JRC TECHNICAL REPORTS

# Assessing the effects of water saving measures on Europe’s water resources

*BLUE2 project – Freshwater quantity*

De Roo, A., Bisselink B., Guenther S., Gelati E., Adamovic M.

2020

EUR 30361 EN

This publication is a Technical report by the Joint Research Centre (JRC), the European Commission's science and knowledge service. It aims to provide evidence-based scientific support to the European policymaking process. The scientific output expressed does not imply a policy position of the European Commission. Neither the European Commission nor any person acting on behalf of the Commission is responsible for the use that might be made of this publication. For information on the methodology and quality underlying the data used in this publication for which the source is neither Eurostat nor other Commission services, users should contact the referenced source. The designations employed and the presentation of material on the maps do not imply the expression of any opinion whatsoever on the part of the European Union concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

Contact information
Name: Ad de Roo
Address: Joint Research Centre, via E. Fermi 2749, TP 121, 21027 Ispra (VA), Italy
Email: ad.de-roo@ec.europa.eu
Tel.: 0039-0332-786240

EU Science Hub
https://ec.europa.eu/jrc

JRC120388

EUR 30361 EN

| | | | |
|---|---|---|---|
| Print | ISBN 978-92-76-21536-3 | ISSN 1018-5593 | doi:10.2760/550523 |
| PDF | ISBN 978-92-76-21537-0 | ISSN 1831-9424 | doi:10.2760/739798 |

Luxembourg: Publications Office of the European Union, 2020

© European Union 2020

The reuse policy of the European Commission is implemented by the Commission Decision 2011/833/EU of 12 December 2011 on the reuse of Commission documents (OJ L 330, 14.12.2011, p. 39). Except otherwise noted, the reuse of this document is authorised under the Creative Commons Attribution 4.0 International (CC BY 4.0) licence (https://creativecommons.org/licenses/by/4.0/). This means that reuse is allowed provided appropriate credit is given and any changes are indicated. For any use or reproduction of photos or other material that is not owned by the EU, permission must be sought directly from the copyright holders.

All content © European Union, 2020, except Cover page: © 4tomania - stock.adobe.com

How to cite this report: De Roo, A., Bisselink B., Guenther S., Gelati E., Adamovic M., *Assessing the effects of water saving measures on Europe's water resources; BLUE2 project – Freshwater quantity*, EUR 30361 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-21537-0, doi:10.2760/739798, JRC120388.

# Contents

# Executive summary

This report presents the freshwater quantity results obtained from a study on EU integrated policy assessment for the freshwater and marine environment (BLUE2).

With the aim to reduce the already existing pressures on Europe's freshwater resources, EU Member States are planning and implementing various water saving measures, as for example described in the Programs of Measures under the Water Framework Directive (WFD).

These measures consist of increasing irrigation efficiency, treated wastewater re-use for irrigation to reduce new abstractions, and urban water efficiency measures to reduce consumption.

In addition, the transformation of the European energy system until 2050 - with changes in energy demand as well as changes in the energy mix - is envisaged to change the requirements and consumption for cooling water.

Furthermore, climate change is expected to change water availability, and socio-economic and demographic changes will change water demand.

All these changes interact, and the resulting water resources and locations with pressures are evaluated. In this study, various water saving measures are evaluated and compared with the current situation using JRC's LISFLOOD water resources model. Furthermore, these measures are evaluated under current and future climate and land use, using Euro-Cordex scenarios and the LUISA land use projection until 2050.

Changes in irrigation efficiency prove to be an important measure to reduce water quantity pressures. Changes in the cooling water requirements for energy production, either caused by a changing demand or a change in the energy mix with more renewable sources, also change the water quantity pressures. Other measures, such as water re-use and urban water efficiency improvements do have positive local effect, but are less noticeable at regional and river basin level.

However, the projections of climate change projections indicate a reduced future water availability, especially in the Mediterranean area. Our results suggest that the climate-induced water availability reduction might outweigh the positive effects of the planned measures.

As the level of detail in the reported measures needs improvements, quite a number of assumptions needed to be made in this assessment. A follow-up study is already ongoing to address a number of improvements in the assessment of water quantity measures.

# 1. Introduction

Growing human water demands, due to projected population, socio-economic and climate, change pressures on our water supplies in many regions of the world (Wada et al., 2013; Schewe et al., 2014). Moreover, it is expected that water scarcity is increasing in the coming decades (Gossling and Arnell, 2013). As water is a primary need for all, access to clean water is one of the key factors of the Sustainable Development Goals (SDGs) as agreed by the United Nations in 2015 (UN-GA, 2015).

Water usage is typically identified for the following sectors or purposes:

- Public water, used for drinking water and sanitation
- Irrigation water, used for the irrigation of crops
- Livestock water, used for the livestock agricultural sector
- Energy cooling water, used for cooling during electricity generation (thermal powerplants)
- Industry cooling water, used for cooling during industrial manufacturing
- Industry manufacturing water, used during the industrial manufacturing process (e.g. paper industry).

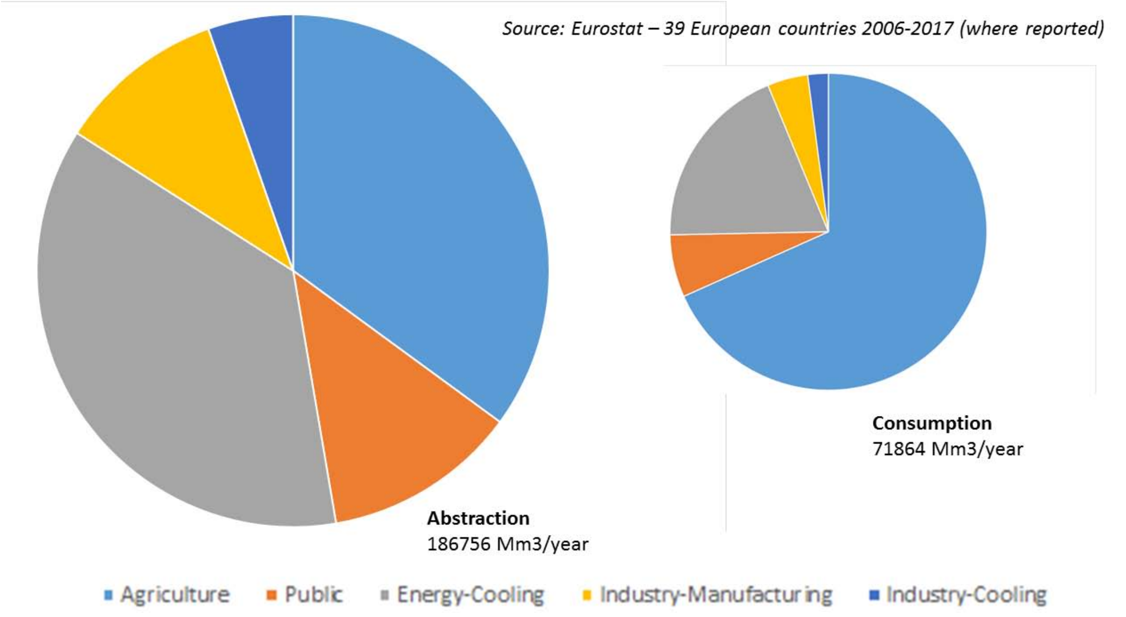

*Figure 1 Reported water abstraction (source Eurostat June 2020) and estimates of water consumption (source JRC), as an average for 2006-2017. Note that data for some countries (Italy, Austria) are not available, and are not included in this figure. The size of the circles reflect the respective quantities.*

As for these components, Figure 1 shows that the agricultural and energy sector abstract the most water, whereas the agricultural sector consumes by far the most water. The difference between abstracted water and consumed water typically flows back in the environment as 'return flow', or is stored in the soil as soil moisture.

The protection of European freshwaters is the subject of several EU legislations, such as the Water Framework Directive (WFD) and its related Directives. Managing and coping with the extremes of water – floods and droughts – are covered under the Floods Directive (FD) and EU Action on water scarcity and droughts.

Various measures are proposed by EU Member States to combat water scarcity and secure water availability for all sectors that require water for their operations.

The understanding of the effectiveness of these measures and future water scarcity is essential to inform and support environment and climate policy makers for mitigation and adaptation strategies.

We use in this study the hydrological modelling system LISFLOOD (V2.0). Water use modules have been already embedded into a number of large-scale hydrological models to investigate water availability and demand on river basin (Bisselink et al., 2018a), European (Aus van der Beek et al., 2010; Bisselink et al., 2018b; Flörke et al., 2012) and global scale (Flörke et al., 2013). However, there is still a need to better assess future water demand and consumption related to water scarcity (Wada et al., 2013).

Therefore, in this study, an integrated assessment is performed considering both socio-economic scenarios and climate change scenarios in relation to water scarcity in Europe.

# 2. Scenarios of water saving

In this study, raw data for four scenarios were made available to the JRC by Benitez et al. (2018). Benitez et al. (2018) assessed the WFD Programs of Measures submitted by the EU Member States and extracted investment data and more detailed information covering the following measures:

- Water efficiency investments in irrigation;
- Water efficiency investments in urban water supply (leakage repair);
- Water re-use; treated waste-water to serve as irrigation water;
- Water use efficiency in the energy sector, due to a changing energy mix;

For all these four measures, and based on the reported information, we identified three scenarios:

- a baseline scenario (REF), reflecting the situation around 2017;
- a business-as-usual (BAU) scenario, reflecting the WFD being executed until 2027;
- a maximum-feasible-technology (MTF) scenario, reflecting a maximum feasible savings option.

## 2.1 Irrigation efficiency

In Figure 2 the actual irrigated areas for EY countries are given. Countries reported to have the largest absolute area of irrigation are Spain, Italy, France and Greece, followed by Portugal, Germany and Denmark.

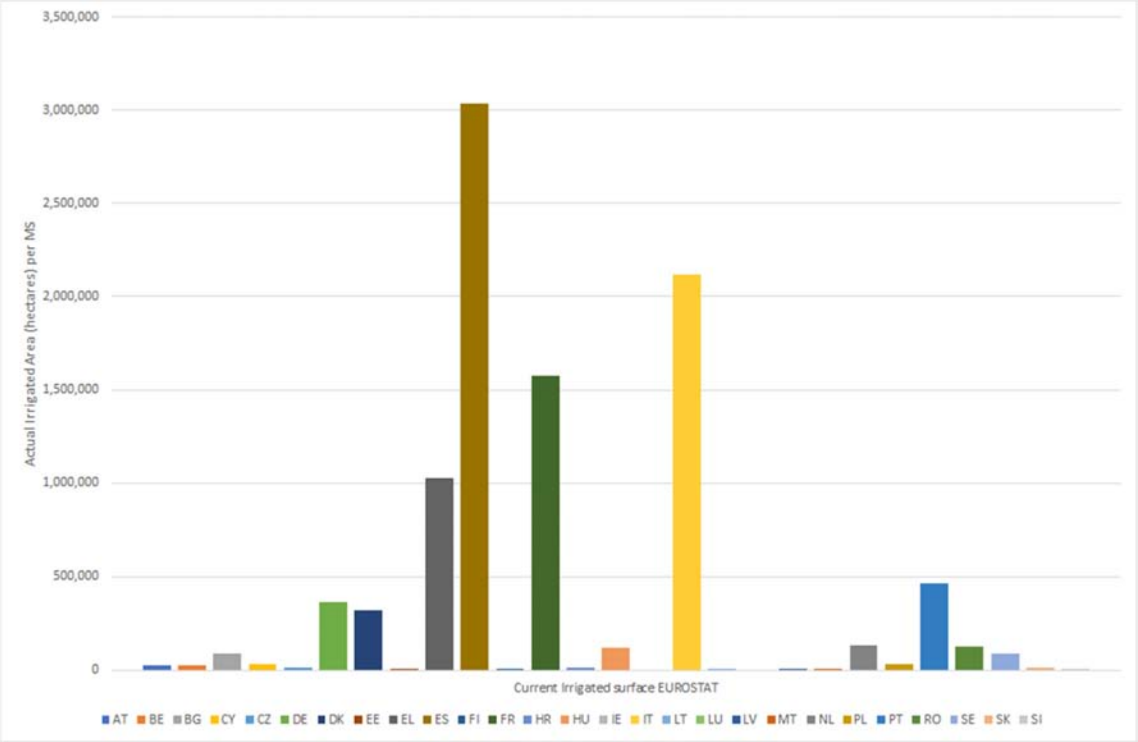

*Figure 2 Current irrigated area per EU Member State (Eurostat 2017).*

Benitez et al. (2018) collected the reported investments in irrigation. These reported investments in irrigation efficiency as planned by MS were translated into percentage efficiency gains as compared to the current reference situation (Figure 3). Most MS plan only marginal new investments in irrigation efficiency in the BAU scenario (Figure 4).

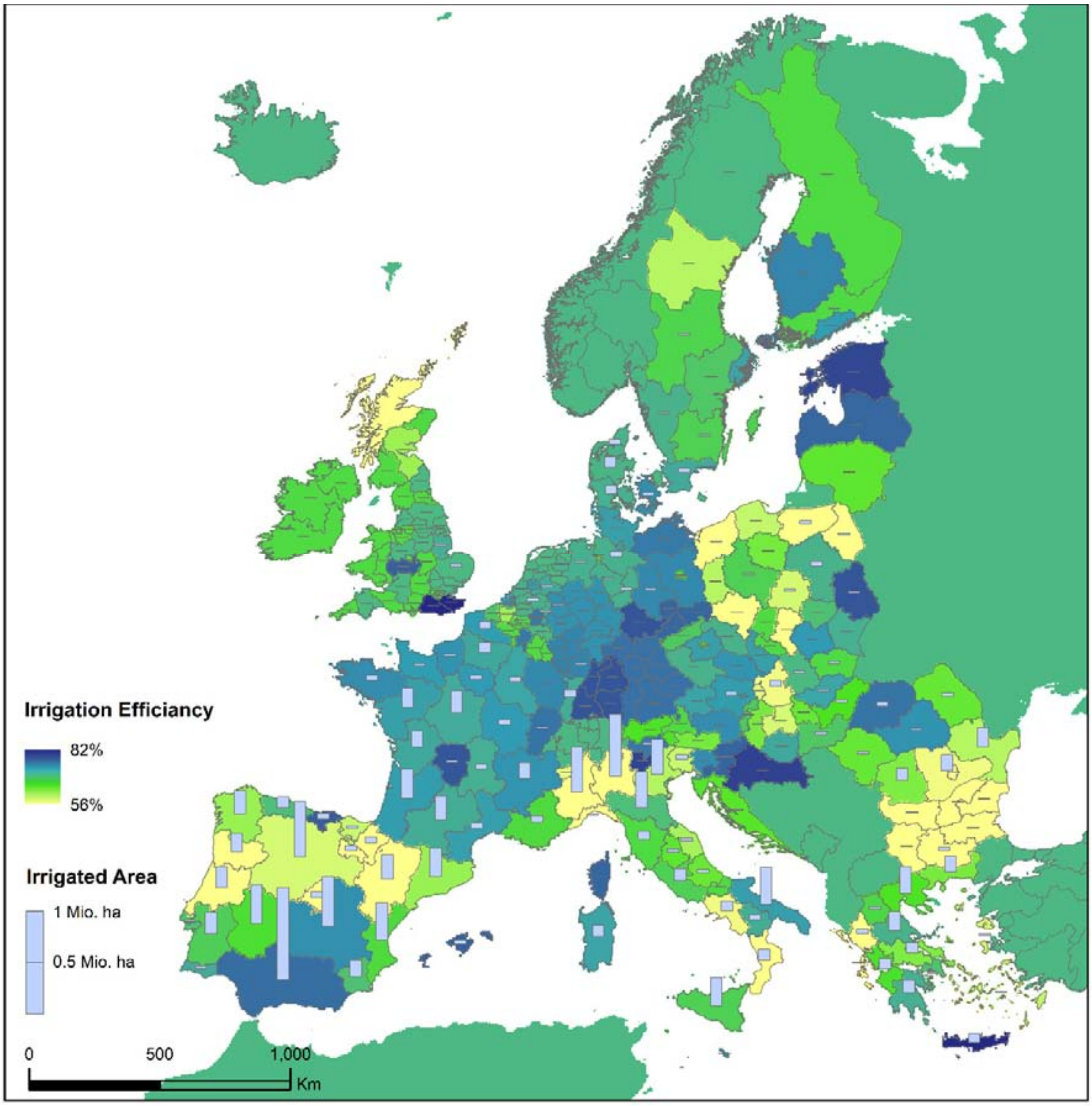

*Figure 3 Current Irrigation Efficiency in NUTS2 regions.*

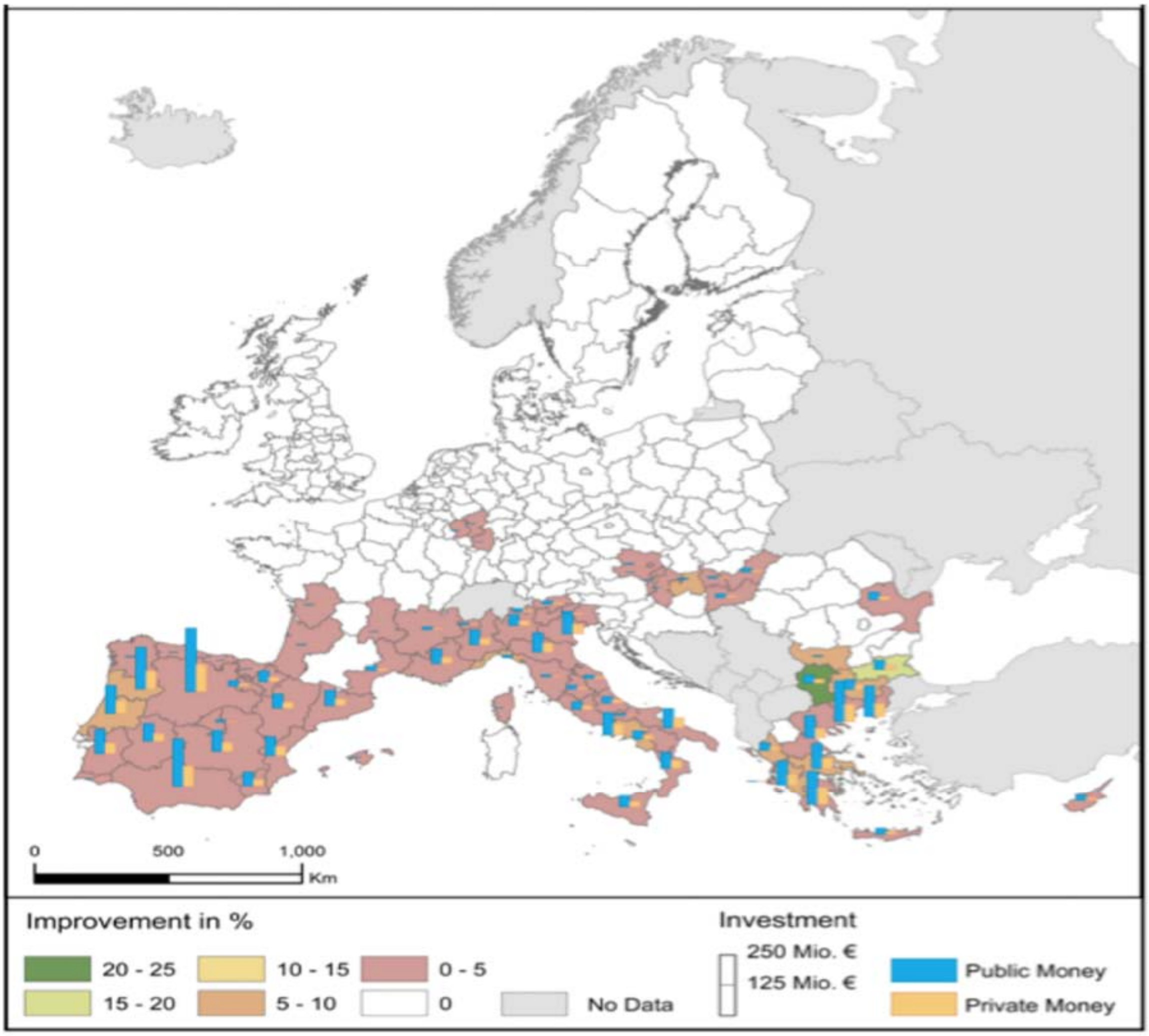

*Figure 4 Reported MS investments in irrigation efficiency for the BAU2027 scenario.*

For the MTF Maximum Technological Feasible scenario it is assumed that everywhere in Europe drip irrigation would be applied, independent of the fact if this would be economical or not.

Irrigation investments were available at regional NUTS2 level, which is already better than national level. For further spatial downscaling we used the irrigation areas within a NUTS2 region. There would be room for improvement to specify the location of the irrigation investments more precisely, which would improve the modelling of water resources.

## 2.2 Urban water savings

In urban areas, substantial amounts of water are lost in the distribution network of water supply to households and the private sector. These losses vary in EU Member States (Figure 5) from approx. 5% in the Netherlands to 48% in Ireland.

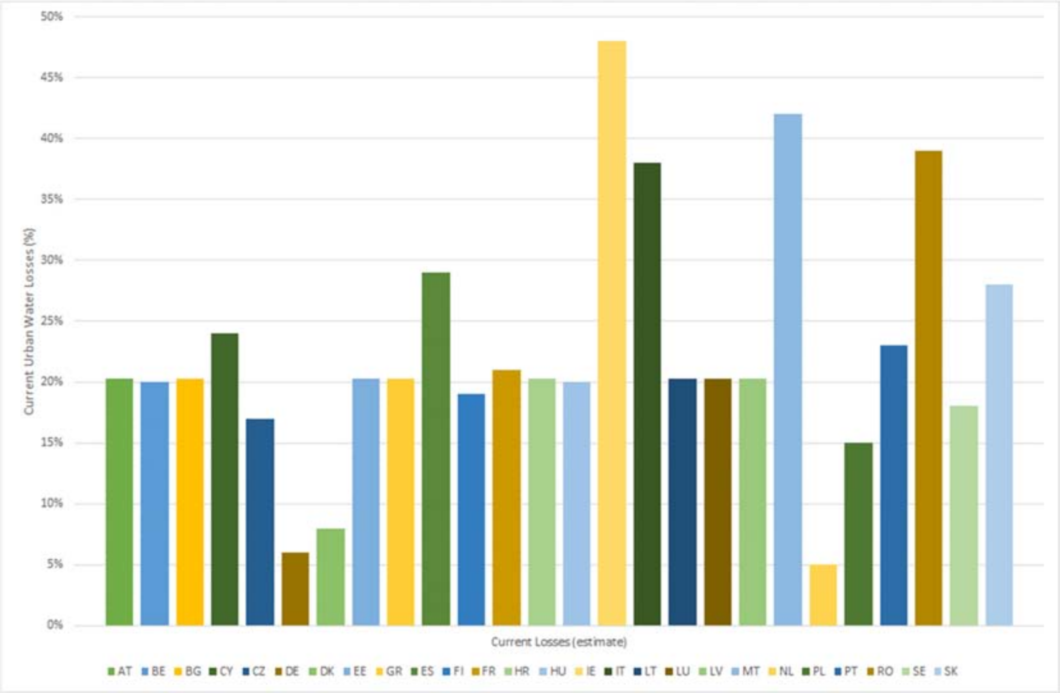

*Figure 5 Current urban water losses (source Benitez et al., 2018)*

Investments reported by MS in the Programs of Measures (Benitez 2018, Figure 6) were used to estimate the reduction percentage of urban water losses under the BAU scenario. In most cases, the changes in the BAU scenario for water losses are only marginal as compared to the reference situation: less that 1% change in the total water losses.

For the MTF we assumed here that urban water efficiency would be raised in all EU Member States to 5% losses – the actual loss percentage in the Netherlands. The requirement investment of this water loss reduction is calculated in Benitez et al., 2018.

Changes to reach the MTF scenario are substantial, and also require substantial investments (Figure 6), ranging from 1 to 4 billion euro depending on the country.

Data on urban water losses and investments were only available at national scale. Therefore, we had to make assumptions for the further spatial downscaling. We used here the current spatial pattern of public sector water use and assumed equal losses over a Member State, both for the present and for future projections. More regional scale data and investments would be beneficial for more precise assessments.

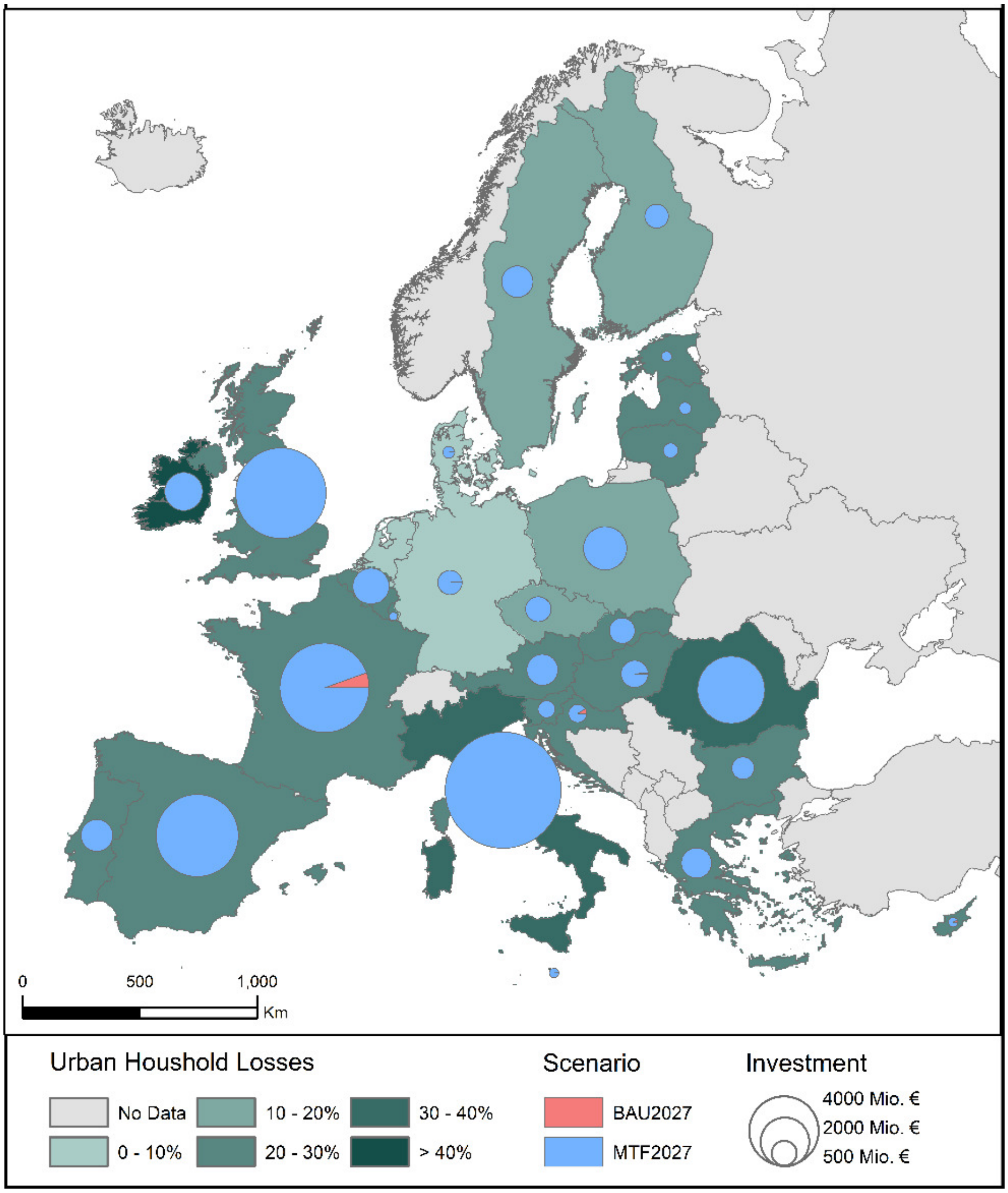

*Figure 6 Reported MS investments to increase urban water efficiency (BAU2027) and the estimated investments required to reach the MTF2027 level of efficiency (95%).*

## 2.3 Cooling water in the energy sector

Another change in water consumption can be achieved by changes in the energy sector. In the energy sector, water is used for cooling (Magagna et al., 2019). Water is used throughout the energy industry, and the water system needs energy for collecting, pumping, treating and desalinising water. Increasing water and energy needs, or changes in water availability due to climate change could have significant effects on the energy system.

Water use in the energy industry depends on:

- the energy demand by society
- the energy mix, i.e. the part of energy generated by thermal power stations that need cooling
- the cooling type of the power station and the water use efficiency.

.

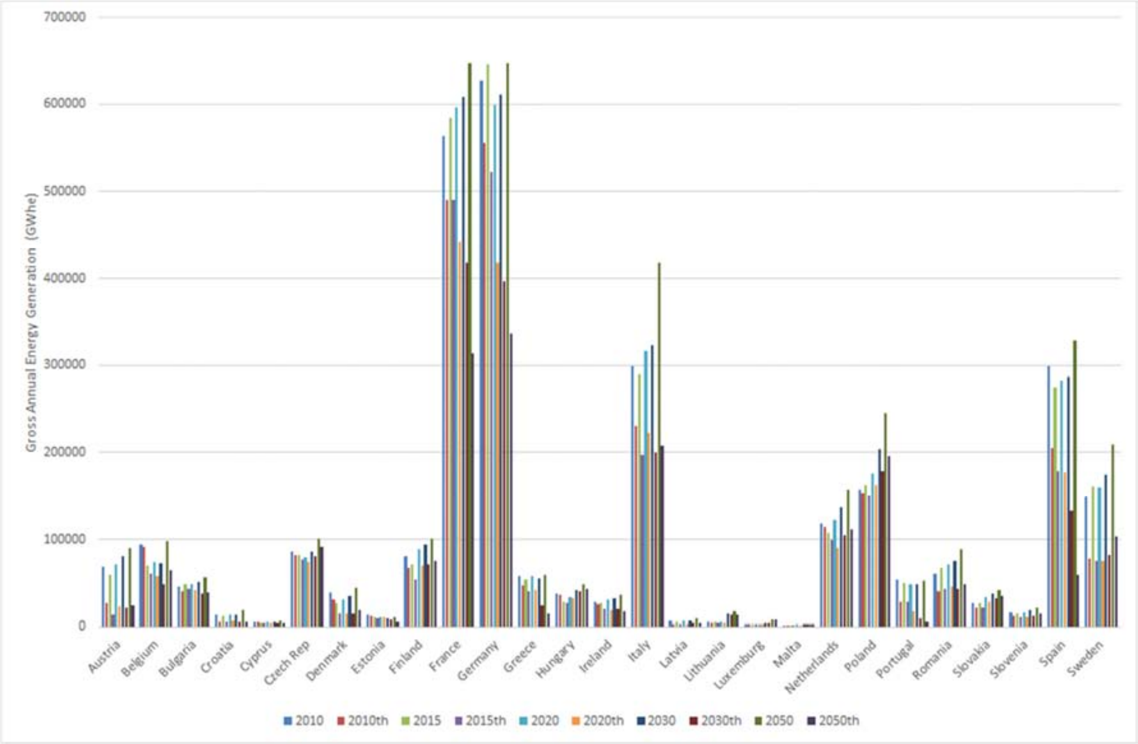

*Figure 7 The EU Energy Reference 2016 for 2010-2050: The total annual electricity generation, and the amount generated by thermal sources that need cooling water for processing (source: https://ec.europa.eu/energy/data-analysis/energy-modelling/eu-reference-scenario-2016_en )*

The largest countries in Europe obviously have the largest energy requirements: Germany, France, Italy, Spain and Poland. Projected changes in the energy requirements until 2050 are shown in Figure 7. For this study, we projected the thermal energy requirement changes on the current water demands, and estimated future water requirements for the energy sector (Figure 8). Relative large increases are projected for Lithuania, Luxemburg and Slovakia, while for countries such as France, Germany, Greece, Portugal and Spain substantial decreases in water demand for the energy sector are projected.

As projections for energy for this study were available at national level, we used the current spatial distribution of cooling water requirements to downscale the projected future changes.

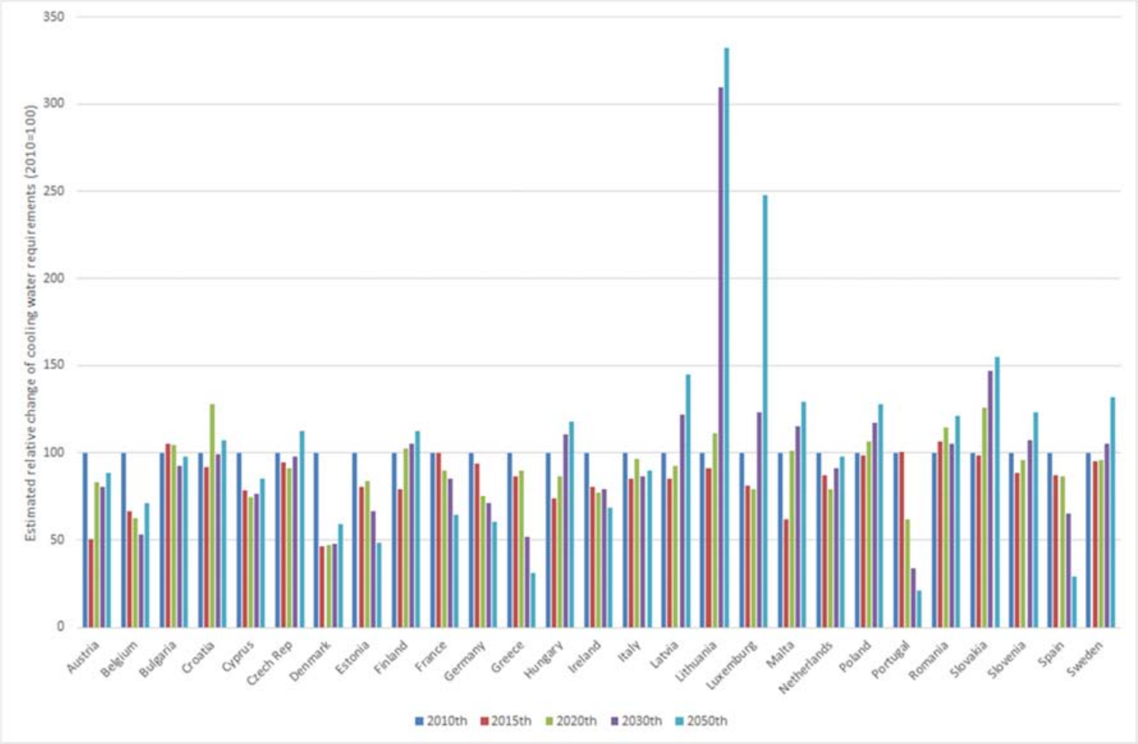

*Figure 8 Estimated relative change in required cooling water for energy production, using the EU Reference Scenario 2016 for 2010-2050.*

## 2.4 Waste-water re-use for irrigation

The re-usage of treated waste-water from the public sector as a source of irrigation water would obviously reduce the requirement for new abstraction of irrigation water from surface or groundwater sources. While in the meantime more data are available, at the time of this study, Benitez et al. (2018) only had water re-use data available for Spain (Figure 9). For water-re-use, regional investments and regional data were available, which allows a much more targeted modelling of the overall effects to water resources.

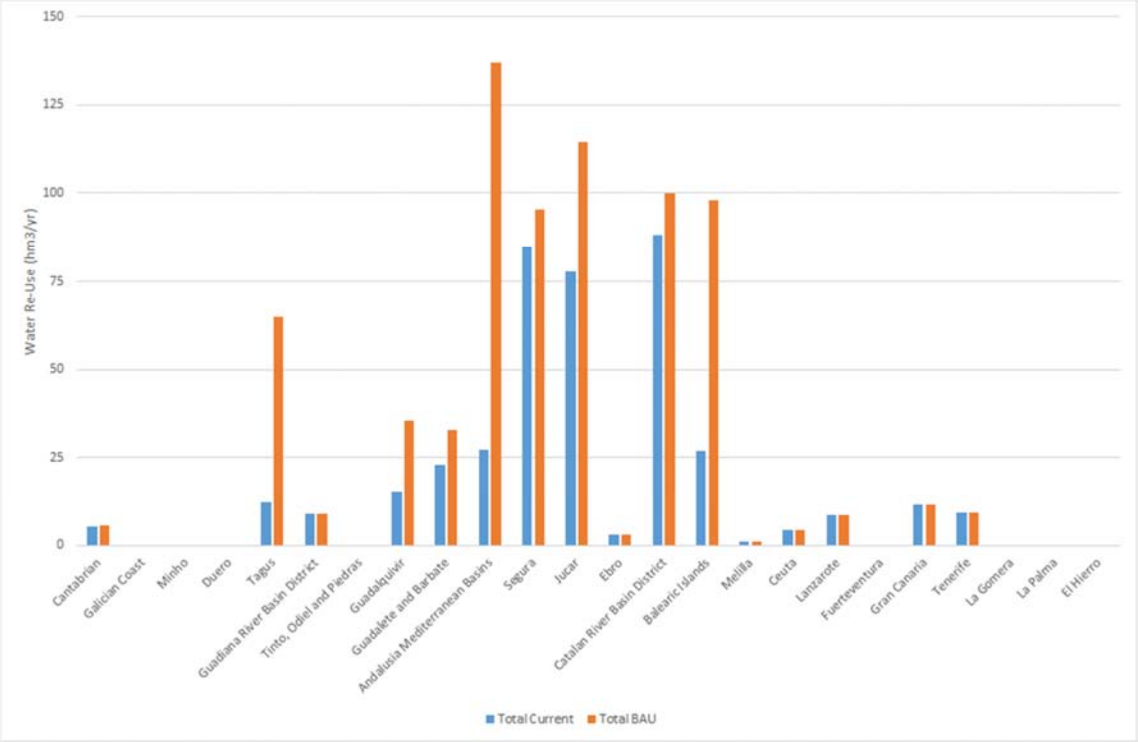

*Figure 9  Current and planned (until 2027) wastewater re-use for irrigation in Spain.*

Therefore, for this study, we could only evaluate the effects of water re-use for Spain for the BAU scenario. Estimations for MTF and other European countries were not available.

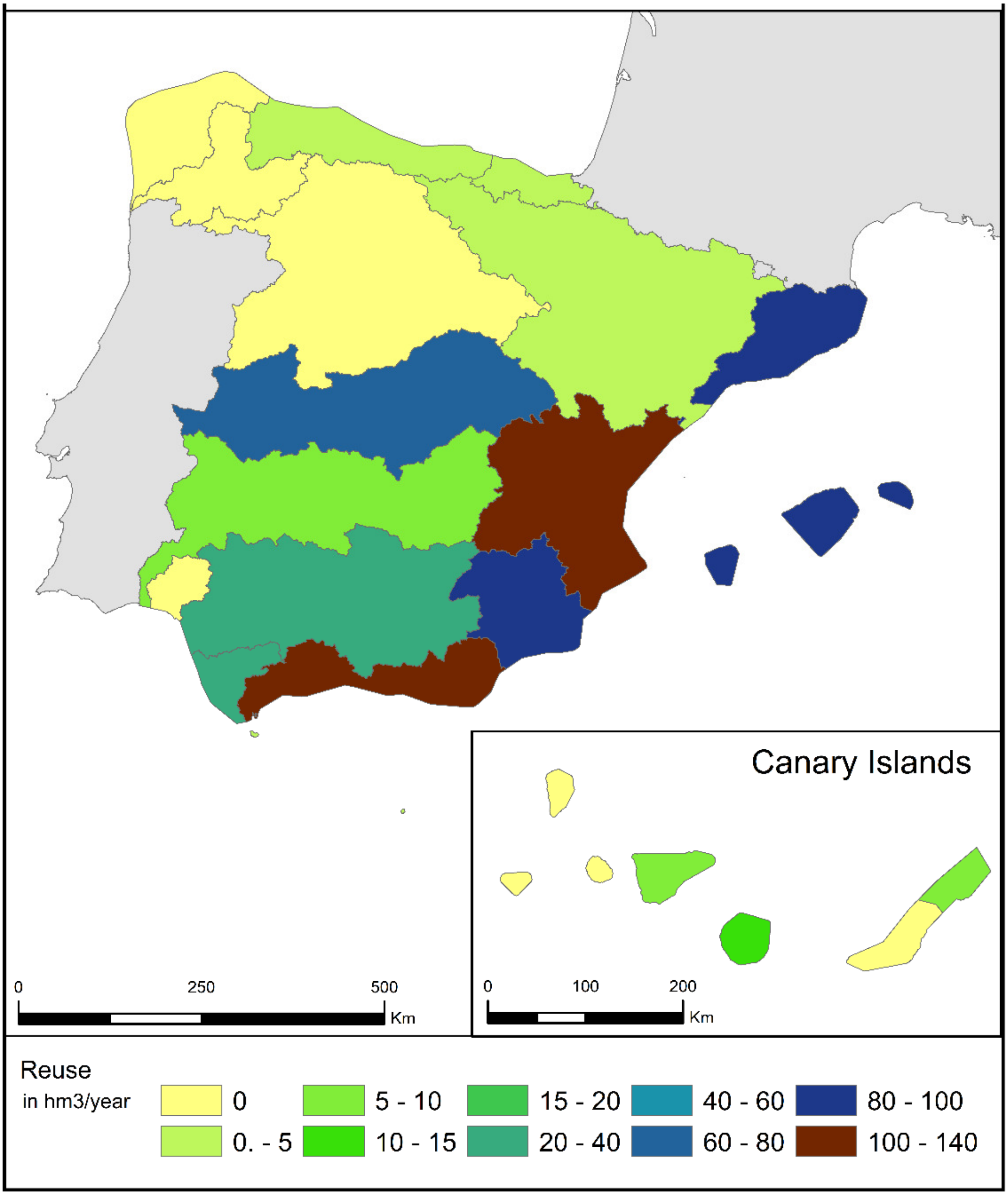

*Figure 10  Planned water re-use for irrigation in Spain (BAU2027).*

# 3. Methodology

The water quantity modelling for the Blue2 project is done using the latest version of JRC's LISFLOOD water resources model (De Roo et al., 2000; Van der Knijff et al., 2010, Burek et al., 2013), which includes several improvements to simulate water demand and consumption. Driven by climate projections, LISFLOOD calculates a complete water balance at a daily timestep and for every grid cell, here 5x5 km for the European domain.

During the EU Blueprint modelling work carried out around 2011, LISFLOOD had been modified already to include irrigation and irrigation efficiency, cooling water requirements for energy production, a leakage parameter to identify losses in the public water supply network, and application of an ecological flow threshold of streamflow below which abstractions are prohibited.

For BLUE2, LISFLOOD was further modified to better simulate water re-use, groundwater abstractions, as well as a better data management allowing for large climate simulations and interactions with the models GREEN and the Marine Modelling Framework.

## 3.1 The LISFLOOD model

LISFLOOD uses daily rainfall or snowfall at the start. Evapotranspiration by soils, crops, vegetation, water or urban surfaces is calculated. Soil moisture balances are computed, as well as surface and subsurface flows to river and groundwater aquifers.

Water demands for irrigation are embedded in the model LISFLOOD and computed depending on crop stage, climate and soil moisture conditions, taking into account losses during application (efficiency) and transportation (conveyance losses). Using a Penman-Monteith approach, the model estimates the required amount of transpiration by vegetation or crop. If this amount of water is not available from soil moisture above wilting point level, the missing amount is designated as the irrigation water demand.

Water demands for other sectors – livestock, energy, manufacturing industry, and public water demands - are used as well. The model abstracts the water that is demanded from either surface or groundwater sources. These may include lakes, reservoirs, rivers and groundwater aquifers, depending on local information available on sources of water. The model takes a local eflow threshold into account – which may be user defined – below which abstraction of water is stopped and flagged as 'shortage'.

For the eflow threshold, we have used here a location specific but constant 10th percentile of the natural river discharge at that particular location.

Although LISFLOOD is a regular grid-based model with a constant spatial grid more detailed sub-grid land use classes are used to simulate the main hydrological processes. The model distinguishes for each grid the fraction open water, urban sealed area, forest area, paddy rice irrigated area, crop irrigation area and other land uses. Specific hydrological processes (evapotranspiration, infiltration etc.) are then calculated in a different way for these land use classes. Moreover, sub-gridded elevation information is used to establish detailed altitude zones which are important for snow accumulation and melting processes, and to correct for surface temperature.

River flow is routed through the river network. Discharges are calibrated and validated on a regular basis using reported discharge data by Member State water authorities, from approximately 900 gauging stations. Soil moisture patterns and snow extent patterns are regularly validated using satellite data or by visual checks.

LISFLOOD produces a number of outputs, such as daily river discharge, soil moisture conditions, groundwater amounts and water in lakes and reservoirs. In addition a number of water resources indicators are produced, such as flood and low flow extremes, water scarcity days, eflow breachings, water availability per capita, and the water exploitation index.

The Water Exploitation Index Plus (WEI+) indicator is used to estimate the intensity, duration and the socio-economic impacts of water scarcity. We use here the same method of calculating the WEI+ as the European Environmental Agency (EEA) (ETC/ICM, 2016).

The WEI+ is defined as the ratio of the total water net consumption divided by the available freshwater resources in a region, including upstream inflowing water. The total water net consumption is the difference between the water abstraction and the return flow. Water abstractions in LISFLOOD consist of five components from which the irrigation water demand is estimated dynamically within the model as it is driven by climate conditions. The other four sectorial components are used as input data. These are (manufacturing) industrial water demand, water demand for energy and cooling, livestock water demand and domestic water demand. In general, water use estimated for these four sectors are derived from mainly country-level data (EUROSTAT, AQUASTAT) with different modelling and downscaling techniques. Output of the LUISA platform (see Annex A1.2) is used for the spatial downscaling of both present and future water use trends to ensure consistency between land use, population and water demand. Improved water efficiency, based on historical trends, is only taken into account for the industrial water demand. The WEI+ includes return flow, resulting from drained irrigation water, (warmed up) cooling water returned to the river, and (treated) wastewater returned to surface waters. Per sector, water consumption factors are used and applied to split water abstraction into net water consumption and return flow (Bisselink at al., 2018).

Water abstractions take place at regional level, and also the WEI+ is therefore calculated at this regional level at a monthly timescale to avoid averaging skewed results. However, in this report the results are converted to a daily scale.

WEI+ values have a range between 0 and 1. For distinguish water scarcity gradations across Europe, we used the water scarcity values as applied by the EEA Values between 0-0.1 denote “low water scarcity”, “moderate water scarcity” if the ratio lies in the range 0.1-0.2, “water scarcity” when this ratio is in larger than 0.2, and “severe water scarcity” if the ratio exceeds the 0.4 threshold (Faergemann, 2012).

The following impact indicators regarding freshwater quantity were assessed for BLUE2:

- Qmean: impact on mean annual streamflow in rivers
- WeiC: the water exploitation index plus (WEI+), calculated at regional and monthly basis
- WeiD: a water demand indicator
- Shortage: water abstraction ‘scarcity’
- FK3 (freshwater availability per capita, in a region)
- Eflow (environmental flow breaches; when streamflow falls below the Eflow-threshold, which is defined in this study as the 10th percentile (low end) of daily streamflow
- Q10 (low flow): the 10th percentile low-end of daily streamflow, and indicator for low flows
- Q9995 (high flows & floods); the 99.95th percentile of daily streamflow, which can be seen as an equivalent of a 5-year return period river flood
- LZ (groundwater resources): a measure of groundwater resources

For this study, measures are evaluated in the following way:

- Current climate, reference run
- Current climate, BAU measures
- Current climate, MTF measures
- Future climate, reference run
- Future climate, BAU measures
- Future climate, MTF measures

## 3.2 Weather and climate data

For the meteorological forcing of the LISFLOOD model – i.e. the weather data used as input – we have been using three sets of data:

- Observed weather data: 1990-2016 (JRC LISFLOOD-EFAS forcing)
- Control climate CLMcpm-CCLM4-8-17-ICHEC-EC-EARTH: 1981-2010.
- Changed climate CLMcpm-CCLM4-8-17-ICHEC-EC-EARTH 2011-2060.

The observed weather aim to reflect the most accurate historic weather conditions in Europe. The sources of the JRC-LISFLOOD-EFAS forcing are various state-of-the-start data sets, added with several country datasets (Ntegeka, 2013). This gridded weather data set is updated every year, and for this study the period 1990-2016 has been used.

Projections of future climate are available from the Euro-Cordex initiative (Jacob et al., 2014) and are based on two Representative Concentration Pathways (RCPs): RCP4.5 and RCP8.5. RCP4.5 may be viewed as a moderate-emissions-mitigation-policy scenario and RCP8.5 as a high-end emissions scenario.

As computational power did not allow to estimate the effects of measures under various climate scenarios, we selected from 11 RCP8.5 climate scenarios the scenario for which the control climate 1981-2010 simulations - while run with LISFLOOD - most closely matched observed river discharge (Figure 11). For Europe, the CLMcpm-CCLM4-8-17-ICHEC-EC-EARTH comes closest to observed discharges and was therefore selected as climate scenario for BLUE2.

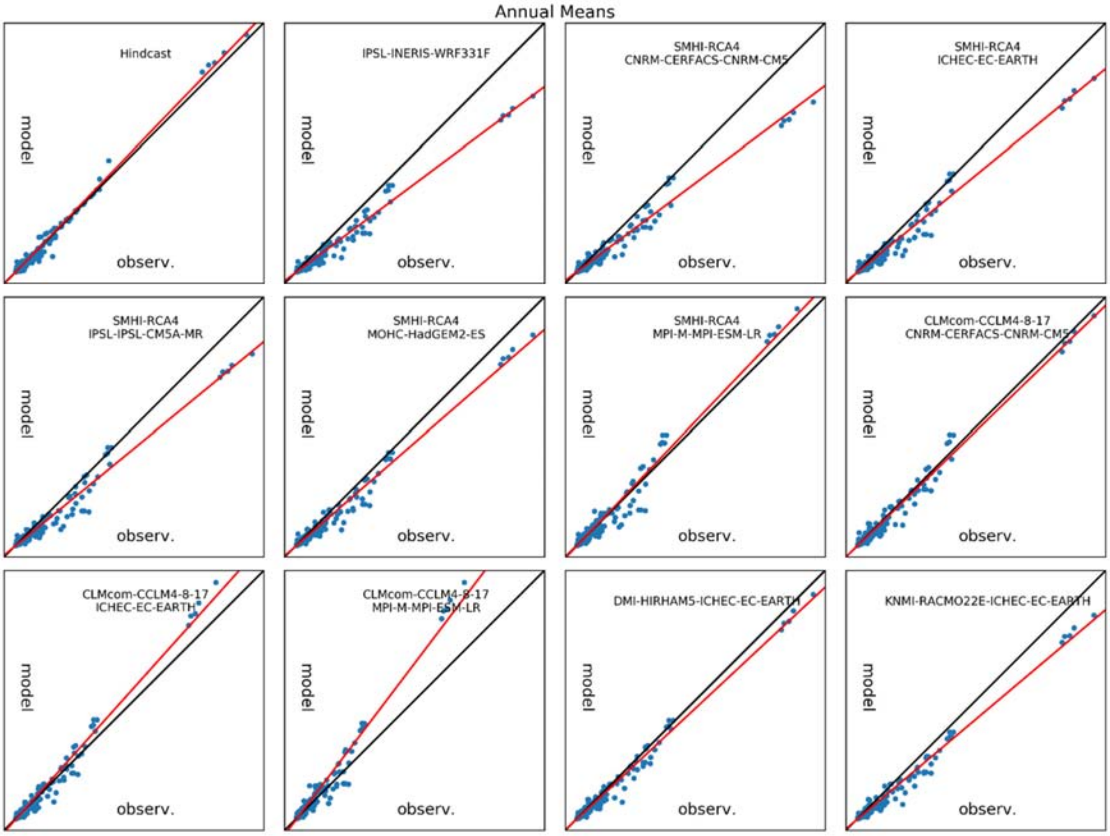

*Figure 11 Comparison of observed and simulated annual streamflow using the LISFLOOD model, using the observed 1990-2016 meteorological data (upper left picture 'hindcast'), and for the 11 1981-2010 CORDEX climate control scenarios. Note: the CLMcpm-CCLM4-8-17-ICHEC-EC-EARTH is used for BLUE2.*

As this is thus a single scenario, and authors are aware that climate projections vary from one model to the other, this is a compromise due to computational restrictions at the time of this study.

Statistical and quantitative analyses in this report are performed over longer, preferably 30-year time periods:

- Observed weather 1990-2016 (27 years);
- Control climate 1981-2010 (30 years);
- Climate scenario data 2011-2060, for which we examined 2027-2056 (30 years).

The reference scenario spans the period 1981-2010. For the climate scenario, we compare the 30-year time slices centred on the year that global average temperature is 2°C above pre-industrial temperature, which is this case is in 2041. Thus, we selected 2027-2056 as a 30 year evaluation period for Blue2 against the 1981-2010 control climate. The 1.5°C and 2°C warming scenarios are explicitly considered in the Paris Agreement, while a 3°C global warming is a scenario that could be expected by the end of the 21st century if adequate mitigation strategies are not taken.

It should be noted that we derived climate at global warming levels from transient climate projections, which may differ from stabilized climate at those warming levels. Studies (e.g., Maule et al., 2017) suggest that the effect of pathway to global warming levels is small compared to the models' variability, expect for strongly not time-invariant variables such as sea level rise.

## 3.3 Socio-economic and land-use projections

We performed the model assessment with static socio-economic conditions in Europe during 1990-2010, due to a lack of more precise data. For the static maps, 2010 is the reference year.

For the future assessments we are using future projections of land use derived from the LUISA modelling platform (Jacobs-Crisioni et al., 2017). LUISA translates socio-economic trends and policy scenarios into processes of territorial development. Among other things, LUISA allocates (in space and time) population, economic activities and land use patterns which are constrained by biophysical suitability, policy targets, economic criteria and many other factors. Except from the constraints, LUISA incorporates historical trends, current state and future projections in order to capture the complex interactions between human activities and their determinants. The mechanisms to obtain land-use demands are described in Baranzelli et al. (2014) and Jacobs-Crisioni et al. (2017). Key outputs of the LUISA platform are fine resolution maps (100m) of accessibility, population densities and land-use patterns covering all 28 EU member states including Serbia, Bosnia Herzegovina and Montenegro until 2050. Corine land use maps are used to cover the rest of Europe. Although LISFLOOD normally operates on a coarser resolution (here 5km), the details of the LUISA output (100m) remain for a large part due to the use of sub-grid land cover fractions in LISFLOOD. For a complete description of the LUISA modelling platform and its underlying mechanics we refer to (Batista e Silva et al., 2013; Lavalle et al., 2011).

Water demand in LISFLOOD consist of five components from which the irrigation water demand is estimated dynamically within the model as it is driven by climate conditions. The irrigation water demand with a distinction in simulation methods for crop irrigation and paddy rice irrigation is described in Bisselink et al. (2018).

The other four sectorial components are used as input data. These are (manufacturing) industrial water demand, water demand for energy and cooling, livestock water demand and domestic water demand. Per sector, water consumption factors are used and applied to split water abstraction into net water consumption and return flow (Bisselink at al., 2018).

In general, water use estimated for these four sectors are derived from mainly country-level data (EUROSTAT, AQUASTAT) with different modelling and downscaling techniques as described in Vandecasteele et al. (2014). Output of the JRC LUISA land use projection platform is used for the spatial downscaling of both present and future water use trends to ensure consistency between land use, population and water demand. A brief description of each sectorial component is given below.

Livestock water withdrawals are estimated by combining water requirements from literature with livestock density maps for cattle, pigs, poultry, sheep and goats. The methods are described in detail by Mubareka et al. (2013).

For the energy and cooling demand, national water use statistics are downscaled to the locations of large power thermal power stations registered in the European Pollutant Release and Transfer Register data base (E-PRTR). Subsequently, the temporal trend of energy water use is simulated based on electricity consumption projections from the POLES model (Prospective Outlook on Long-term Energy Systems).

Industrial water demands are based on country-level Figures from national statistics offices for the total water use by manufacturing industries, mining, construction and services. Future industrial water use trends are simulated based on GVA projections for these sub-sectors from the GEM-E3 model to represent industrial activity and an efficiency factor, based on historical trends, to represent improving water efficiency due to technical developments (Bernhard et al. 2019a). Since the GEM-E3 model only provide projections for the EU-28, industrial water use projections are assumed constant for countries outside EU-28.

Water demands for the household sector are derived from a specific household water usage module (Bernhard et al. 2019b) which simulates water use per capita based on socio-economic, demographic and climate variables. This model was based on collected data at NUTS-3 from 2000-2013 for all EU-28 countries on household water use, water price, income, age distribution and number of dry days per year. Subsequently, regression models were fitted to quantify relationships between water use, water price and the other relevant variables for four European clusters of NUTS-3 regions with similar socio-economic and climate conditions. This household water usage module allows us to estimate present and future domestic water use per capita at NUTS3 level using socio-economic, demographic and climate projections. The water use per capita are multiplied with population maps from the LUISA platform from 2010 up to 2050 for every 5 years. For the years in between the 5yr-window a linear growth is assumed. Consumptive use for the domestic sector is assumed at 20% (EEA, 2005) meaning that 80% flows back in the hydrological system as waste water.

## 3.4 Conversion of measures into LISFLOOD model input

Benitez et al. (2018) provided the basic data – typically in the form of excel spreadsheets – for four scenarios to the JRC:

- Water efficiency investments in irrigation;
- Water efficiency investments in urban water supply (leakage repair);
- Water re-use; treated waste-water to serve as irrigation water;
- Water use efficiency in the energy sector, due to a changing energy mix;

For all these four measures we identified a baseline scenario (REF), a business-as-usual (BAU) scenario, and a maximum-feasible-technology (MTF) scenario. This has been mainly described in chapter 2.

### 3.5 Combined scenarios

Hydrological simulations have been performed with the JRC' LISFLOOD water resources model. Using the measures, the weather and climate data, the LUISA land use projections for Europe 2010-2050, as well as population projections for Europe until 2050, we established a set of 23 scenarios for freshwater quantity analysis that have been evaluated using the LISFLOOD model:

| **Scenario** | **Measure** | **Climate** | **Population** | **Landuse** |
|---|---|---|---|---|
| 1 | none | Obs19902016 | 2006 | 2006 |
| 2 | BAU (irrigation) | Obs19902016 | 2006 | 2006 |
| 3 | BAU (cooling) | Obs19902016 | 2006 | 2006 |
| 4 | BAU (household) | Obs19902016 | 2006 | 2006 |
| 5 | BAU (reuse) | Obs19902016 | 2006 | 2006 |
| 6 | BAU (all 4 msr) | Obs19902016 | 2006 | 2006 |
| 7 | MTF (irrigation) | Obs19902016 | 2006 | 2006 |
| 8 | MTF (cooling) | Obs19902016 | 2006 | 2006 |
| 9 | MTF (household) | Obs19902016 | 2006 | 2006 |
| 10 | MTF (reuse) | Obs19902016 | 2006 | 2006 |
| 11 | MTFR (all 4 msr) | Obs19902016 | 2006 | 2006 |
| 12 | none | Cordex19812010 | 2010 | 2010 (LUISAstart) |
| 13 | none | Cordex20112060 | 20112060 | 20112060 |
| 14 | BAU (irrigation) | Cordex20112060 | 20112060 | 20112060 |
| 15 | BAU (cooling) | Cordex20112060 | 20112060 | 20112060 |
| 16 | BAU (household) | Cordex20112060 | 20112060 | 20112060 |
| 17 | BAU (reuse) | Cordex20112060 | 20112060 | 20112060 |
| 18 | BAU (all 4 msr) | Cordex20112060 | 20112060 | 20112060 |
| 19 | MTF (irrigation) | Cordex20112060 | 20112060 | 20112060 |
| 20 | MTF (cooling) | Cordex20112060 | 20112060 | 20112060 |
| 21 | MTF (household) | Cordex20112060 | 20112060 | 20112060 |
| 22 | MTF (reuse) | Cordex20112060 | 20112060 | 20112060 |
| 23 | MTFR (all 4 msr) | Cordex20112060 | 20112060 | 20112060 |

# 4. Results

In this chapter, the results of the scenario computations are presented.

As mentioned before, we evaluated four sets of measures:

- Irrigation efficiency
- Urban water losses
- Water re-use
- Efficiency changes in cooling water requirements

These were evaluated for:

- A reference (~2010) situation
- A Business As Usual scenario (BAU) including reported MS planned measures
- A Maximum Technical Feasible scenario (MTF) for all individual measures

These measures were simulated against:

- Observed climate (1990-2016), for which the JRC meteorological data have been used that are used as a reference for the LISFLOOD and EFAS systems, using JRC-MARS data appended with additional MS and project data
- Euro-Cordex control climate 1981-2010, to evaluate the changed climate against.
- The future climate: for computation reasons a single EURO-CORDEX scenario CLMcom-EC-EARTH RCP8.5 climate scenario for 2011-2100, because it was closest in simulating observed climate between 1981-2010, evaluated by simulated river discharge. This climate scenario reaches the point of 2 degree global temperature increase by 2041. We analysed the 30 year time window 2027-2056 for the results on water resources.

## 4.1 Water indicators under current climate and baseline measures

As a starting point, we calculated river flow, soil moisture and all sorts of water indicators for the observed climate 1990-2016 with no measures applied (REFerence run).

Figure 12 presents the Water Exploitation Index, computed on a monthly scale and then averaged over the 27 years. Like this, the extremes during the dry summer period are still reflected and not averaged out by wetter winters. From figure 12, we can deduct that the areas with a high WEI+ are located in the Mediterranean region (Portugal, Spain, Italy, Malta, Greece, Cyprus), with some intermediate issues in Central Europe (Germany, France, Hungary, UK, Belgium).

The most critical areas under current climate and water requirements are Southern Spain, Portugal, Greece and Italy, the Baleares, Sicily, Malta Crete and Cyprus.

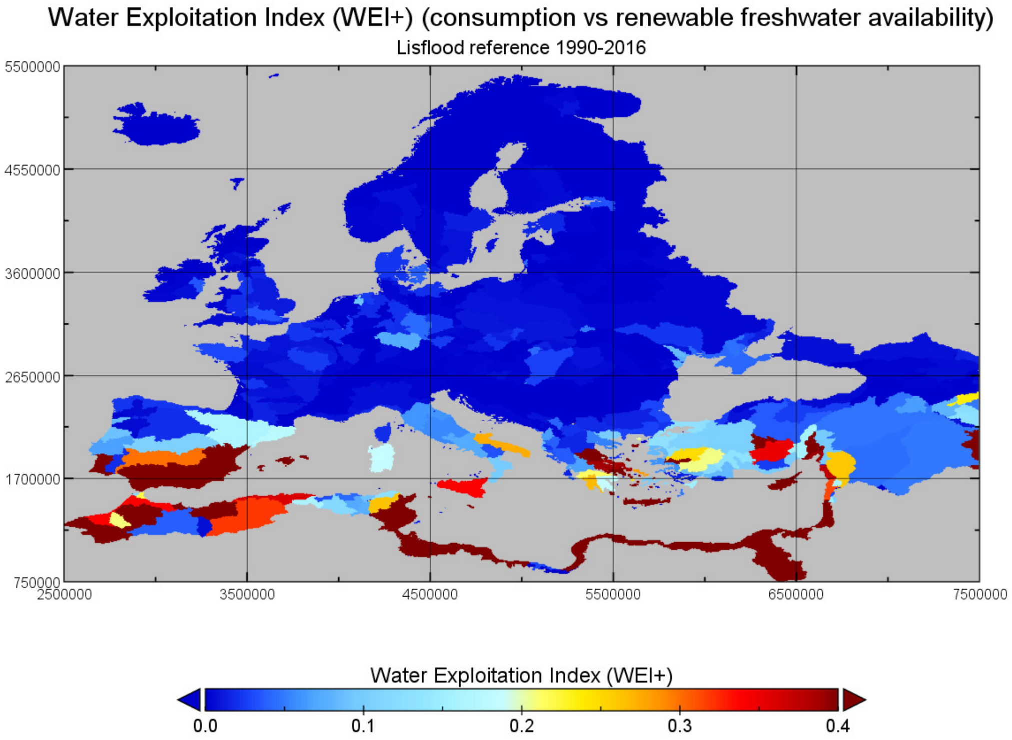

*Figure 12 Water Exploitation Index (WEI+) for the 1990-2016 Reference scenario, simulated with LISFLOOD.*

We do not further discuss the control climate runs 1981-2010 here, since the results proved to be similar to the observed weather runs. Thus we can conclude that the selected climate scenario only has very little bias as compared to the observed weather.

## 4.2. Changes in water quantity pressures due to changes in irrigation efficiency

From the four evaluated measures related to water abstractions, efforts to increase irrigation efficiency demonstrate to have more influence on water quantity indicators than the other three measures evaluated here: urban water losses reduction, water re-use, and cooling water changes.

Figure 13 shows that the irrigation efficiency investments under the BAU scenario do have a moderate effect on the Water Exploitation Index in several regions of southern Spain, Portugal, Greece and Cyprus. In other countries, no significant effects of the irrigation investments are detected. In absolute terms , improvements in WEI+ due to inrrigation efficiency increase are around 10% of the reference WEI+ indicator.

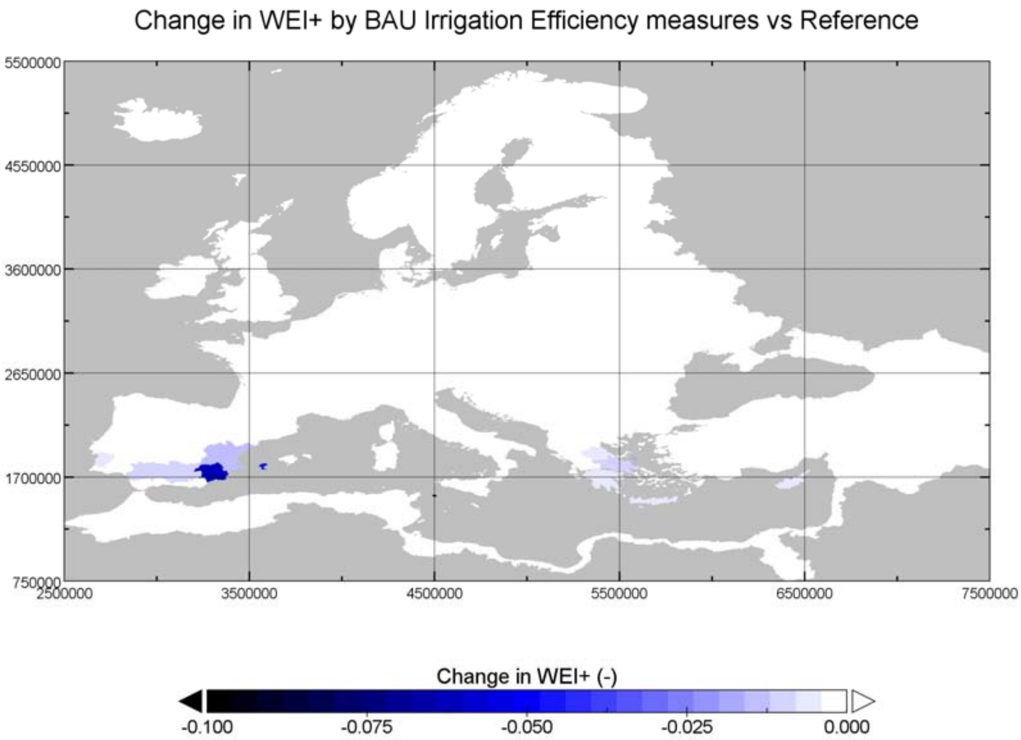

*Figure 13 Influence of planned irrigation investments (BAU) on WEI+. Note that 0.1 is equivalent to values of WEI+ of 10 as used by EEA: EEA scales from 0 to 100%; JRC scales from 0 to 1.*

For the MTF scenario (figure 14) the positive effects of the irrigation efficiency increases to the level of drip irrigation are most pronounced in Spain, Italy, Greece, Portugal and Cyprus. In absolute terms , improvements in WEI+ due to irrigation efficiency increase are around 20% of the reference WEI+ indicator.

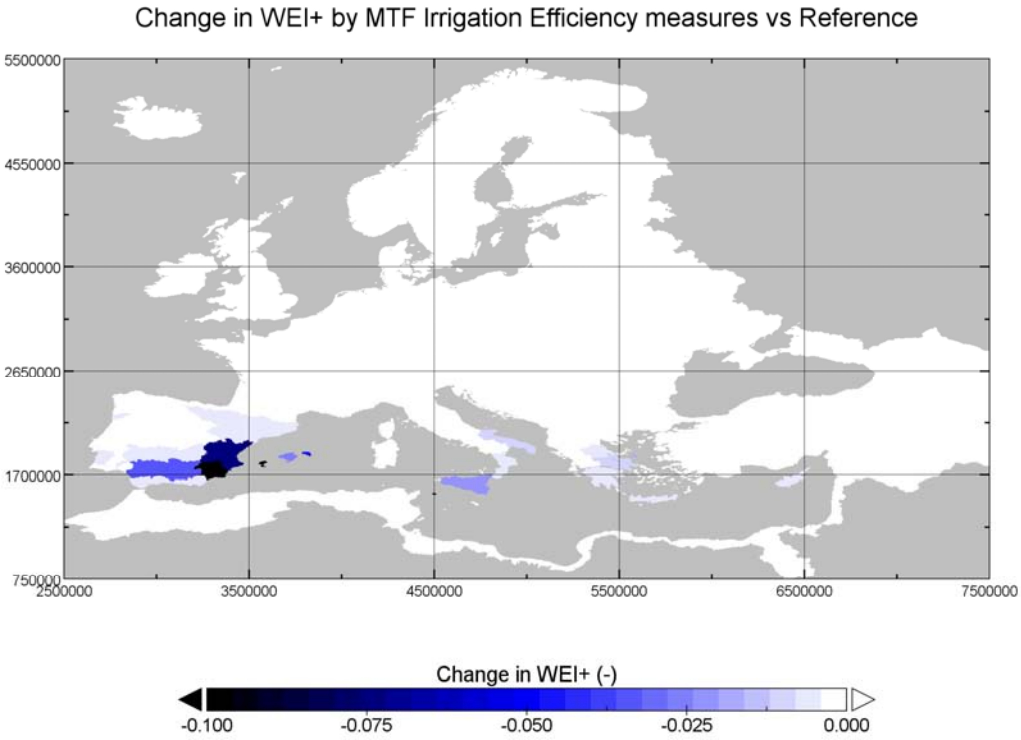

*Figure 14 Influence of planned irrigation investments (MTF) on WEI+.*

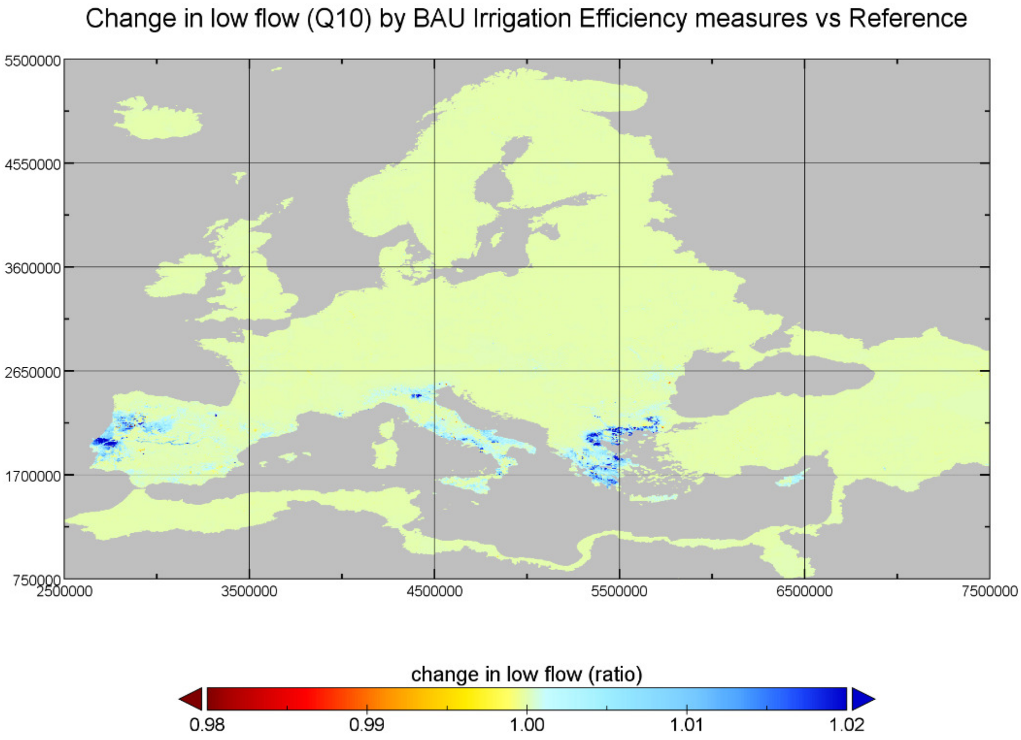

*Figure 15 Effects of BAU Irrigation Efficiency measures on low flow (Q10).*

Figure 15 shows the effects of the BAU irrigation efficiency measures on low flow magnitude. From the 30-year runs, we calculate the 10th percentile low flow. When compared, we observe that for the BAU scenario, the low flow improves (increases) as compared to the REFerence run. Note that the change is in the order of 1%-2%.

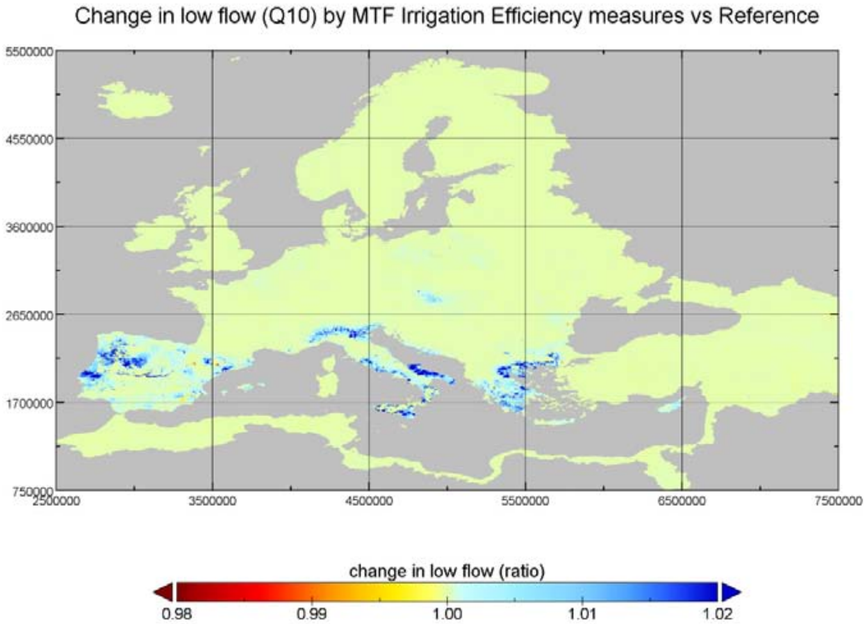

*Figure 16 Effects of MTF Irrigation Efficiency measures on low flow.*

Under the MTF scenario, the positive effect of the measures on low-flow magnitude is emphasized, but still in the order of 1-2% of the baseline value without measures. Note that water is abstracted not only from rivers itself, but also groundwater, lakes and reservoir. Also, there can be timing issues, where water maybe abstracted in periods other than the lowflow periods. Thus, there does not need to be a 1:1 influence of irrigation efficiency.

## 4.3. Changes in water quantity pressures due to changes in urban water efficiency

The scenario dealing with preventing urban water supply losses – effectively reducing leakage of the public supply network - leads to changes of the WEI+ in some regions in Spain only (figure 17). Please note that these changes in the WEI+ are marginal, even for the MTF scenario. Where WEI+ in those regions typically is 0.20 – 0.50, we estimate changes here of $4*10^{-8}$., so several orders of magnitude less.

Public water usage is not the dominant water usage in a river basin (Figure 1), and substantial changes in efficiency would need to be made to observe significant changes in WEI+.

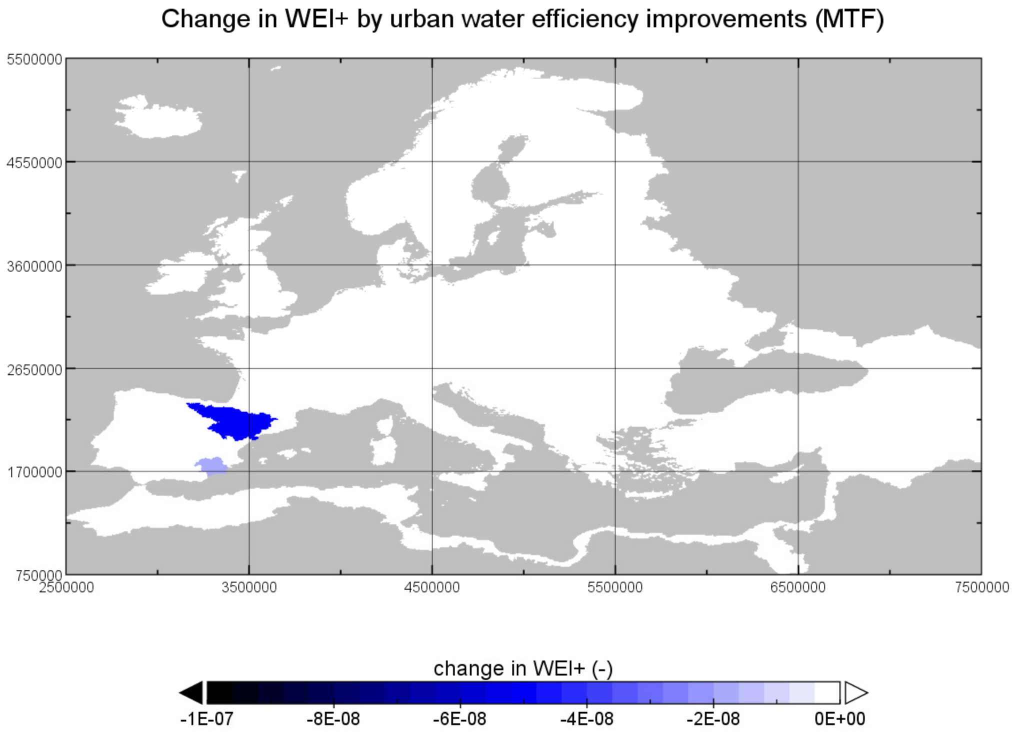

*Figure 17 Changes in WEI+ as a consequence of efforts to reduce urban water losses (MTF scenario).*

## 4.4. Changes in water quantity pressures due to water re-use

As mentioned, in this study we only had available investments data for water re-use in Spain. Figure 18 shows that the water re-use scenario – in which treated waste water is used for irrigation, and thus reduces the need for abstraction from ground and or surface water – is effective in several regions in Spain. The re-use scenario increases the amount of remaining groundwater resources, and is reducing the groundwater depletion to some extent.

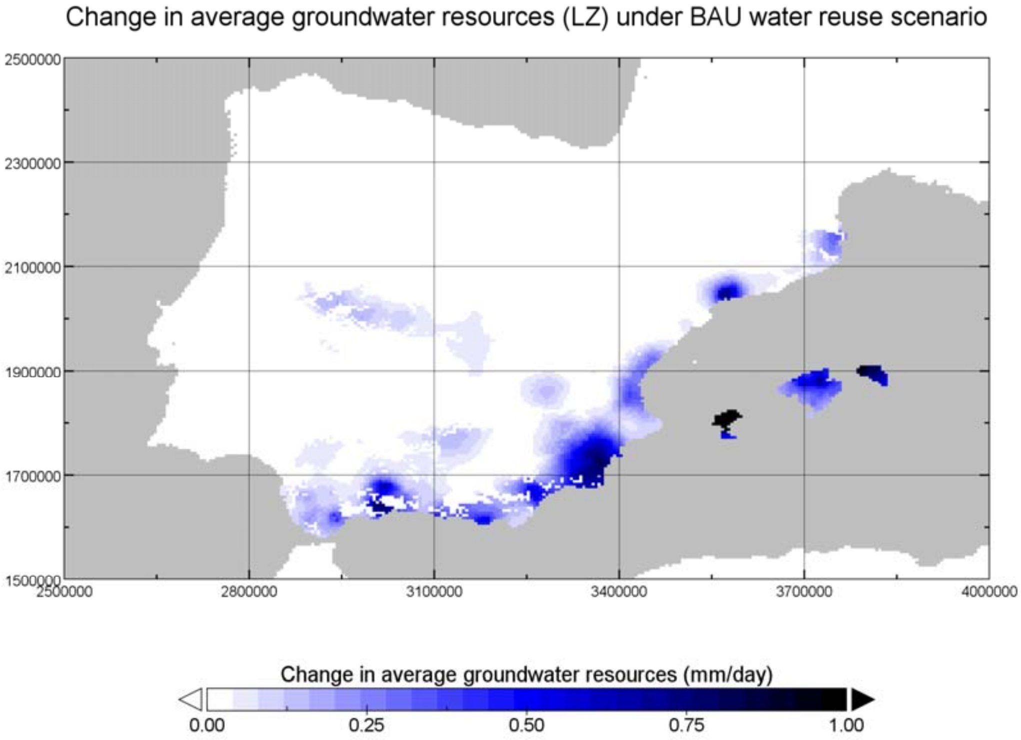

*Figure 18 Effects of the water re-use scenario for Spain - BAU scenario.*

## 4.5. Changes in water quantity pressures due to EU Reference Energy Scenario

The fourth measure evaluated here is not so much a measure, but changes in energy demand, the energy mix, and cooling efficiency methods as identified in the EU Reference Scenario 2016, do change the water requirements and consumption as well.

Figure 19 shows the combined effects of changes in the energy mix, which might lead to reduced cooling water needs for energy production, but in some cases increases in cooling water usage due to an overall energy demand. For EU28 a reduction of 20% by 2050 is projected for energy demand from energy sources that require cooling water.

A number of single countries, such as Croatia (+8%), Czech Republic (+13%), Finland (+12%), Hungary (+18%), Latvia (+45%), Lithuania (+232%), Poland (+28%), Romania (+21%), Slovakia (+55%), Slovenia (+23%), Sweden (+32%) are projected to have an increased demand of energy sources that require cooling water in their production.

Countries such as France, Germany, Greece, Portugal and Spain are projected to have substantial decreases in water demand for the energy sector, and this is reflected in improvements in several water indicators, such as here the effect on low-flow (figure 19)..

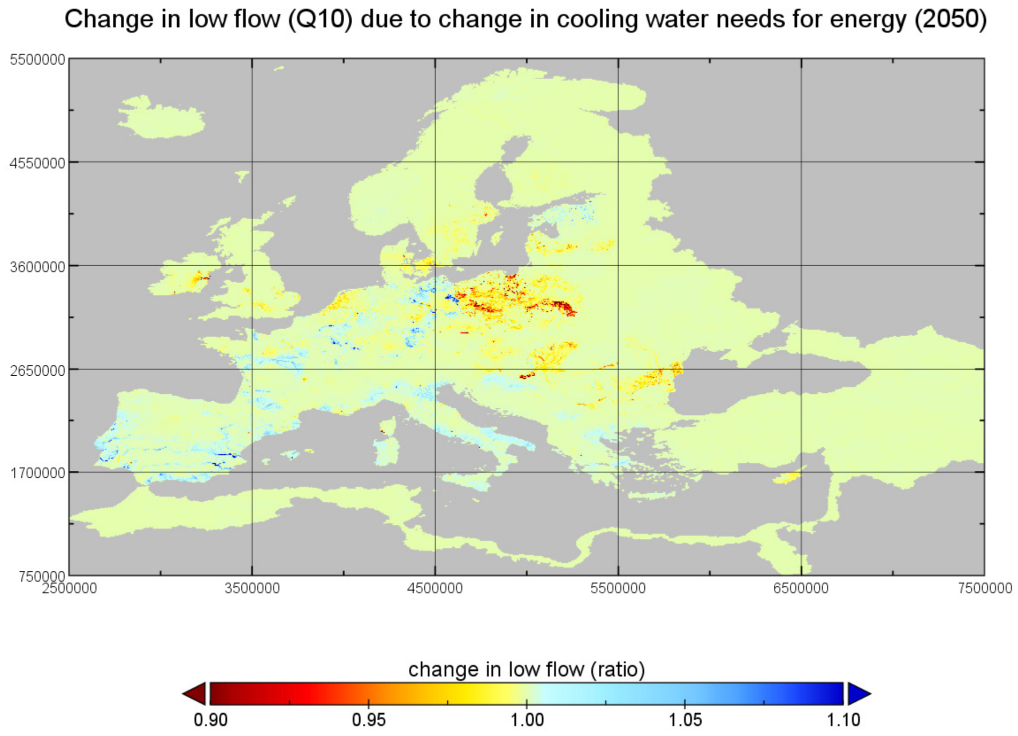

*Figure 19 Effects of the European Reference Energy Scenario 2016 (projections 2010-2050) under current reference climate.*

## 4.6 Water quantity pressure changes after 4 combined BAU and MTF measures under current and future climate.

When the four measures presented earlier (irrigation efficiency, urban water losses, water re-use, and changes in the energy demand – are combined, we see a mixture of overall effect (Figure 20).

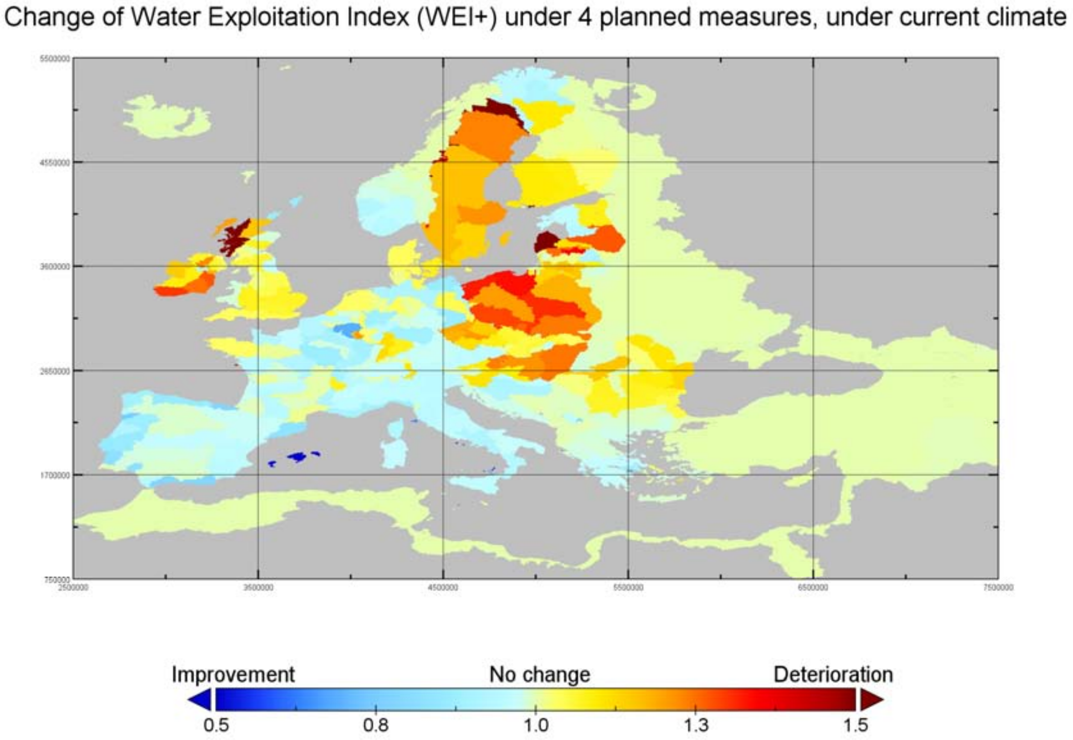

*Figure 20 Change (relative) of the WEI+ as a consequence of the four combined measures, under current climate conditions.*

We see an improvement in water resources – with WEI+ taken as in indicator for that – in countries such as Spain, Italy, Greece, France, Germany, Portugal, Belgium, Austria and Croatia. However, in countries with increased energy demands from sources that require cooling water we do observe a deterioration of the overall WEI+, even when some of the other three measures have some positive effects. Countries that show this overall deterioration are Poland, Sweden, Hungary, Lithuania, UK and Ireland.

When climate change projections are taken into account (Figure 21) however, the combined effect of measures and climate change shows especially in the Mediterranean area still a net deterioration of water resources – as indicated by the WEI+, due to the reduction of net water availability. Thus the positive effect of water savings is basically countered by an even larger reduction of water availability.

This might be an indication that the level of ambition for some measures might need to be increased, in order to compensate for envisaged reduced future water availability under a changed climate.

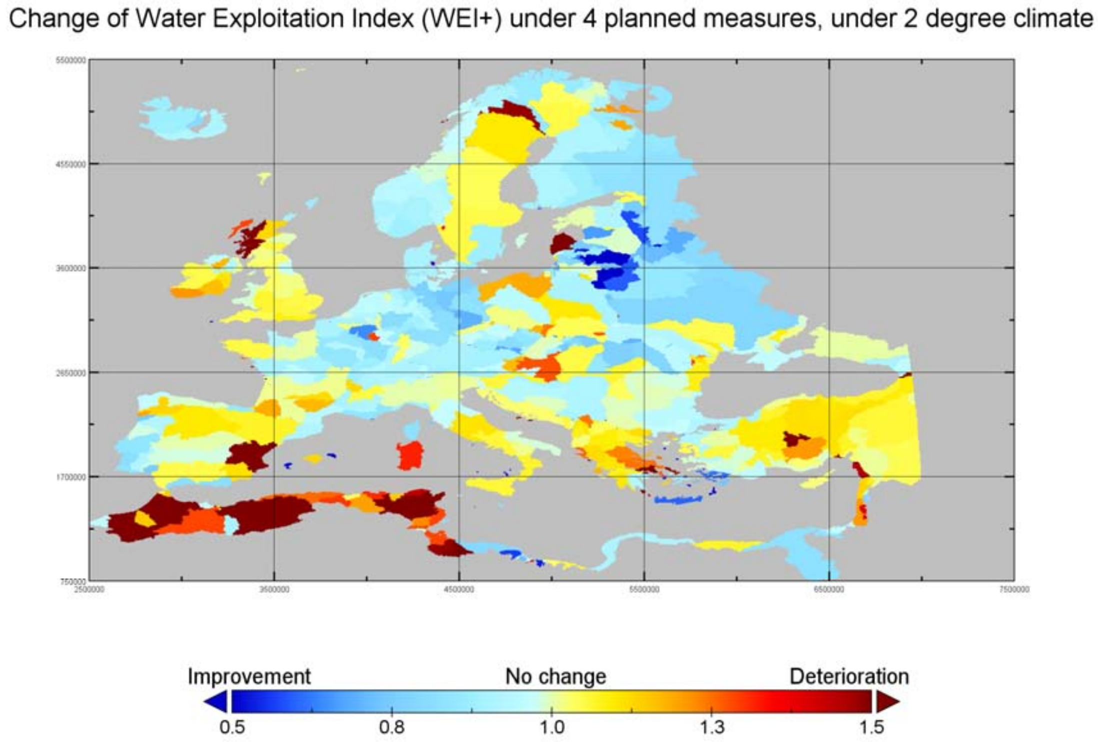

*Figure 21 Change of the WEI+ as a consequence of the 4 measure scenarios, under a 2 degree climate scenario.*

It should be noted that BAU measures here are based on planned investments until 2027. Should similar investment efforts be taken into account beyond 2027 (i.e. for irrigation, leakage and water re-use) and taken into account in the computations, the overall conclusions will change. As for water re-use, only data for Spain were available at the time of the study. Using data for other countries would change the outcome as well. Last, only one EURO_CORDEX climate scenario was used to come to these conclusions. It would be better to use all of the available Euro-Cordex climate scenarios, to take into account the uncertainty in the climate projections as well. This could and should all be part of future work.

## 5. Discussion and limitations of the study

The results presented here are a first attempt to assess the effects of planned measures that influence water quantity in Europe. There are several aspects of this study where there is room for improvement. There are both practical/computational issues, as well as issues beyond our control. In order of importance, the following issues are important:

- The level of detail in the MS reporting of the planned measures is hardly sufficient to allow for a proper assessment of the measures on the water quantity situation;
  - often, investment amounts are only information available at national scale, and specific information of the location, type, or implementation date of a certain measure is not available;
  - Benitez et al (2018) could only find sufficient information on three measures - irrigation, urban water loss, and water re-use -, where the information on re-use was available only for Spain; we are convinced MS have more measures, more detailed information and plans, but apparently it is very difficult to get access to it.
- These limited available data on measures makes it necessary for the modelling to make assumptions about spatial downscaling of the measures, and assumptions about what exactly is implemented for the planned investment.
- Planned measures and investments information was only available until 2027, and we did not assume a continuation of the same effort of investments beyond 2027. This could be done.
- Due to computational limitations at the time of the study, combined with the fact that the results needed embedding in the Marine Modelling Framework which is even more computational intensive than the freshwater model, we made a choice for a single representative climate scenario. There is a choice of 11 climate models which project current and future climate under two Representative Concentration Pathways (RCPs): RCP4.5 and RCP 8.5 emission scenario. With 4 measures and three variations (reference, BAU and MTF), under current climate, 22 control climates, and 22 climate scenarios, there would be a requirement for at least 4*3*45=540 runs, plus a series of combinations, such as the combined effects of all the measures. Therefore, we have chosen here a set of 23 simulations around a single climate scenario. This is not optimal, and has the risk that we are not capturing all the variations of the climate models; In an ongoing study, this number is increased
- As for irrigation, we cannot guarantee that all the recent implemented projects related to irrigation have been taken into account; again, it would help here if the MS reporting or information readily available about these projects is improved.
- There would be room for improvement to specify the location of the irrigation investments more precisely, which would improve the modelling of water resources. Data were available at NUTS2, which is already better than national scale, but more detail would be helpful, especially since irrigation is one of the dominant components for water saving.
- Also investments to improve urban water efficiency are available at national scale, which required us to make assumptions about downscaling where the efficiency changes would be implemented. We assumed an equal spread over the current urban areas.
- Water re-use data were at the time of this study only available for Spain. In the meantime, this has improved, and we are currently executing assessments with more data on water re-use
- As for this study only projects of energy were available at national level, we used the current spatial distribution of cooling water requirements to downscale the projected future changes, based on the change in energy demand produced by thermal methods. Macagna et al., (2019) produced in the meantime specific water requirements for the energy sector, which are used in an ongoing study.

# 6. Conclusions

With the aim to reduce the already existing pressures on Europe's freshwater resources, EU Member States are planning and implementing various water saving measures, as for described in the Programs of Measures under the Water Framework Directive (WFD).

These measures consist of increasing irrigation efficiency, treated wastewater re-use for irrigation to reduce new abstractions, and urban water efficiency measures to reduce consumption.

In addition, the transformation of the European energy system until 2050 - with changes in energy demand as well as changes in the energy mix - is envisaged to change the requirements and consumption for cooling water.

Furthermore, climate change is expected to change water availability, and socio-economic and demographic changes will change water demand.

All these changes interact, and the resulting water resources and locations with pressures are evaluated in this study, Various water saving measures are evaluated and compared with the current situation using JRC's LISFLOOD water resources model. Furthermore, these measures are evaluated under current and future climate and land use, using Euro-Cordex scenarios and the LUISA land use projection until 2050.

Changes in irrigation efficiency prove to be an important measure to reduce water quantity pressures, especially in Spain, Portugal, Italy and Greece..

Changes in the cooling water requirements for energy production, either caused by a changing demand or a change in the energy mix with more renewable sources, also change the water quantity pressures. In large parts of Europe, our results indicate an improvement on water pressures as cooling water requirements are reduced. In some countries however (Poland, Lithuania, Hungary, Sweden, Ireland), we project future increases in cooling water requirements. This is estimated to lead to increased pressures on water quantity, indicated by the Water Exploitation Index.

Other measures, such as water re-use – although only assessed for Spain here - and urban water efficiency improvements do have positive local effect, but are less noticeable at regional and river basin level.

However, the projections of climate change projections indicate a reduced future water availability, especially in the Mediterranean area. Our results suggest that the climate-induced water availability reduction might outweigh the positive effects of the planned measures.

As the level of detail in the reported measures needs improvements, quite a number of assumptions needed to be made in this assessment. A follow-up study is already ongoing to address a number of improvements in the assessment of water quantity measures.

# References

Aus der Beek, T., Flörke, M., Lapola, D. M., and R. Schaldach (2010), Modelling historical and current irrigation water demand on the continental scale: Europe, Adv. Geosci., 27, 79–85, https://doi.org/10.5194/adgeo-27-79-2010.

Baranzelli, C., et al. (2014), The reference scenario in the LUISA platform – Updated configuration 2014 towards a common baseline scenario for EC impact assessment procedures. Report EUR 27019 EN, Luxembourg: Publications office of the European Union, doi: 10.2788/85104.

Batista e Silva, F., Gallego, J., and C. Lavalle (2013), A high-resolution population grid map for Europe, J. Maps, 9, 16-28, doi: 10.1080/17445647.2013.764830.

Benitez Sanz, C., Wolters, H., Martí B. and Mora B. (2018): "EU Water and Marine Measures Data base". Deliverable to Task B2 of the BLUE2 project "Study on EU integrated policy assessment for the freshwater and marine environment, on the economic benefits of EU water policy and on the costs of its non- implementation"; Report to DG ENV - BLUE2 study;INTECSA-INARSA S.A., Madrid, Spain.

Bernhard, J., Reynaud, A., De Roo, A., Karssenberg, D., and S. De Jong (2019a), Household water use in Europe at regional scale: analysis of trends and quantification of main drivers, Under Review.

Bernhard, J., Reynaud, A., De Roo, A., Karssenberg, D., and S. De Jong (2019b), Mapping industrial water use and water productivity levels in Europe at high sectoral and spatial detail, Under review.

Bisselink, B., Bernhard, J., Gelati, E., Adamovic, M., Jacobs, C., Mentaschi, L., Lavalle, C. and De Roo, A.(2018a), Impact of a changing climate, land use, and water usage on water resources in the Danube river basin, EUR 29228 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-79-85888-8, doi: 10.2760/561327, JRC111817.

Bisselink, B., Bernhard, J., Gelati, E., Adamovic, M., Guenther, S., Mentaschi, L. and De Roo, A. (2018b), Impact of a changing climate, land use, and water usage on Europe's water resources, EUR 29130 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-79-80287-4, doi: 10.2760/847068, JRC110927.

Burek, P., De Roo, A., and J. van der Knijff (2013), LISFLOOD - Distributed Water Balance and Flood Simulation Model - Revised User Manual. EUR 26162 10/2013; Publications Office of the European Union. Directorate-General Joint Research Centre, Institute for Environment and Sustainability, ISBN: 978-92-79-33190-9, doi: 10.2788/24719.

De Roo, A.P.J., Wesseling, C.G., and W.P.A. Van Deursen (2000), Physically-based river basin modelling within a GIS: The LISFLOOD model, Hydrological Processes, Vol.14, 1981-1992, doi: 10.1002/1099-1085(20000815/30)14:11/12<1981::AID-HYP49>3.0.CO;2-F.

EEA (2005), The European environment – State and outlook 2005, Copenhagen, ISBN 92-9167-776-0.

ETC/ICM (2016), Use of freshwater resources in Europe 2002-2012. Supplementary document to the European Environment Agency's core set indicator 018. ETC/ICM Technical Report 1/2016, Magdeburg: European Topic Centre on inland, coastal and marine waters, 62 pp.

Faergemann, H. (2012), Update on water scarcity and droughts indicator development, May 2012, presented at the Water Director's Meeting, 4–5 June 2012, Denmark.

Flörke, M., Bärlund, I., and E. Kynast (2012), Will climate change affect the electricity production sector? A European study, J. Water Clim. Change, 3, 44–54, https://doi.org/10.2166/wcc.2012.066.

Flörke, M., Kynast, E., Bärlund, I., Eisner, S., Wimmer, F., and J. Alcamo (2013), Domestic and industrial water uses of the past 60 years as a mirror of socio-economic development: A global simulation study, Global Environ. Chang., 23, 144–156, https://doi.org/10.1016/j.gloenvcha.2012.10.018.

Gosling, S.N., and N.W. Arnell (2016), A global assessment of the impact of climate change on water scarcity, Climatic Change, 134, 371, https://doi.org/10.1007/s10584013-0853-x.

Jacob, D., et al. (2014), EURO-CORDEX: new high-resolution climate change projections for European impact research, Reg. Environ. Change, 14, 563–578, doi: 10.1007/s10113-013-0499-2.

Jacobs-Crisioni, C., Diogo, V., Perpiña Castillo, C., Baranzelli, C., Batista e Silva, F., Rosina, K., Kavalov, B., and C. Lavalle (2017), The LUISA Territorial Reference Scenario 2017: A technical description, Publications Office of the European Union, Luxembourg, ISBN 978-92-79-73866-1, doi: 10.2760/902121, JRC10816.

Lavalle C., Baranzelli, C., Batista e Silva, F., Mubareka, S., Rocha Gomes, C., Koomen, E., and M. Hilferink (2011), A high resolution land use/cover modelling framework for Europe. In: ICCSA 2011, Part I, LNCS 6782, 60–75, https://doi.org/10.1007/978-3-642-21928-3_5.

Magagna, D., González, I.H., Bidoglio, G., Peteves, S.D., Adamović, M., Bisselink, B., Felice, M.D., Roo, A.D., Dorati, C., Ganora, D., Medarac, H., Pistocchi, A., Bund, W.V., and D. Vanham (2019), Water – Energy Nexus in Europe, Publications Office of the European Union, Luxembourg, 2019, ISBN 978-92-76-03385-1, doi: 10.2760/968197, JRC115853.

Maule, C. F., Mendlik, T., and O. B. Christensen (2017), The effect of the pathway to a two degrees warmer world on the regional temperaturechange of Europe, Climate Services, 7, 3–11. https://doi.org/10.1016/j.cliser.2016.07.002.

Mubareka, S., Maes, J., Lavalle, C., and A. De Roo (2013), Estimation of water requirements by livestock in Europe, Ecosyst. Serv. 4, 139–145, https://doi.org/10.1016/j.ecoser.2013.03.001.

Ntegeka,V., P Salamon, G Gomes, H Sint, V Lorini, M Zambrano-Bigiarini, J Thielen (2013), EFAS-Meteo: A European daily high-resolution gridded meteorological data set for 1990–2011. JRC, EUR 26408

Schewe, J. et al. 2014, Multimodel assessment of water scarcity under climate change. Proc. Natl Acad. Sci., USA111, 3245–3250, https://doi.org/10.1073/pnas.1222460110.

UNFCCC, 2015, *Adoption of the Paris Agreement FCCC/CP/2015/L.9/Rev.1* http://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf

Vandecasteele, I., Bianchi, A., Batista e Silva, F., Lavalle, C., and O. Batelaan (2014), Mapping current and future European public water withdrawals and consumption, Hydrol. Earth Syst. Sci., 18, 407- 416, doi: 10.5194/hess-18-407-2014, https://doi.org/10.5194/hess-18-407-2014.

Van der Knijff J.M., Younis, J., and A.P.J. De Roo (2010), a GIS-based distributed model for river-basin scale water balance and flood simulation, International Journal of Geographical Information Science, Vol. 24, No.2, 189-212, https://doi.org/10.1080/13658810802549154.

Vanham D. (2016), Does the water footprint concept provide relevant information to address the water–food–energy–ecosystem nexus?, Ecosyst. Serv., 2016, 17, 298–307, https://doi.org/10.1016/j.ecoser.2015.08.003.

Wada, Y., van Beek, L. P. H., Wanders, N., and M. F. P. Bierkens (2013), Human water consumption intensifies hydrological drought worldwide, Environ. Res. Lett., 8, 1–14, doi: 10.1088/1748-9326/8/3/034036.

## List of abbreviations

| | |
|---|---|
| EEA | European Environment Agency |
| GCM | Global Climate Model |
| GVA | Gross Value Added |
| GWL | Global Warming Level |
| RCP | Representative Concentration Pathway |
| RCM | Regional Climate Model |
| SoE | State of Environment |
| WEI+ | Water Exploitation Index + |
| WFD | Water Framework Directive |
| WS | Water Scarcity |

## List of Figures

## List of tables

No table of figures entries found.

KJ-NA-30361-EN-N

## The European Commission's science and knowledge service

Joint Research Centre

### JRC Mission

As the science and knowledge service of the European Commission, the Joint Research Centre's mission is to support EU policies with independent evidence throughout the whole policy cycle.

**EU Science Hub**
ec.europa.eu/jrc

@EU_ScienceHub

EU Science Hub - Joint Research Centre

EU Science, Research and Innovation

EU Science Hub

Publications Office
of the European Union

doi:10.2760/739798

ISBN 978-92-76-21537-0