry is an important determinant of water use by the manufacturing industry. The WaterGAP model uses assumptions of future manufacturing output (in the form of gross value added of products) to compute water use in the manufacturing industry sector. (See Section 3.2.5).

**(f) Irrigated areas:** An obviously important driving force of irrigation water use is the extent of irrigated land. The WaterGAP model uses assumptions about the future coverage of irrigated area (and other data, as described in Section 3.2.6) to compute water use for irrigation.

**(g) Climate change:** Not only the extent of irrigated land, but also climate is an important driver of irrigation water requirements. The WaterGAP model takes into account local climate (see Section 3.2.6) in calculating irrigation water requirements.

**(h) Number of livestock:** Water use by livestock in a country is obviously driven, among other factors, by the number of livestock. This driving force is taken into account by WaterGAP to compute livestock water use. (See Section 3.2.7).

**(i) Technological changes leading to improvements in water use efficiency:** This driving force is particularly important because it tends to reduce water use whereas the preceding driving forces in most cases increase water use. The impact of technological change on improving water use efficiency is taken into account in all sectors. (See Section 3.2.4).

# 3. METHODOLOGY

In order to attain the goals of this study (estimating future water use and availability for 30 separate European countries), we decided to combine two approaches: a scenario approach and a modeling approach. The scenario approach was chosen to combine qualitative images of possible futures with quantitative data of water use in Europe. However, due to the very short time available (11 months) for the study, we could only develop two alternative scenarios. The modeling approach was selected to quantify the current and future European water use in a consistent way and thus support the scenarios. Here, we selected the existing WaterGAP model and focused on the most critical driving forces although we recognize that there are many more driving forces that have an influence on future water use. We further used newly available European data to improve previous European-scale estimates of future water use in the domestic, manufacturing, and electricity production sectors.

## 3.1 The Scenario Approach

The basic methodology of this study is 'scenario analysis' which has become a common tool for assessing future trends of environmental problems, particularly those that are complex and poorly described. The aim of scenario analysis is not to predict the future but rather to support the understanding of complex systems, to examine the interactions of trends within a given domain and time frame, and to identify critical issues. In this sense, scenarios provide images of possible futures and complement conventional forecasting and simulation. In order to be meaningful to science and policy, scenarios must be based on a set of assumptions and/or theories of the key relationships and driving forces of change that are coherent, internally consistent, reproducible and plausible (IPCC, 2000). If these requirements are fulfilled, scenarios can provide useful results for decision making.

The scenario approach is used in this study to produce two main scenarios of water use – a **baseline scenario** and a **climate policy scenario**. Variants of these scenarios are also produced for analysing the importance of the various driving forces.

There are different types of scenarios that can be built to describe the future of water use in Europe. One way of classifying scenarios is into *qualitative* and *quantitative* categories. *Qualitative* scenarios describe in words or other non-numerical form the trends of future water use, whereas *quantitative* scenarios provide numerical information about future changes in water use. The appropriate type of scenario depends on the goals of the scenario exercise. In this study, the EEA needs numerical estimates of future water use indicators for its regular environmental reporting and assessment so that the quantititive trends of water use indicators can be compared to the trends of other environmental indicators. Hence, our scenario approach here is to develop *quantitative* scenarios that provide the numerical data needed for the EEA assessments. It is important to note, however, that under other circumstances and objectives it might be equally useful to develop *qualitative* scenarios or *combined* qualitative-quantitative scenarios.

## 3.2 Modeling Approach

### 3.2.1 Introduction

In order to build quantitative scenarios of future water use, it is necessary to use a suitable instrument for quantifying current and future water use. The instrument used in this study is the WaterGAP model (Alcamo et al., 2003a, b; Döll et al., 2003). It has been applied in several international assessments of European and world water resources:

- *EuroWasser*: first assessment of the impacts of climate change on both the frequency of droughts and occurrence of flooding in Europe (Lehner et al., 2001).
- *UNEP Global Environmental Outlook 3*: assessment of the impact of climate change and socio-economic changes on water resources in Europe and the world for the time horizon between 2002 and 2032 (UNEP, 2002).
- *Water for People – Water for Life.* The United Nations World Water Development Report: analyses of the current water situation in Europe and the world (UNESCO, 2003).
- *International Dialogue on Water and Climate*: assessment of the impact of climate change and variability on water resources in Europe and the world (Kabat and van Schaik, 2002).
- *Millennium Ecosystem Assessment*: assessment of ecosystem services provided by the world's freshwater system.
- *World Water Vision Exercise of the World Water Commission*: assessment of the impact of different economic and population pathways on water use in Europe and the world (Alcamo et al., 2000).
- *World in Transition: Ways towards sustainable management of freshwater resources:* assessment of the future water use and water availability in Europe and the world up to 2025 (WBGU, 1999).

WaterGAP is used to compute both water use and availability on different scales within Europe. It consists of two main components: a Global Hydrology Model to simulate the terrestrial water cycle and a Global Water Use Model to estimate water withdrawals and consumption. The Global Water Use Model consists of five submodels to determine both the water withdrawals and water consumption in the household, electricity, manufacturing, irrigation, and livestock sector. In this context, water withdrawals depict the total amount of water used in each sector while the consumptive water use indicates the part of withdrawn water that is lost to evapotranspiration, consumed by industrial products or humans. For most water use sectors, only a small amount of water is actually consumed, whereas most of the water withdrawn is returned, probably with reduced quality, to the environment for subsequent use.

### 3.2.2 WaterGAP: Water Availability

The aim of the Global Hydrology Model is to simulate the characteristic macro-scale behavior of the terrestrial water cycle in order to estimate water availability. Herein, water availability is defined as the total river discharge, which is the sum of surface runoff and groundwater recharge.

The model covers most of the terrestrial surface of the earth with a geographic grid containing 66896 grid cells with a size of 0.5° by 0.5° (geographical longitude and latitude, respectively) which covers the entire global land area except Antarctica (IMAGE 2.2 land mask). For each grid cell, information on the fraction of land area and of freshwater area (lakes, reservoirs, and wetlands) is available. Land cover is assumed to be homogeneous within each grid cell. The upstream/downstream relationship among the grid cells is defined by a global drainage direction map (DDM30) which indicates the drainage direction of surface water (Döll and Lehner, 2001). Thus, each individual grid cell is assigned to a drainage basin.

The model calculates a daily vertical water balance for each grid cell, separately for the fraction of land area and for the freshwater area. The vertical water balance of land areas is described by a canopy water balance (representing interception) and a soil water balance. The canopy water balance determines which part of the precipitation is intercepted (evaporates) by the canopy, and which part reaches the soil. The model balances incoming precipitation with actual evapotranspiration and total runoff. Then, the total runoff from land area is divided into surface runoff and groundwater recharge, using information on cell-specific slope characteristics, soil texture, hydrogeology, and the existence of permafrost and glaciers. Aside from calculating the land area water balance, a vertical water balance for the freshwater areas (lakes, reservoirs, and wetlands) is calculated. The runoff from open freshwater bodies is defined as the difference between effective precipitation and potential evaporation. Finally, the total runoff of a grid cell is the sum of the runoff from land and from open freshwater bodies. In the model, it is distinguished between 'local' and 'global' open freshwater bodies. In contrast to the local lakes and wetlands, which only consider flow-through processes within a cell, global open freshwater bodies are additionally flowed through from neighboring cells. The runoff produced within the cell and the volume of water coming from upstream cells is transported through a series of storages representing the groundwater, lakes, reservoirs, wetlands, and rivers. Then, the total cell discharge is routed along the drainage direction map (DDM30) to the next downstream cell.

The hydrological model requires data about precipitation, potential evapotranspiration, and temperature for each grid cell. As climate input, the data by New et al. (2000) provide observed monthly values of precipitation, temperature, number of wet days, average daily sunshine hours, cloudiness, and global radiation, interpolated onto a 0.5° by 0.5° grid and for each of the years 1901 to 1995. In the Global Hydrology Model, the calculations are performed on a daily resolution. Synthetic daily precipitation values are generated using monthly precipitation values and the number of wet days per month, the monthly precipitation is distributed equally to all rainy days. In order to take into account the effect of snow, effective precipitation, which is the sum of precipitation as rainfall and snowmelt, is calculated using a degree-day algorithm. Future climate is simulated by changing the monthly temperature and precipitation observed in the so-called climate normal period (1961-1990) according to future climate projections from general circulation models (GCMs).

The Global Hydrology Model is calibrated against long-term average annual discharges measured at 724 gauging stations world-wide, the drainage areas of which cover half the global land area except Greenland and Antarctica. In Europe, the model has been calibrated in 126 drainage basins, covering 65% of Europe's land area (Lehner et al., 2001).

### 3.2.3 WaterGAP: Domestic Water Use

The domestic water use model calculates the annual withdrawals and consumption of water by households and small businesses. The basic approach of this submodel is to first compute the domestic water use intensity [$m^3/(cap\cdot year)$] and then to multiply this by the population of water users. The main concept of the model follows the approach described in Alcamo et al. (2000, 2003a, b). Changes in water use intensity can be expressed by *structural changes* and *technological changes.*

To calculate total water withdrawals in the domestic sector, the net water use intensity is multiplied by country population. Country-wide values are allocated to grid cells within the country based on population density which, in turn, is aggregated from the CIESIN world population density map 2000 (Global Population Density Map, 2.5' x 2.5' resolution) (CIESIN, 2001).

*Structural Change*

The concept of structural change, as it is used to estimate domestic water use, is based on the observation that as average income increases, water consumers tend at first towards a more water-intensive lifestyle (washing machines, dishwashers, more bathrooms, more car-washing). Finally a maximum level is reached after which per capita water use is either stable or declines. This structural change is represented in the *baseline scenario* by a sigmoid curve which indicates how water use intensity (per capita water use) changes with income (GDP/cap). (See Figure 6).

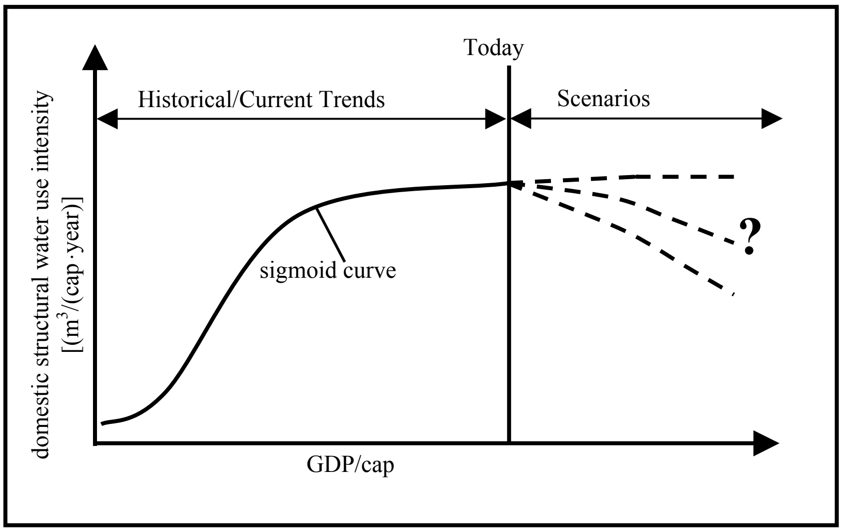


Figure 6. Conceptual model of structural change in the domestic sector.

The relationship between water intensity and income is derived for each country by fitting a sigmoid curve to historical data from each country:

$$DSWI = DWSI_{\min} + \alpha \cdot \left(1 - e^{-\gamma \cdot GDP^2}\right) \qquad \left[\frac{m^3}{cap \cdot year}\right] \qquad (1)$$

where:

DSWI = Domestic structural water use intensity for each country [$m^3$/(cap·year)]

GDP = Annual gross domestic product in [Euro/(cap · year)]

$\gamma$ = Fitting parameter for each country, fitted using historical data [1/Euro²]

$DWSI_{min}$ = Minimum water use intensity for human activities [$m^3$/(cap·year)]. Set to 18 $m^3$/(cap·year) for each country, corresponding to Gleick (1996)

$\alpha$ = Water use intensity parameter for each country, fitted using historical data [$m^3$/(cap·year)]

Data for these curves were provided by the EEA, EUROSTAT, and other national statistical agencies of the EEA member states covering up to forty years in the past. Figure 7 gives an example of the fitted curve for Germany. (Note that the water intensities shown in Figure 7 are not the observed water intensities. These are adjusted data from which the estimated effect of technological improvements in water use efficiency on past water intensities have been subtracted. Hence the water intensities in these graphs are somewhat higher than the observed per capita water use.)

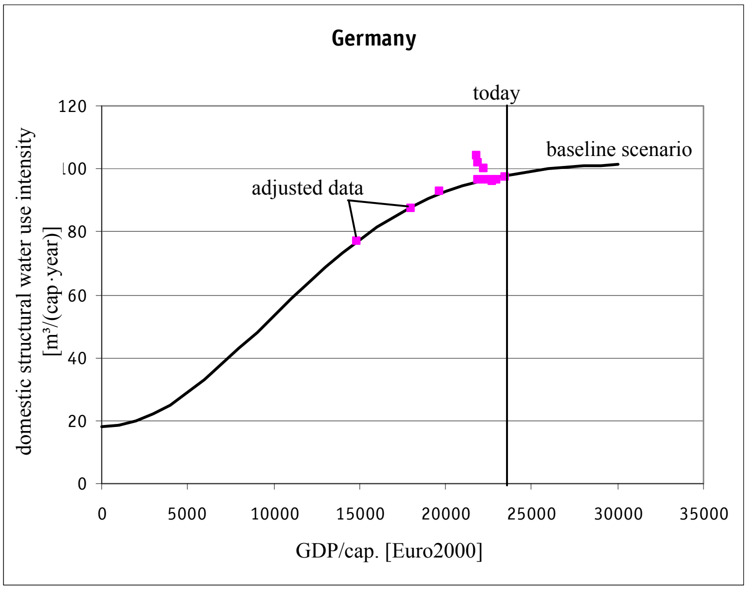


Figure 7. Structural change in water intensity in the domestic sector in Germany. Source: DESTATIS[3].

To evaluate the fit of the curves, we use the index of agreement of Willmott (1984) which is suitable for evaluating sigmoid curves. The resulting index of agreement for each country is given in Table 2. The index of agreement varies between 0.0 and 1.0, where a value of 1.0 expresses a perfect agreement between the observed and calculated values, and 0 describes a complete disagreement. The index ranges from 0.47 for Romania to 0.99 for the United Kingdom and Italy. For 70% of the countries considered in this study, the index of agreement is higher than 0.80, for 50% the index is higher than 0.90. (See Table 2 and Appendix A). The calibrated curves were used for almost all European countries to compute future water use intensity and water withdrawals according to Equation (1).

Table 2. Index of agreement for structural change model of domestic water intensity.

| country | Index of agreement | country | Index of agreement |
|---|---|---|---|
| Austria | 0.96 | Lithuania | — |
| Belgium | 0.91 | Luxembourg | 0.68 |
| Bulgaria | 0.66 | Malta | 0.82 |
| Cyprus | 0.90 | The Netherlands | 0.97 |
| Czech Republic | — | Norway | 0.83 |
| Denmark | 0.91 | Poland | — |
| Estonia | — | Portugal | 0.73 |
| Finland | 0.91 | Romania | 0.47 |
| France | 0.83 | Slovak Republic | — |
| Germany | 0.94 | Slovenia | 0.86 |
| Greece | 0.70 | Spain | 0.78 |
| Hungary | — | Sweden | 0.85 |
| Ireland | 0.96 | Switzerland | 0.69 |
| Italy | 0.99 | Turkey | — |
| Latvia | — | United Kingdom | 0.99 |

[3] DESTATIS. Federal Statistical Office, Germany.

The curves could not be used for the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, the Slovak Republic, and Turkey whose historical data could not be fitted to a sigmoid curve because the trend of their data shows a sharp break after 1990. Therefore, we used the following alternative approach. Water use patterns in these countries drastically changed after 1990. For all countries but Turkey, this could be explained by the transition from a socialist to a market economy; in the case of Turkey, historical data show the same trend. This break in the temporal trend means that there is no clear relationship between per capita water use and GDP/cap. Hence historical data do not provide insight into the direction of per capita water use under future changes in the economy. We must therefore assume a trend in future per capita water use *a priori*.

Two extreme assumptions are shown in Figure 8 for the example of the Czech Republic. The bottom flat curve assumes that domestic water use will remain at its year 2000 level despite strong economic growth projected up to 2030. This might be achieved if water conservation programs can keep pace with the pressure to use more water because of wealthier lifestyles. The upper steep curve in Figure 8 assumes that per capita water use in the Czech Republic will converge by 2030 with the average value of other Europe-30 countries. Under this assumption per capita water use in the Czech Republic will regain eventually its high level of 1990. These two assumptions ‘bracket’ a plausible range of possibilities for changing per capita water use. For the *baseline scenario* we assume that the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, the Slovak Republic, and Turkey follow the *upper curve* in Figure 8 (adjusted for the historical data trends in each of these countries.). That is, we assume that water intensity in the domestic sector (per capita water use) converges with the pan-European average in 2030. In Chapter 7, we use the lower curve in Figure 8 to compute water use and compare it with the baseline scenario as a sensitivity analysis.

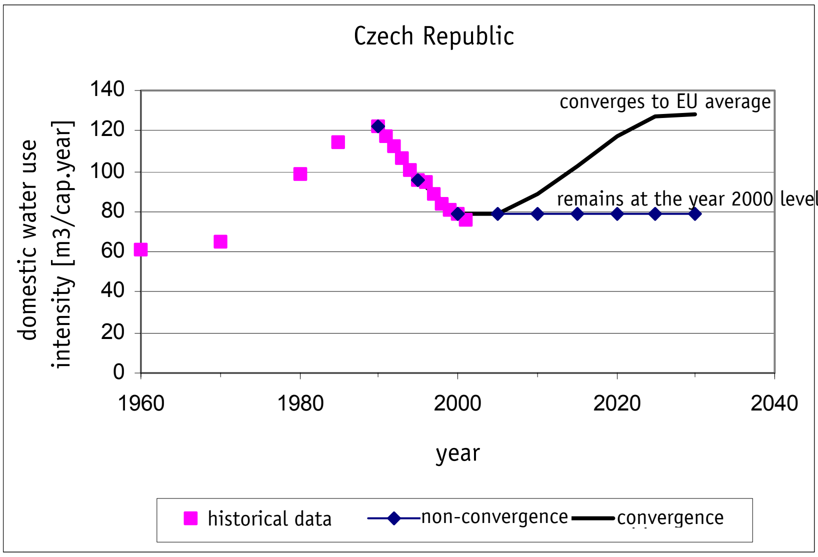


Figure 8. Temporal trend of per capita water use in the domestic sector in the Czech Republic. Source: EUROSTAT.

*Technological Change*

The concept of technological change is used in the domestic sector and in other sectors to account for the important effect that improving technology tends to improve water use efficiency. Continuous improvements in technology make appliances and industrial processes more water efficient and hence, contribute to reductions in water use. (See Figure 9).

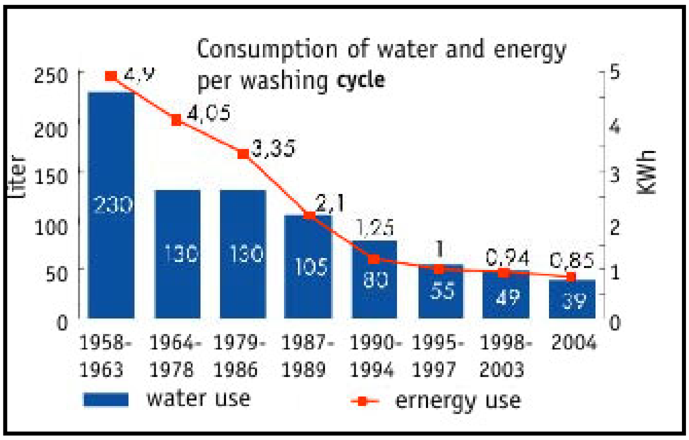


Figure 9. Technological improvements leading to higher water use efficiency in the domestic use sector. Source: V-ZUG AG (2004).

While structural changes can lead to both, an increase or a decrease of water use intensity, technological changes are assumed to result only in a reduction in water use intensity (See Figure 10). Technological improvements are included in calculations of water use by specifying the rate at which new water using devices become more efficient over time. For every scenario, this rate of efficiency improvement (technological change) is specified in Equation (2):

$$DWI = DWSI \cdot Tch_D \qquad \left[\frac{m^3}{cap \cdot year}\right] \qquad (2)$$

where:

DWI = Domestic water use intensity for each country [$m^3/(cap \cdot year)$]

DWSI = Domestic structural water use intensity for each country [$m^3/(cap \cdot year)$]

$Tch_D$ = Technological change for the domestic sector for each country [-]

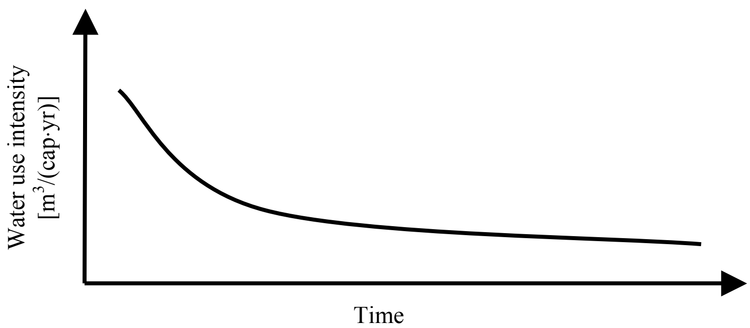


Figure 10. Impact of technological change on water use intensity.

### 3.2.4 WaterGAP: Water Use for Electricity Production

The objective of this submodel is to compute water use for producing electricity. Here, the model simulates the amount of water withdrawn and consumed for cooling purposes in the electricity sector. (Some of the water is converted to the steam which drives the generator producing the electricity). Since thermal power plants[4] use freshwater for cooling we calculate location-specific annual values for water withdrawals as well as water consumption. The allocation of the water used for cooling purposes to the global grid with a spatial resolution of 0.5° by 0.5° (geographical longitude and latitude) was possible because all power stations are given by their geographical coordinates.

The amount of water withdrawn by each power plant using freshwater for cooling is computed by multiplying the annual electricity production [MWh/year] with the water use intensity of the power station (water withdrawal per unit electricity production, in m³/MWh). The total annual thermal power plant water withdrawal (TPWW) in each grid cell is then calculated as the sum of the withdrawals of all power plants within the cell (Vassolo and Döll, 2004):

$$TPWW = \sum_{i=1}^{n} EP_i \cdot WI(CS_i) \cdot Tch_{TP_i} \qquad \left[\frac{m^3}{year}\right] \tag{3}$$

where:

$EP_i$ = Electricity produced by a thermal power plant i within the cell [MWh/year]

$WI_i$ = Station-specific water withdrawal intensity [m³/MWh]. This figure depends on the cooling system of the plant, $CS_i$

$Tch_{Pi}$ = Technological change for water cooling in a thermal power plant i [-]

n = Number of stations in the cell

The consumption of water by each power plant is computed by substituting in Equation (3) the water withdrawal intensity with the water consumption intensity. The main driving force of water use in the electricity sector is the amount of electricity produced by thermal power plants which is represented by $EP_i$ (Equation (3)).

The technological change that will lead to a higher water use efficiency is taken into account as the factor $Tch_{Pi}$. Further, TPWW depends on the water use intensity which is solely impacted by the cooling system of the power station. In this approach, two types of cooling systems are distinguished: i) the ‘once-through flow’ system and ii) the ‘tower cooling’ system. In contrast to the once-through flow system, where the cooling water is returned to the river after it has cooled down the condenser, the water in a tower cooling system flows in a closed circuit. As a result, the water use intensity of a once-through flow cooling system is much higher compared to a tower cooling system. On the other hand, the fraction of water consumed is very small compared to the tower cooling system. In the once-through flow system, only 0.36% of the water withdrawn is consumed and the rest is returned to the source, whereas in the tower cooling system, almost 30% of the water withdrawn leaves the station by evaporation in the tower. The water withdrawal intensities for each cooling system are derived from various power station operators and related data. The values obtained are:

[4] Thermal power plant: A power-generating plant which uses heat to produce energy. Such plants may burn fossil fuels, biomass or use nuclear energy to produce the necessary thermal energy.

- 180 $m^3$/MWh for power plants with once-through flow cooling system and
- 4.5 $m^3$/MWh for power plants with tower cooling systems.

The water consumption intensities for each of the two cooling systems are taken from data of Unipede (1999):

- 0.65 $m^3$/MWh for power plants with once-through flow cooling and
- 1.33 $m^3$/MWh for power plants with cooling tower systems.

Input data on location, type and size of power station are based on the World Electric Power Plants Data Set of the Utility Data Institute (UDI, 2000). This database contains comprehensive global data on all types of electric power stations including information on the name of the station, installed capacity, year of connection to the net, fuel type, and cooling type. All these values are based on statistical data from 1995. Unfortunately, the exact geographical locations of the power stations are not included. To determine the geographic coordinates of the stations, the database of foreign geographic features (NIMA – National Imagery and Mapping Agency, 2000) was used. For Europe, 10469 power stations are taken into account, 97% are fossil-fueled, 2% nuclear-fueled, and another 1% are geothermal. Figure 11 shows the distribution of all European power plants taking into account in this study. The different symbols separate power plants according to the cooling system. In Europe, 66% of the power plants are cooled by once-through flow cooling system, while 34% used tower cooling.

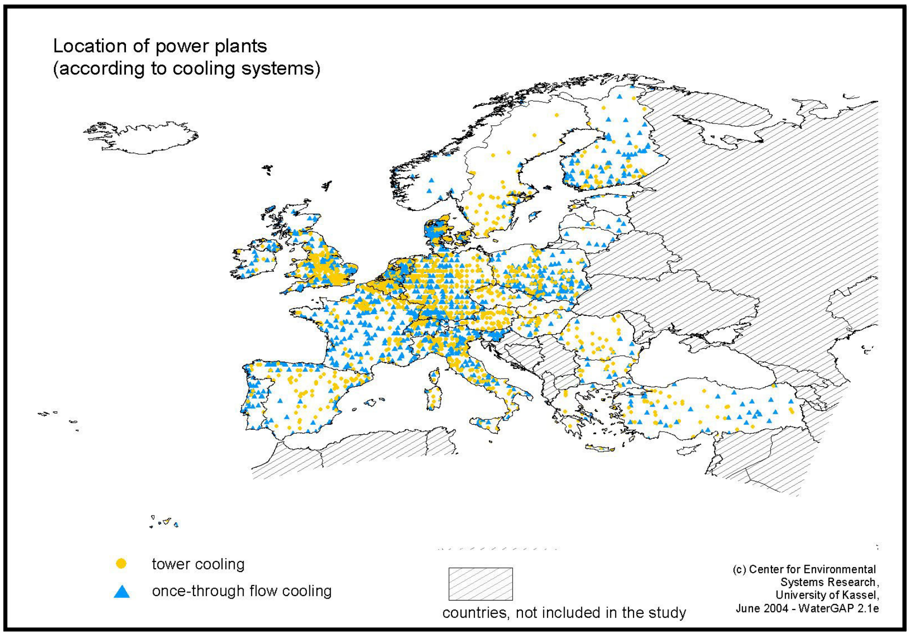


Figure 11. Location of European power plants taken into account in this study. Sources: UDI (2000) and NIMA (2000).

To validate the estimated water withdrawals for electricity production, the values computed for the year 2000 are compared to data from EUROSTAT and other national Statistical Agencies for almost all countries considered in this study (Europe-30 region). Figure 12 shows a scatter-diagram for the model efficiency indicating the goodness-to-fit with respect to the 1:1 line. The model efficiency is calculated according to Equation (4):

$$ME = 1 - \frac{\sum_{i=1}^{n}(PWW_{calculated,i} - PWW_{published,i})^2}{\sum_{i=1}^{n}(PWW_{published,i} - \overline{PWW_{published,i}})^2} \quad (4)$$

where:

ME = Model efficiency, where ME = 1 indicates a perfect fit [-]

PWW = Water withdrawal for electricity production per country [m³/year]

$\overline{PWW}$ Mean water withdrawal electricity production per country [m³/year]

n = Number of countries

The overall model results show a ME of 0.99. It is, thus, concluded that the applied methodology leads to an adequate evaluation of the spatially distributed water withdrawals for power plants.

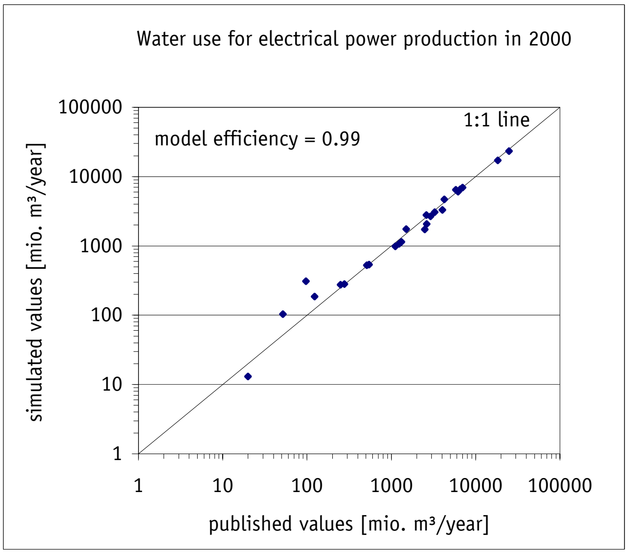


Figure 12. Comparison of simulated and published water use in the electricity production sector and model efficiency. 25 European countries are taken into account[5].

### 3.2.5 WaterGAP: Water Use in the Manufacturing Industry

The objective of this submodel is to compute water used by the manufacturing industry. To take into account the great diversity of industrial processes and the variety of input and output specifications, the manufacturing water use model distinguishes between 6 manufacturing sectors:

- Food products; beverages and tobacco;
- Textiles and textile products;
- Pulp, paper; publishing and printing;
- Chemicals, man-made fibres;

[5] No published references were available for Luxembourg, Malta, Norway, and Slovak Republic. In Cyprus, only salt-water is used for cooling purposes.

- Non-metallic, mineral products; and
- Basic metals and fabrication of metal products.

These six sectors are classified in the NACE sectoral code system of the EU (Nomenclature générale des Activités dans les Communautés Européenes). This system is a standard system for classifying economic activities. Based on EUROSTAT (Pau Vall, 2001) these six sectors together account for more than 80% of the total manufacturing water withdrawal.

For each of these sectors the model simulates the amount of water withdrawn and consumed in production processes, except for cooling for power generation. For most of the countries, water withdrawal per sector is available from national statistics for the base year 2000. Since we are however interested in water withdrawals in the future, a water use intensity has to be derived that can then be multiplied with the driving force for water use in the respective sector. Sector-specific gross value added is used as this driving force. Thus the sector-specific water use of the base year is devided by the GVA of the base year to obtain the sector-specific water use intensity SMWI. The model then takes SMWI and multiplies it with the future sector-specific GVA. Technological improvements are taken into account by a sector-specific technological change factor (as specified in the scenarios). To obtain the total manufacturing water withdrawal at national level, the sum over the six sectors is computed according to Equation (5):

$$MWW = \sum_{i=1}^{6} SMWI_i \cdot Tch_{M_i} \cdot GVA_i \qquad \left[ \frac{m^3}{year} \right] \tag{5}$$

where:

MWW = Manufacturing water withdrawal per country [$m^3$/year]

$SMWI_i$ = Sectoral manufacturing water intensity per country [$m^3$/1000€ GVA]

$Tch_{Mi}$ = Technological change for the manufacturing sector i [-]

GVA = Gross value added per country [Euro/year]

The water consumption for each sector is obtained as the difference between the water withdrawal and the waste water. For countries where no data are available, the fraction of consumptive water use is derived from neighboring or economically comparable countries.

With respect to manufacturing water use, there is no information on the specific locations of water users. Therefore, manufacturing water use is assumed to be distributed among the grid cells of a country proportional to its urban population.

Base year data (year 2000) for water withdrawals are taken from EUROSTAT and other national statistical agencies. About one-half of the Europe-30 countries have sector-specific water withdrawals for the base year. For the remaining countries, total manufacturing water withdrawals are distributed to the different sectors according to the ratio of the sectoral gross value added to the total industrial gross value added. The improvement in water use efficiency due to technological changes is derived for each sector and extrapolated based on historical data (see Appendix B).

### 3.2.6 WaterGAP: Irrigation Water Use

The objective of this submodel is to compute net and gross irrigation requirements which reflect an optimal supply of water to irrigated crops. In this context, ‘net irrigation requirement’ refers to the part of the irrigation water that is evapotranspirated by plants, while ‘gross irrigation requirement’ refers to the total volume of water that is withdrawn from its source (Döll and Siebert, 2002; Alcamo et al., 2003a). The ratio of net to gross irrigation requirement is called 'irrigation water use efficiency'. This concept is similar to the water use efficiency of the previous sectors described.

In contrast to the other water use models, the irrigation model computes monthly rather than annual results. The model calculation is based on a global map of irrigated areas (Döll and Siebert, 2000) with a spatial resolution of 0.5° by 0.5° (geographical longitude and latitude). This map shows the fraction of agricultural area of each grid cell that is equipped for irrigation.

The computation of the net irrigation requirement per unit irrigated land is a function of climate, cropping intensity, and crop type (distinguishing rice and other crops). First, the cropping patterns for each grid cell with irrigated land are modeled using a rule-based system, among other things considering data on total irrigated area, long-term average temperature and cropping intensity. In general, cropping intensity refers to the average number of crops that are consecutively grown within a year, and set to 1 for European countries. The cropping pattern describes whether rice or other crops or both are irrigated and whether there are one or two cropping seasons. Then, in a second step, the start day of the growing season is determined, assuming a growing period of 150 days for all crops. The start date of a growing season within a year is ranked according to a temperature and precipitation criteria. After these two initial steps, the net irrigation requirement is computed for each day of the growing season similar to the CROPWAT (Smith, 1992) approach:

$$IR_{net} = k_c \cdot E_{pot} - P_{avail} \qquad \left[\frac{mm}{d}\right] \qquad \text{if } k_c E_{pot} > P_{avail} \tag{6}$$

$$IR_{net} = 0 \qquad \text{if } k_c E_{pot} \le P_{avail}$$

where:

$IR_{net}$ = Net irrigation requirement [mm/d]

$E_{pot}$ = Potential evapotranspiration [mm/d]

$P_{avail}$ = Precipitation that is available to the crop [mm/d]

$k_c$ = Crop coefficient, depends on the growing stage of the crop [-] (Doorenbos and Kassam, 1979)

Equation (6) indicates that the net irrigation water intensities are calculated as the difference between crop-specific potential evapotranspiration and the precipitation available to the plant. The crop-specific potential evapotranspiration is described by the product of $k_c$ and $E_{pot}$, in which a daily potential evapotranspiration is computed according to the Priestley-Taylor formulation as a function of net radiation and temperature. Finally, gross irrigation requirement is calculated by dividing the net irrigation requirement by the efficiency of irrigation water use, a value that depends on irrigation technology and management (see Equation (7)).

$$IR_{gross} = \frac{IR_{net}}{eff_{IR}} \qquad \left[\frac{mm}{d}\right] \tag{7}$$

where:

$IR_{gross}$ = Gross irrigation requirement [mm/d]

$IR_{net}$ = Net irrigation requirement [mm/d]

$eff_{IR}$ = Irrigation field efficiency [-]

The irrigation field efficiencies vary regionally between 0.5 and 0.65 in the Europe-30 region. Here, higher efficiencies are estimated for southern countries because these countries make use of water saving systems (e.g. drip systems instead of sprinklers). With respect to climate as a main driving force on the irrigation water requirement, monthly temperature and precipitation values are taken into account on a 0.5° by 0.5° global grid (geographical longitude and latitude, respectively). Today's climate is depicted by a 30-year time series (climate normal, 1961-90) of observed monthly data by New et al. (2000). To derive appropriate future scenarios, today's climate is scaled by applying changes projected by GCMs. Next to the climate input, the rate of expansion of irrigated areas or change in area exploited for irrigation is an additional driving force in water use scenarios.

As a validation of the global irrigation model, irrigated areas and gross irrigation requirements were compared with independent data of the year 2000. Data regarding irrigation water withdrawals are obtained from EUROSTAT or other national Statistical Offices. In most cases, model calculations reflect adequately published data as can be seen from Figure 13.

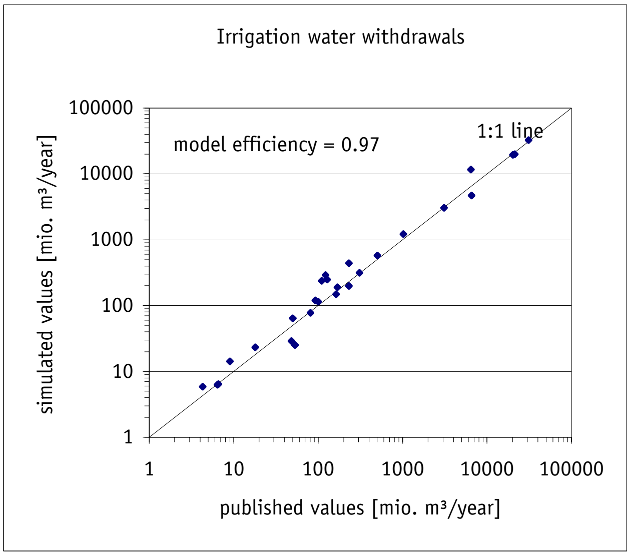


Figure 13. Validation of the irrigation model: calculated irrigation water withdrawals versus published data.

### 3.2.7 WaterGAP: Livestock Water Use

The aim of this submodel is to compute the amount of water used by animals which is in most countries very small compared to domestic, industrial or irrigation water use. However, if irrigation water use is low the livestock water use may play a considerable role. We therefore distinguish between ten different varieties of livestock (Alcamo et al., 2003a). It is assumed that the water withdrawals for livestock are equal to their consumptive water use. In WaterGAP the water withdrawals for livestock are computed annually on a global grid (0.5° by 0.5°) by multiplying the number of animals per grid cell (GlobalARC, 1996) by the livestock-specific water use intensity [$m^3$/(head·year)].

To quantify livestock-specific water use intensities, a wide range of estimates exist. For the WaterGAP livestock water use model, several literature sources were considered (Kirchgeßner, 1997; Mc Nitt, 1983; Jeroch, 1986; van der Leeden, 1990).

## 3.3 Improved Estimates Achieved in this Study

The methodology used in this report represents a significant advance to the methodology used in previous studies to compute European-scale water use (UNEP, 2002; Henrichs et al., 2002; Alcamo et al., 2000):

1. The reliability of estimating domestic water use has been improved by calibrating the model to newly available data on historical trends of domestic water use on a country scale in Europe. Model calculations have been shown to fit very well to historical data in most countries (see Table 2 and Appendix A).
2. A newly available data base on power stations and their cooling characteristics (Vassolo and Döll, 2004) has been used for the first time, in order to greatly improve the estimation of future water use in the electricity sector. For the first time important structural changes in the type of power station cooling were taken into account in a large scale water scenario study. WaterGAP estimates compare very well with independent country scale estimates. (See Section 3.2.4).
3. Estimates of future water use in the manufacturing sector have been greatly improved over previous estimates by performing separate estimates of water use for each of 6 water-intensive industrial sectors. This is the first time that water use scenarios were systematically developed for manufacturing on the European scale. (See Section 3.2.5).
4. The reliablility of estimates of water use in European agriculture has been tested by comparing WaterGAP calculations to data from several European countries. Model estimates were found to closely agree with independent estimates. (See Section 3.2.6).

Despite these improvements in methodology, many uncertainties remain in the procedure for calculating water use that should be kept in mind when interpreting and using scenario results. (See Chapter 7). These uncertainties should be addressed in follow-up studies. (See Chapter 8).

# 4. ASSUMPTIONS OF THE BASELINE SCENARIO *(LREM-E)*

In this and the next chapter we describe the assumptions of the two scenarios developed in this study – the 'baseline scenario' (LREM-E) and the 'climate policy scenario' (SEP).

The goal of the baseline scenario is to provide a reference scenario of future developments of water use (and availability) in Europe assuming that current environmental policies continue, but also supposing that specific policies are *not implemented* to curtail water use. Many of the assumptions in the baseline scenario are derived from the Long Range Energy Modelling scenario project (LREM-E), commissioned by the Directorate-General for Energy and Transport (EU, 2003). The original LREM-E scenario was built as a benchmark for the assessment of future energy and transport options. A detailed analysis of the assumptions as well as the results for this scenario can be found in the 'European Energy and Transport – Trends to 2030' report (EU, 2003). The National Technical University of Athens (NTUA) was responsible for the development of this outlook in the context of the LREM contract with the Directorate-General for Energy and Transport. The PRIMES Energy System Model was used to develop the scenarios.

## 4.1 The World of the Baseline Scenario – A Qualitative Description

The baseline scenario describes a world up to 2030 in which technological developments continue to be an important factor for economic growth and less attention is paid to ecological sustainability. In this world the expansion of the EU turns out to be a boom for the economies of most Europe-30 countries as trade flourishes between the old and new EU countries, and markets in these countries expand. Exports to other world regions from Europe-30 also increase. Mobility of workers to booming industrial areas reduces unemployment and increases the consumer spending of workers. Following these and other factors, the economy in the Europe-30 grows at a rate of 2.3% per year between 2000 and 2030 as compared to 1.5% per year in the 1990s. Economic growth is particularly strong in the 'new' (post 2004) and 'candidate' (as of 2004) EU countries.

The demographic transition continues in Europe-30, as population stabilizes in most countries and decreases in others. Overall, the population in these countries only grows by 24 million.

In the domestic sector, higher overall incomes tend to cause much higher per capita water use in the new EU countries. This is manifested by, for example, the installation of new washing machines, dishwashers, etc. However, in some of the richer countries domestic water use had already reached its highest level in the 1990s and continues its decline. But in the new EU countries, the building boom accompanying economic expansion in the first decades of this century leads to increasing water use in households. This increase is slowed by an increasing efficiency of appliances as described in Section 4.2.9.

One of the pillars of the new economic expansion between 2000 and 2030 is increased production of manufactured products for expanding domestic and export markets. Since the output also increases of water-intensive industries (paper and pulp, chemicals, food products), water use in the manufacturing sector grows. Additionally, the higher standard of living and increased manufacturing output requires more electricity production at all power facilities, including thermal power stations. The increased electricity generation of thermal power stations tends to increase water used in the electricity sector. However, there is a very important offsetting tendency. – While electricity generation increases, many older power stations are also phased out and all new power stations in Europe have tower cooling which drastically lowers water withdrawals compared to the older stations that had once-through cooling. As a result almost all countries have declining water use in the electricity production sector in the 2010s and 2020s.

The economic expansion also affects the agricultural sector. Increasing income raises food consumption and this leads to a greater demand for food grown on irrigated land. This larger domestic food demand, combined with growing food exports from Europe lead to a vast expansion of irrigated cropland in many Europe-30 countries.

Higher overall industrial activity is accompanied by an acceleration of investments in new technologies and improved management of businesses, industrial processes and agricultural activity. A spinoff of this ‘technological improvement’ is improved efficiency of water use in all sectors. For example, fewer raw materials are used for manufacturing chemicals and this is accompanied by a reduction in water requirements for chemical manufacturing processes. Another example is that water-intensive traditional flood irrigation is replaced on many farms by water-saving sprinkler irrigation. As a result of these changes, water use becomes more efficient at a faster rate than in the last decades of the 20$^{th}$ century.

While economic activity becomes very lively, many climate and environmental policies practically die-out. For example, the hard-fought-for Kyoto Protocol is abandoned by nearly all of its signatories so that emissions of greenhouse gases increase even faster than anticipated back in the 1990s. However, not all air pollution policies are abandoned in Europe so some renewable energy continues to penetrate the energy market as a tactic for controlling local and regional air pollution. Some water conservation policies are also continued, especially in countries where domestic water use was already levelling off or declining in the 1990s. However, no new large water conservation initiatives were launched in the first decades of the 21$^{st}$ century.

Continuing climate change leads to a somewhat drier climate in Southern Europe and wetter climate over the northern Europe-30 countries. Mean annual temperature increases on average by 1 degree Celsius between 2000 and 2030. These changes lead to a small increase in water requirements for irrigated farming in Spain and Greece. The effect of climate is compensated somewhat by the continuing improvements in the efficiency of irrigation water use, noted above.

## 4.2 Driving Force Assumptions

### 4.2.1 Population

Assumed population is based on EUROSTAT and UN-HABITAT data. The trends in population are driven by on-going economic growth. Table 3 shows the population levels and growth rates of the Europe-30 countries, aggregated into regions.

Table 3. Population trends in the Europe-30 region, 1990 to 2030. Source: EUROSTAT, Global Urban Observatory and Statistics Unit of UN-HABITAT, PRIMES. Regions are defined in Table 1.

| | Inhabitants [million] | | | | | Annual growth rate [%] | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 2000 | 2010 | 2020 | 2030 | 90/00 | 00/10 | 10/20 | 20/30 | 00/30 |
| Northern Europe | 203.16 | 211.50 | 216.08 | 218.76 | 219.51 | 0.40 | 0.21 | 0.12 | 0.03 | 0.12 |
| Southern Europe | 173.80 | 178.85 | 183.56 | 183.68 | 181.68 | 0.29 | 0.26 | 0.01 | -0.11 | 0.05 |
| New EU Member States | 75.12 | 74.73 | 73.40 | 71.67 | 69.14 | -0.05 | -0.18 | -0.24 | -0.36 | -0.26 |
| EU Candidate States | 88.13 | 98.07 | 105.18 | 111.45 | 117.06 | 1.07 | 0.70 | 0.58 | 0.49 | 0.59 |
| Europe-30 | 540.20 | 563.14 | 578.22 | 585.56 | 587.39 | 0.42 | 0.26 | 0.13 | 0.03 | 0.14 |

A further increase of the Europe-30 population by some 24 million people is projected between 2000 and 2030. However, there are significant differences in the growing rates and contrary trends occur among the different regions. After 2000 the Northern Europe population continues to increase but with a declining growth rate. Beyond 2020 the population in Northern Europe is assumed to grow by only 0.03% per year and to reach 219 million in 2030. In the Southern Europe countries an increase in population by more than 0.25% per year is assumed up to 2010. Between 2010 and 2020 the development in population almost stagnates and declines thereafter by 0.11% per year. The New EU Member States face a considerable reduction in population. The population decreases by 5.6 million inhabitants between 2000 and 2030. A further increase of the EU Candidate States' population by some 19 million people is projected between 2000 and 2030, with a maximum rate of 0.70% per year between 2000 and 2010.

### 4.2.2 Economic growth (GDP/cap·year)

The economic growth assumptions are based on the macroeconomic and sectoral projections from different sources, including the European Commission's Directorate-General for Economic and Financial Affairs (Economic and Financial Affairs DG), Member States' stability programs and long-term projections, macroeconomic forecasts from WEFA (now integrated into DRI-WEFA[6]), and results from the GEM-E3[7] model. The presented economic outlook uses the same underlying assumptions for the New EU Member States as for the pre-2004 EU states. Economic growth assumptions take into account the recent European economic slowdown and the expected long-term positive economic climate. The projected outlook of per capita GDP for the Europe-30 is given in Table 4.

Table 4. Per capita GDP in the Europe-30 region, 1990 to 2030. Source: EUROSTAT, Economic and Financial Affairs DG, PRIMES. Regions are defined in Table 1.

| | GDP per cap [Euro2000] | | | | | annual growth rate [%] | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 2000 | 2010 | 2020 | 2030 | 90/00 | 00/10 | 10/20 | 20/30 | 00/30 |
| Northern Europe | 22308 | 26354 | 32425 | 39863 | 48815 | 1.68 | 2.09 | 2.09 | 2.05 | 2.08 |
| Southern Europe | 16275 | 19169 | 24058 | 30636 | 38894 | 1.65 | 2.30 | 2.45 | 2.42 | 2.39 |
| New EU Member States | 4434 | 5277 | 7819 | 11455 | 15916 | 1.76 | 4.01 | 3.89 | 3.34 | 3.75 |
| EU Candidate States | 2187 | 2391 | 3214 | 5200 | 7838 | 0.90 | 3.00 | 4.93 | 4.19 | 4.04 |
| Europe-30 | 14599 | 17102 | 21332 | 26894 | 33707 | 1.60 | 2.23 | 2.34 | 2.28 | 2.29 |

In the Europe-30 region, GDP per capita increases at a rate of 2.3% per year on average, thereby doubling between 2000 and 2030. In the Northern Europe countries, the GDP per capita increases continuously by almost 2.1% per year, while the economy of Southern Europe shows an average growth rate of 2.4% per year. Much faster growth is experienced in the New EU Member States (3.8%) and the EU Candidate States (4%). The acceleration of economic growth in these two European regions results from the successful integration of these countries into the EU. Nevertheless per capita income in these regions in 2030 remains considerably lower than in other EU regions (Table 4).

[6] DRI-WEFA. DRI-WEFA Model: Economic Dynamic Equilibrium Growth Model. A Global Insight Company.

[7] GEM-E3. General Equilibrium Model for Energy-Economy-Environment Interactions. National Technical University of Athens (NTUA).

### 4.2.3 Structural change in the domestic sector

The concept of structural changes in the domestic sector is explained in Section 3.2.3. Basically we assume that water intensity (per capita water use) first rises as income increases, then stabilizes and in some countries drops. This relationship is confirmed by historical data from most European countries. In Section 3.2.3 we explained that historical data were used to derive a separate sigmoid curve for each European country. This curve depicts the change in water intensity as income changes in a particular country. (See Figure 6 and Figure 7). For the baseline scenario we use the sigmoid curves to estimate future water intensities corresponding to future income in a particular country.

In the case of the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, the Slovak Republic, and Turkey, we assume for the *baseline scenario* that the domestic water use intensities follow the *upper curve* in Figure 8. Therefore, we assume that water intensity in the domestic sector (per capita water use) converges with the pan-European average in 2030.

### 4.2.4 Thermal electricity production

The amount of freshwater used for cooling in the electricity production sector is mainly affected by the electricity generated by thermal power plants. Since thermal power plants may be fossil-fueled or nuclear-fueled both thermal electricity production and nuclear electricity production are taken into account. As noted above, the baseline scenario assumes a continuation of current trends except in climate policy and other environmental areas. Regarding climate policy, it assumes that the Kyoto Protocol will not be implemented and that greenhouse gas emissions will not otherwise be controlled. Thermal electricity production increases by 54% between 2000 and 2030 in the Europe-30 countries. During the same period thermal electricity production increases by 36% in the Northern Europe countries, by 55% in the Southern Europe countries, and by 58% in the New EU Member States, and almost triples (177%) in the EU Candidate States. The significant growth in thermal electricity production in the New EU Member States and the EU Candidate States is attributed to higher economic activity over the scenario period, leading to increased use of electrical appliances in households and service industries (EU, 2003).

Table 5. Projected thermal electricity production for the baseline (LREM-E) scenario. Source: EUROSTAT, PRIMES. Regions are defined in Table 1.

| | Thermal electricity production [TWh]* | | | | | Annual growth rate [%] | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 2000 | 2010 | 2020 | 2030 | 90/00 | 00/10 | 10/20 | 20/30 | 00/30 |
| Northern Europe | 1183 | 1297 | 1437 | 1615 | 1771 | 0.93 | 1.03 | 1.18 | 0.92 | 1.04 |
| Southern Europe | 722 | 963 | 1156 | 1341 | 1492 | 2.92 | 1.85 | 1.50 | 1.07 | 1.47 |
| New EU Member States | 304 | 308 | 362 | 452 | 488 | 0.14 | 1.62 | 2.24 | 0.78 | 1.55 |
| EU Candidate States | 121 | 169 | 213 | 306 | 469 | 3.40 | 2.33 | 3.69 | 4.36 | 3.46 |
| Europe-30 | 2329 | 2737 | 3168 | 3714 | 4220 | 1.63 | 1.47 | 1.60 | 1.28 | 1.45 |

* Thermal electricity production (including biomass) and nuclear electricity production.

### 4.2.5 Structural change in the electricity production sector

The rate of water withdrawals per unit electricity generated is much higher in power stations using traditional once-through cooling than in the more contemporary tower cooled plants. Hence the structural change by which once-through cooling is replaced by tower-cooling is an important driver of water use. Consistent with EU (2001) we assume that all new power stations in the baseline scenario will be tower-cooled. Hence, the rate of penetration of tower-cooling in the baseline scenario is just a matter of the current age of power stations – the shorter the lifetime, the faster the power stations will be replaced and the faster the penetration of tower cooling. In the baseline scenario we assume all power stations have a lifetime of 40 years (Markewitz and Vögele, 2001).

### 4.2.6 Manufacturing output (gross value added)

The gross value added (GVA) of industrial production is a major driving force of water use in manufacturing. The assumptions for the economic growth of the industry sector for the EU15 countries reflect the trend of structural changes in developed economies as well as aspects of international trade and dematerialization (EU, 2003).

To give an overview of the projected GVA, the values for Northern Europe countries are given in Table 6. The GVA projection for the other three European regions are presented in Appendix C. Overall, the development of the GVA corresponds closely to the projected development of the per capita GDP.

Table 6. Gross value added separated by sectors in the Northern Europe economy. Source: EUROSTAT, Economic and Financial Affairs DG, PRIMES. Regions are defined in Table 1.

| | GVA [$10^9$ Euro 2000] | | | | | Annual growth rate [%] | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 2000 | 2010 | 2020 | 2030 | 90/00 | 00/10 | 10/20 | 20/30 | 00/30 |
| Iron and steel | 36 | 30 | 29 | 29 | 29 | -1.83 | -0.24 | 0.13 | 0.01 | -0.03 |
| Non-ferrous metals | 15 | 17 | 24 | 31 | 39 | 1.42 | 3.39 | 2.64 | 2.24 | 2.75 |
| Chemicals | 106 | 133 | 171 | 218 | 271 | 2.28 | 2.55 | 2.49 | 2.19 | 2.41 |
| Non-metallic minerals | 39 | 40 | 46 | 54 | 63 | 0.14 | 1.42 | 1.77 | 1.51 | 1.57 |
| Paper and pulp | 86 | 108 | 135 | 166 | 199 | 2.31 | 2.24 | 2.13 | 1.82 | 2.06 |
| Food, drink, tobacco | 104 | 128 | 157 | 195 | 237 | 2.12 | 2.05 | 2.21 | 1.99 | 2.08 |
| Engineering | 442 | 507 | 652 | 845 | 1083 | 1.39 | 2.55 | 2.62 | 2.51 | 2.56 |
| Textiles | 42 | 32 | 32 | 34 | 37 | -2.74 | -0.07 | 0.70 | 0.64 | 0.43 |
| Other industries | 87 | 98 | 119 | 144 | 173 | 1.17 | 1.96 | 1.94 | 1.87 | 1.92 |
| Total industry | 957 | 1092 | 1364 | 1717 | 2131 | 1.33 | 2.24 | 2.33 | 2.18 | 2.25 |

The GVA is given for nine sectors (see Table 6). The following paragraphs describe changes in particular manufacturing sectors.

While the **iron and steel sector** experienced an economic recession between 1990 and 2010 in the Northern Europe region, the GVA shows a net increase between 2000 and 2030. By 2030, the iron and steel sector accounts for only 1.3% of the total Europe-30 GVA compared to 2.7% in 2000.

The **non-ferrous metals sector** shows the highest growth rates between 2000 and 2030, with an average growth rate of 2.75% per year. However, this sector accounts only for 1.8% of the total GVA in 2030.

The **chemical sector** is a one of the main drivers of increased GVA in the manufacturing sector. In the Northern Europe countries, the chemical industry is one of the fastest growing industrial sectors with an annual increase of 2.4% between 2000 and 2030. By 2030, the chemical industry continues to account for 12% of the total manufacturing GVA as in 2000.

The **non-metallic minerals sector** accounts for a relatively small share of the total Northern Europe manufacturing output (3.6% in 2000 and 3.0% in 2030). This sector is projected to expand at rates well above those observed in the last decade (1.6% per year between 2000 and 2030).

The **paper and pulp sector** is projected to have a growth rate of 2.1% per year for the scenario period 2000 to 2030. By 2030, the sector accounts for 9.3% of industrial economic activity in the EU which remains almost steady compared to 9.8% in 2000.

The **food, drink, and tobacco sector** is amongst the largest industrial activities in the Northern Europe countries, accounting for 11.7% of GVA in 2000 and 11.1% in 2030. For this sector the GVA is projected to grow by 2.1% per year between 2000 and 2030.

The **engineering** sector shows a continuous increase in GVA at an average rate of 2.6% per year between 2000 and 2030. This sector is the main industrial sector in the Northern Europe region and accounts for 50% of the total GVA in 2030 (46% in 2000).

In the Northern Europe countries, the **textile sector** accounts for 2.9% of the total GVA in 2000, but this share declines to 1.7% in 2030. The decline is due to a growth rate of only 0.4% per year between 2000 and 2030. Slow growth, in part, is due to the re-location of this labor-intensive activity outside the region. (EU, 2003).

**Other industries** are those sectors which are not explicitly listed in Table 6. These industries are expected to expand throughout the scenario period at an average rate of 1.9% per year between 2000 and 2030. These miscellaneous industries account for 9% of the regional GVA in 2000 and 8% in 2030.

### 4.2.7 Irrigated area

The main driving force of changes in water withdrawals in the agricultural sector is the change in extent of irrigated area. The larger this area, the more water needed for irrigation, and the larger the water use in the agricultural sector.

Despite the importance of the extent of irrigated land, detailed European-specific projections are not available. Here, we use a variety of sources for deriving assumptions of future irrigated land.

Two major variables concerning irrigated area must be specified. The first is the *area equipped for irrigation* which is the area which is set up for irrigation but not necessarily irrigated. The second important variable is the *percentage of equipped area exploited for irrigation.* This is important because a variety of sources confirm that in many countries a large percentage of the equipped area is *not exploited* for irrigation, for example, because adequate rain sometimes occurs during the growing season, or because it is uneconomic to irrigate. (Baldock, 2000; Penov, 2001; Hristova, 2001; Siemianowski, 2001; Petkov, 2001; Leonte, 2001; ICID, 2004; DSI, 1991; Bazzani et al., 2003; Manos, 2003; Morris, 2003; FAO, 2002). For example, these references indicate that only about 5.5% of Romania's equipped irrigated area was actually used for irrigation in 2000. The current percentage of area exploited for irrigation is given in Table 7.

For specifying the future change in extent of exploited irrigated land we adapt assumptions from a global study presented in the 'Global Environment Outlook 3 (GEO-3)' report (UNEP, 2002). Specifically, we have adapted the 'Market Forces' scenario which has basic assumptions that resemble the baseline scenario in this report (Table 8). The projection in Table 8 is fairly consistent with estimates for some other European countries contained in Baldock et al. (2000) and Magat and Vallée (2000). For example, the change in irrigated area is of the same direction (increasing or decreasing) for two-thirds of the countries considered by all three references.

Table 7. ‘Area equipped for irrigation’ and the ‘percentage of equipped area exploited for irrigation’ (base year 2000). Sources: (Baldock, 2000; Penov, 2001; Hristova, 2001; Siemianowski, 2001; Petkov, 2001; Leonte, 2001; ICID, 2004; DSI, 1991; Bazzani et al., 2003; Manos, 2003; Morris, 2003; FAO, 2002).

| Country | Area equipped for irrigation [km²] | Percentage of equipped area exploited for irrigation in 2000 |
|---|---|---|
| Austria | 580 | 78 |
| Belgium | 400 | 11 |
| Bulgaria | 8000 | 5 |
| Cyprus | 397 | 53 |
| Czech Republic | 1412 | 26 |
| Denmark | 4604 | 15 |
| Estonia | 40 | 92 |
| Finland | 638 | 47 |
| France | 26337 | 37 |
| Germany | 6262 | 23 |
| Greece | 14500 | 70 |
| Hungary | 2100 | 42 |
| Ireland | — | 0 |
| Italy | 38513 | 76 |
| Latvia | 171 | 100 |
| Lithuania | 136 | 100 |
| Luxembourg | 0.037 | 100 |
| Malta | 20 | 61 |
| The Netherlands | 4983 | 59 |
| Norway | 1240 | 100 |
| Poland | 1000 | 89 |
| Portugal | 7920 | 82 |
| Romania | 26700 | 6 |
| Slovak Republic | 1800 | 20 |
| Slovenia | 30 | 83 |
| Spain | 37000 | 59 |
| Sweden | 1188 | 100 |
| Switzerland | 172 | 100 |
| Turkey | 45000 | 60 |
| United Kingdom | 2674 | 70 |

Table 8. Baseline (LREM-E) scenario assumptions for the change in extent of irrigated land and change in irrigation water use efficiency.

| Country | % change in extent of irrigated area (2030 relative to 2000)* | Improvement in irrigation water use efficiency [%/year] |
|---|---|---|
| Austria | 0.0 | 0.5 |
| Belgium | 0.0 | 0.5 |
| Bulgaria | +20.0 | 0.4 |
| Cyprus | +20.0 | 0.4 |
| Czech Republic | 0.0 | 0.5 |
| Denmark | 0.0 | 0.5 |
| Estonia | 0.0 | 0.4 |
| Finland | 0.0 | 0.5 |
| France | +27.0 | 0.5 |
| Germany | 0.0 | 0.5 |
| Greece | +20.0 | 0.4 |
| Hungary | +20.0 | 0.4 |
| Ireland | — | — |
| Italy | +27.0 | 0.5 |
| Latvia | 0.0 | 0.5 |
| Lithuania | 0.0 | 0.5 |
| Luxembourg | 0.0 | 0.5 |
| Malta | +27.0 | 0.5 |
| The Netherlands | 0.0 | 0.5 |
| Norway | 0.0 | 0.5 |
| Poland | 0.0 | 0.5 |
| Portugal | +27.0 | 0.5 |
| Romania | +20.0 | 0.4 |
| Slovak Republic | 0.0 | 0.5 |
| Slovenia | 0.0 | 0.5 |
| Spain | +27.0 | 0.5 |
| Sweden | 0.0 | 0.5 |
| Switzerland | 0.0 | 0.5 |
| Turkey | +20.0 | 0.4 |
| United Kingdom | 0.0 | 0.5 |

* The change in extent of irrigated area can be achieved either by an expansion of area exploited for irrigation or by the expansion of area equipped for irrigation (if the area exploited for irrigation will be larger than 100%). Both attain the goal of an increase in irrigated land.

### 4.2.8 Livestock density

The number of livestock in a particular area drives the livestock water use in that area. For the baseline scenario, national projections for 2000 to 2030 data were provided by IIASA. The projection does not include the effects of the 'Common Agricultural Policy' (CAP[8]) reform and was developed with the use of modeling results from the Directorate-General for Agriculture (EU, 2002), future projections given by Bruinsma (2003) and available national projections. The modeled

[8] CAP reform. The reform will completely change the way the EU supports its farm sector. For example, in future, the vast majority of subsidies will be paid independently from the volume of production.

future projections are also based on historical data reported by the United Nations Food and Agriculture Organization (FAO, 2000) and the International Fertilizer Industry Association (IFA, 1998). In general, on the one hand, the future projections assume a decrease in the number of dairy (-15%) and non-diary cattles (-21%) in the Europe-30 region between 2000 and 2030. On the other hand, an increase in the number of poultry (16%) and swines (12%) is estimated for the same time period. The number of sheep and goats is projected to increase (12%) in the New EU Member States but decreases in Northern and Souterhn Europe.

### 4.2.9 Technological change – Improvements in water use efficiency

Also important for determining future water are the future rates of technological change that lead to technological improvements and an increase in water use efficiency. Continuous improvements in technology make water-using appliances more efficient and hence, contribute to reductions in water use.

While structural changes can lead to either, an increase or a decrease of water use intensity, technological changes are assumed to result only in a reduction in water use (See Figure 9). Technological improvements are included in calculations of water use by specifying the rate at which new water using devices become more efficient over time. For every scenario, this rate of efficiency improvement (technological change) is specified for every sector (domestic, electricity, manufacturing, and agriculture) and region.

For the **domestic sector** of Northern and Southern Europe, technological changes continue at 1% per year over the entire scenario period. In the New EU Member States, a higher rate (1.5% per year) is assumed for the decade 2000 to 2010, reflecting the acceleration of economic growth during this decade. After this time period, when economic growth slows down, the rate of efficiency declines to 1% per year and remains at this rate until 2030.

The estimation of the future water use efficiency rates are based on available data about historical improvements. For the domestic sector, information on efficiency rates for the last twenty years are available for Germany (Roth, 1995; Möhle and Masannek, 1990). According to this reference, a rate of efficiency improvement of 2% per year between 1980 and 2000 is used for the domestic sector and applied to Northern and Southern Europe. To take into account a lower development in technical improvement of water saving appliances, a smaller rate of 1% per year is used for the New EU Member States as well as for the EU Candidate States for the last twenty years.

For the **electricity production sector** and the **manufacturing sector**, improvements in water use efficiency are assumed to continue at about 1% per year, regardless of the region. For both the electricity and the manufacturing sector, former technological changes have been calculated based on data available for Germany (Vattenfall Europe, 2002; DESTATIS). Detailed information is given in Appendix B.

For the **agricultural sector**, improvements in the water use efficiency continue to reduce water withdrawals depending on the country by 0.4% to 0.5% per year up to 2030. This takes into account that water-intensive irrigation systems are replaced by more water-saving irrigation systems. Estimates of future water use efficiency rates for irrigation are derived from the GEO-3 'Market Forces' scenario and specified per country (see Table 8).

### 4.2.10 Climate change

Estimates of future climate change depend on many factors including the trend of greenhouse gas (GHG) emissions and the climate model used for calculating climate change. Climate change projections used in this study were calculated by the IMAGE 2.2 model in connection with earlier studies (van Vuuren et al., 2003).

Figure 14 shows the computed increase in greenhouse gas concentration in the atmosphere for the baseline scenario (LREM-E) and for the climate policy scenario (SEP). The concentration of the greenhouse gases increases up to nearly 1000 ppm $CO_2$ equivalents under the baseline scenario ('$CO_2$ equivalents' takes into account all greenhouse gases addressed by the Kyoto Protocol), and stabilizes at about 550 ppm under the climate policy scenario. However, the differences between the scenarios are small up to 2030, the time horizon of this scenario study.

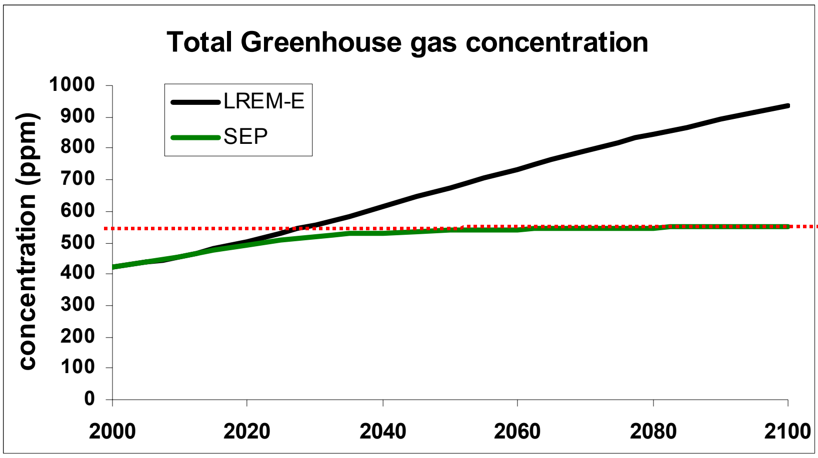


Figure 14. Atmospheric GHG concentration ($CO_2$ equivalents) for the baseline (LREM-E, upper line) and the climate policy (SEP, lower line) scenarios. Source: EEA (2004).

With respect to climate we focus our analysis on altogether 7 time slices: Today's climate (climate normal), future climate representatives for the years 2005 up to 2030 in 5-year intervals. For the WaterGAP model, future climate data (temperature and precipitation) are derived from the IMAGE 2.2 model in combination with results from the general circulation model (GCM) 'HadCM2' and the observed time series 1961-90 (New et al., 2000). For temperature, the observed time series are scaled by adding the respective difference between the future (IMAGE 2.2 values) and present-day temperature (HadCM2 values). For precipitation, observed precipitation time series are scaled by multiplication with the respective ratio between future and present-day precipitation. An exception to this rule occurs when present-day precipitation is close to zero (< 1mm); in this case the respective value is added. Following this method, monthly values for 30-year climate time series are constructed for each time slice.

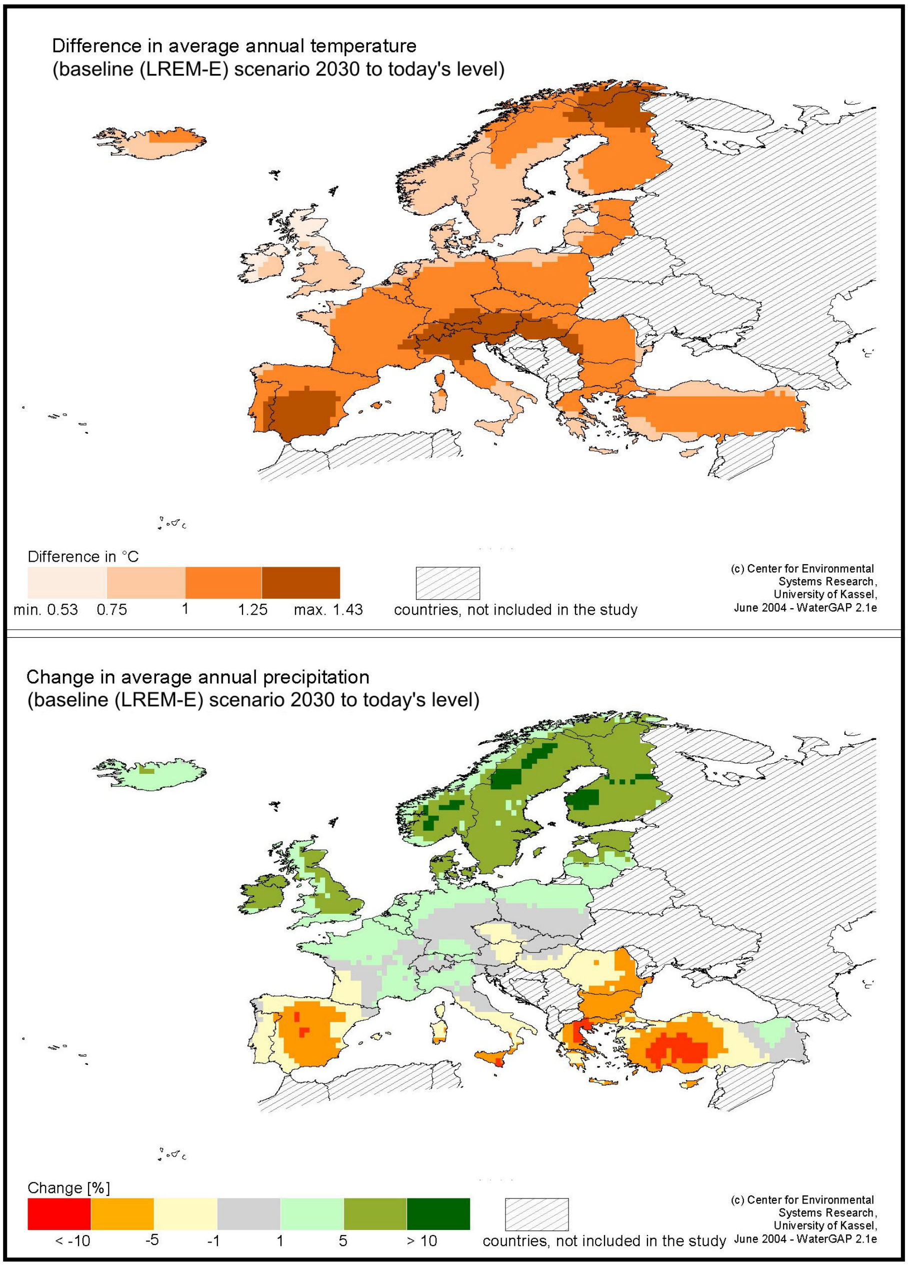


Figure 15. Differences in long-term average annual temperature (top) and percentage change in long-term average precipitation (bottom) as calculated for the baseline (LREM-E) scenario; 2030 projections compared to today's level.

The map on the top of Figure 15 shows the increase in temperature calculated for the baseline (LREM-E) scenario for the year 2030. The differences compared to today's level vary between 0.53°C to 1.43°C. In most parts of Europe the average annual temperature will increase between 1°C and 1.25°C in 2030. Temperature increases of more than 1.25°C occur in Southern Spain and Central Europe as a band over the Alps up to Hungary and parts of Romania.

The map on the bottom illustrates the changes in long-term average precipitation compared to today's level for the baseline (LREM-E) scenario for 2030. The changes vary between -18.8% to 15.5% in the LREM-E scenario. The distribution of precipitation indicates a wetter climate in Northern Europe (> 5%) and a drier climate (< -5%) in the Southern parts of Europe, especially in Spain, Sicily, Greece, Romania, Bulgaria, and Turkey. In the Western and mid European countries only slight changes (+/- 5%) in average annual precipitation are computed.

# 5. ASSUMPTIONS OF THE CLIMATE POLICY SCENARIO (*SEP)*

The goal of the climate policy scenario (SEP) is to investigate the impact of drastic climate policies on water use (and availability) in Europe. The climate policy scenario is derived from the 'sustainability emission pathway' scenario (hence the abbreviation 'SEP') developed by the EEA's European Topic Centre on Air and Climate Change (ETC/ACC, 2004). The climate policy scenario assumes the same basic driving forces as the baseline scenario except that dastic climate policies are assumed (in terms of GHG emissions limits) which have direct effects on the fuel profile of the electricity sector and on the intensity of climate change.

## 5.1 The World of the Climate Policy Scenario – A Qualitative Description

This world resembles that of the baseline scenario in that the expansion of the EU and integration of Europe has turned out to be a stimulus for successful and sustained economic growth in Europe-30. The main difference is that decision makers implement strong policies to reduce greenhouse gas emissions. The emission reduction targets of these policies are much more rigorous than the Kyoto targets.

Emissions are lowered mainly by reducing carbon dioxide emissions from combustion of fossil fuels in electricity production. This action has two effects. First, less overall electricity is needed as a result of successful energy conservation activities. This means that overall production of electricity at thermal power stations is lower here than in the baseline scenario, and this tends to reduce water use in the electrical sector. Second, much more electricity is produced by low or no-carbon fuels – natural gas, wind, solar and biomass. Producing electricity with wind or solar power has very low water requirements, and this also tends to decrease overall water use in the electrical sector.

Under this scenario, improvements in renewable energy technologies make it possible to produce electricity with renewable energy at only slightly higher costs than current technologies and therefore the shift to renewable energy does not appreciably increase the operating costs of manufacturing nor the household expenses of domestic consumers. However, since this is an environmentally-oriented scenario, society invests more heavily in improving technology so that greater efficiencies in energy, materials and water use are achieved. As a result, water use efficiency improves rather rapidly and tends to lower water use.

The implementation of stronger climate policies in Europe-30 and elsewhere in the world leads to a significant reduction in greenhouse gas emissions, and this slows down the rate of climate change slightly as compared to the baseline scenario. However, the difference is not big because of the enormous inertia built into the global climate system. Climate policies implemented in the period 2000 to 2030 might have their greatest effect on global climate only after 2030. Consequently, the impact of climate change on irrigation water use and on water stress in this scenario is nearly the same as in the baseline scenario.

## 5.2 Driving Force Assumptions

**Socio-economic**

Assumptions for population, gross domestic product per capita (GDP/cap·year), and gross value added of manufacturing are the same as for the baseline scenario.

### Thermal electricity production

The implementation of climate policies in this scenario leads to a mix of fuels different from the baseline scenario. In particular renewable energies (solar, wind, biofuels) are introduced in order to reduce greenhouse gas emissions. Since much of this new renewable energy capacity is non-thermal solar and wind energy, the total thermal electricity generation is lower in this scenario than in the baseline scenario. (Table 9, Table 10).

Table 9. Projected thermal electricity production for the climate policy (SEP) scenario. Source: EUROSTAT, PRIMES. Regions are defined in Table 1.

| | SEP [TWh]* | | | | | Annual growth rate [%] | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 2000 | 2010 | 2020 | 2030 | 90/00 | 00/10 | 10/20 | 20/30 | 00/30 |
| Northern Europe | 1183 | 1297 | 1421 | 1510 | 1488 | 0.93 | 0.92 | 0.61 | -0.15 | 0.46 |
| Southern Europe | 722 | 963 | 1143 | 1302 | 1404 | 2.92 | 1.73 | 1.31 | 0.75 | 1.27 |
| New EU Member States | 304 | 308 | 358 | 441 | 474 | 0.14 | 1.52 | 2.10 | 0.72 | 1.45 |
| EU Candidate States | 121 | 169 | 207 | 287 | 434 | 3.40 | 2.05 | 3.30 | 4.22 | 3.19 |
| Europe-30 | 2329 | 2737 | 3130 | 3540 | 3799 | 1.63 | 1.35 | 1.24 | 0.71 | 1.10 |

* Thermal electricity production (including biomass) and nuclear electricity production.

Thermal electricity production grows by 39% in the EU-30 countries between 2000 and 2030, and by 15% in Northern Europe, by 46% in Southern Europe, by 54% in the New EU Member States, and will more than double (157%) in the EU Candidate States.

Table 10 below shows a comparison between the thermal electricity productions expected for the climate policy (SEP) and the baseline scenarios (LREM-E) between 2000 and 2030. Although the thermal electricity production declines in all the regions, the largest reduction occurs in the Northern Europe countries (-16%). In Southern Europe the generation of electricity decreases by 6%, in the New EU Member States by 3%, and in the EU Candidate States by 7% between 2000 and 2030.

Table 10. Difference in thermal electricity production for the baseline (LREM-E) and climate policy (SEP) scenarios. Source: EUROSTAT, PRIMES. Regions are defined in Table 1.

| | | LREM-E [TWh]* | | | SEP [TWh]* | | | Difference between SEP and LREM-E [%] | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2000 | 2010 | 2020 | 2030 | 2010 | 2020 | 2030 | 2010 | 2020 | 2030 |
| Northern Europe | 1297 | 1437 | 1615 | 1771 | 1421 | 1510 | 1488 | -1.08 | -6.52 | -15.98 |
| Southern Europe | 963 | 1156 | 1341 | 1492 | 1143 | 1302 | 1404 | -1.15 | -2.93 | -5.91 |
| New EU Member States | 308 | 362 | 452 | 488 | 358 | 441 | 474 | -1.04 | -2.36 | -2.92 |
| EU Candidate States | 169 | 213 | 306 | 469 | 207 | 287 | 434 | -2.63 | -6.20 | -7.47 |
| Europe-30 | 2737 | 3168 | 3714 | 4220 | 3130 | 3540 | 3799 | -1.21 | -4.69 | -9.96 |

* Thermal electricity production (including biomass) and nuclear electricity production.

### Irrigated area and livestock density

The assumptions for irrigated area and livestock density are the same as in the baseline scenario.

### Technological change – Improvements in water use efficiency

Because this is a more environmentally-oriented scenario, we assume that society invests more heavily in improving technology so that greater efficiencies in energy, materials and water use can be achieved. Technological changes are assumed to improve water use efficiency at a faster rate in some regions than in the baseline scenario. Technological changes for the domestic sector are assumed to reduce water use by about 1.5% per year over the entire time horizon in the New EU Member States. For the other regions (Northern and Southern Europe and EU Candidate States) the assumptions for the SEP scenario are the same as for the baseline scenario.

Assumptions for the technological development of water-saving appliances for the electricity sector, manufacturing sector, and agricultural sector are the same as for the baseline scenario.

### Climate change

Climate change estimates are derived from the same source as the baseline scenario. However greenhouse gas emissions in the climate policy scenario are substantially lower than in the baseline scenario. As we noted earlier, up to 2030 there is only a small difference between the scenarios.

Figure 16 shows the change in long-term average temperature (top map) and precipitation (bottom map) for the climate policy scenario between the climate normal period (1961 to 1990) and climate normal periods representative for 2030.

The temperature increases in the Europe-30 region vary between 0.54°C and 1.29°C. A temperature increase between 1°C and 1.25°C is computed in most parts of the Europe-30 region, larger differences only occur in Southern Spain.

The changes in long-term average precipitation vary between –17.8% and 14.2%. with a wetter climate in Northern Europe (> 5%) and a drier climate (< -5%) in the sSouthern parts of Europe. In the Western and mid European countries only slight changes (+/- 5%) in the average annual precipitation are computed.

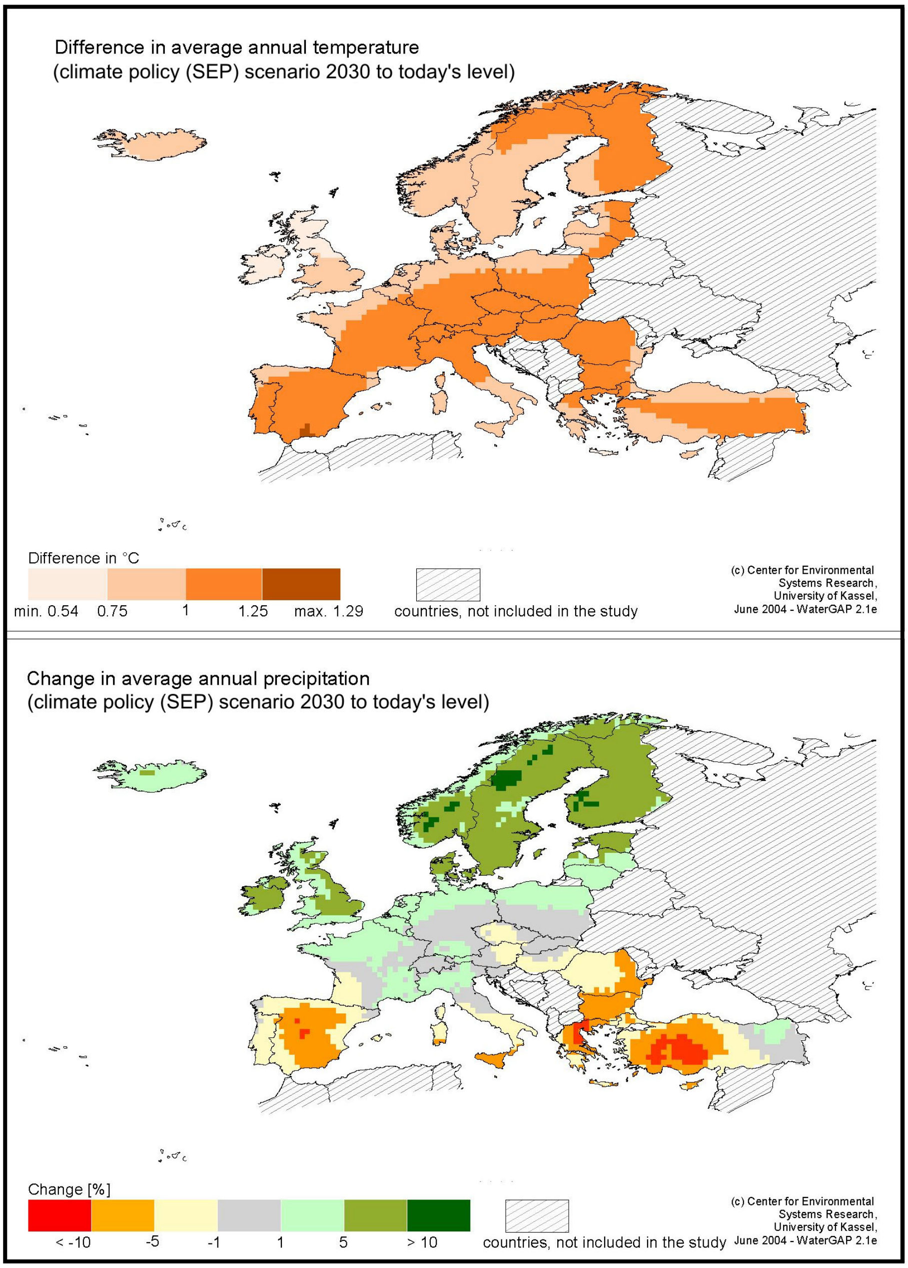


Figure 16. Differences in long-term average annual temperature (top) and percentage change in long-term average precipitation (bottom) as calculated for the climate policy (SEP) scenarios; 2030 projections compared to today's level.

Figure 17 presents the difference in long-term average annual temperature (top map) and precipitation (bottom map) between the baseline (LREM-E) and the climate policy (SEP) scenario for the year 2030. The slightly higher atmospheric concentrations of greenhouse gases in the baseline scenario results in somewhat larger climate changes. Nevertheless, these differences are small. The temperature differences between the baseline and the climate policy scenario are at maximum 0.15°C. In the case of precipitation, the distribution of the differences indicates a wetter climate in Northern Europe and a drier climate in Southern Europe (see Section 4.2.10). Those regions with an increase in precipitation are wetter in the baseline scenario than in the climate policy scenario (green colours in right map). Similarly, those regions with less precipitation in the future are drier in the baseline scenario than in the climate policy scenario (red colour in right map). But the difference in average annual precipitation between the LREM-E and SEP scenarios varies only from –7 mm to 8 mm per year.

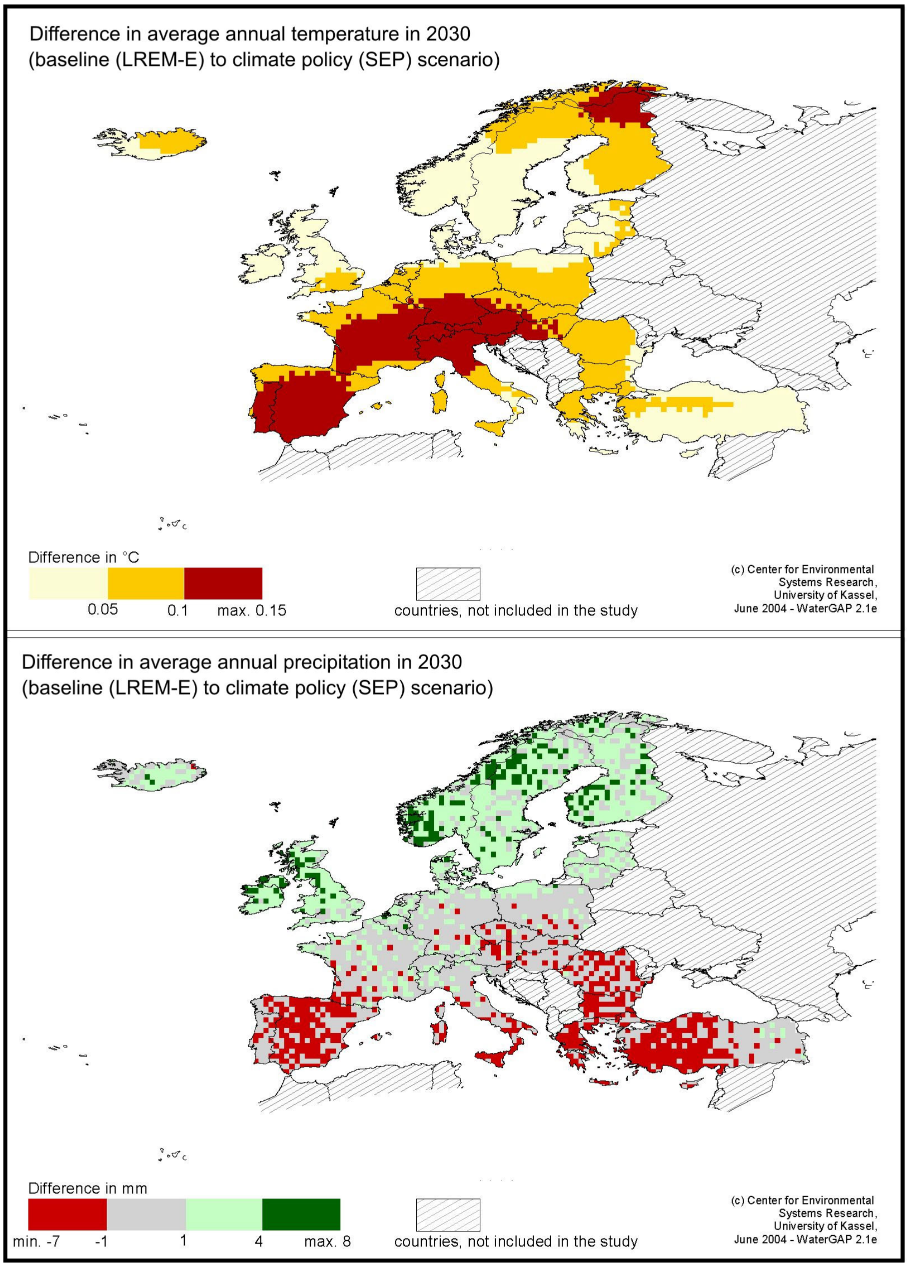


Figure 17. Difference between the baseline (LREM-E) and climate policy (SEP) scenarios. Differences in long-term average annual temperature (top) and precipitation (bottom).

# 6. SCENARIO RESULTS

The scenario input data described in the previous chapters were taken as input into the WaterGAP model to compute future water use, water availability, and water stress in 5-year intervals until 2030. Since the focus of the study was on water use, we first give the quantitative results for the baseline scenario, discuss the results of the climate policy scenario, and compare our scenario results with other published European studies. Subsequently, we present quantitative results of our scenarios for water availability and water stress. At the end, we discuss the policy relevance of our results with regard to the European Water Framework Directive.

## 6.1 Water Use

Country-by-country results for water use are presented in Appendix D. Here we present the scenario results aggregated into the four regions defined in Table 1. For most figures we only present results for the baseline scenario because of the small differences between baseline and climate policy scenario results. The following four sections describing the scenario results per region only describe the results of the baseline scenario; results of the climate policy scenario are discussed together for all four regions in the section ‘Comparing Water Use in the Baseline and Climate Policy Scenarios’.

### Northern Europe

The profile of water withdrawals in 2000 in Northern Europe region is dominated by water use in the electrical production sector (45%), followed by the domestic sector (32%), the manufacturing sector (20%) and agriculture sector (3%) (See Figure 18). Computed future projections between 2000 and 2030 are shown in Figure 19.

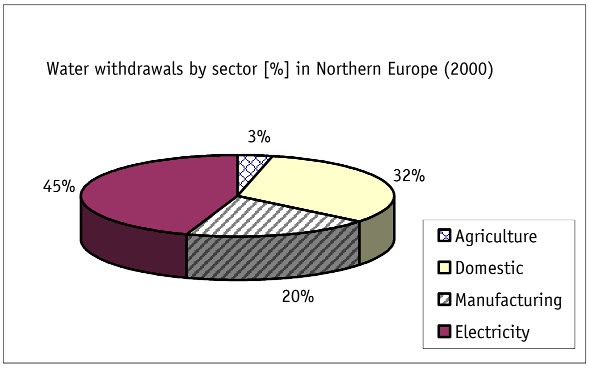


Figure 18. Profile of sector-specific water withdrawals in the Northern Europe in 2000. Sources: EUROSTAT and national Statistical Offices.

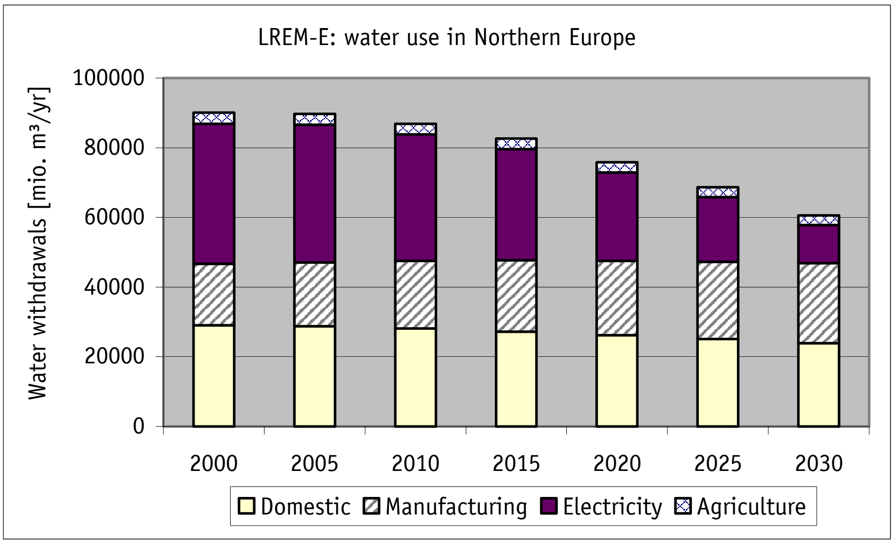


Figure 19. Computed water withdrawals for the baseline (LREM-E) scenario for Northern Europe.

Water withdrawals in Northern Europe have decreased steadily during the 1990s (EEA, 2003) and the baseline and climate policy scenarios show a continuation of this trend.

In the domestic sector, water withdrawals stabilize and then slowly decline because per capita water use in households and businesses reaches its saturation point, and the efficiency of water use continues to improve (for example, municipal water distribution losses are reduced with new technology). The amount of water declines between 2000 and 2030 by 18% from 29045 million $m^3$ to 23924 million $m^3$.

Manufacturing output increases and this tends to increase water use, but improving efficiency of water use in this sector tends to dampen the increase somewhat. A continuous increase in water use in the manufacturing industry of 30% between 2000 and 2030 is calculated. Water withdrawals from electricity production show the largest sectoral changes. Water withdrawals sharply decrease as older power stations with once-through cooling are replaced by new ones with tower cooling which requires much smaller water withdrawals. (See Figure 19). Therefore, in the electricity sector, the expected water uses for cooling will decrease by 73%.

Agricultural water use in Northern Europe only constitutes a minor 3% of total water withdrawal in 2000. Due to the short time horizon covered by the scenarios, the effect on temperature and precipitation in 2030 is relatively small in Northern Europe. Because of slightly higher temperatures and precipitation, the amount of water withdrawal for irrigation declines by 11% between 2000 and 2030. Compared to other sectors (in particular electricity production), this however, only constitutes a relatively small overall change.

**Southern Europe**

The profile of water withdrawals in Southern Europe is distinctly different from that of Northern Europe. Here agriculture dominates water withdrawals (44 %), followed by the electrical production sector (23%), the domestic sector (22%) and manufacturing (11%). (See Figure 20). In Figure 21 the computed water withdrawals per sector are presented for the future time slices between 2000 and 2030 in 5-year intervals.

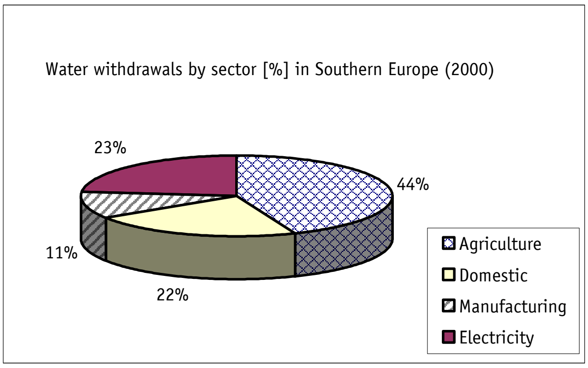


Figure 20. Profile of sector-specific water withdrawals in Southern Europe in 2000. Sources: EUROSTAT and national Statistical Offices.

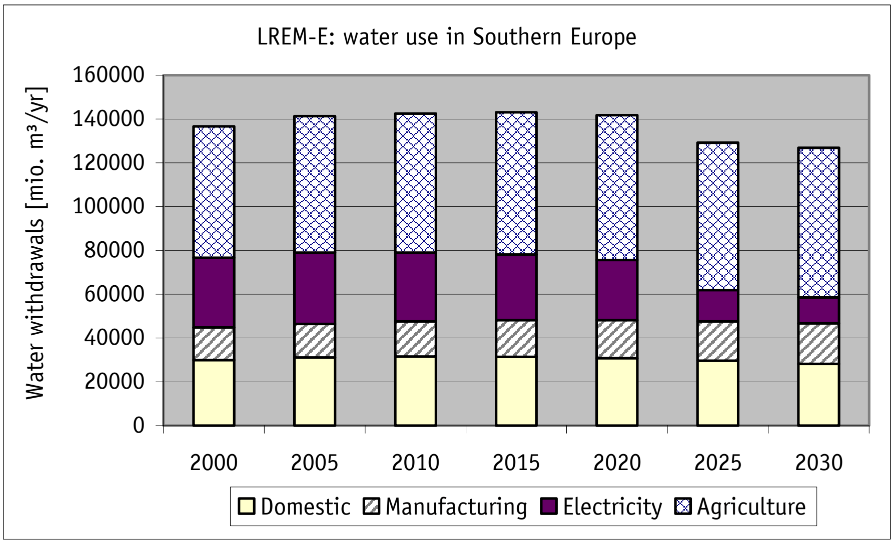


Figure 21. Computed water withdrawals for the baseline (LREM-E) scenario for Southern Europe.

Changes in water use are similar to those in Northern Europe in that the most dynamically-changing sector is electricity production where older plants are replaced, especially after 2020, and this leads to more plants with tower cooling (see Figure 21). The water withdrawals in the electricity production sector are 63% lower in 2030 than in 2000 in the baseline scenario.

Water withdrawals increase slightly, but continuously, in the manufacturing sector by 24% between 2000 and 2030. In the domestic sector, water withdrawals increase slightly, and then stabilize for the same reasons as in Northern Europe.

A variety of compensating changes go on in the agricultural sector. On the one hand, gross irrigation water requirements increase by 14% because of a somewhat warmer and drier climate. Irrigation water requirements also increase because the total area irrigated in this region increases by 27% between 2000 and 2030. On the other hand, this region makes steady progress in improving the efficiency of irrigation water use. The net result of these changes is an increase in irrigation water withdrawals of 32% (including the expansion of irrigated areas) in 2030 compared to 2000. If we keep the irrigated area constant, a net increase of 5% in irrigation water withdrawals is computed for the year 2030 compared to 2000.

The decrease in total water withdrawals is smaller in Southern Europe than in Northern Europe because the electricity production sector does not account for as large a percentage of total withdrawals as it does in Northern Europe, and because the decrease in the electricity sector is compensated by an increase in water withdrawals in the agricultural sector.

**New EU Member States**

The profile of water withdrawals in 2000 in the New EU Member States is different from the previous two regions. Electrical production is the largest water-using sector as in Northern Europe, but it claims a higher percentage of total withdrawals (61%) than in Northern Europe. The domestic water sector is in second place, as in the previous two regions, but has a smaller percentage of total withdrawals (22%). The manufacturing sector claims a slightly higher percentage than the agriculture sector (10% and 7%). (See Figure 22). The copmuted future water withdrawals are shown in Figure 23 for the time horizon up to 2030.

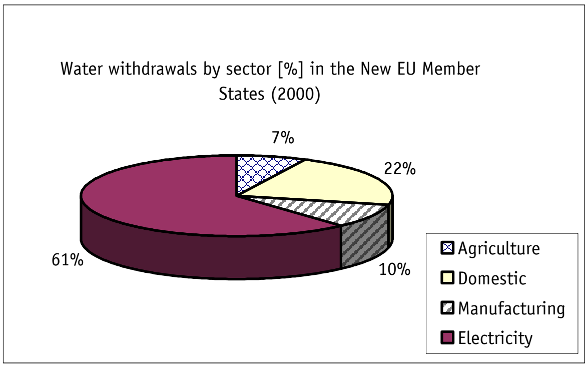


Figure 22. Profile of sector-specific water withdrawals in the New EU Member States in 2000. Sources: EUROSTAT and national Statistical Offices.

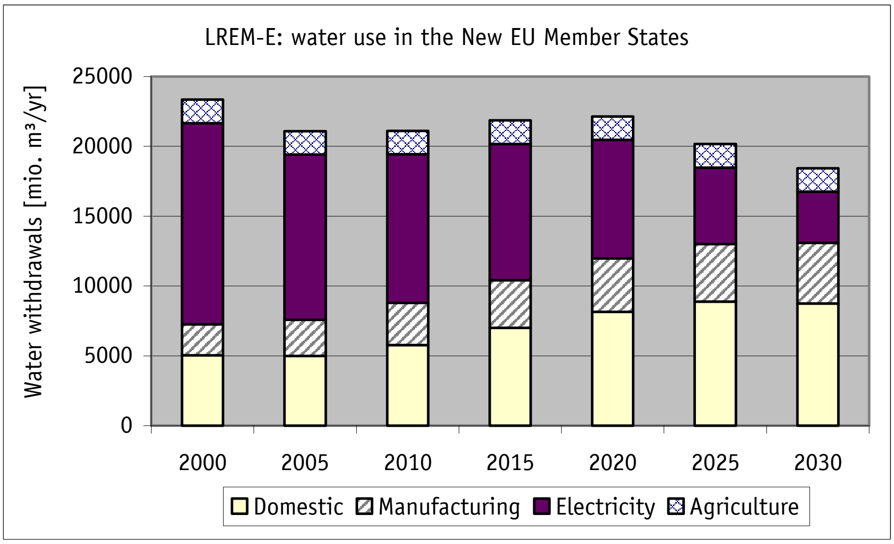


Figure 23. Computed water withdrawals for the baseline (LREM-E) scenario for the New EU Member States.

Two sectors are very dynamic in this region – the electrical production sector (as in the previous regions) and the domestic sector. As in Northern and Southern Europe, water withdrawals decline in the electrical production sector because of the replacement of power stations with once-through cooling with plants having tower cooling. The water withdrawal used for cooling puposes in the electricity production is 75% lower in the baseline projection (2030) than in the year 2000.

Water withdrawals in the domestic sector steadily increase up to 2025 as per capita water use converges with the higher water use of Northern and Southern Europe by 2030 (see Sections 3.2.3 and 4.2.3, Figure 23). In the case of convergence, the domestic water withdrawals increase from 5025 million m³ to 8753 million m³ (+74%) between 2000 and 2030. As we explain in Sections 3.2.3 and 4.2.3, this assumption of convergence is very uncertain, and in Section 7.2 we analyse the result of an alternative assumption, namely that per capita water use in this region remains at its current level. The increase in domestic water withdrawals is dampened somewhat by a continuous decrease in population which is the main driving force in this sector. Water withdrawals stabilize in the domestic sector by 2025 as the convergence to higher per capita water use is balanced by the decline in population growth.

Water withdrawals strongly increase in the manufacturing sector as it does in other regions and almost doubles between 2000 and 2030. In the year 2000, 2236 million m³ are used by manufacturing industry whereas 4340 million m³ of freshwater will be used in 2030. The increase in water use is a result of the expansion of manufacturing production.

Agricultural water use remains about the same because of compensating changes in this sector. – Higher temperatures tend to increase water requirements of irrigation, while increasing precipitation and improving water use efficiency tend to decrease these requirements.

The temporal trend of total withdrawals is uneven over the scenario period as water withdrawals strongly decline in the electrical production sector while they sharply increase and then stabilize in the domestic sector. The combination of these changes create a 'wavy' tendency for total withdrawals.

**EU Candidate Countries**

The profile of water withdrawals in this region resembles that of the Southern region since they are in similar climate zones. The profile is dominated by agriculture (60%), followed by domestic sector (16%), the electrical production (15%), and the manufacturing (9%) sector. (See Figure 24). Figure 25 visualizes the calculated water withdrawals per sector for the projected time period between 2000 and 2030.

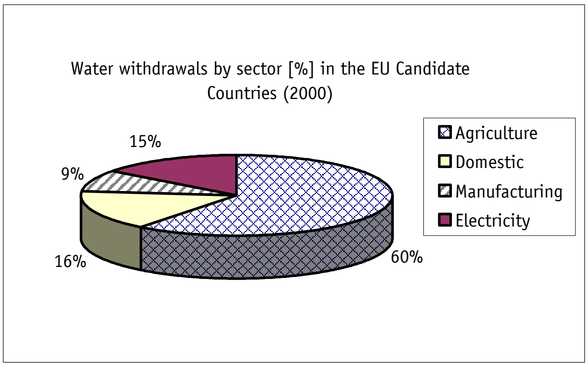


Figure 24. Profile of sectoral-specific water withdrawals in the EU Candidate States in 2000. Sources: EUROSTAT and national Statistical Offices.

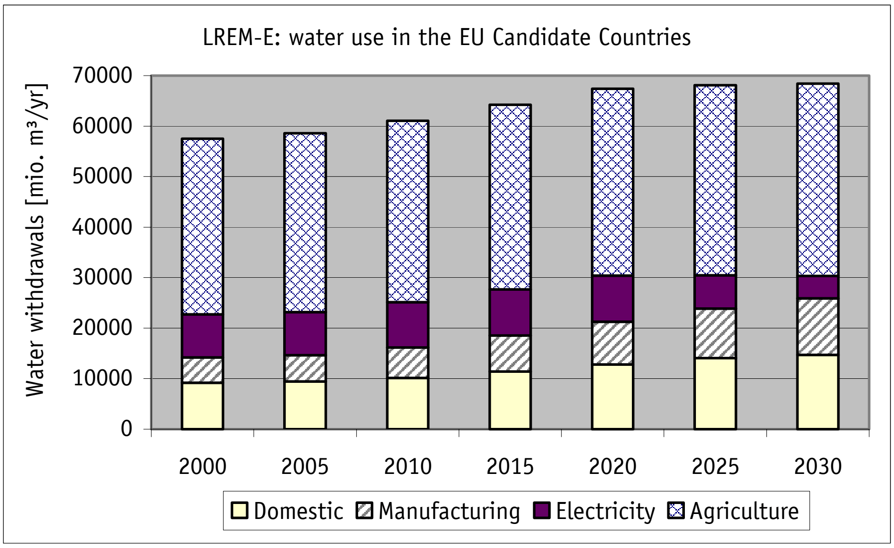


Figure 25. Computed water withdrawals for the baseline (LREM-E) scenario for the EU Candidate Countries.

Here, as in other regions, the biggest changes are occurring in the electricity production sector where withdrawals decrease for the same reasons as in the other regions (Figure 25).

The manufacturing sector has the next biggest changes as withdrawals sharply increase because of expanded industrial production and more than doubles between 2000 and 2030. The total amount of water used in this sector of 4968 million m³ in the year 2000 will increase to 11143 million m³ in the year 2030.

Withdrawals in the domestic sector increase as higher incomes lead to higher per capita water use (Bulgaria and Romania). But also as per capita water use in Turkey converges with the higher water use of Northern and Southern Europe by 2030 and in Turkey, the population is projected to increase by 23.5 million inhabitants (+35%) between 2000 and 2030. Hence, in the case of convergence, the domestic water withdrawals increase from 9230 million m³ to 14728 million m³ (+60%) between 2000 and 2030.

Water withdrawals in the agricultural sector have a small net increase (by 10% between 2000 and 2030) for the same combination of factors as in Southern Europe. Water withdrawals tend to increase because a drier and warmer climate increases the per hectare water requirements of irrigation while the area of irrigation increases by 20% between 2000 and 2030. Withdrawals tend to decrease because of efficiency improvements in irrigation water use.

Total water withdrawals slightly increase (by 19% in 2030 over 2000) as the decrease in withdrawals from electricity production is outweighed by the combined increases in the manufacturing and domestic sectors.

**Comparing water use in the baseline and climate policy scenarios**

Climate policy, as represented in the climate policy scenario, affects water use in two major ways. The first effect is obvious – the lower greenhouse gases in Europe and elsewhere slow down the rate of climate change and lead to more moderate changes in precipitation and temperature. These more moderate climate changes lead to more moderate changes in the amount of irrigation water required.

How different is the climate between the baseline and climate change scenarios? Figure 17 shows that under the baseline scenario the temperature would be a few tenths of a degree warmer throughout Europe. The North would receive a few percent more millimeters of precipitation and the South a few percent less. That is, under the stronger climate change of the baseline scenario the North would become a bit wetter and the South a bit drier. We explained earlier that the difference is not big because there is enormous inertia built into the global climate system which means that that climate responds slowly to changes in greenhouse gas emissions.

Figure 26 gives an overview of the amount of water used for irrigation in the base year (2000) and for the projected time horizon 2030 for both scenarios. The water withdrawals are aggregated according to the four regions as listed in Table 1. The small differences in climate (between the baseline and the climate policy scenarios) lead to similarly small differences in water requirements of irrigation and in water withdrawals in the agriculture sector. However, the differences between the baseline (LREM-E) and climate policy (SEP) scenarios are less than 1% within a region in 2030.

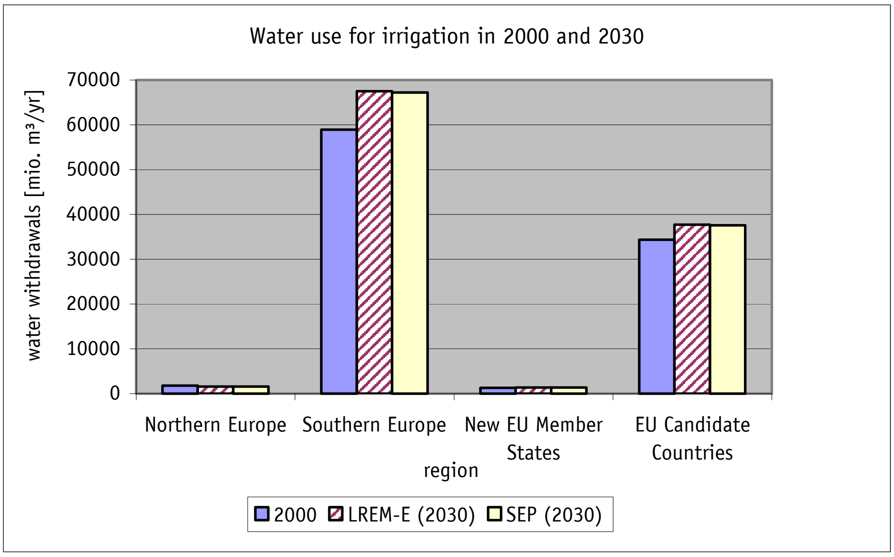


Figure 26. Computed water withdrawals for irrigation in the base year 2000 and in 2030 for the baseline (LREM-E) and climate policy (SEP) scenarios.

Regarding the country scale, water withdrawals for irrigation, for example, in Spain are 23106 million $m^3$ in 2030 under the baseline scenario, and slightly smaller 23007 million $m^3$ in the same year (-0.4%) under the climate policy scenario because Spain's temperature does not increase quite as much and it does not become quite as dry as under the baseline scenario. These results, however, are highly uncertain because not all possible impacts of climate change on irrigation were evaluated (for example, the impacts of possible changes in wind velocity were not included).

The second and more noticeable effect of climate policies is that greenhouse emissions are reduced by replacing fossil fuels with renewable energy. The introduction of renewable energy implies that some thermal power stations will be replaced by wind generators and solar photovoltaic systems which use very small volumes of water both directly or indirectly. Consequently the amount of water used for electricity production by power plants is smaller in the climate policy scenario than in the baseline scenario, and this reduces water withdrawals in the electrical production sector as shown in Figure 27. Hence, Europe-30 water withdrawals for power plants in 2030 under the climate policy scenario are 9% lower than under the baseline scenario. The decreases are 16% in Northern Europe, 5% in Southern Europe, 3% in the New EU Member States, and 7% in the EU Candidate Countries.

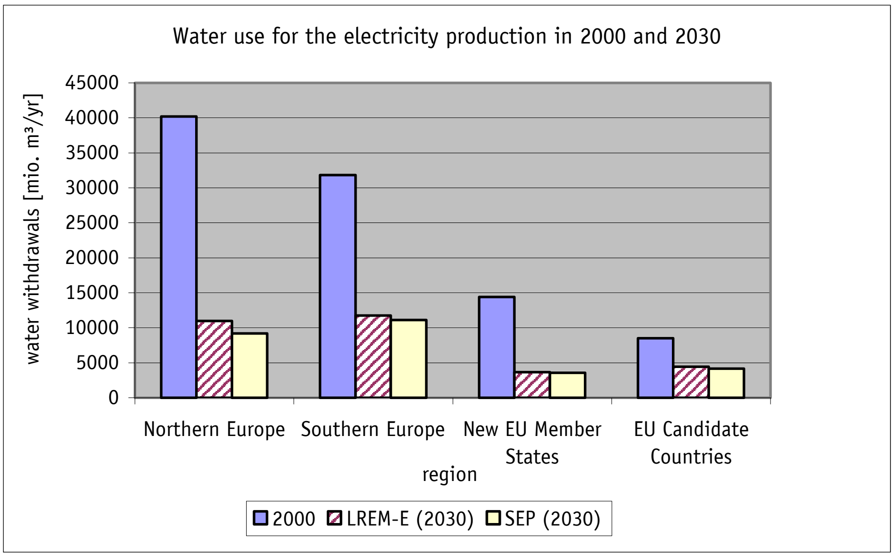


Figure 27. Computed water withdrawals for the electricity production in the base year 2000 and in 2030 for the baseline (LREM-E) and climate policy (SEP) scenarios.

**Comparing water use scenarios with other estimates**

In the framework of this study, the baseline (LREM-E) and climate policy (SEP) scenarios are compared to other scenarios of European water withdrawals. Since all of these scenarios were generated by the WaterGAP model, the differences in scenarios are due to differences in scenario assumptions. It should be noted that the baseline and climate policy scenarios are prescriptive as opposed to the others which are explorative scenarios. Three different studies are taken into consideration: The 'Global Environment Outlook 3' (GEO-3) (UNEP, 2001), 'An integrated Analysis of Changes in Water Stress in Europe' (Henrichs et al., 2002), and the 'Dialogue on Water and Climate' (Kabat and van Schaik, 2002). Altogether, they describe nine possible futures for Europe (and the world). Since all of these studies look forward to, at least, the year 2025, this time slice will be considered in the comparison. In the following text the studies and scenarios are briefly introduced.

*Global Environment Outlook 3* (Scenarios 1 to 4 in Figure 28) is a study, which looks back thirty years and forward thirty years. A set of four scenarios was used to examine environmental and social goals. The thematic issues are analyzed from first the global level and then at the regional level, e.g. Europe. In GEO-3 a set of four scenarios has been developed: (1) 'Market First' (2) 'Policy First', (3) 'Security First', and (4) 'Sustainability First'. The Market First scenario assumes relatively low population growth for Europe, a strong economic growth rate, a relatively large expansion of irrigated area, and intermediate rates of technological improvement in the water sector. The Policy First scenario has similar assumptions to the Market First scenario except that irrigated areas expand more modestly and a high level of water-conserving behavior is assumed. In the Security First scenario the population growth rate is higher than the first two scenarios and economic growth is lower. The Sustainability First scenario has a population growth similar to the first two scenarios, an intermediate economic growth rate, a much higher use of sustainable energy, and a high level of water-saving behavior.

*An Integrated Analysis of Changes in Water Stress in Europe* (Scenario 5 in Figure 28) presents an 'integrated' analysis of global change impacts on European river basins with regard to projected changes in water withdrawals and water availability. With the combination of both, changes in future water withdrawals and future water availability, pressure on European river basins was estimated. With the focus on three time slices, model calculations were done for 1995 (as base year), the 2020s, and the 2070s. Figure 28 shows the 'Baseline A' scenario from this study (labeled Scenario 5). This scenario has socio-economic driving forces, largely consistent with the no-climate policy 'IPCC-IS92a' scenario of the Intergovernmental Panel on Climate Change (IPCC, 1992). Although the economic and demographic driving forces of this scenario were once considered 'intermediate', they are on the higher side of current scenarios.

*Dialogue on Water and Climate* (Scenarios 6 to 9 in Figure 28) presents an integrated assessment of future water availability and water withdrawals following the assumptions of the IPCC SRES scenarios A2 and B2. To take into account climate change, climate data from two different climate models were used (ECHAM4-OPYC3 of the Max Planck Institute for Meteorology and HadCM3 of the Hadley Center). Figure 28 shows results for the A2 scenario (6 and 7) using climate inputs from the Max Planck and Hadley models, respectively, and for the B2 scenario (8 and 9) also using inputs from the two climate models. The A2 scenario has higher population growth and lower economic growth in Europe than the B2 scenario. The B2 scenario assumes faster rates of improvement in water use efficiency.

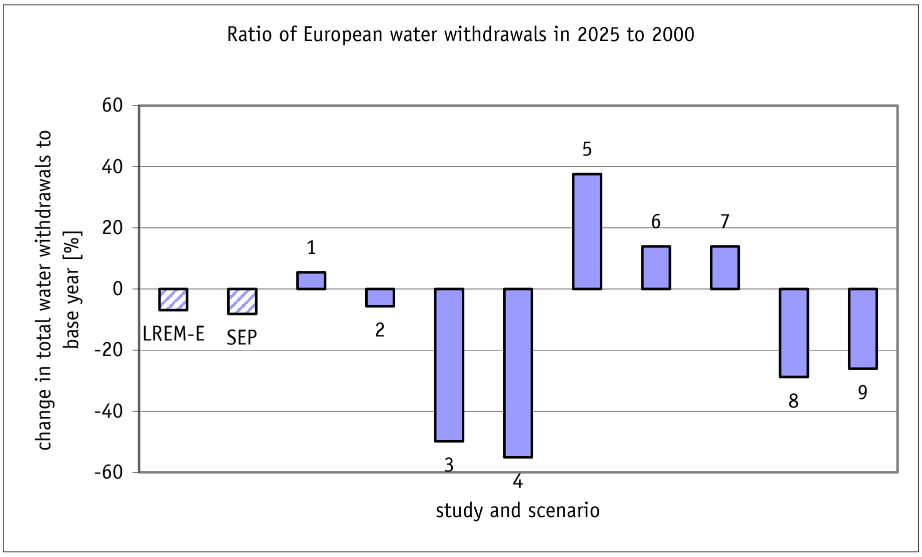


Figure 28. Comparison of water use scenarios. (See text for explanation of numbers).

We can observe the following from the comparison of different studies. The results in this report fall mid-way in the range of scenarios produced for the GEO-3 report of UNEP (Scenarios 1 to 4). The lower scenarios in the GEO-3 report compute a lower domestic water use because of assumed water-saving behavior, and lower industrial water use because of lower electricity production. The higher GEO-3 scenarios assume higher population and economic growth and less attention is given to water conservation.

Results in this report also fall mid-way between a set of scenarios developed by the Dialogue on Water and Climate (Scenarios 6 to 9). These scenarios are less extreme than the GEO-3 scenarios because they have less extreme assumptions for socio-economic driving forces.

The lower scenarios in other studies (Scenarios 3, 4, 8, and 9) are caused by the assumption of water-saving behavior in the domestic sector. While this is an important factor in this report, other factors are also important, for example the transition from once-through cooling to tower cooling in power stations.

The baseline and climate policy scenarios in this report are much lower than the Baseline A scenario (Scenario 5). This is because the Baseline A scenario has much higher assumptions for population and economic growth. Also, data were not available to check country-scale calculations of domestic water use in Europe. Therefore it is likely that estimates of future domestic water use in the Baseline A scenario were much higher than the present study.

To sum up, the scenarios presented in this report give intermediate estimates of future water use in Europe as compared to earlier studies.

In addition to the comparison with other WaterGAP studies, we compared the results of the baseline and climate policy scenarios with forecasts obtained by Shiklomanov and Rodda (2003). To obtain future values of water withdrawals and water consumption for the time period up to 2025, Shiklomanov and Rodda (2003) considered the UN (1995) population development scenario as well as UN (1993) and International Monetary Fund (IMF, 1994) trends for the GDP/cap. The growth in industrial water use was derived for the year 2025 from data relative to 1990 (Strzepek and Bowling, 1995). Data on irrigated areas based on information given in Zonn and Nosenko (1981) and FAO (1995) and the extent of future irrigated areas was calculated for the European countries taking into account economic and population growth. These data were used to extrapolate future irrigated areas and future irrigation water withdrawals. As a result, the dynamics of water withdrawals and water consumption are given by sector and by continent up to 2025. Based on these assumptions, Shiklomanov and Rodda (2003) calculate that, in Europe, total water withdrawal will continuously increase and will be 21% higher in 2025 compared to 1995.

However, it should be noted that the main goal of the present study is to evaluate the impact of climate change on the water withdrawal, which is not explicitly considered by Shiklomanov and Rodda (2003). Their results are based on extrapolation of actual trends and are thus, not directly comparable to our results.

## 6.2 Water Availability and Water Stress

### 6.2.1 Water Availability

We define water availability here as the total river discharge, which is the combined surface runoff and groundwater recharge. Figure 29 shows the change in annual water availability in the baseline scenario.

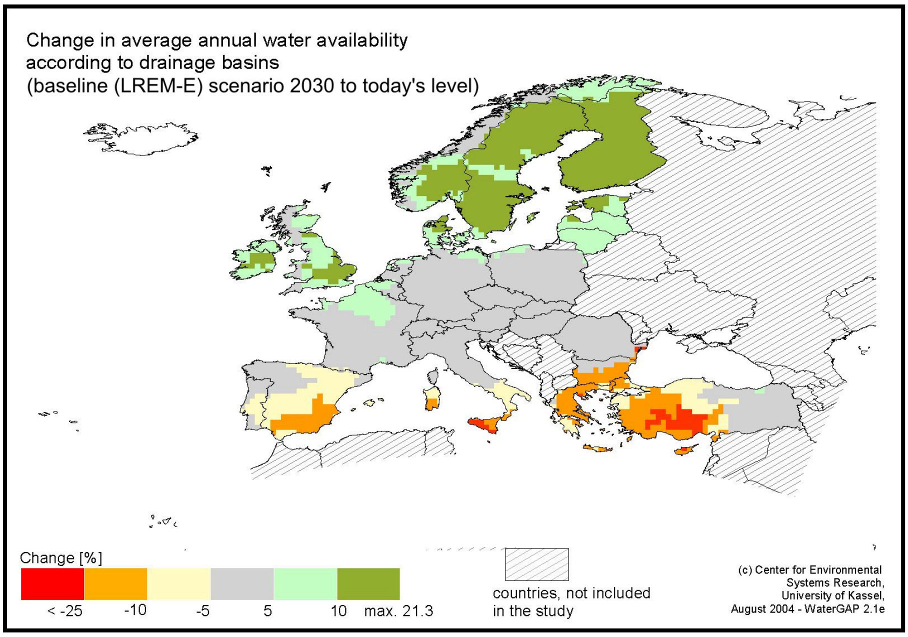


Figure 29. Change in average annual water availability for European river basins under the baseline (LREM-E) scenario compared to today's level.

Under the baseline scenario water availability declines in parts of Southern and Southeastern Europe because of higher temperatures (causing higher evapotranspiration) and lower precipitation.

Water availability increases throughout the rest of Europe despite increasing temperatures because precipitation also increases significantly. The increase in water availability ranges up to about 20 percent, although the magnitude of increase is very different in different parts of Europe.

Under the climate policy scenario, the rate of climate change is lower than in the baseline. We noted above that this slower rate of climate change will reduce the amount of water needed for irrigation in the South which also means that less available water will be consumed. Temperatures are also not as high in parts of Southern and Southeastern Europe as they are under the baseline scenario, nor does precipitation decline as much. These differences should lead to a higher water availability in the climate policy scenario, but these are not observed because they are so small. Over the rest of Europe, water availability should be somewhat lower than in the baseline scenario because temperature and precipitation are not as high. But this effect is barely visible in Figure 30. To sum up, differences in water use and climate between the climate policy and baseline scenarios do not cause significant differences in water availability.

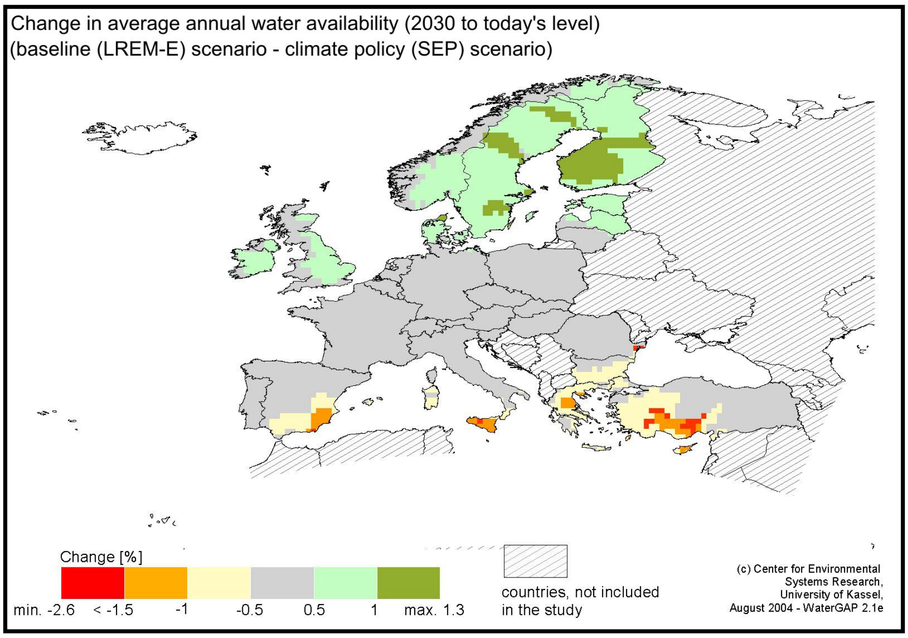


Figure 30. Comparison of the baseline (LREM-E) and climate policy (SEP) scenarios. Differences in changes in average annual water availability for European river basins.

### 6.2.2 Water Stress

Water stress is a measure of the amount of pressure put on water resources and aquatic ecosystems by the users of these resources, including municipalities, industries, power stations and agricultural users (see, for example, Alcamo et al., 2000; Vorösmarty et al., 2000; Cosgrove and Rijsberman, 2000). To estimate stress we use a conventional indicator, namely the ratio of withdrawals to availability (w.t.a.). Roughly speaking, the higher the w.t.a.-ratio, the more repeatedly the water in a basin is used and the more it is degraded or depleted, therefore limiting further use of these water drainage resources to downstream users. This indicator has the advantage of being transparent and computable for all river basins.

Figure 31 (left map) depicts current water stress conditions for the different drainage basins of Europe. (Current conditions are defined as water use for the year 2000, and water availability averaged over the climate normal period, 1961-90). Drainage basins are in the severe stress category where water use is very high per unit area (Belgium, The Netherlands, Southeast England)

and in countries having arid climates and where water availability is low relative to water use (Greece, Southern Italy, Portugal, Spain, and Turkey).

Figure 31 (right map) shows the same indicator for the baseline scenario in 2030. The Central European areas in the medium stress category in 2000 have disappeared because of lower water withdrawals and slightly wetter climate, while areas that earlier had low water stress in eastern Turkey, now have medium stress because of increasing water use. Areas of central and western Turkey that were in the medium stress category in 2000 jump to the severe water stress category in 2030 because of both increasing water use and slightly decreasing water availability. Other areas of severe water stress in the south remain about the same because of compensating changes – both water use and water availability slightly decrease. Te pattern of water stress for the climate policy scenario is very close to that of the baseline scenario, and is therefore not shown.

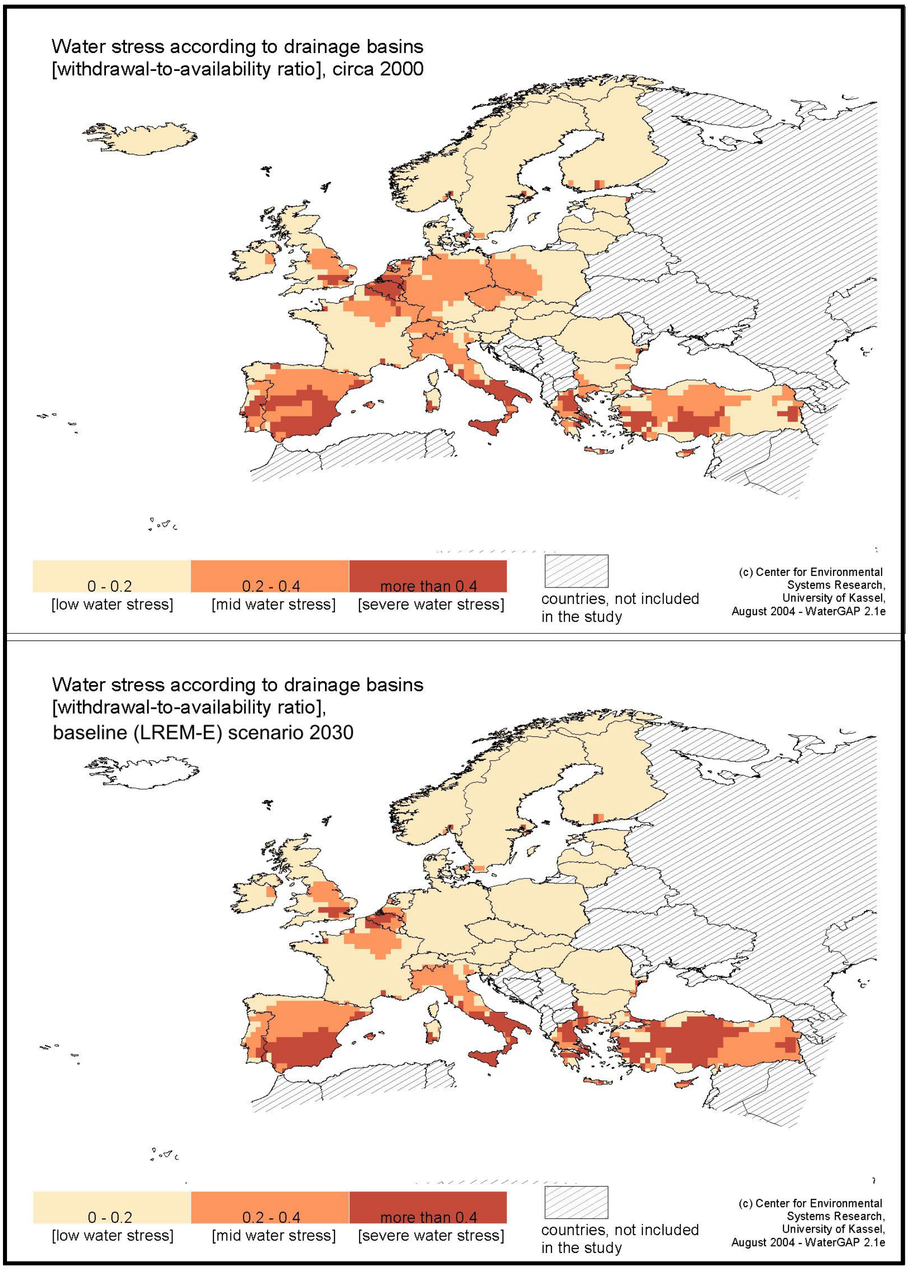


Figure 31. Water stress under current conditions and under the baseline scenario. Top: Current conditions. Bottom: Baseline scenario, 2030.

## 6.3 Contribution to the Water Framework Directive

### The Water Framework Directive

The Water Framework Directive (WFD) entered into force in October 2000, breaking a new ground in the European water policy. The WFD establishes a framework for the protection of all aquatic systems, including surface waters, groundwater, and coastal waters; land ecosystems depending on groundwater are also included. Its overall environmental objective is to achieve a *good status* for all water bodies in the Community by 2015 in terms of good ecological status *and* good chemical status (Article 4). Article 1 further details the specific purposes of the Directive:

**(a)** To prevent further deterioration, protect and enhance the status of water resources;

**(b)** To promote sustainable water use based on long-term protection of water resources;

**(c)** To aim at enhancing protection and improvement of the aquatic environment through specific measures for the progressive reduction of discharges, emissions and losses of priority substances and the cessation or phasing-out of discharges, emissions and losses of the priority hazardous substances;

**(d)** To ensure the progressive reduction of pollution of groundwater and to prevent its further pollution; and

**(e)** To contribute mitigating the effects of floods and droughts.

In order to attain the Directive's goals, all waters are to be characterized according to their biological, chemical, and hydro-morphological characteristics. Therefore, Member States shall ensure that a River Basin Management Plan is produced for each river basin. But many of the river basins are international and this requires that all partners in a given river basin manage their waters together in close cooperation. As a consequence, administrative or political boundaries become less important in their respective countries compared to natural geographical and hydrological units. The concept of river basins brings together upstream and downstream interests.

### Contribution of this study

With this study we contribute to the overall objective by calculating water stress in all river basins of the Europe-30 region, thereby addressing the question of good ecological status of all European water bodies. So far, we do not address the question of good chemical status because the focus of this study is on the quantitative water availability and use. In the following, we list the contribution of this study to the individual purposes identified above.

**(a)** *To prevent further deterioration, protect and enhance the status of water resources*. Water stress under current conditions and two different scenario assumptions has been calculated for all river basins within Europe-30 regions. Based on the future projections, countries can decide on their future pathways as to how to enhance the status of water resources.

**(b)** T*o promote sustainable water use based on long-term protection of water resources*. Water use has been calculated under current conditions and two different scenario assumptions for four distinct economic sectors per country and been attributed to all river basins within Europe-30 regions. Together with the water stress of the river basin and the scenario information, sector-specific policy measures can be designed to promote sustainable water use.

**(c)** *To aim at enhancing protection and improvement of the aquatic environment through specific measures for the progressive reduction of discharges, emissions and losses of priority substances and the cessation or phasing-out of discharges, emissions and losses of the priority hazardous substances*. The scenarios compute increases (or decreases) in water availability and potential sector-specific reductions (or increases) in water use. This again allows the countries to focus on the water use reduction potentials to formulate their policies in order to minimize discharges and thereby improving the aquatic environment.

**(d)** *To ensure the progressive reduction of pollution of groundwater and to prevent its further pollution*. Although this study does not explicitly address water quality, water use and discharge to surface water bodies and groundwater from the agricultural sector is calculated for current and alternative future climatic conditions. Based on the extent of irrigated areas and amount of water withdrawn, the agricultural return flow (water withdrawal minus consumption) carries a specific pollution load of agrochemicals. The larger the extent of irrigated areas and the higher the amount of water withdrawal, the higher is the potential pollution load. Based on this information, countries can formulate their future agricultural policies.

# 7. UNCERTAINTY AND SENSITIVITY OF RESULTS

The scenario approach used in this report addresses uncertainty by showing different feasible pathways into the future based on different sets of input assumptions. But we also know intuitively that some input assumptions and some scenario pathways are more feasible, or more uncertain, than others. Here is a list of some of the factors determining water use that are particularly uncertain. In principle, reducing the uncertainties of these factors will increase the reliability of the scenarios and lead to better estimates of future water use.

*Domestic* – In most European countries the relationship between future income and water use seems to be well defined (see Table 2 and Appendix A). However, in a few countries undergoing a major economic transition (see Section 7.2) it is not possible to define a relationship between income and water use. For these countries more detailed studies are needed to identify the factors that help explain historical and future trends in water use. Another source of uncertainty in estimating future water use in the domestic sector is the future population of water users.

*Manufacturing* – The water intensity of different industries ($m^3$ per gross value added) is a major uncertainty in most countries. But perhaps more important is the water use of industries that are not now important but will become important over the next 30 years. Key questions are, what will these industries be and how much water will they use? As an example, it is possible that the electronics industry will emerge as a major water user in Europe, although it is not considered now as important as the industries listed in Section 3.2.5 or 4.2.6.

*Electricity Production* – Major uncertainties in this sector are the useful lifetime of power stations, the percentage of new power stations having tower versus once-through cooling, and their future geographic location. Also important is the uncertainty of future thermal electricity production.

*Agriculture* – Major unknowns in the agriculture sector are the future extent of irrigated crops, the types of crops to be irrigated, and future climate.

While the preceding factors are clearly uncertain, it is not necessarily true that they have a big impact on computed water use. To address this impact question we now present sensitivity analyses of selected driving forces. These analyses help identify the sensitivity of computed water outputs to key input assumptions.

## 7.1 Uncertainty of Domestic Water Use Trends

In Section 4.2.3 we noted that the historical trend of per capita water use in the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, the Slovak Republic, and Turkey shows an important break after the 1980s. This obviously has to do with the important economic transition going on in these countries. The break in this temporal trend also means that there is no clear relationship in these countries between per capita water use and GDP/cap. Hence historical data do not provide insight into the direction of per capita water use under future changes in the economy. We must therefore assume a trend in future per capita water use *a priori*. We reported earlier that under the baseline and climate policy scenarios we assumed that per capita water use in these countries would converge with the average value of the other Europe-30 countries by 2030. Here we compare this assumption with the assumption that per capita water use in these countries *remains constant* at its year 2000 level. This would correspond to the lower curve in Figure 8.

As expected, computed domestic water use is very sensitive to this assumption. In Figure 32 we present results for the New EU Member States because they are particularly affected by these uncertainties. Currently the per capita water use in the Czech Republic and other countries mentioned above are considerably below the EU average. Hence assuming that per capita water use remains at its current level (the middle bar in Figure 32) leads to much lower water use than the baseline scenario (left bar) which assumes that per capita water use will rise to the EU average in 2030 (See Section 4.2). In the New EU Member States, the amout of water used in the domestic sector computed with the non-convergence approach is 48% lower than in the baseline scenario (including the convergence approach) in 2030 (15% in 2010). The conclusion of this analysis is that the trend of future per capita water use in many of the the New EU Member States is an important uncertainty that needs to be investigated in future water outlooks.

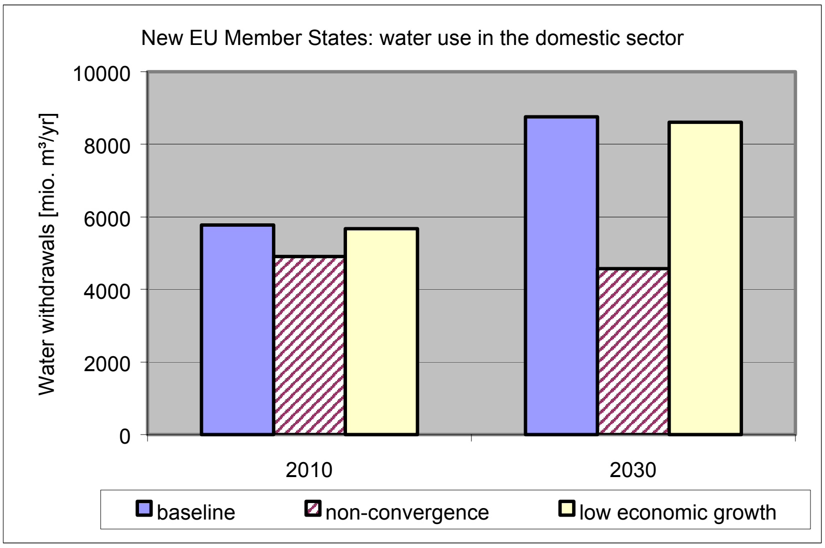


Figure 32. Sensitivity analysis of the domestic sector, New EU Member States.

## 7.2 Sensitivity to Lower per Capita Income

In this section we investigate the sensitivity of computed water use to assumptions of economic growth. The variant described here addresses the question of the impact on economic growth on the water uses. Will a lower economic growth cause a more sustainable use of water in Europe?

For this sensitivity analysis, we use a projection of income (GDP/cap·year) that has lower economic growth rates than assumed for the baseline and climate policy scenarios (Section 4.2). These projections were produced by the PROMETHEUS model (Section 4.2). In the low economic growth variant, the annual average growth rate of GDP per capita in the Europe-30 region is approximately 1.7% between 2000 and 2030 as compared to the 2.3% per year of the baseline assumption. This decrease in economic growth rates is unequally distributed between the four Europe-30 regions. Greater reductions in economic growth rate are projected for Northern and Southern Europe whereas the economic growth rates decrease more moderately in the New EU Member States and EU Candidate Countries. (See Table 11).

Table 11. Per capita GDP in the Europe-30 region under the low economic growth assumptions, 1990 to 2030. Source: EUROSTAT, Economic and Financial Affairs DG, PRIMES, PROMETHEUS[9]. Regions are defined in Table 1.

| GDP per cap. [Euro2000] | | Baseline and climate policy scenario | | | Low economic growth variant | | | Difference between low economic growth variant and baseline [%] | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2000 | 2010 | 2020 | 2030 | 2010 | 2020 | 2030 | 2010 | 2020 | 2030 |
| Northern Europe | 26354 | 32425 | 39863 | 48815 | 30256 | 35078 | 40347 | -6.69 | -12.00 | -17.35 |
| Southern Europe | 19169 | 24058 | 30636 | 38894 | 22052 | 26417 | 31881 | -8.34 | -13.77 | -18.03 |
| New EU Member States | 5277 | 7819 | 11455 | 15916 | 7470 | 10688 | 14531 | -4.46 | -6.70 | -8.70 |
| EU Candidate States | 2391 | 3214 | 5200 | 7838 | 3278 | 5050 | 7360 | 1.98 | -2.89 | -6.10 |
| Europe-30 | 17102 | 21332 | 26894 | 33707 | 19852 | 23661 | 28116 | -6.94 | -12.02 | -16.59 |

The lower economic growth rates have a direct and indirect impact on the driving forces of different water-using sectors.

- *Domestic sector:* The new economic growth rates directly affect per capita water use.
- *Electricity production sector*: Along with slower economic growth, the production of electricity will also be lower than in the baseline and climate policy scenarios (See Appendix E).
- *Manufacturing sector:* Consistent with the lower economic growth rate is a lower industrial output in terms of gross value added (See Appendix E).

The difference between the baseline scenario and the low economic growth variant is very small (Figure 32) because for most countries within this region (New EU Member States) domestic water use is not computed on the approach described by the relationship between per capita water use and GDP/cap. However, the difference between the low economic growth variant and the baseline scenario is about 2% in 2010 and 2030, respectively. Figure 33 shows that water withdrawals are 8% lower under the low economic growth variant in the electricity production sector in 2030. In the same year, water withdrawals are 7% lower in the manufacturing sector under the low economic growth variant (Figure 34). Hence, calculations are not sensitive to the lower GDP/cap assumptions in Table 11. Results are only presented for the New EU Member States but were similar for other European regions. Apparently the combination of other factors (population, transition to tower cooling, improvements in water use efficiency) is more important than income in determining water use in these sectors. On the other hand the economic growth rates in the 'low growth scenario' were not extremely low compared to the baseline scenario. Hence, large differences in water use were not expected.

[9] PROMETHEUS. A tool for the generation of Stochastic Information for Key Energy, Environment and Technology Variables. National Technical University of Athens (NTUA).

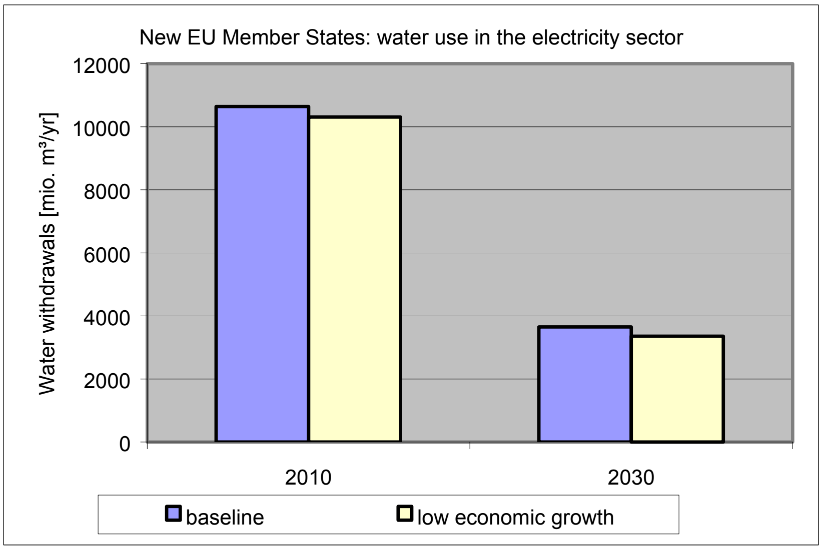


Figure 33. Sensitivity analysis of the electricity production sector, New EU Member States.

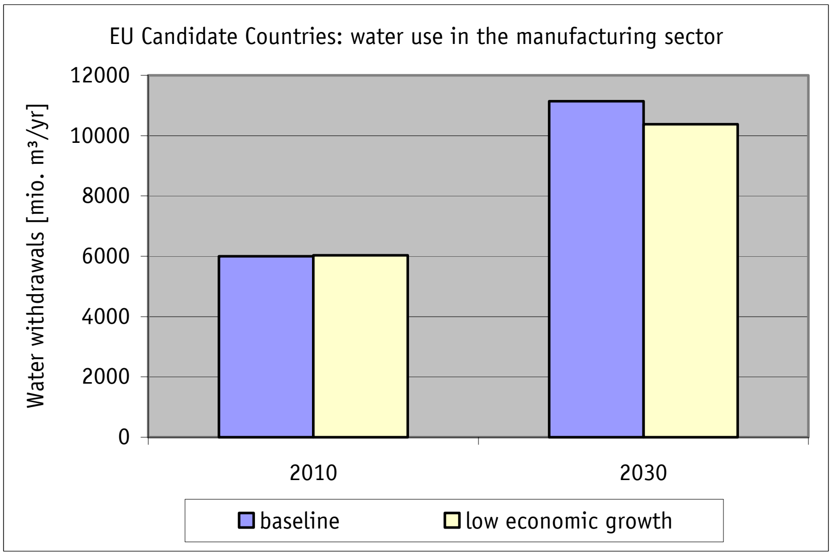


Figure 34. Sensitivity analysis of the manufacturing sector, New EU Member States.

## 7.3 Sensitivity to Uncertain Future Irrigated Area

The main driving force of changes in water withdrawals in the agricultural sector is the change in extent of irrigated area. The larger this area, the more water needed for irrigation, and the larger the water use in the agricultural sector. We pointed out in Section 4.2.7 that despite the importance of future projections of irrigated area, no detailed studies are available for Europe. Hence the projections used in this study are quite uncertain. Here we investigate the sensitivity of water use calculations to the uncertain extent of future irrigated area.

We investigate two variants around the baseline scenario (which is the 'reference' variant):

*Lower variant:* The 'area equipped for irrigation' (the total area of irrigation) and 'percentage of equipped area exploited for irrigation' (the small part that is actually used for irrigation in some countries) both remain constant between 2000 and 2030. This gives lower estimates of water withdrawals (in countries with irrigation) than the baseline scenario because the baseline scenario assumes that the extent of area for irrigation grows in many countries up to 2030 (although the percentage of equipped area that is actually exploited remains constant).

*Higher variant:* It is assumed that the area equipped for irrigation expands in several countries as in the baseline scenario, and that the percentage of exploited area also increases step-wise up to 100% from 2000 to 2030. This gives higher water withdrawals (in countries with irrigation) than the baseline scenario because the baseline scenario assumes that the percentage of equipped area exploited for irrigation remains constant between 2000 and 2030.

Figure 35 shows that the Higher variant (right bar) leads to large differences with the baseline scenario (left bar). Only results for the New Member States are shown, but this region together with the EU Candidate Countries is most affected by these uncertainties.

In the New EU Member States, 1689 million m³ of water will be used in the agricultural sector in the year 2030 considering the baseline assumptions. This result differs only slightly from the amount of water used in the base year (2000). If we assume that the extent of irrigated areas and the percentage of exploited area are constant during the projected time period (Lower variant), the water withdrawals in the agricultural sector will decrease by 3% in 2010 and 9% in 2030 compared to the baseline scenario. But taking into account that the whole area equipped for irrigation will be irrigated (Higher variant), the amount of water used in this sector will increase by 49% in the year 2030 (respective 15% in 2010).

We have mentioned earlier that the future extent of irrigated area is an obviously important driving force, and this sensitivity analysis confirms this point. It is urgent in future water outlooks to improve projections of irrigated area, both the area equipped for irrigation as well as the area anticipated to be exploited on a regular basis.

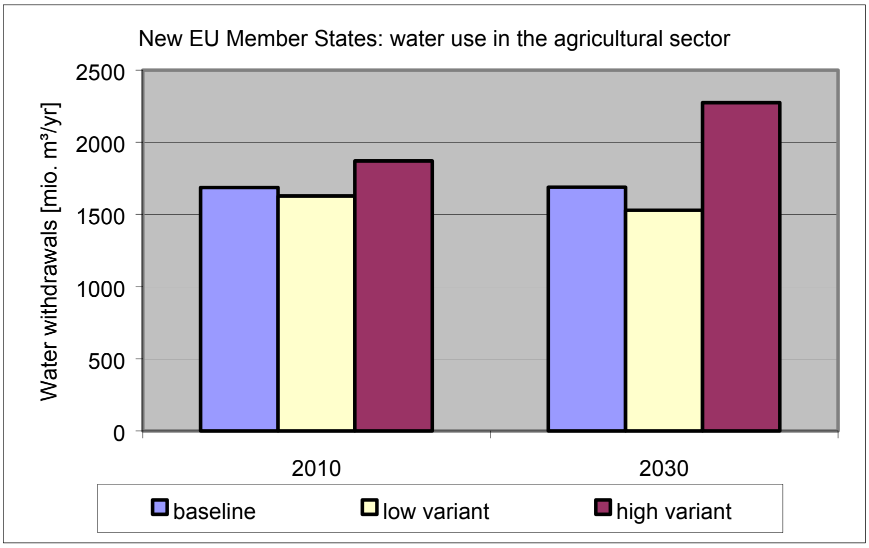


Figure 35. Sensitivity analysis of the agricultural sector, New EU Member States.

# 8. RECOMMENDATIONS FOR IMPROVING WATER OUTLOOKS FOR EUROPE

This report has been prepared on behalf of the European Environment Agency (EEA) as a contribution to the next State of the Environment and Outlook Report 2005 (SoEOR2005). In particular, it provides background information for the outlook on water use in Europe up to 2030 by estimating future water use and availability for 30 separate European countries. In order to attain this goal, we decided to combine two approaches: a scenario approach and a modeling approach. Due to the short time available (11 months), only two alternative scenarios were developed – a baseline and a climate policy scenario. The WaterGAP model was used to compute future water availability and use estimates, and focused on the most critical driving forces. Due to the limited number of scenarios and driving forces considered, the results cover the main aspects of future water availability and use. It should be noted, however, that a much wider and more refined range of scenarios is possible, and that additional driving forces may also have a considerable influence. In the following, we summarize our main recommendations for such future studies.

- *Build multiple baselines.* The terms of reference for this study called for the development of only one baseline. Unfortunately it is difficult to argue that one particular baseline scenario is more probable than another. Therefore it is common in international scenario exercises (e.g. the greenhouse gas emission scenarios of IPCC, 2000) to generate multiple baseline scenarios that indicate a range of plausible future developments. It is strongly recommended that future EEA water outlooks (and other environmental outlooks) produce multiple rather than single baseline scenarios.

- *Collect and analyse data on domestic water use.* We have pointed out that the trends in domestic water use in some (but not all) of the New EU Member States is very uncertain. The EEA should give special attention to understanding trends in per capita water use in these countries in order to reduce these uncertainties and improve esimates of future water use in the domestic sector. In particular, a consistent European-wide data set regarding domestic water use should be compiled, including information about the relationship between water use and household profile and size, types of residences, and location (e.g. rural vs. urban residences). These data will greatly improve the estimation of future water use in the domestic sector.

- *Include the effects of water prices.* The price of water, no doubt, has an effect on water use in all sectors. Yet the lack of data and appropriate models makes it difficult at this time to include price effects in estimates of future water use in Europe. The EEA should support the collection of European-wide data documenting the relationship between price changes and water use and should also support the development of models based on these data. These developments will improve the estimation of future water use in the domestic, and other sectors.

- *Analyse the importance of emerging industries on water use.* We noted in Section 7 that a major uncertainty in anticipating future water use in manufacturing is the uncertainty about the emergence of new water-intensive industries or the growing importance of existing water-intensive industries such as electronics. We recommend that the EEA support detailed studies of the future importance of existing and emerging water-intensive industries. Information from these studies will improve estimations of the water use in the manufacturing sector.

- *Project the extent of irrigated land.* Although irrigated land is a decisive driving force of future water use in agriculture, there are no available pan-European projections of this land. We recommend that the EEA support the development of detailed projections of future irrigated land that take into account economic, geographic and other factors. These projections will greatly improve estimates of future water use in the agricultural sector.

- *Collect and analyse data on technological developments.* The data used in this report to estimate rates of improvement of water use efficiency are very sketchy and by no means comprehensive. To improve estimates of future water use the EEA should support the compilation of a European-wide data set that provides examples of changes in water use efficiency in all sectors over time. These data will afford a more solid basis for estimating future rates of technological improvements in water use efficiency.

# 9. CONCLUSIONS

This study explored quantitative scenarios of future water use up to 2030 in 30 European countries (the EU plus 5 EEA member countries). Estimates are also presented for future water availability and water stress. Two scenarios were developed – a baseline scenario reflecting a continuation of current trends and a climate policy scenario assuming drastic policies to limit greenhouse gas emissions. The scenarios account for a wide range of driving forces of water use including changing population, economic growth, technological changes, changes in electricity production, transition to new types of power station cooling, structural changes in domestic water use, extent and exploitation of irrigated areas, and climate change.

From the results of the study, several conclusions can be drawn that constitute not only important scientific findings but carry considerable policy relevance. Due to the inherent uncertainties of such scenario studies covering 30 years into the future, we will attempt to qualify our conclusions by adding estimates of certainty based on expert judgement.

- *The trend of total European water withdrawals is downward.* Under the two scenarios developed in this study, total water withdrawals in the Europe-30 countries decrease by approximately 11% between 2000 and 2030. These results are intermediate compared to previously published estimates. This will allow policy makers to set relatively stringent goals with regard to water use management.

- *The profile of water use is changing.* The profile of water use in Europe is expected to change in important ways over the next few decades (medium to high certainty). Different water sectors dominate total water withdrawals in different parts of Europe, and the relative importance of these sectors is likely to change up to 2030 (with high certainty):

  - Water withdrawals in *Northern Europe* are currently dominated by water use in the electricity production sector but, by 2030, we expect (with low to medium certainty) that water use in the manufacturing and domestic sectors will be more important.

  - Water withdrawals in *Southern Europe* and in the *EU Candidate States* are currently dominated by agricultural water use, and this will remain the same in 2030 (medium to high certainty).

  - Water withdrawals in the *New EU Member States* are dominated by water use in the electricity production sector but, by 2030, we expect (with low certainty) that the domestic sector will dominate water withdrawals.

  These projections should help countries focus in their water use management policies on the most important economic sectors.

- *A multi-sector approach is needed.* Since no single sector dominates water use in Europe, it is not advisable to focus water conservation efforts in Europe on any individual sector. A pan-European strategy to reduce water use should concentrate on different sectors in different countries, that is, it should take a multi-sector approach. Here, the implementation of the Water Framework Directive by individual countries becomes important and offers a good policy instrument to further water conservation efforts.

- *A river basin approach is also needed.*. For administrative and technical reasons it makes sense to carry out water conservation programs on the country-scale. However, the river basin approach required by the Water Framework Directive makes it also necessary to address water use issues (including the reduction of water use and treatment of runoff from water use) on the river basin scale.

- *A major unknown is future domestic water use in New EU Member States*. If per capita water use in New EU Member States rises to the level of other EU countries by 2030, then water use in the domestic sector here will substantially increase, and it will become the most important water-using sector by far in this region. If per capita domestic water use stays at its current level in New EU Member States, then total water withdrawals in the domestic sector in 2030 will be about the same as those of the electricity production and manufacturing sectors taken together. One conclusion from these results is that intervening now to encourage water conservation could avoid large increases in the domestic sector of these states (with low to medium certainty) and could contribute to their attaining the goals of the Water Framework Directive.
- *Water use in the electricity production sector is expected (with medium certainty) to significantly decrease during the scenario period.* The reason for this decline is primarily the assumption that all new power stations will have tower cooling rather than once-through cooling. Tower cooling requires much lower withdrawals than once-through cooling. It is apparent (with medium certainty) that requiring the use of tower cooling in all new power stations is an effective strategy for reducing overall water withdrawals. Although water withdrawals decline, water consumption per unit electricity generated is much higher with tower cooling. This has to be taken into account when implementing the Water Framework Directive and other national policies.
- *Technological development lowers water use*. We expect (with medium certainty) that technological improvements in water use sectors will continue to lead to significant improvements in the efficiency of water use. Between 2000 and 2030, we estimate that technological improvements will tend to decrease water use by 25% to 36% depending on the sector and scenario. Technological improvements will tend to dampen the increase of water use in those sectors and regions of Europe that still show an overall increase (medium to high certainty). We estimate that without technological improvements in these sectors, their water use would be from 34% to 56% higher. Therefore countries should support technological improvements in the water use sector in order to make use of these important potential savings.
- *Irrigation water withdrawals may increase in the South.* A combination of drier/warmer climate and expanding irrigated area may increase water withdrawals for agriculture in the South. (lower medium uncertainty). However, this increasing tendency will be dampened somewhat by continuing improvements in the water use efficiency of irrigation. Countries may have to take this into account when formulating their agricultural policies.
- *Increase in irrigated areas and/or irrigation water withdrawals may deteriorate the ecological and chemical status of freshwater bodies.* Based on the extent of irrigated areas and amount of water withdrawn, the agricultural return flow (water withdrawal minus consumption) carries a specific pollution load. The larger the extent of irrigated areas and the higher the amount of water withdrawal, the higher is the potential pollution load. Countries will have to take this into account when implementing the Water Framework Directive in order to maintain or improve the ecological and chemical status of freshwater bodies.
- *Climate policies will lead to lower water use in the electricity production sector.* The emission reductions assumed in the climate policy scenario do not dampen climate change very much in the coming decades (because of inertia in the climate system). However, these policies could have a more noticeable effect on the future magnitude and profile of energy production and thereby on the volume of water used in the electricity production sector (medium to high certainty). Greenhouse gas emissions are reduced under this scenario by replacing fossil fuels with renewable energy. The introduction of renewable energy implies that some thermal power stations will be phased out or replaced by low water-using technologies, and this reduces overall water withdrawals (medium to high certainty).

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# APPENDIX A: DOMESTIC WATER USE MODEL – CONCEPT OF STRUCTURAL CHANGE

In the domestic water use model, changes in water use intensity are expressed by structural and technological changes. The concept of structural change is represented in the baseline scenario by a sigmoid curve which indicates how water use intensity (water use per capita) changes with income (GDP/cap). Here, the relationship between structural water use intensity and income is derived for each country by fitting a sigmoid curve to adjusted data from each country. These adjusted data are historical data from which the estimated effect of technological improvements in water use efficiency have been subtracted. This approach, using a sigmoid curve to describe the baseline scenario, has been used for 22 countries within the Europe-30 region. To evaluate the fit of the curves, we use the index of agreement of Willmott (1984) which is defined as follows:

$$d = 1 - \frac{n \cdot RMSE^2}{PE} \qquad (8)$$

$$RMSE^2 = RMSE_s^2 + RMSE_u^2 \qquad (9)$$

where

| | | |
|---|---|---|
| d | = | Index of agreement [-] |
| n | = | Number of cases |
| RMSE | = | Root mean square error |
| $RMSE_s$ | = | Average systematic portion of RMSE |
| $RMSE_u$ | = | Average unsystematic portion of RMSE |
| PE | = | Potential error variance |

The approach of using a sigmoid curve to represent the baseline scenario could not be used for the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, the Slovak Republic, and Turkey whose historical data could not be fitted to a sigmoid curve. Therefore we used an alternative approach which is described in Section 3.2.3.

The following Figure 36 to Figure 65 show the baseline curves representing the domestic (structural) water use intensities for each country within the Europe-30 region. The countries are allocated according to the four regions defined in Table 1.

## Northern Europe

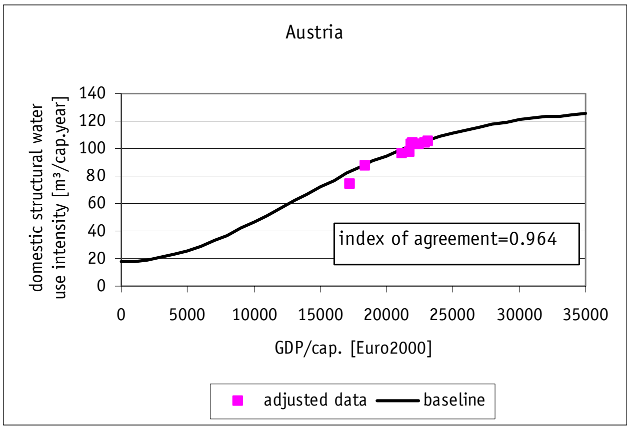


Figure 36. Domestic structural water use intensity (baseline curve) for Austria. Source: EUROSTAT and national Statistical Office.

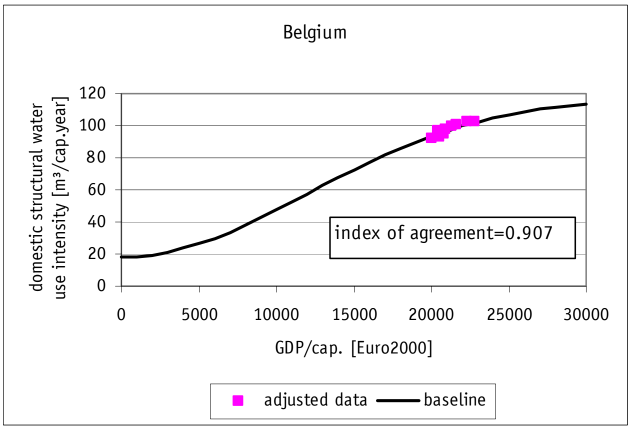


Figure 37. Domestic structural water use intensity (baseline curve) for Belgium. Source: EUROSTAT and national Statistical Office.

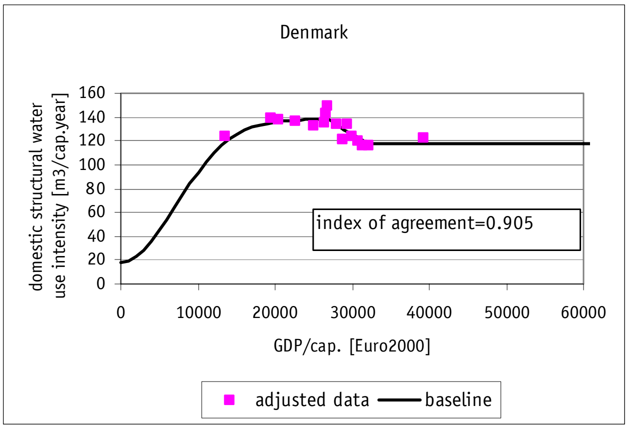


Figure 38. Domestic structural water use intensity (baseline curve) for Denmark. Source: EUROSTAT and national Statistical Office.

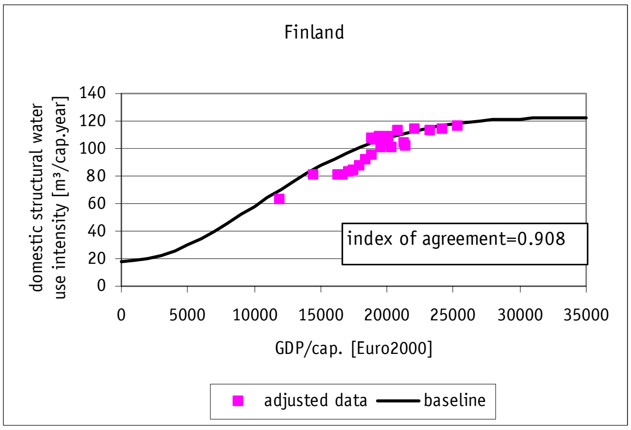


Figure 39. Domestic structural water use intensity (baseline curve) for Finland. Source: EUROSTAT and national Statistical Office.

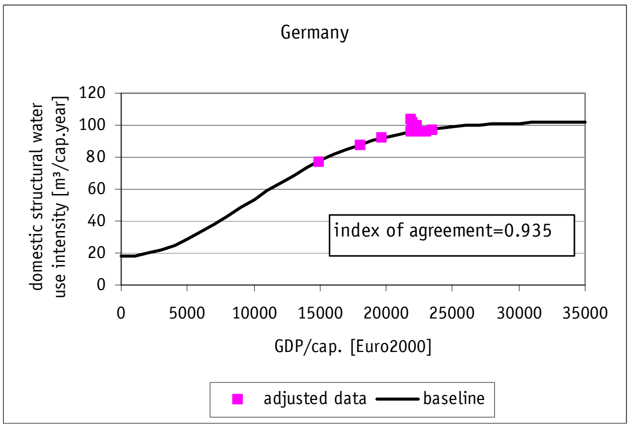


Figure 40. Domestic structural water use intensity (baseline curve) for Germany. Source: EUROSTAT and national Statistical Office.

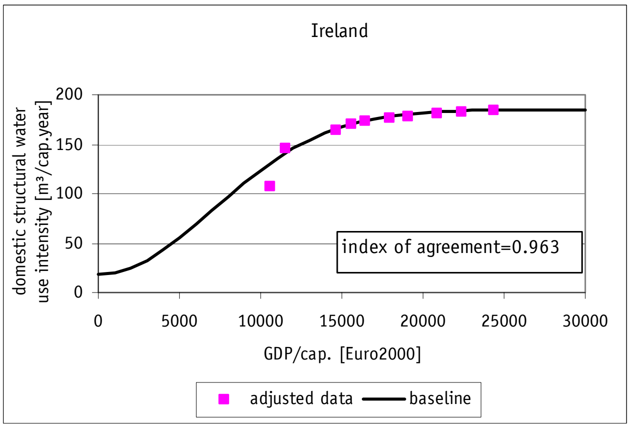


Figure 41. Domestic structural water use intensity (baseline curve) for Ireland. Source: EUROSTAT and national Statistical Office.

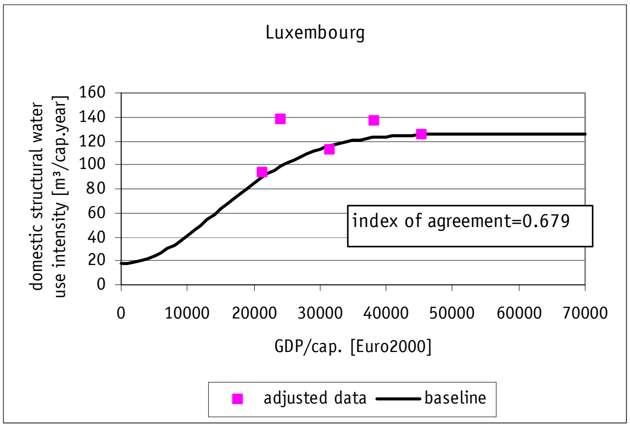


Figure 42. Domestic structural water use intensity (baseline curve) for Luxembourg. Source: EUROSTAT and national Statistical Office.

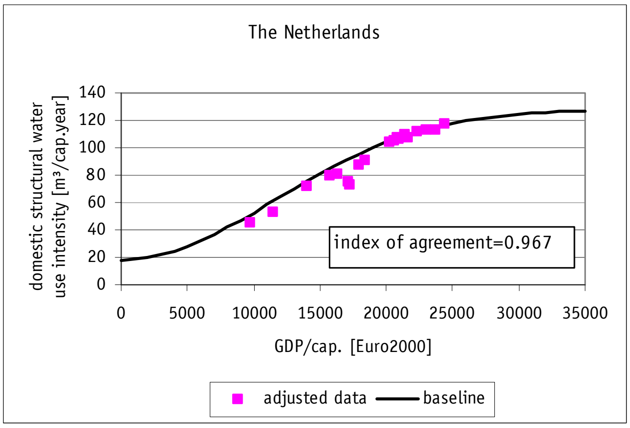


Figure 43. Domestic structural water use intensity (baseline curve) for The Netherlands. Source: EUROSTAT and national Statistical Office.

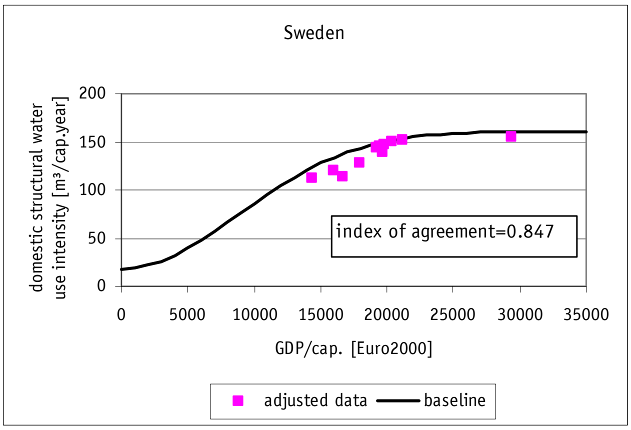


Figure 44. Domestic structural water use intensity (baseline curve) for Sweden. Source: EUROSTAT and national Statistical Office.

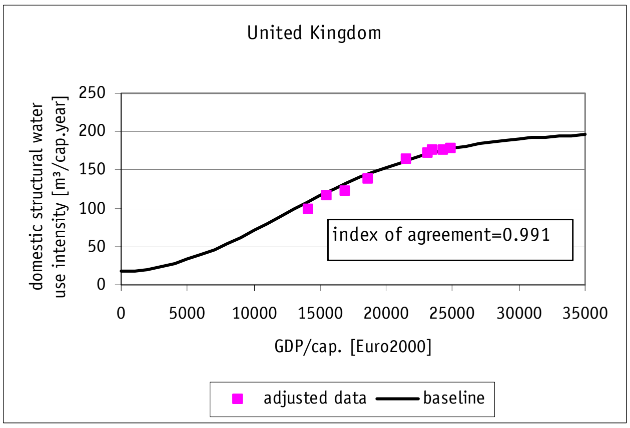


Figure 45. Domestic structural water use intensity (baseline curve) for United Kingdom. Source: EUROSTAT and national Statistical Office.

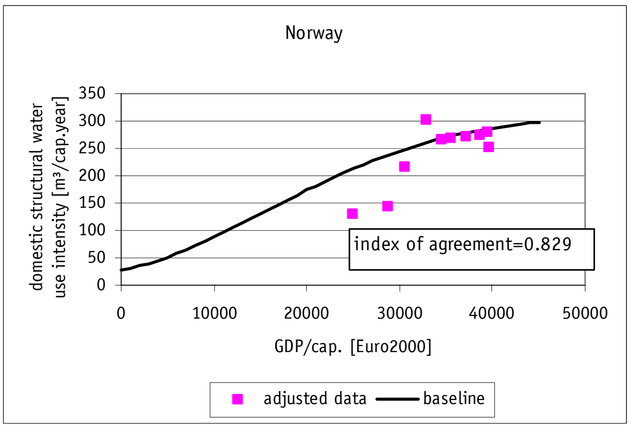


Figure 46. Domestic structural water use intensity (baseline curve) for Norway. Source: EUROSTAT and national Statistical Office.

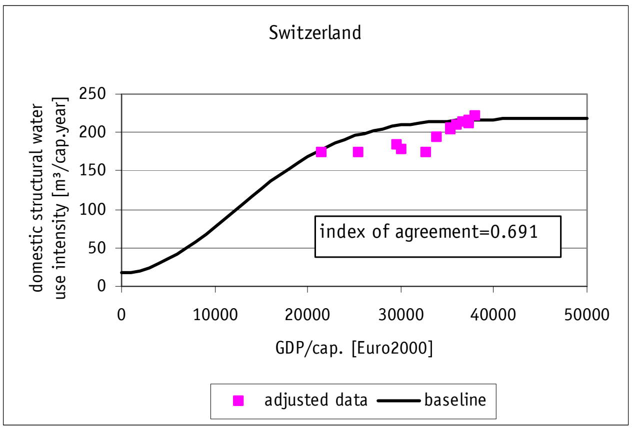


Figure 47. Domestic structural water use intensity (baseline curve) for Switzerland. Source: EUROSTAT and national Statistical Office.

## Southern Europe

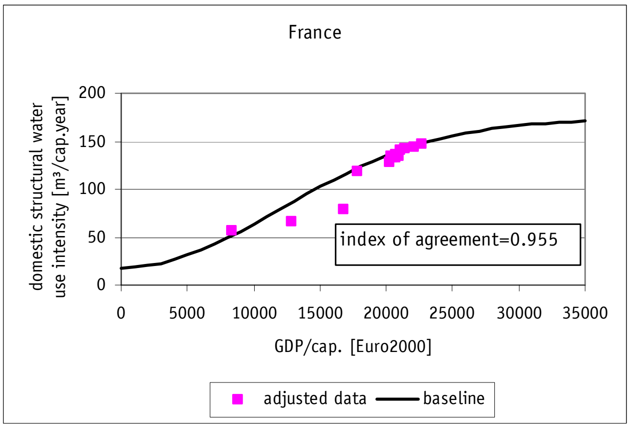


Figure 48. Domestic structural water use intensity (baseline curve) for France. Source: EUROSTAT and national Statistical Office.

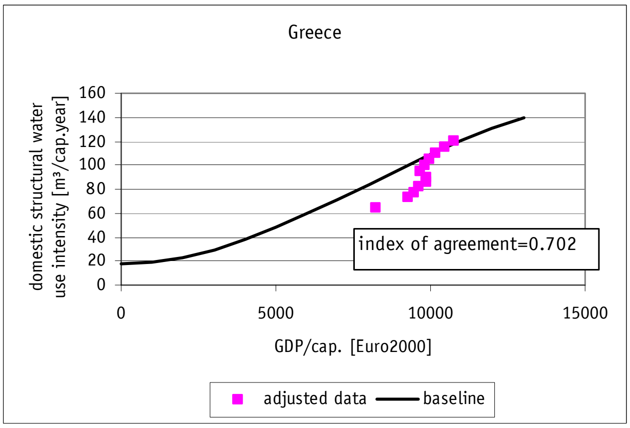


Figure 49. Domestic structural water use intensity (baseline curve) for Greece. Source: EUROSTAT and national Statistical Office.

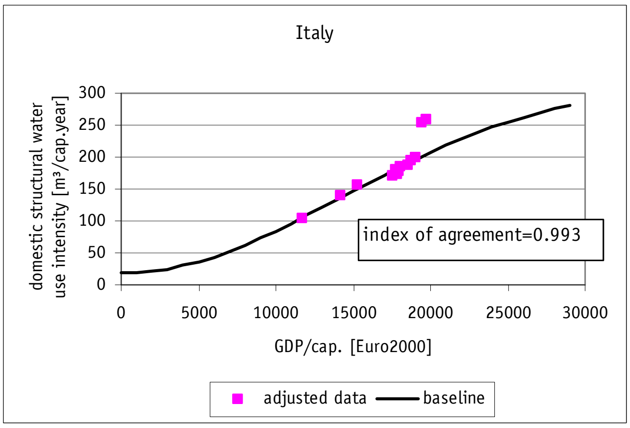


Figure 50. Domestic structural water use intensity (baseline curve) for Italy. Source: EUROSTAT and national Statistical Office.

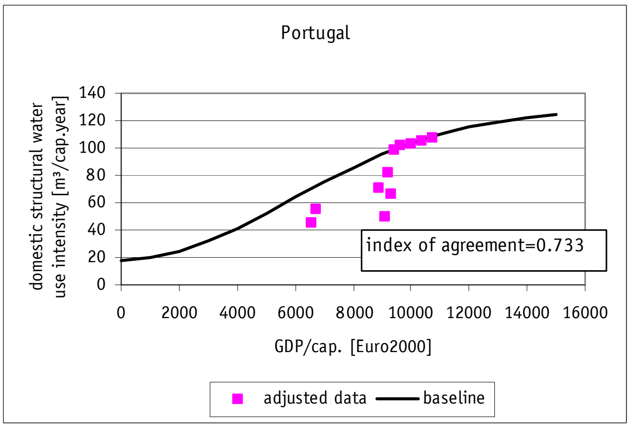


Figure 51. Domestic structural water use intensity (baseline curve) for Portugal. Source: EUROSTAT and national Statistical Office.

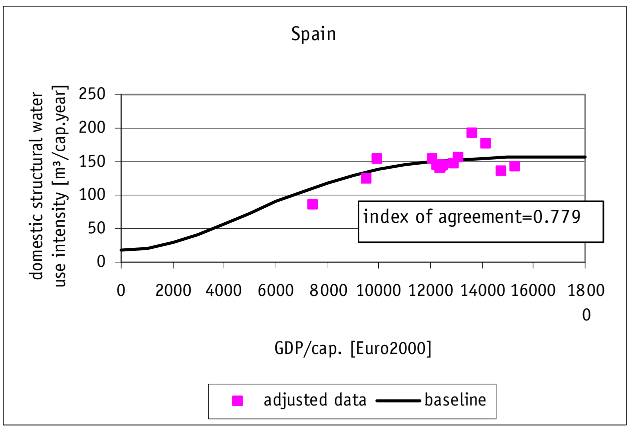


Figure 52. Domestic structural water use intensity (baseline curve) for Spain. Source: EUROSTAT and national Statistical Office.

## New EU Member States

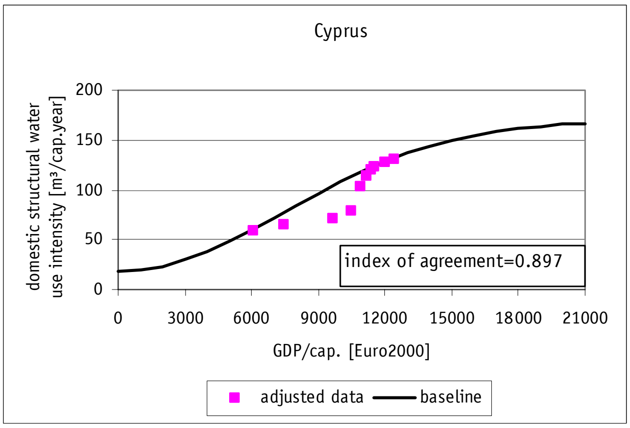


Figure 53. Domestic structural water use intensity (baseline curve) for Cyprus. Source: EUROSTAT and national Statistical Office.

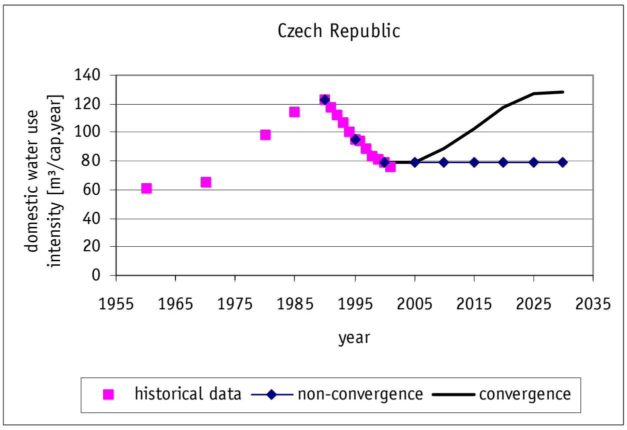


Figure 54. Domestic water use intensity (baseline curve) for the Czech Republic. Source: EUROSTAT and national Statistical Office.

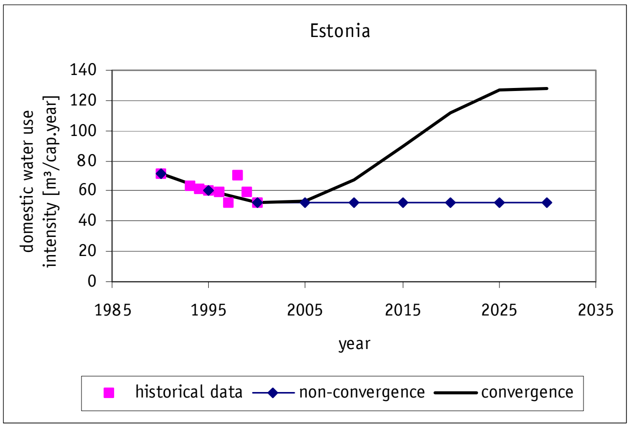


Figure 55. Domestic water use intensity (baseline curve) for Estonia. Source: EUROSTAT and national Statistical Office.

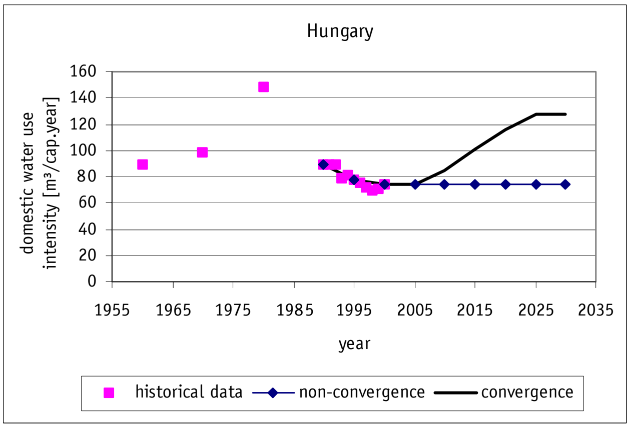


Figure 56. Domestic water use intensity (baseline curve) for Hungary. Source: EUROSTAT and national Statistical Office.

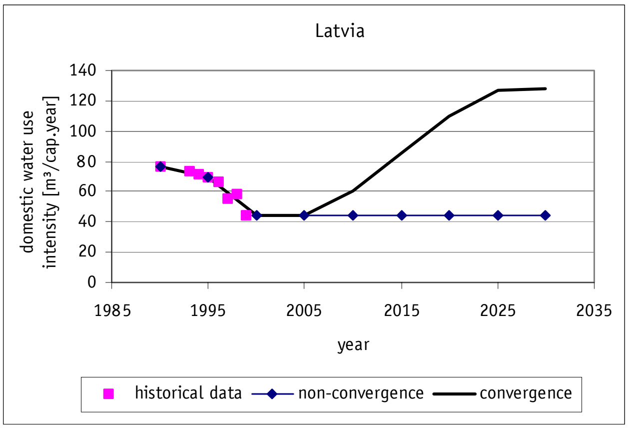


Figure 57. Domestic water use intensity (baseline curve) for Latvia. Source: EUROSTAT and national Statistical Office.

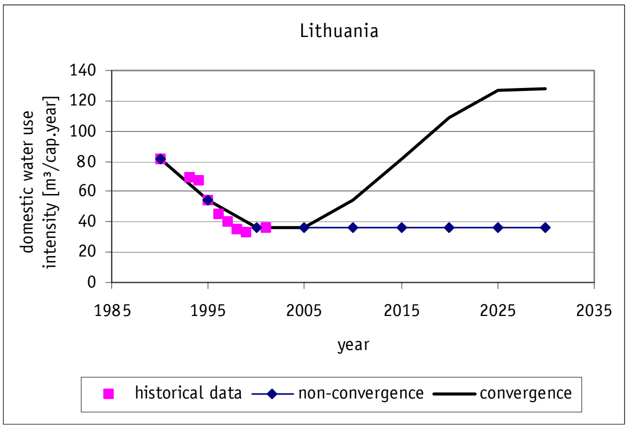


Figure 58. Domestic water use intensity (baseline curve) for Lithuania. Source: EUROSTAT and national Statistical Office.

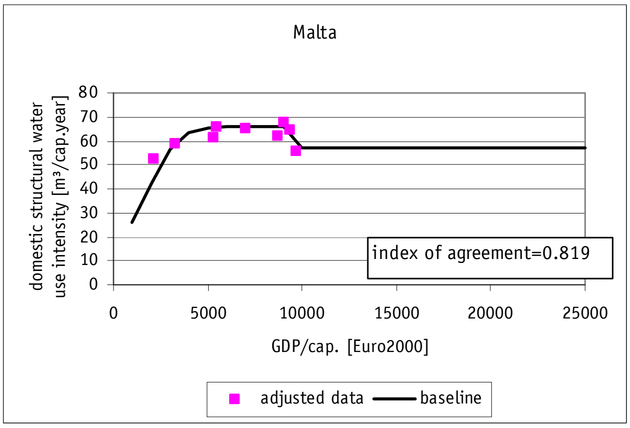


Figure 59. Domestic structural water use intensity (baseline curve) for Malta. Source: EUROSTAT and national Statistical Office.

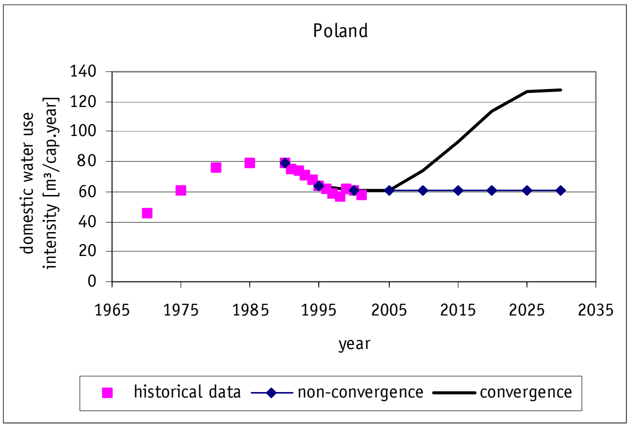


Figure 60. Domestic water use intensity (baseline curve) for Poland. Source: EUROSTAT and national Statistical Office.

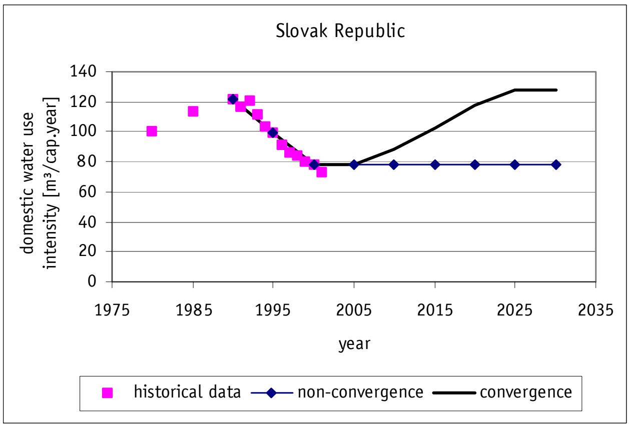


Figure 61. Domestic water use intensity (baseline curve) for the Slovak Republic. Source: EUROSTAT and national Statistical Office.

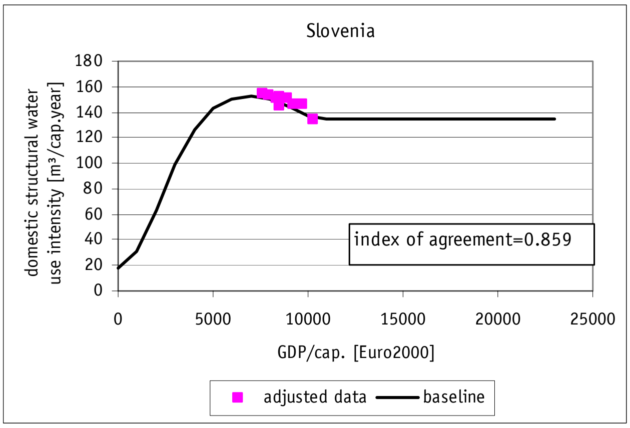


Figure 62. Domestic structural water use intensity (baseline curve) for Slovenia. Source: EUROSTAT and national Statistical Office.

## EU Candidate Countries

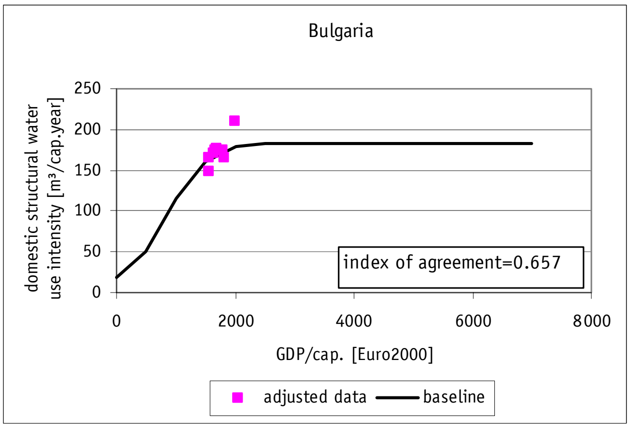


Figure 63. Domestic structural water use intensity (baseline curve) for Bulgaria. Source: EUROSTAT and national Statistical Office.

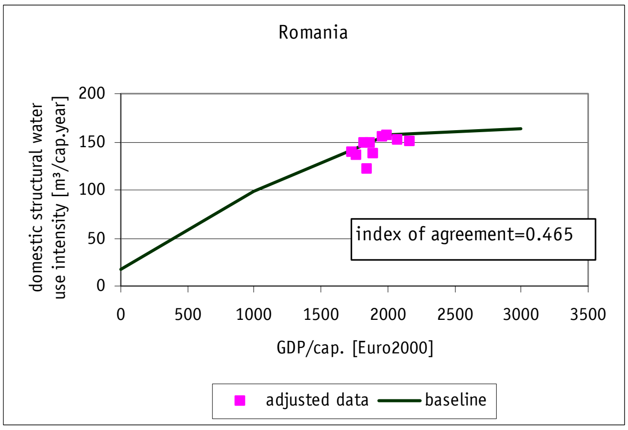


Figure 64. Domestic structural water use intensity (baseline curve) for Romania. Source: EUROSTAT and national Statistical Office.

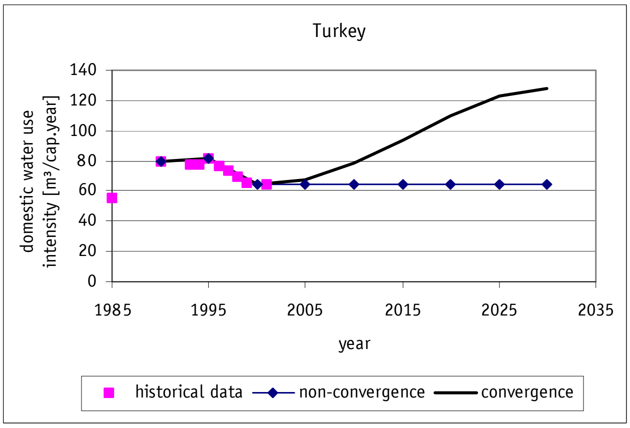


Figure 65. Domestic water use intensity (baseline curve) for Turkey. Source: EUROSTAT and national Statistical Office.

# APPENDIX B: CALCULATION OF TECHNOLOGICAL CHANGES

The concept of technological change takes into account the important effect of improving technologies tend to improve water use efficiency. In this Section, the calculation of the historical technological changes in water use efficiency in the electricity and manufacturing sectors are described. All information about former technological changes were derived from data collected for Germany.

## Historical technological changes of water intensity: Electricity production sector

In the water use model of the electricity production sector, two water intensities are distinguished: the water use intensity for once-through flow cooling systems and water use intensity for tower cooling systems. Existing time series on electricity production and water use are used for calculating water use intensities. It is possible to separate the thermal electricity production because water is mainly used by thermal power stations. But the problem that occurs is the lack of data concerning different cooling systems.

Technological changes for tower cooling systems of thermal power stations are determined from data given by Vattenfall (2002), one of the leading European energy companies.

Data to determine historical technological changes for once-through flow cooling systems are not available. Figure 66 shows the water use intensities of thermal power stations using tower cooling systems recorded between 1989 and 2002. The decrease in water use intensity is attributed to improvements in multiple-shift usage of water and reduction of evaporating water. These improvements are described by technological changes.

For the whole time period (1989 to 2002) an annual technological change of 4.3% can be estimated. But it can be seen that the decrease in water use intensity slows down since 1997. As a result, two time periods for the basic approach of technological changes are used: A first time period from 1989 to 1997 and a second from 1997 up to 2002 (which describes the reduction in technological efficiency). The determination of the historical technological change taking into account two different time periods, is shown in Figure 67 For the first time period (1989 to 1997) a more rapid decrease in water use intensity can be seen compared to the second phase (1997 to 2002). The annual technological change calculated for time period one is 5.3% and 1.5% for the second period. Taking into account this consideration, a smooth technological change for future estimates will be more realistic.

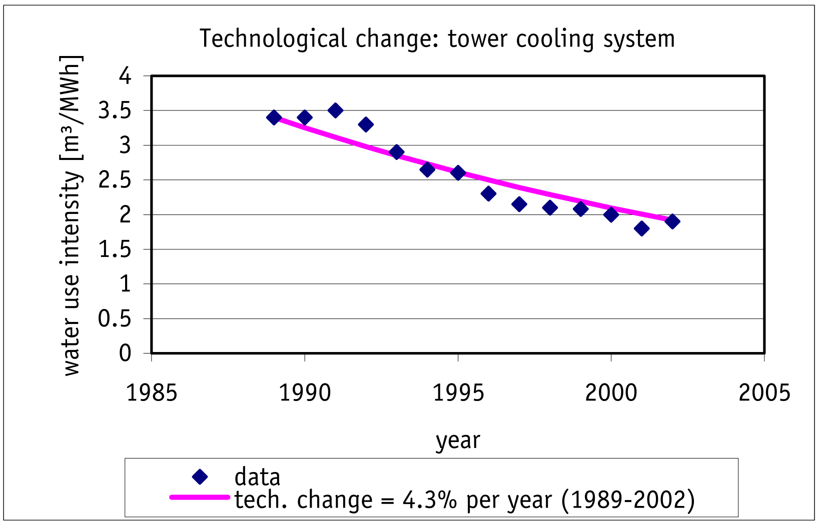


Figure 66. Historical technological change of water intensity of tower cooling systems, (time period 1989-2002). Source: Vattenfall (2002).

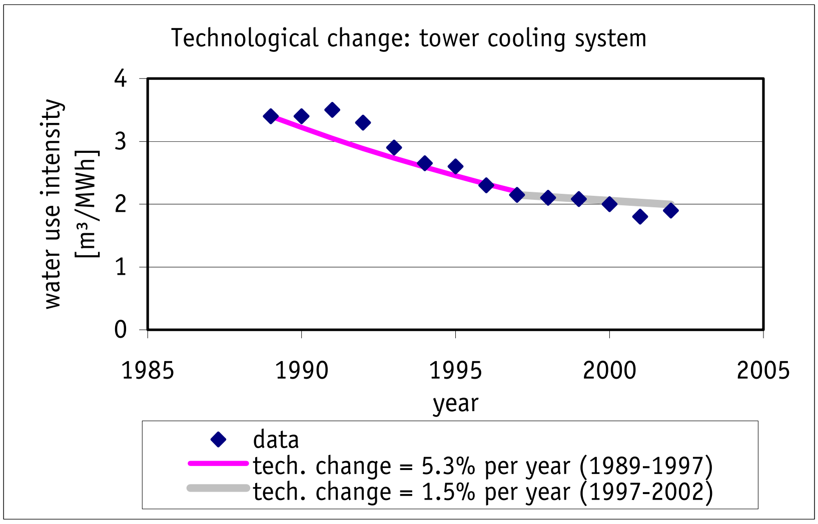


Figure 67. Historical technological change of water intensity of tower cooling systems, considering two time periods (1989-1997 and 1997-2002). Source: Vattenfall (2002).

### Historical technological changes of water intensity: Manufacturing sector

Different technological changes are determined for different manufacturing sectors (see Figure 68 to Figure 73). The sectoral-specific water use intensities are calculated for each year as the quotient of the sectoral-specific production and the sectoral-specific water use. Time series for the time period between 1965 and 1995 (from DESTATIS and several statistical yearbooks of Germany) are taken into account. The historical technological changes are derived concerning data about the following manufacturing sectors: food products, beverages, and tobacco; textiles; pulp, paper, publishing, and printing; chemicals and man-made fibres; non-metallic and mineral products; basic metals and fabrication of metal products.

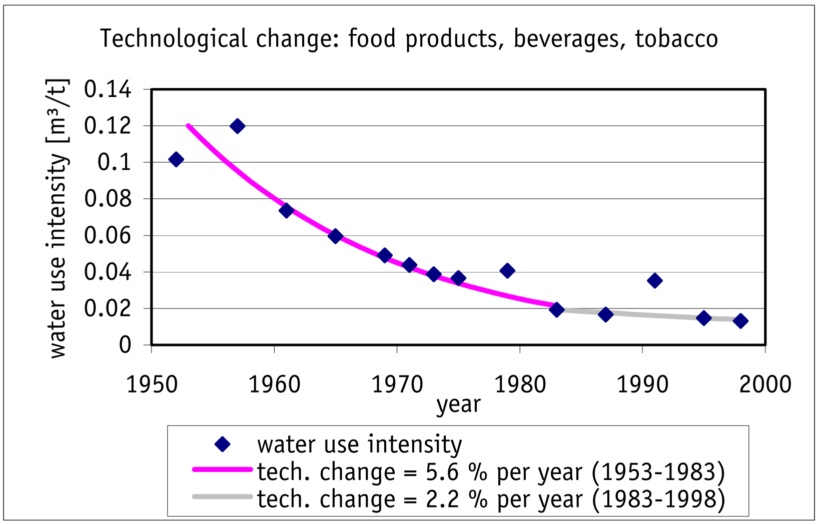


Figure 68. Determination of the historical technological change in water intensity of the manufacturing of food products, beverages, and tobacco, considering two time periods (1953-1983 and 1983-1998). Source: DESTATIS.

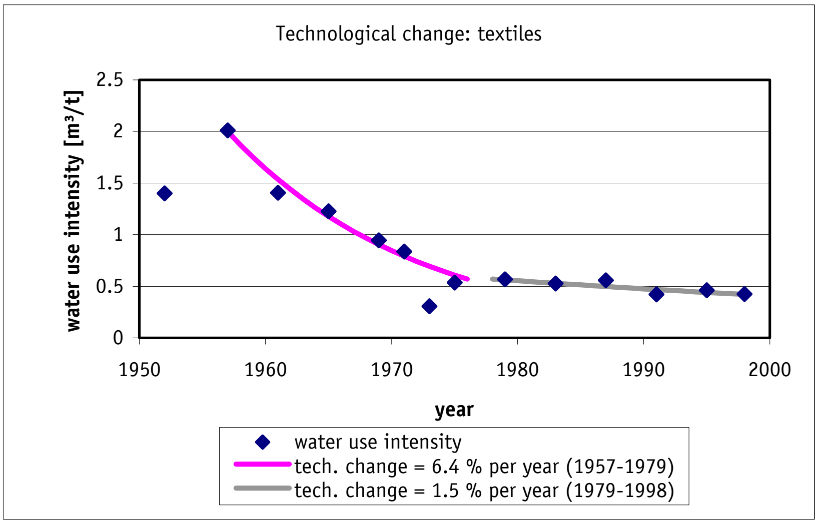


Figure 69. Determination of the historical technological change of water intensity of the manufacturing of textiles, considering two time periods (1957-1979 and 1979-1998). Source: DESTATIS.

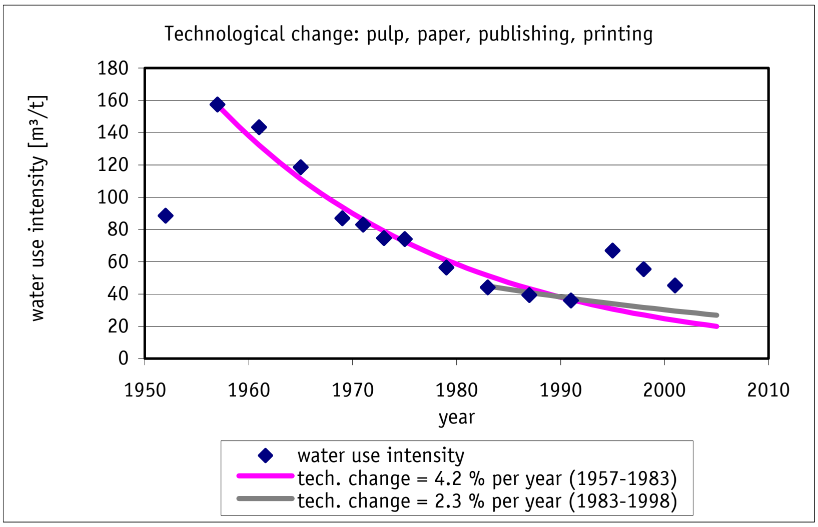


Figure 70. Determination of the historical technological change of water intensity of the manufacturing of pulp, paper, publishing and printing, considering two time periods (1957-1983 and 1983-1998). Source: DESTATIS.

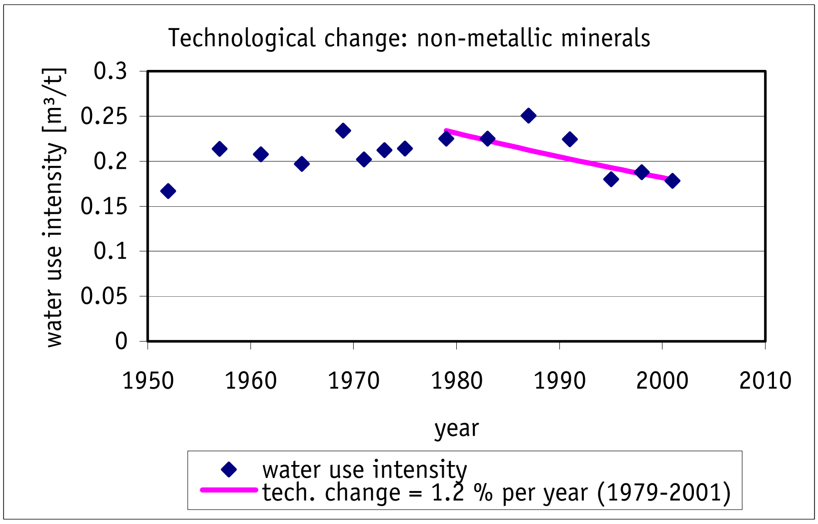


Figure 71. Determination of the historical technological change of water intensity for the manufacturing of, non-metallic, mineral products considering one time period (1979-2001). Source: DESTATIS.

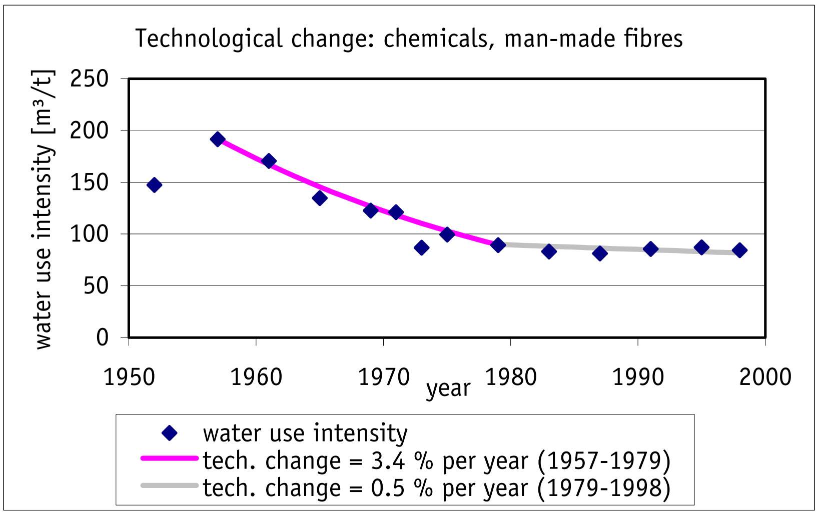


Figure 72. Determination of the historical technological change of water intensity for the manufacturing of chemicals and man-made fibres, considering two time periods (1957-1979 and 1979-1998). Source: DESTATIS.

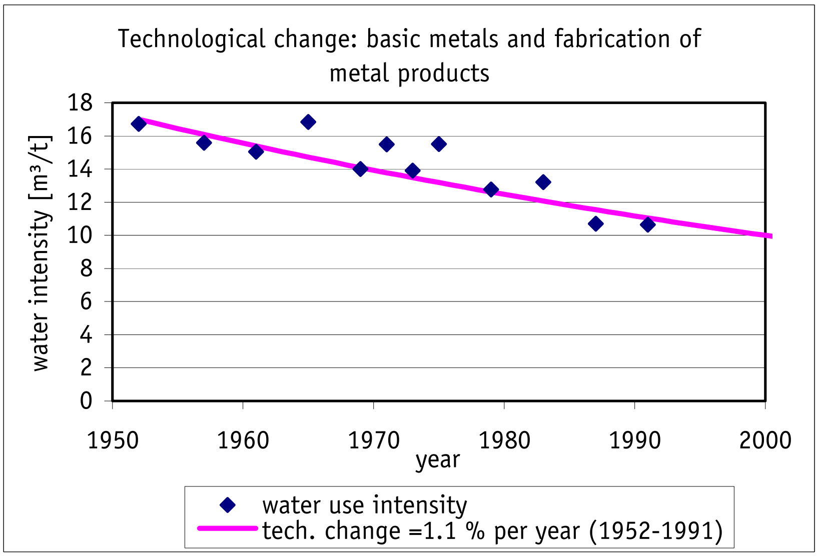


Figure 73. Determination of historical technological change of water intensity for the manufacturing of basic metals and fabrication of metal products, considering one time period (1952-1991). Source: DESTATIS.

# APPENDIX C: GROSS VALUE ADDED FOR THE BASELINE *(LREM-E)* AND CLIMATE POLICY *(SEP)* SCENARIOS

The gross value added (GVA) of industrial production is the main driving force of water use in the manufacturing industry. The assumptions for the economic growth of the industry by sector for the baseline and climate policy scenarios are listed in Table 12 to Table 14 for Southern Europe, the New EU Member States, and the EU Candidate Countries.

Table 12. Gross value added separated by sectors in the Southern Europe economy. Source: EUROSTAT, Economic and Financial Affairs DG, PRIMES. Regions are defined in Table 1.

| | GVA [$10^9$ Euro2000] | | | | | Annual growth rate [%] | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | 1990 | 2000 | 2010 | 2020 | 2030 | 90/00 | 00/10 | 10/20 | 20/30 | 00/30 |
| Iron and steel | 20 | 21 | 22 | 23 | 23 | 0.50 | 0.68 | 0.38 | 0.21 | 0.42 |
| Non-ferrous metals | 7 | 9 | 12 | 15 | 18 | 2.45 | 2.90 | 2.40 | 2.06 | 2.45 |
| Chemicals | 55 | 70 | 93 | 120 | 150 | 2.48 | 2.81 | 2.61 | 2.28 | 2.57 |
| Non-metallic minerals | 30 | 34 | 41 | 49 | 58 | 1.00 | 2.00 | 1.88 | 1.60 | 1.83 |
| Paper and pulp | 38 | 46 | 59 | 75 | 90 | 1.81 | 2.52 | 2.44 | 1.89 | 2.29 |
| Food, drink, tobacco | 60 | 71 | 92 | 116 | 142 | 1.63 | 2.63 | 2.32 | 2.04 | 2.33 |
| Engineering | 209 | 262 | 355 | 474 | 623 | 2.27 | 3.08 | 2.93 | 2.78 | 2.93 |
| Textiles | 53 | 50 | 51 | 53 | 54 | -0.75 | 0.31 | 0.35 | 0.16 | 0.27 |
| Other industries | 45 | 58 | 74 | 92 | 108 | 2.45 | 2.53 | 2.16 | 1.62 | 2.11 |
| Total industry | 518 | 619 | 798 | 1016 | 1266 | 1.79 | 2.57 | 2.44 | 2.23 | 2.41 |

Table 13. Gross value added separated by sectors in the New EU Member States economy. Source: EUROSTAT, Economic and Financial Affairs DG, PRIMES. Regions are defined in Table 1.

| | GVA [$10^9$ Euro2000] | | | | | Annual growth rate [%] | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | 1990 | 2000 | 2010 | 2020 | 2030 | 90/00 | 00/10 | 10/20 | 20/30 | 00/30 |
| Iron and steel | 4 | 3 | 4 | 4 | 5 | -2.16 | 1.70 | 1.13 | 0.80 | 1.21 |
| Non-ferrous metals | 1 | 1 | 1 | 1 | 1 | 2.58 | 2.19 | 2.44 | 1.38 | 2.00 |
| Chemicals | 6 | 7 | 13 | 19 | 25 | 1.51 | 6.06 | 4.17 | 2.71 | 4.30 |
| Non-metallic minerals | 3 | 5 | 7 | 10 | 12 | 4.61 | 3.25 | 2.94 | 1.87 | 2.68 |
| Paper and pulp | 4 | 6 | 9 | 13 | 17 | 3.78 | 4.56 | 3.98 | 2.51 | 3.68 |
| Food, drink, tobacco | 12 | 17 | 26 | 34 | 41 | 3.58 | 4.01 | 2.85 | 1.87 | 2.91 |
| Engineering | 27 | 30 | 46 | 69 | 90 | 1.38 | 4.21 | 4.15 | 2.68 | 3.68 |
| Textiles | 9 | 6 | 8 | 9 | 9 | -3.43 | 1.76 | 1.25 | 0.84 | 1.28 |
| Other industries | 12 | 12 | 18 | 25 | 32 | -0.21 | 4.39 | 3.32 | 2.24 | 3.31 |
| Total industry | 78 | 88 | 131 | 185 | 232 | 1.22 | 4.06 | 3.47 | 2.29 | 3.27 |

Table 14. Gross value added separated by sectors in the EU Candidate Countries economy. Source: EUROSTAT, Economic and Financial Affairs DG, PRIMES. Regions are defined in Table 1.

| | GVA [$10^9$ Euro2000] | | | | | Annual growth rate [%] | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | 1990 | 2000 | 2010 | 2020 | 2030 | 90/00 | 00/10 | 10/20 | 20/30 | 00/30 |
| Iron and steel | 3 | 3 | 4 | 4 | 5 | 1.74 | 1.93 | 1.25 | 0.85 | 1.34 |
| Non-ferrous metals | 1 | 1 | 1 | 1 | 1 | -3.44 | 1.98 | 3.17 | 2.49 | 2.54 |
| Chemicals | 4 | 5 | 8 | 13 | 21 | 2.66 | 4.29 | 5.91 | 4.53 | 4.91 |
| Non-metallic minerals | 3 | 4 | 6 | 10 | 16 | 2.33 | 3.95 | 5.92 | 4.34 | 4.73 |
| Paper and pulp | 1 | 2 | 3 | 6 | 10 | 5.57 | 4.26 | 6.18 | 5.47 | 5.30 |
| Food, drink, tobacco | 6 | 10 | 15 | 23 | 34 | 5.29 | 4.02 | 4.43 | 3.82 | 4.09 |
| Engineering | 9 | 11 | 19 | 40 | 68 | 1.76 | 5.56 | 7.57 | 5.51 | 6.21 |
| Textiles | 10 | 8 | 9 | 11 | 13 | -1.79 | 0.53 | 2.11 | 2.34 | 1.65 |
| Other industries | 11 | 12 | 16 | 29 | 45 | 1.24 | 3.18 | 5.88 | 4.57 | 4.54 |
| Total industry | 47 | 56 | 80 | 137 | 212 | 1.71 | 3.64 | 5.52 | 4.48 | 4.54 |

# APPENDIX D: OVERVIEW OF MODEL OUTPUTS

In this Section, both, water withdrawals for the base year (2000) and 2030 are presented for each country and summed for the four Europe-30 regions. The water withdrawals are subdivided into four sectors: domestic, agriculture, manufacturing, and electricity. Table 15 shows the results for the domestic and agricultural sectors, Table 16 those for the manufacturing and electricity sectors.

Table 15. Water use in 2030 (in million m³). Overview of the model outputs (domestic and agricultural sector).

| Country/Region | Domestic | | | | | Agriculture | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2000 | 2030 | | | | 2000 | 2030 | | | |
| | | Baseline (LREM-E) | Climate policy (SEP) | Non-convergence | Low economic growth variant | | Baseline (LREM-E) | Climate policy (SEP) | Sensitivity run | |
| | | | | | | | | | Lower variant | Higher variant |
| **Northern Europe** | **29045** | **23924** | **23924** | **23856** | **23856** | **3140** | **2783** | **2785** | **2783** | **3298** |
| Austria | 906 | 771 | 771 | 771 | 765 | 175 | 155 | 155 | 155 | 270 |
| Belgium | 1078 | 925 | 925 | 925 | 913 | 124 | 108 | 108 | 108 | 108 |
| Denmark | 626 | 491 | 491 | 491 | 491 | 216 | 190 | 190 | 190 | 190 |
| Finland | 612 | 481 | 481 | 481 | 481 | 92 | 72 | 71 | 72 | 125 |
| Germany | 8139 | 6168 | 6168 | 6168 | 6165 | 738 | 659 | 660 | 659 | 659 |
| Ireland | 700 | 637 | 637 | 637 | 637 | 149 | 124 | 124 | 124 | 124 |
| Luxembourg | 55 | 51 | 51 | 51 | 51 | 1 | 1 | 1 | 1 | 1 |
| The Netherlands | 1881 | 1690 | 1690 | 1690 | 1664 | 565 | 511 | 508 | 511 | 569 |
| Sweden | 1420 | 1107 | 1107 | 1107 | 1107 | 300 | 274 | 274 | 274 | 274 |
| United Kingdom | 10840 | 9301 | 9301 | 9301 | 9292 | 513 | 454 | 457 | 454 | 743 |
| Norway | 1233 | 1128 | 1128 | 1128 | 1117 | 225 | 198 | 198 | 198 | 198 |
| Switzerland | 1554 | 1174 | 1174 | 1174 | 1174 | 42 | 38 | 38 | 38 | 38 |
| **Southern Europe** | **29922** | **28211** | **28211** | **27436** | **27436** | **59995** | **68344** | **68081** | **54584** | **77799** |
| France | 9097 | 8356 | 8356 | 8356 | 8256 | 3554 | 4095 | 4071 | 3312 | 4820 |
| Greece | 1343 | 1500 | 1500 | 1500 | 1495 | 11624 | 12714 | 12666 | 10601 | 13306 |
| Italy | 12098 | 12688 | 12688 | 12688 | 12018 | 19722 | 22769 | 22691 | 17966 | 29725 |
| Portugal | 1129 | 1013 | 1013 | 1013 | 1013 | 4791 | 5451 | 5435 | 4301 | 6632 |
| Spain | 6255 | 4655 | 4655 | 4655 | 4655 | 20304 | 23316 | 23217 | 18404 | 23316 |
| **New EU Member States** | **5025** | **8753** | **8725** | **4568** | **8611** | **1684** | **1689** | **1690** | **1530** | **2275** |
| Cyprus | 103 | 104 | 94 | 104 | 104 | 295 | 271 | 276 | 227 | 271 |
| Czech Republic | 808 | 1218 | 1218 | 748 | 1198 | 59 | 54 | 54 | 54 | 137 |
| Estonia | 71 | 126 | 126 | 51 | 123 | 13 | 12 | 12 | 12 | 13 |
| Hungary | 746 | 1099 | 1099 | 639 | 1081 | 620 | 702 | 698 | 591 | 1113 |
| Latvia | 104 | 253 | 253 | 87 | 249 | 39 | 36 | 36 | 36 | 36 |
| Lithuania | 128 | 406 | 406 | 116 | 399 | 72 | 67 | 67 | 67 | 67 |
| Malta | 22 | 17 | 15 | 17 | 17 | 7 | 15 | 15 | 12 | 26 |
| Poland | 2350 | 4690 | 4690 | 2227 | 4612 | 441 | 408 | 408 | 408 | 434 |
| Slovak Republic | 423 | 669 | 669 | 410 | 658 | 117 | 106 | 107 | 106 | 161 |
| Slovenia | 268 | 170 | 154 | 170 | 170 | 19 | 16 | 16 | 16 | 17 |
| **EU Candidate Countries** | **9230** | **14728** | **14432** | **8934** | **14533** | **34774** | **38104** | **38012** | **31824** | **70817** |
| Bulgaria | 1420 | 765 | 692 | 765 | 765 | 396 | 454 | 452 | 383 | 6843 |
| Romania | 3464 | 2307 | 2085 | 2307 | 2307 | 1343 | 1525 | 1519 | 1291 | 25104 |
| Turkey | 4346 | 11656 | 11656 | 5862 | 11461 | 33034 | 36125 | 36041 | 30150 | 38869 |
| **Europe-30** | **73222** | **75616** | **75292** | **64794** | **74436** | **99593** | **110920** | **110568** | **90721** | **154189** |

Table 16. Water use in 2030 (in million m³). Overview of the model outputs (manufacturing and electricity sector).

| Country/Region | Manufacturing | | | Electricity | | | |
|---|---|---|---|---|---|---|---|
| | 2000 | 2030 | | 2000 | 2030 | | |
| | | Baseline | Low economic growth variant | | Baseline | Climate policy | Low economic growth variant |
| **Northern Europe** | **17628** | **22918** | **19794** | **40215** | **10975** | **9182** | **9368** |
| Austria | 1786 | 2527 | 2235 | 1146 | 314 | 258 | 226 |
| Belgium | 1441 | 1719 | 1482 | 4712 | 1244 | 1084 | 1093 |
| Denmark | 112 | 136 | 124 | 104 | 85 | 65 | 73 |
| Finland | 1491 | 1414 | 1262 | 276 | 189 | 158 | 162 |
| Germany | 5995 | 7880 | 6683 | 23253 | 3259 | 2733 | 2777 |
| Ireland | 466 | 816 | 695 | 283 | 83 | 58 | 70 |
| Luxembourg | 14 | 22 | 18 | 1 | 17 | 15 | 10 |
| The Netherlands | 782 | 911 | 715 | 6069 | 1594 | 1313 | 1257 |
| Sweden | 1934 | 2571 | 2268 | 310 | 85 | 70 | 71 |
| United Kingdom | 1472 | 1925 | 1723 | 2197 | 2418 | 2035 | 2137 |
| Norway | 1679 | 2293 | 1986 | 120 | 1531 | 1224 | 1367 |
| Switzerland | 457 | 704 | 603 | 1744 | 157 | 170 | 126 |
| **Southern Europe** | **14905** | **18542** | **15807** | **31831** | **11736** | **11108** | **9641** |
| France | 3950 | 5191 | 4473 | 17170 | 6902 | 6787 | 5878 |
| Greece | 110 | 200 | 178 | 186 | 245 | 232 | 218 |
| Italy | 9217 | 10486 | 8821 | 6974 | 3540 | 3202 | 2633 |
| Portugal | 328 | 527 | 436 | 1077 | 413 | 292 | 319 |
| Spain | 1300 | 2138 | 1898 | 6424 | 637 | 595 | 593 |
| **New EU Member States** | **2236** | **4340** | **4056** | **14401** | **3658** | **3554** | **3359** |
| Cyprus | 14 | 24 | 21 | 0 | 0 | 0 | 0 |
| Czech Republic | 425 | 610 | 532 | 528 | 275 | 274 | 242 |
| Estonia | 27 | 47 | 45 | 990 | 66 | 60 | 63 |
| Hungary | 152 | 309 | 269 | 3294 | 899 | 902 | 763 |
| Latvia | 65 | 165 | 157 | 13 | 40 | 26 | 36 |
| Lithuania | 52 | 101 | 97 | 1724 | 1056 | 1013 | 989 |
| Malta | 2 | 4 | 3 | 0 | 0 | 0 | 0 |
| Poland | 748 | 1730 | 1647 | 6614 | 1159 | 1116 | 1114 |
| Slovak Republic | 649 | 1200 | 1147 | 698 | 123 | 123 | 116 |
| Slovenia | 103 | 151 | 138 | 540 | 41 | 41 | 36 |
| **EU Candidate Countries** | **4968** | **11143** | **10379** | **8526** | **4447** | **4143** | **3818** |
| Bulgaria | 516 | 883 | 787 | 3071 | 874 | 840 | 766 |
| Romania | 955 | 1800 | 1609 | 2672 | 2398 | 2223 | 2123 |
| Turkey | 3497 | 8460 | 7983 | 2784 | 1175 | 1081 | 928 |
| **Europe-30** | **39737** | **56943** | **50036** | **94973** | **30816** | **27987** | **26186** |

# APPENDIX E: DRIVING FORCE ASSUMPTIONS FOR THE LOW ECONOMIC GROWTH VARIANT

For the sensitivity run we use a projection of GDP/cap that has considerably lower economic growth rates than assumed for the baseline and climate policy scenario. These projections were produced by the PROMETHEUS model. Table 17 to Table 20 present the gross value added for the low economic growth variant separated by manufacturing sectors for the four Europe-30 regions. Along with a slower economic growth, the production of electricity will also be lower than in the baseline and climate policy scenarios. The results of this sensitivity run are given in Table 21 and Table 22.

Table 17. Gross value added separated by sectors in the Northern Europe economy (low economic growth variant). Source: EUROSTAT, Economic and Financial Affairs DG, PRIMES, PROMETHEUS. Regions are defined in Table 1.

| | GVA [$10^9$ Euro2000] | | | | | Annual growth rate [%] | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | 1990 | 2000 | 2010 | 2020 | 2030 | 90/00 | 00/10 | 10/20 | 20/30 | 00/30 |
| Iron and steel | 36 | 30 | 28 | 27 | 27 | -1.83 | -0.60 | -0.15 | -0.24 | -0.33 |
| Non-ferrous metals | 15 | 17 | 23 | 29 | 35 | 1.42 | 2.91 | 2.25 | 1.89 | 2.35 |
| Chemicals | 106 | 133 | 160 | 195 | 230 | 2.28 | 1.91 | 1.97 | 1.67 | 1.85 |
| Non-metallic minerals | 39 | 40 | 43 | 50 | 56 | 0.14 | 0.94 | 1.38 | 1.14 | 1.15 |
| Paper and pulp | 86 | 108 | 129 | 153 | 175 | 2.31 | 1.80 | 1.71 | 1.39 | 1.63 |
| Food, drink, tobacco | 104 | 128 | 148 | 175 | 202 | 2.12 | 1.50 | 1.69 | 1.43 | 1.54 |
| Engineering | 442 | 507 | 611 | 747 | 902 | 1.39 | 1.88 | 2.03 | 1.91 | 1.94 |
| Textiles | 42 | 32 | 31 | 32 | 33 | -2.74 | -0.37 | 0.43 | 0.34 | 0.13 |
| Other industries | 87 | 98 | 112 | 128 | 147 | 1.17 | 1.35 | 1.41 | 1.37 | 1.37 |
| Total industry | 957 | 1092 | 1286 | 1537 | 1808 | 1.33 | 1.65 | 1.80 | 1.64 | 1.69 |

Table 18. Gross value added separated by sectors in the Southern Europe economy (low economic growth variant). Source: EUROSTAT, Economic and Financial Affairs DG, PRIMES, PROMETHEUS. Regions are defined in Table 1.

| | GVA [$10^9$ Euro2000] | | | | | Annual growth rate [%] | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | 1990 | 2000 | 2010 | 2020 | 2030 | 90/00 | 00/10 | 10/20 | 20/30 | 00/30 |
| Iron and steel | 20 | 21 | 21 | 21 | 21 | 0.50 | 0.25 | 0.09 | 0.00 | 0.11 |
| Non-ferrous metals | 7 | 9 | 11 | 13 | 16 | 2.45 | 2.35 | 2.01 | 1.78 | 2.04 |
| Chemicals | 55 | 70 | 86 | 105 | 127 | 2.48 | 2.04 | 2.06 | 1.85 | 1.98 |
| Non-metallic minerals | 30 | 34 | 39 | 45 | 51 | 1.00 | 1.45 | 1.46 | 1.27 | 1.39 |
| Paper and pulp | 38 | 46 | 55 | 68 | 79 | 1.81 | 1.93 | 1.99 | 1.55 | 1.82 |
| Food, drink, tobacco | 60 | 71 | 86 | 102 | 119 | 1.63 | 1.89 | 1.76 | 1.59 | 1.75 |
| Engineering | 209 | 262 | 325 | 408 | 512 | 2.27 | 2.18 | 2.30 | 2.28 | 2.26 |
| Textiles | 53 | 50 | 49 | 49 | 48 | -0.75 | -0.19 | 0.02 | -0.10 | -0.09 |
| Other industries | 45 | 58 | 69 | 81 | 91 | 2.45 | 1.79 | 1.61 | 1.19 | 1.53 |
| Total industry | 518 | 619 | 741 | 892 | 1064 | 1.79 | 1.81 | 1.88 | 1.77 | 1.82 |

Table 19. Gross value added separated by sectors in the New EU Member States economy (low economic growth). Source: EUROSTAT, Economic and Financial Affairs DG, PRIMES, PROMETHEUS. Regions are defined in Table 1.

| | GVA [$10^9$ Euro2000] | | | | | Annual growth rate [%] | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | 1990 | 2000 | 2010 | 2020 | 2030 | 90/00 | 00/10 | 10/20 | 20/30 | 00/30 |
| Iron and steel | 4 | 3 | 4 | 4 | 5 | -2.16 | 1.45 | 1.04 | 0.67 | 1.05 |
| Non-ferrous metals | 1 | 1 | 1 | 1 | 1 | 2.58 | 1.79 | 2.31 | 1.19 | 1.76 |
| Chemicals | 6 | 7 | 12 | 18 | 23 | 1.51 | 5.59 | 3.98 | 2.46 | 4.00 |
| Non-metallic minerals | 3 | 5 | 7 | 9 | 11 | 4.61 | 2.85 | 2.83 | 1.68 | 2.45 |
| Paper and pulp | 4 | 6 | 9 | 13 | 16 | 3.78 | 4.23 | 3.84 | 2.32 | 3.46 |
| Food, drink, tobacco | 12 | 17 | 25 | 32 | 38 | 3.58 | 3.65 | 2.65 | 1.62 | 2.64 |
| Engineering | 27 | 30 | 43 | 64 | 81 | 1.38 | 3.57 | 4.02 | 2.42 | 3.33 |
| Textiles | 9 | 6 | 7 | 8 | 9 | -3.43 | 1.51 | 1.14 | 0.70 | 1.12 |
| Other industries | 12 | 12 | 18 | 24 | 29 | -0.21 | 3.88 | 3.17 | 2.00 | 3.01 |
| Total industry | 78 | 88 | 126 | 174 | 213 | 1.22 | 3.59 | 3.31 | 2.05 | 2.98 |

Table 20. Gross value added separated by sectors in the EU Candidate Countries economy (low economic growth). Source: EUROSTAT, Economic and Financial Affairs DG, PRIMES, PROMETHEUS. Regions are defined in Table 1.

| | GVA [$10^9$ Euro2000] | | | | | Annual growth rate [%] | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | 1990 | 2000 | 2010 | 2020 | 2030 | 90/00 | 00/10 | 10/20 | 20/30 | 00/30 |
| Iron and steel | 3 | 3 | 4 | 4 | 5 | 1.74 | 1.93 | 1.25 | 0.85 | 1.34 |
| Non-ferrous metals | 1 | 1 | 1 | 1 | 1 | -3.44 | 1.98 | 3.17 | 2.49 | 2.54 |
| Chemicals | 4 | 5 | 8 | 13 | 21 | 2.66 | 4.29 | 5.91 | 4.53 | 4.91 |
| Non-metallic minerals | 3 | 4 | 6 | 10 | 16 | 2.33 | 3.95 | 5.92 | 4.34 | 4.73 |
| Paper and pulp | 1 | 2 | 3 | 6 | 10 | 5.57 | 4.26 | 6.18 | 5.47 | 5.30 |
| Food, drink, tobacco | 6 | 10 | 15 | 23 | 34 | 5.29 | 4.02 | 4.43 | 3.82 | 4.09 |
| Engineering | 9 | 11 | 19 | 40 | 68 | 1.76 | 5.56 | 7.57 | 5.51 | 6.21 |
| Textiles | 10 | 8 | 9 | 11 | 13 | -1.79 | 0.53 | 2.11 | 2.34 | 1.65 |
| Other industries | 11 | 12 | 16 | 29 | 45 | 1.24 | 3.18 | 5.88 | 4.57 | 4.54 |
| Total industry | 47 | 56 | 80 | 137 | 212 | 1.71 | 3.64 | 5.52 | 4.48 | 4.54 |

Table 21. Projected thermal electricity production for the low economic growth variant. Source: EUROSTAT, PRIMES. Regions are defined in Table 1.

| | Sensitivity run [TWh]* | | | | | Annual growth rate [%] | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | 1990 | 2000 | 2010 | 2020 | 2030 | 90/00 | 00/10 | 10/20 | 20/30 | 00/30 |
| Northern EU15 + EFTA2 | 1183 | 1297 | 1363 | 1461 | 1502 | 0.93 | 0.49 | 0.69 | 0.28 | 0.49 |
| Southern EU15 | 722 | 963 | 1071 | 1169 | 1255 | 2.92 | 1.07 | 0.88 | 0.72 | 0.89 |
| New EU Member States | 304 | 308 | 348 | 433 | 452 | 0.14 | 1.23 | 2.21 | 0.44 | 1.29 |
| EU Candidate Countries | 121 | 169 | 207 | 265 | 382 | 3.40 | 2.03 | 2.51 | 3.72 | 2.75 |
| Europe-30 | 2329 | 2737 | 2989 | 3327 | 3591 | 1.63 | 0.88 | 1.08 | 0.76 | 0.91 |

* Thermal electricity production (including biomass) and nuclear electricity production.

Table 22. Difference in thermal electricity production for the baseline scenario and low economic growth variant. Source: EUROSTAT, PRIMES. Regions are defined in Table 1.

| | | LREM-E [TWh]* | | | Sensitivity run [TWh]* | | | Difference between Sensitivity run and LREM-E [%] | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | 2000 | 2010 | 2020 | 2030 | 2010 | 2020 | 2030 | 2010 | 2020 | 2030 |
| Northern EU15 + EFTA2 | 1297 | 1437 | 1615 | 1771 | 1363 | 1461 | 1502 | -5.15 | -9.58 | -15.20 |
| Southern EU15 | 963 | 1156 | 1341 | 1492 | 1071 | 1169 | 1255 | -7.35 | -12.86 | -15.86 |
| New EU Member States | 308 | 362 | 452 | 488 | 348 | 433 | 452 | -3.83 | -4.16 | -7.38 |
| EU Candidate States | 169 | 213 | 306 | 469 | 207 | 265 | 382 | -2.84 | -13.31 | -18.55 |
| Europe-30 | 2737 | 3168 | 3714 | 4220 | 2989 | 3327 | 3591 | -5.65 | -10.41 | -14.90 |

* Thermal electricity production (including biomass) and nuclear electricity production.