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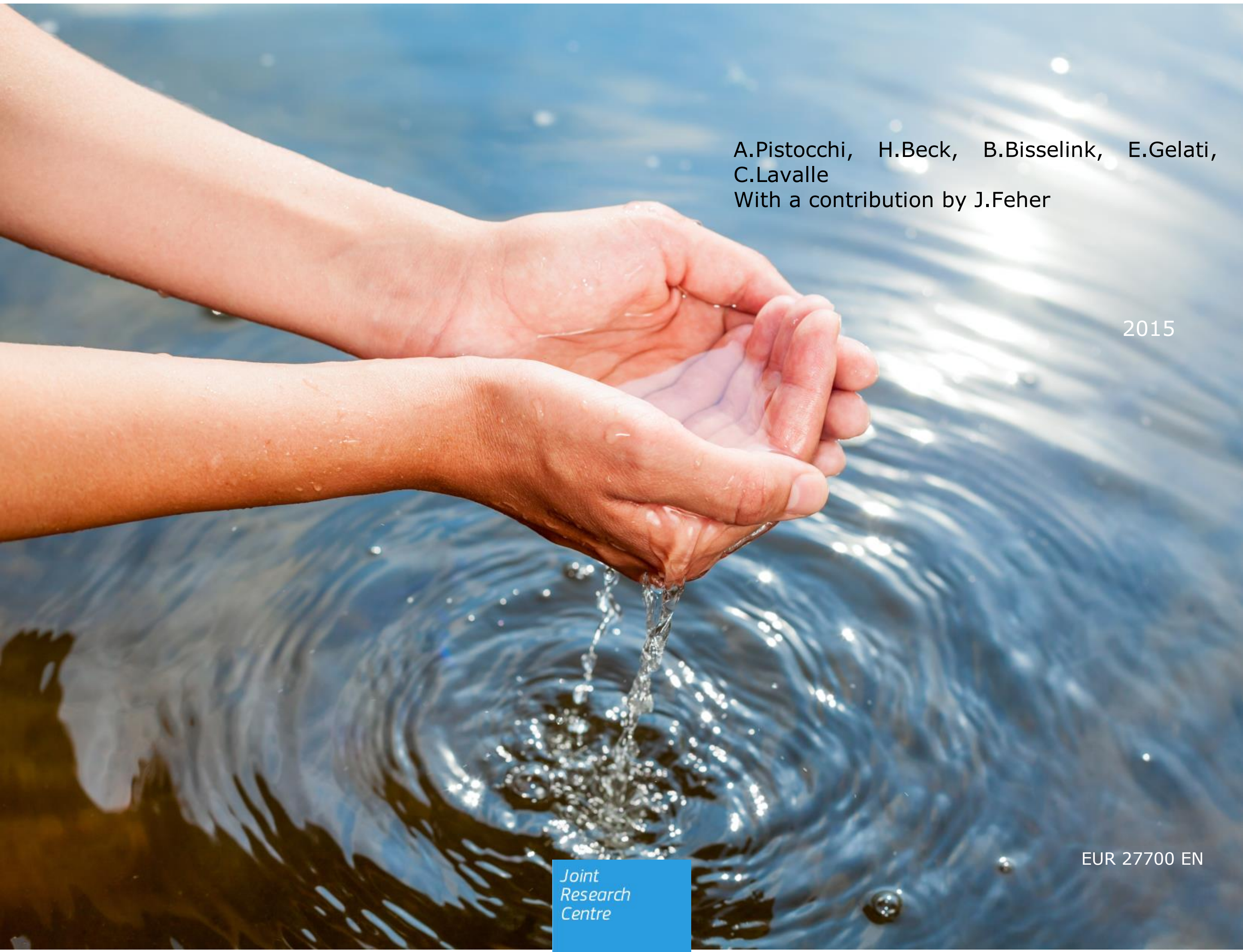
JRC TECHNICAL REPORTS

Water scenarios for the Danube River Basin

Elements for the assessment of the Danube agriculture-energy-water nexus



A.Pistocchi, H.Beck, B.Bisselink, E.Gelati, C.Lavalle
With a contribution by J.Feher

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Abstract

This report provides background material for the identification and elicitation of scenarios relevant for the futures of the agriculture-energy-ecosystems-water nexus in the Danube region. We present a summary of the regional climate scenarios available as input for water resources simulations, and the consequent long term average water balance figures estimated using a Budyko framework. Then we introduce the LUISA model for the simulation of land use-related variables in the region. Finally, we include a contribution by a water expert from the Danube region, presenting an initial reasoning on important elements to be addressed in scenario simulations. This report is intended as a reader for water professionals, stakeholders and decision makers in the Danube region, in order to stimulate the foresight of scenarios worth being simulated with JRC models, so to further our understanding of the water-energy-agriculture-ecosystems nexus and its management in the mid- and long-term.

1. Introduction and objectives

In 2013, the JRC launched an initiative in support to the European Union Strategy for the Danube Region (EUSDR), including a "Danube Water Nexus" flagship cluster of activities defined as follows[1]:

"*The 'Danube Water Nexus' flagship cluster will address the **environmental and socio-economic consequences of changing agriculture-energy pressures on water**. This requires a basin-wide perspective and cooperation with countries in the region taking into account needs of all stakeholders. Allocation of available water across different sectors needs to be integrated into the overall economic strategy of the Danube Region based on optimization concepts in order to maximize growth and minimize the environmental impact. Central to the assessment will be the development and application of an optimisation model linked with dynamic, spatially explicit water quality and quantity bio-physical models allowing the selection of measures affecting water availability and water demand based on environmental and economic considerations, and hydrological extremes such as floods and droughts. Optimization will particularly focus on the competing demand between the energy, agriculture, domestic, transport (e.g. inland navigation) and industrial sectors and ecosystems under a changing environment.*"

This report aims at supporting the ***identification of scenarios*** of environmental and macro-economic impacts of alternative water allocation measures across competing water-using sectors (agriculture, energy, industry, human consumption, ecosystems, i.e. the Nexus) under changing land use and climate adaptation conditions for the years 2030-2050, ***that will be simulated in details using JRC models at a later stage***.

The identification of scenarios requires a ***foresight*** exercise, of qualitative nature although based on evidence and fundamental facts. We want to identify a few representative storylines for the Danube, with the goal to describe:

(1) scenarios of water availability, demand and pressures on water;

(2) environmental and socioeconomic consequences of scenarios.

The first aspect focuses on:

- what are the impacts of different types of water use on rivers and on green water (evapotranspiration), possibly through examples of conflicts happened in the recent past; the analyses include consideration of the water provisioning ecosystem services in the Danube River Basin.

- what are the climatic and land use trends that pose threats to water availability for different usages.

Particularly, we expect that the Danube region may face strategic development questions related to the future availability of water, on aspects such as:

- Changes in plant water requirements and irrigation demand depending on climate as well as agricultural economic development;
- Changes in household water demand reflecting economic and demographic change;
- Changes in energy demand and sources, including biofuels and fuel crops, and non-conventional hydorcarbons
- Changes in water requirements for the cooling of power plants and for mini- and conventional hydropower
- Trends in industrial activities and related water use
- Land use dynamics in the Danube region

[1] https://ec.europa.eu/jrc/sites/default/files/jrc-danube-water-nexus.pdf

- Morphological pressure on water bodies related to infrastructure, navigation and urban development
- Evolution of water treatment also in the context of the circular economy and a resource-efficient economy.

The second aspect focuses on:

- conflicts and competition on water resources for the most important usages (hydropower, irrigation, environmental flow, navigation, industrial water usages, cooling of thermal plants…)

- the socio-economic relevance (value added, jobs) of the water-using sectors, under present conditions and in the "near" future (2030-2050)

- the threats and opportunities for societal resilience and capacity to adapt to climate change.

In this report, we present some background information (chapter 2) and preliminary considerations (chapter 3) that aim at stimulating discussions on the identification of the key drivers and implications of scenarios for the Danube region; such discussions will help formulating the assumptions that will enable quantitative water resources modelling in the region, in support to the management of the "water nexus".

2. Climate and land use scenarios

2.1 The JRC climate and land use scenarios: Evaluating RCP4.5 and RCP8.5 climate projections for the Danube

Climate projections data were taken from the Coordinated Downscaling Experiment over Europe (EURO-CORDEX; Jacob et al., 2014), which is an international climate downscaling initiative that aims to provide high-resolution climate projections up to 2100. Scenario simulations within EURO-CORDEX use the new Representative Concentration Pathways (RCPs; Moss et al, 2010). The RCP scenarios are four greenhouse gas concentration (not emissions) trajectories towards the end of 21st century, adopted by the IPCC for its fifth Assessment Report (AR5) in 2014[2]. It supersedes Special Report on Emissions Scenarios (SRES) projections published in 2000[3]. The pathways describe four possible climate futures, all of which are considered possible depending on how much greenhouse gases are emitted in the years to come. The four RCPs, RCP2.6, RCP4.5, RCP6.0, and RCP8.5, are named after a possible range of radiative forcing values in the year 2100 relative to pre-industrial values (+2.6, +4.5, +6.0, and +8.5 W/m^2, respectively).

Future projections from four regional climate models (RCMs; DMI, IPSL, KNMI, and SMHI) at 0.11° horizontal resolution were analysed. The climate projections are based on both RCP4.5 and RCP8.5 corresponding to an increase in radiative forcing of 4.5 W/m^2 and 8.5 W/m^2 by the end of the century, respectively. Meteorological fields analysed are both temperature and precipitation which are bias-corrected to tailor the data for the application in climate impact research. The statistical bias correction technique applied to the set of RCMs in the EURO-CORDEX framework is based on a transfer function (Piani et al., 2010; Dosio and Paruolo, 2011; Dosio et al., 2012), which is constructed from climate statistics of the E-OBS 30-yr (1961–1990) dataset (Haylock et al., 2008) and transferred to future climate. The gridded E-OBS dataset includes daily observations of temperature and precipitation based on station networks covering the whole European land area. Poor station coverage in Turkey, Northern Africa and some Mediterranean islands reduces the utility to use E-OBS for calculating the transfer function due to inhomogeneities (both spatial and temporal). In these regions gaps were filled with raw model output instead of the bias-corrected scenarios.

Here, an analysis was made of the end of the century (2071–2099) climate change signal of both the RCP4.5 and RCP8.5 emission scenarios relative to present climate (1981–2010) as simulated by the RCMs. Figure 1 shows the temperature change at the end of the 21st century. In both scenarios and for all four RCMs an increase in temperature is observed with values ranging from 0°C to 3°C for the RCP4.5 scenario and up to 7°C for the RCP8.5 scenario. The most pronounced temperature increase is likely to be in the southeast part of the Danube catchment.

For the precipitation (Figure 2), all models project in general an increase in precipitation for the end of the 21st century for both scenarios. Although some models predict a slight precipitation decrease for the southeastern part, a common feature in the RCMs is the slight increase in precipitation between the RCP4.5 and RCP8.5 scenario. The precipitation increase is most pronounced in the upstream part of the catchment. The intermodel variability is in general small with the exception of the IPSL-INERIS-WRF2331F model which projects much larger precipitation amounts compared to the other three RCMs.

Figure 3 shows the change in number of precipitation days larger than 0.1 mm. The projections show an increase in the number of precipitation days for the western part and a decrease in the eastern part of the catchment for the RCP4.5 scenario. Apart from the results of the IPSL-INERIS-WRF331F model, the RCP8.5 scenario projects towards an

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[2] https://www.ipcc.ch/report/ar5/

[3] http://www.ipcc.ch/ipccreports/sres/emission/index.php?idp=0

decrease in the number of precipitation days, especially in the (south)eastern part of the catchment.

Looking at the more extreme events the climate projections show an increase in the number of precipitation days larger than 20 mm for all RCMs and both climate scenarios (Figure 4). These findings are most pronounced in the western part of the catchment.

In summary, it is expected according the climate projections that both the temperature and precipitation will increase at the end of the 21st century. In those parts where a large increase in temperature is predicted some models show a decrease in the precipitation amount and precipitation days, but an increase in precipitation days larger than 20mm. Most likely the increase in temperature triggers convection in summertime resulting in more heavy precipitation events.

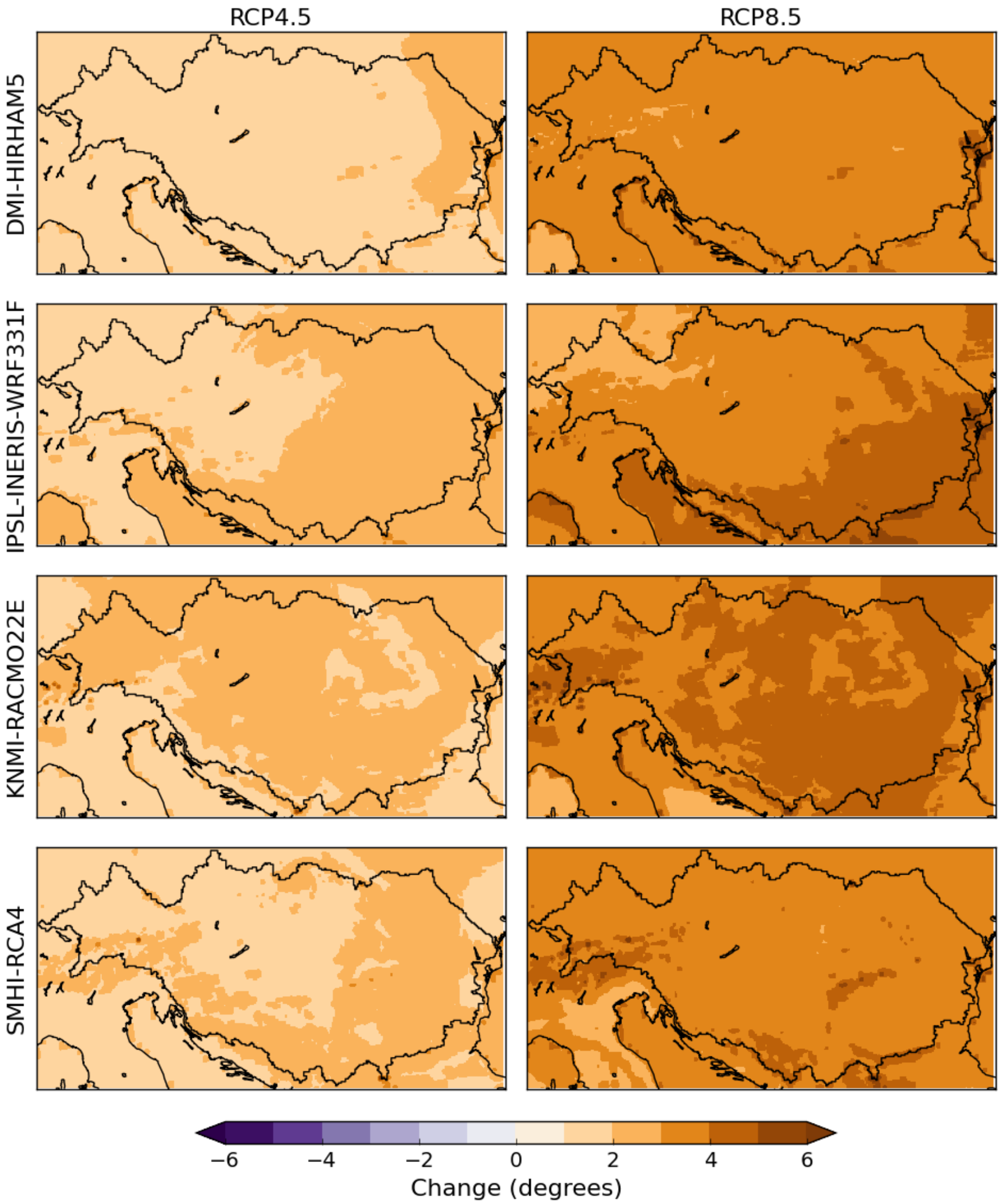


Figure 1 - Average daily temperature change as simulated by the RCMs at the end of the century (2071–2099) for the RCP4.5 and RCP8.5 scenarios. The temperature change is relative to the present reference climate (1981–2010) according to the RCMs.

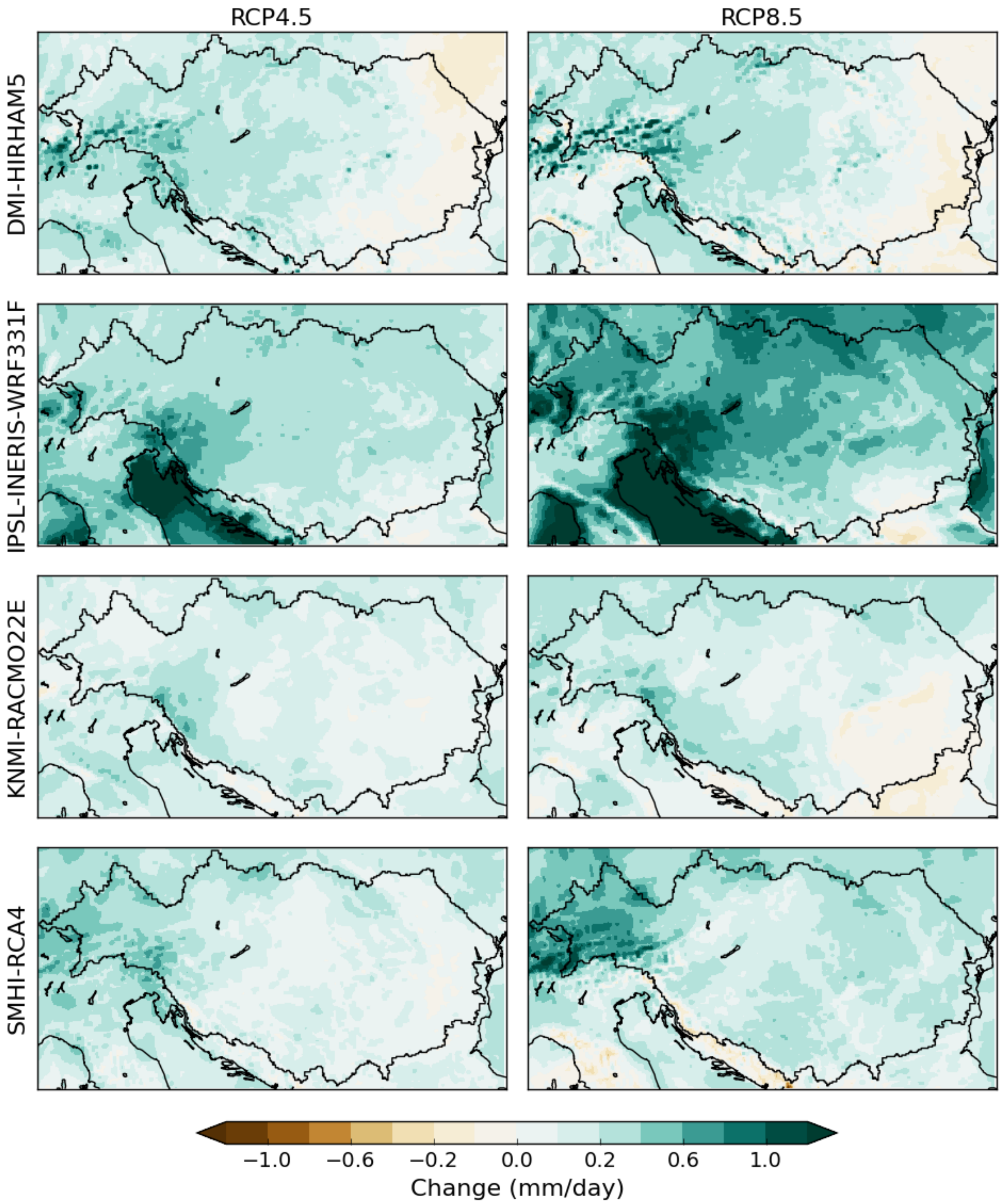


Figure 2 - Average daily precipitation change as simulated by the RCMs at the end of the century (2071–2099) for the RCP4.5 and RCP8.5 scenarios. The temperature change is relative to the present reference climate (1981–2010) according to the RCMs.

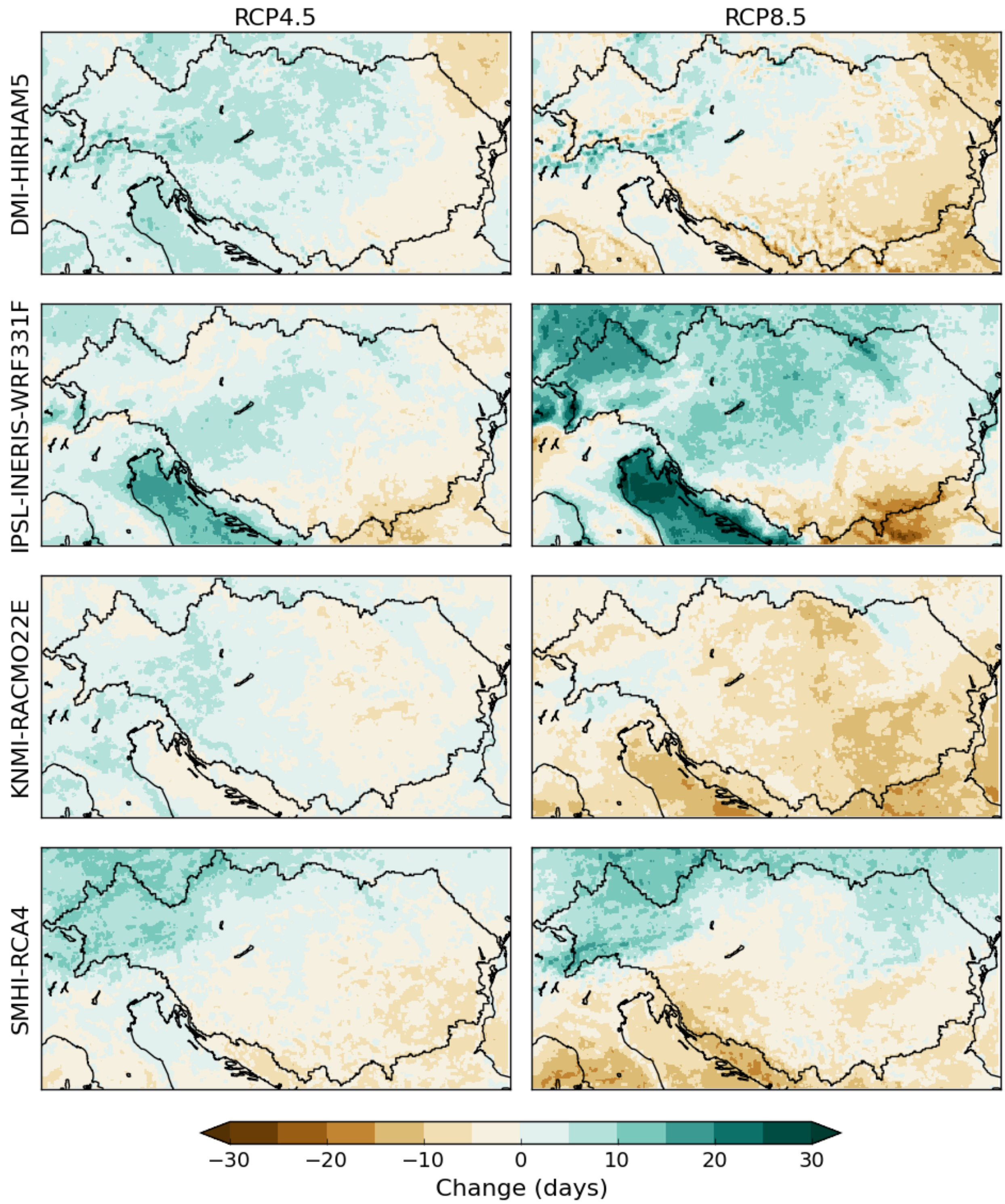


Figure 3 - Average daily change in the number of precipitation days (>0.1 mm) as simulated by the RCMs at the end of the century (2071–2099) for the RCP4.5 and RCP8.5 scenarios. The temperature change is relative to the present reference climate (1981–2010) according to the RCMs.

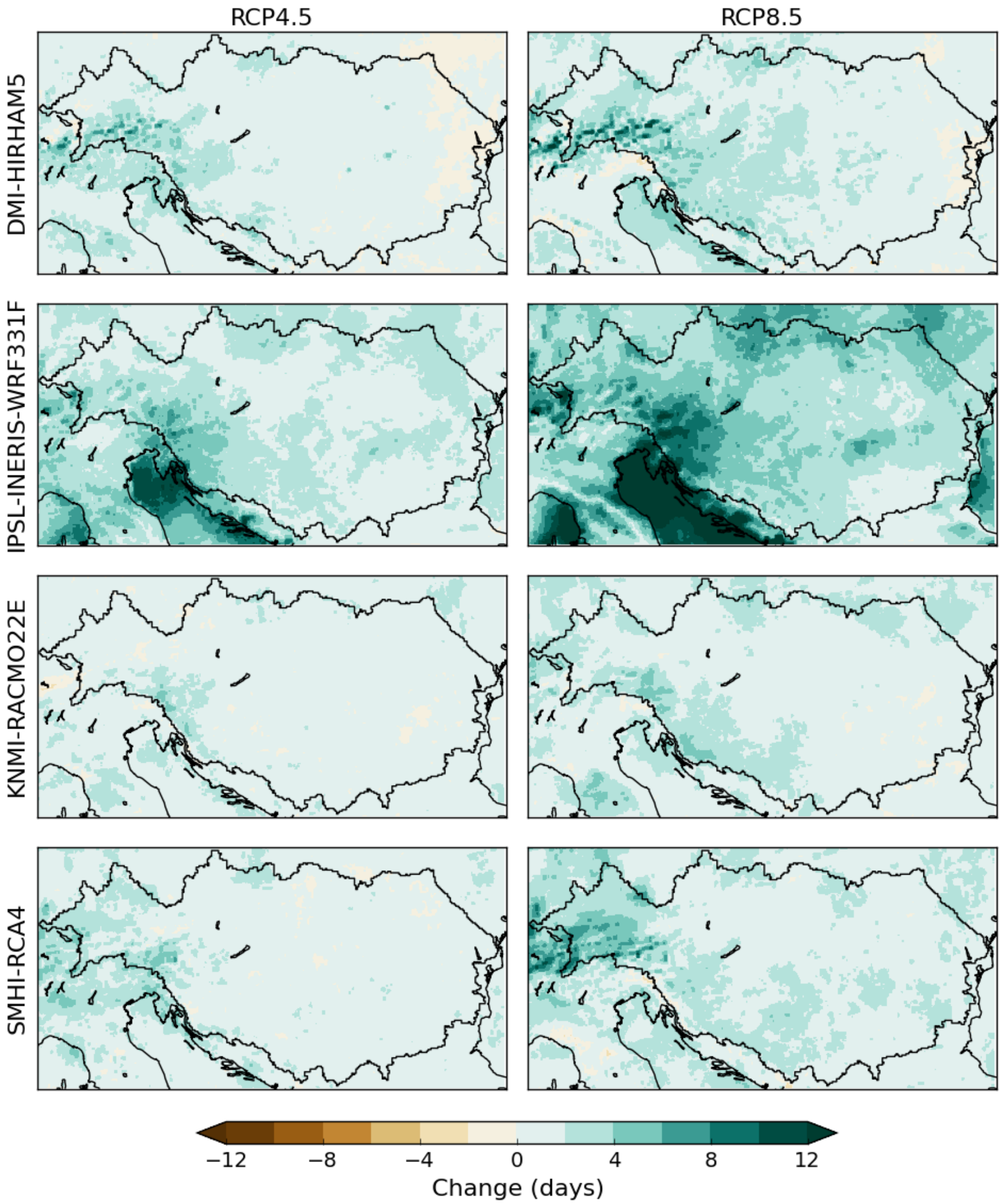


Figure 4 - Average daily change in the number of precipitation days (>20 mm) as simulated by the RCMs at the end of the century (2071–2099) for the RCP4.5 and RCP8.5 scenarios. The temperature change is relative to the present reference climate (1981–2010) according to the RCMs.

2.2 Hydrological implications of climate scenarios in a Budyko framework

Climate model scenarios may be used for a first-order estimation of their expected hydrological implications. To this end, we adopted the simple and well-known Budyko framework for the prediction of long-term annual mean actual evaporation (ET) depending on changes in precipitation (*P*) and potential evaporation (PET).

For quantifying the current (1990–2010) long-term actual evaporation coeffcient (ET/*P*) we used the European Flood Awareness System (EFAS) forcing data (Ntegeka et al., 2013). We used the same EURO-CORDEX climate projections as those described in Section 2.1 and the Budyko formulation from Zhang et al. (2001) with the plant-available water coefficient (*w*) set to 1. To compute the change in the long-term actual evaporation coefficient (ΔET/*P*), we first offset the long-term *P* and PET estimates of the climate models to match those of EFAS.

Figure 5 shows the ΔET/*P* projections from 1990–2010 to 2070–2100 for the different climate models and RCPs. Figure 6a shows the current (1990–2010) ET/*P*. Figure 6b shows the ensemble-mean of the different ΔET/*P* projections. Figure 6c shows the ensemble standard deviation of the different ΔET/*P* projections, reflecting the uncertainty in the climate projections.

The ET estimates provided by this simple model can be verified using measured discharge, assuming that ET corresponds to the difference between *P* and measured discharge. A comparison of the model with measurements in the Danube region (Figure 7) indicates quite good correspondence (correlation = 0.89; relative mean error[4] =+8%; and relative standard deviation error = +9%), suggesting that the model can be applied with confidence in this region.

Based on these results, it is anticipated that the Danube region will experience no increase or even a decrease in ET/*P* in the upper Danube basin, and a clear increase in the lower basin. These changes in ET/*P* correspond to a shift from "blue" to "green" water in the lower basin, with possible reduction of available water resources for domestic, industrial and energy production uses. These general trends in the hydrology of the region will be further explored using more detailed simulation models.

[4] Relative mean error = 1 - mean(estimated) / mean(observed). The same applies for the relative standard deviation error.

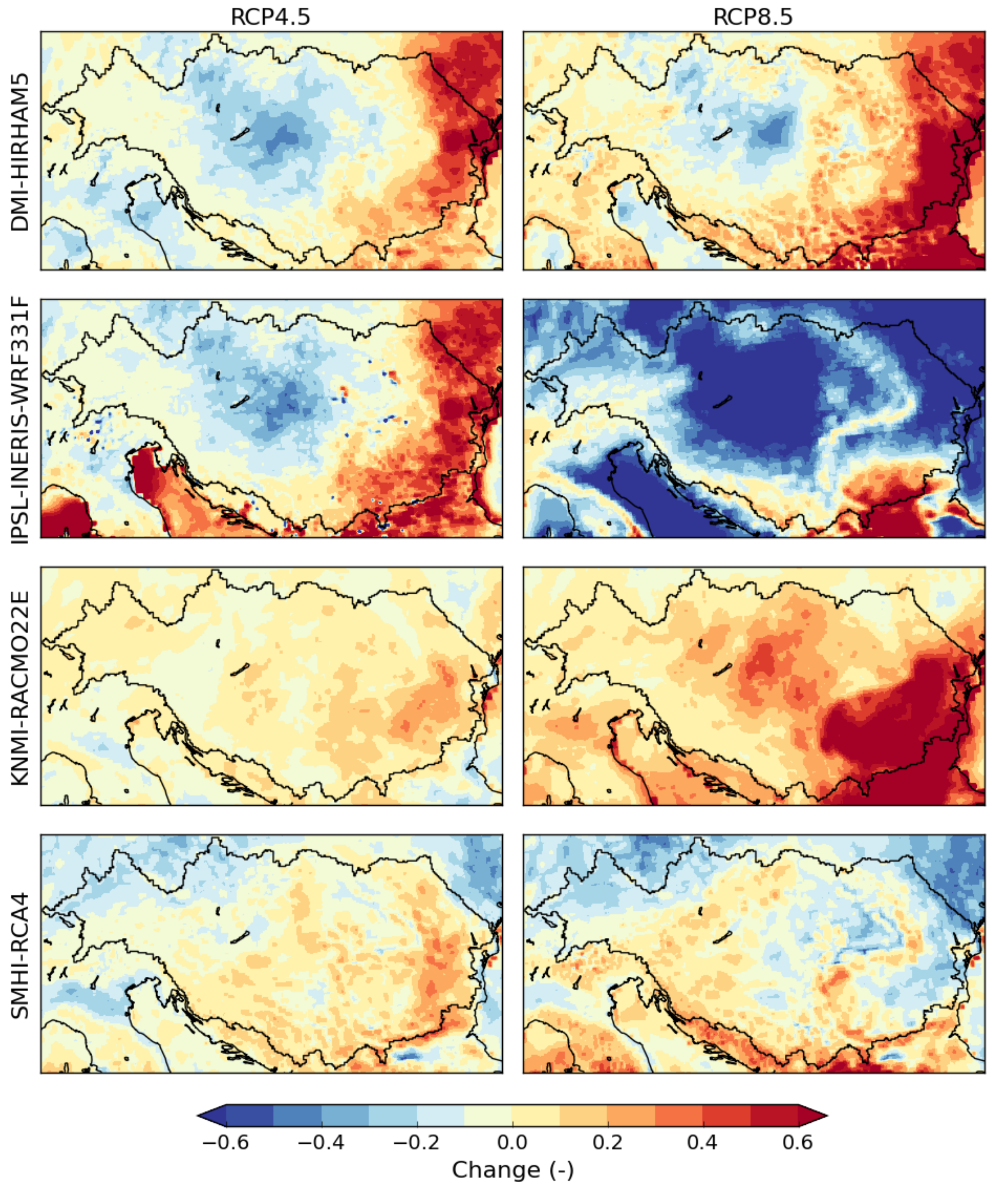


Figure 5 - The change in the long-term evaporation coefficient (∆ET/P) as simulated by the RCMs at the end of the century (2071-2099) for both the RCP4.5 and RCP8.5 scenario. The change is relative to the present reference climate (1981-2010) according to the RCMs.

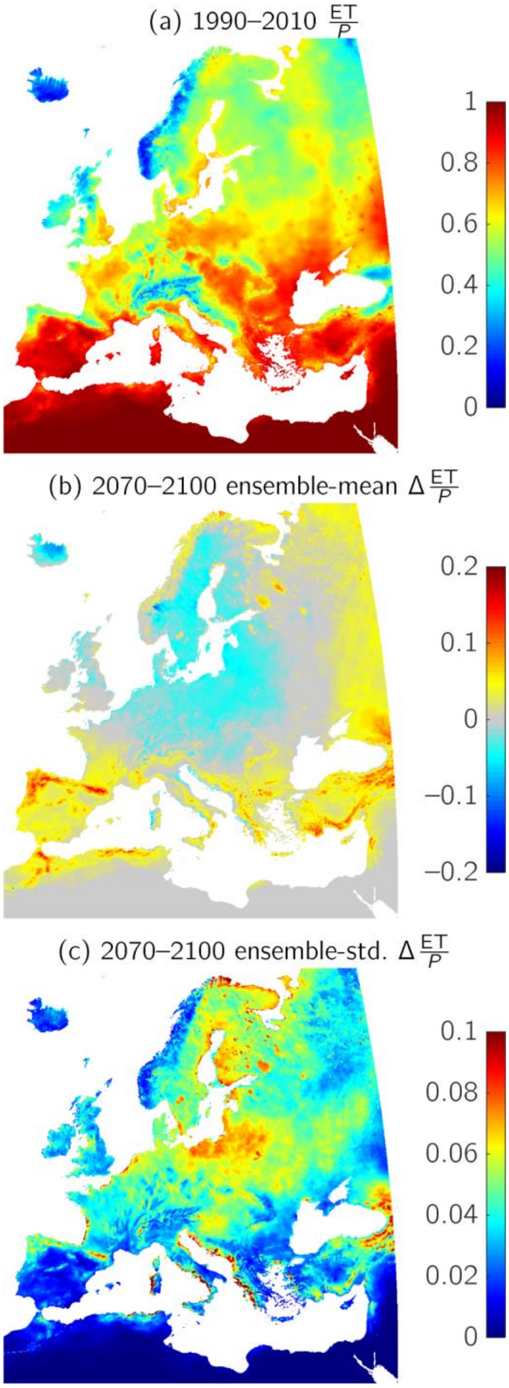


Figure 6 – Top: current evaporation coefficient (ET/*P*). Middle: model ensemble mean change in long-term actual evaporation coefficient (ΔET/*P*). Bottom: standard deviation of ΔET/*P*.

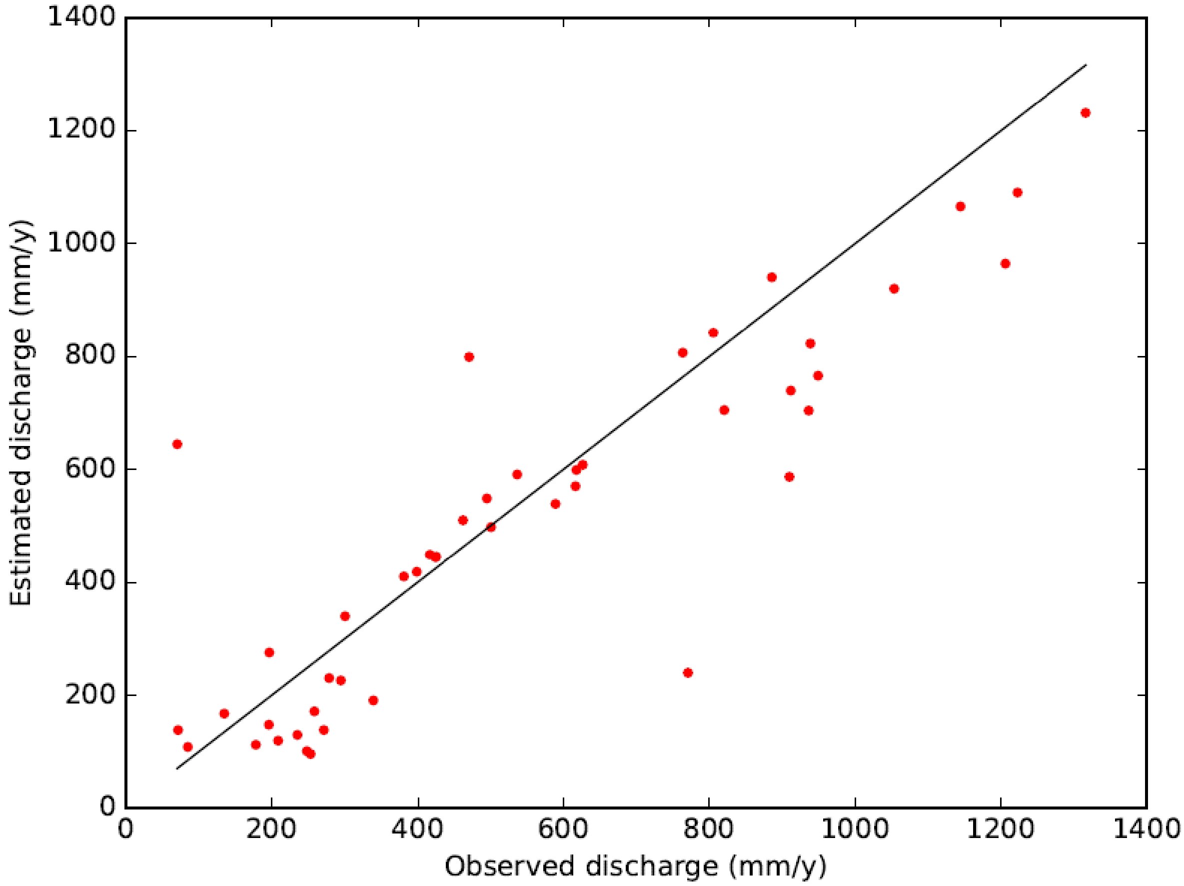


Figure 7 – Verification of mean annual discharge estimated using the Budyko framework using measured mean annual discharge for the Danube region

2.3 The Land-Use based Integrated Sustainability (LUISA) modelling platform. Description and example of application in the Danube areas

2.3.1 Introduction and overview

The Directorate General Joint Research Centre (DG JRC) of the European Commission (EC) is contributing to the analysis of European regions and cities with the Land-Use-based Integrated Sustainability Assessment (LUISA) Modelling Platform, the aim of which is to provide an integrated methodology based on a set of spatial tools that can be used for assessing, monitoring and forecasting the development of urban and regional environments. LUISA allows quantitative and qualitative comparisons at pan-European level, among areas subject to transformation due to policy intervention. A further characteristic is that it adopts a methodology that simultaneously addresses the EU perspective on the one hand, and the regional / local dimension on the other. These features allow investigating and understanding territorial dynamics in a wider continental dimension while considering local and regional driving forces.

The platform accommodates multi-policy scenarios, so that several interacting and complementary dimensions of the EU are represented. At the core of LUISA is a computationally dynamic spatial model that allocates activities, services and population based on biophysical and socio-economic drivers. This model receives direct input from several external models covering demography, economy, agriculture, forestry and hydrology, which define the main macro assumptions that drive the model (Lavalle, et al. 2011). LUISA is also compliant with given energy and climate scenarios, which are modelled further upstream and link directly to economy, forestry, or hydrology models. The model projects future land/use cover changes, accessibility maps and gridded population distribution at the relatively fine spatial resolution of 1 hectare (100 × 100 metres, Batista et al. 2013b, Batista et al., 2013c) for the time period 2010-2050, with the most relevant groups of land use/cover types being represented. LUISA is usually run for all EU countries, but can be used for more detailed case studies or, on the contrary, be expanded to cover pan-European territory.

In contrast to many other land-use models LUISA incorporates additional information on 'Land Functions'. Those Land functions are a new concept for cross-sector integration and for the representation of complex system dynamics. They are instrumental to better understand land use/cover change processes and to better inform on the impacts of policy options. LUISA simulates future land use changes, and land functions related to the resulting land use patterns are then inferred and described by means of spatially explicit indicators. A land function can, for example, be physical (e.g. related to hydrology or topography), ecological (e.g. related to landscape or phenology), social (e.g. related to housing or recreation), economic (e.g. related to employment or production or to an infrastructural asset) or political (e.g. consequence of policy decisions). Commonly, one portion of land is perceived to exercise many functions. Land functions are temporally dynamic, depend on the characteristics of land parcels, and are constrained and driven by natural, socio-economic, and technological processes. Since it is centred on this novel concept, LUISA is far beyond a single, stand-alone model. It can be best described as a platform with a land use model at its core, linked to other upstream and downstream models. LUISA was designed to yield, ultimately, a comprehensive, consistent and harmonised analysis of the impacts of environmental, socio-economic, and policy changes in Europe.

The main direct outputs of LUISA are: 1) a simulated map of the land use/cover for a given year in the future; 2) projected population maps at high geographical resolution; 3) detailed accessibility maps

The combination of direct outputs with other data layers and with thematic models further allow the computation of a wide range of indicators, representing the simulated land functions.

Output indicators can be grouped according to specific definition of land functions, e.g.:

[1] Economic (employment, Sectorial GVA)

[2] Social (Recreational and cultural/educational services)

[3] Provision of products (food, feed, fuel)

[4] Settlement and infrastructures

[5] Regulation services by (natural) physical structures and processes

[6] Ecosystems Services

[7] Regional patterns of energy consumption and production

Direct outputs and computed indicators can be aggregated at different geographical level (NUTS or grid based). When computed for various scenarios, differences in the indicators can be geographically identified, sensitive regions can be pinpointed, and impacts can be related to certain driving factors assumed in the definition of the scenarios.

Of specific relevance for the assessment of the agriculture-energy-water nexus is the provision of the high-resolution projected land use/cover and population maps to hydrological models (Burek et al., 2012, DeRoo et al., 2012) to ensure consistency of water-related parameters and quantities with reference assumptions in socio-economic projections.

2.3.2 Territorial evolutions for a reference scenario in Europe.

LUISA has been configured to project a reference (or baseline) scenario of land use changes up to 2050, assuming likely socio-economic trends, business as usual urbanisation processes, and the effect of established European policies with direct and/or indirect land-use impacts. This baseline configuration is defined as the 'LUISA EU Reference Scenario 2014' and is described in details in Baranzelli et al. (2014). Variations to that reference scenario may be used to estimate impacts of specific policies, or of alternative macro-assumptions.

LUISA includes a set of procedures that capture top-down or macro drivers of land-use change (taken from a set of upstream models) and transform them into actual regional quantities of the modelled land-use types. Regional land demands for agricultural commodities are taken from the CAPRI, which simulates market dynamics using nonlinear regional programming techniques to forecast the consequences of the Common Agricultural Policy. Demographic projections from Eurostat and tourism projections from the United Nations World Tourism Organization (UNWTO) are used to derive future demand for urban areas in each region; land demand for industrial and commercial areas are driven primarily by the economic growth as projected by the Directorate-General for Economic and Financial Affairs of the European Commission (DG ECFIN); and the demand for forest is determined by extrapolating observed trends of afforestation and deforestation rates reported under the scheme of the United Nations Framework Convention on Climate Change (UNFCCC). The demand for the different land-use types is ultimately expressed in terms of acreage and defined yearly and regionally (NUTS2).

In the LUISA Reference scenario 2014, the economic and demographic assumptions are consistent with the 2012 Ageing Report (EC, 2012). The demographic projections, hereinafter referred as EUROPOP2010, were produced by Eurostat, whereas the long-term economic outlook was undertaken by DG ECFIN and the Economic Policy Committee. The actual economic figures used in LUISA were taken from the GEM-E3 model, which modelled the sector composition of future economy (GVA per sector) consistently with the DG

ECFIN's projections (EC, 2014). Both projections are mutually consistent in terms of scenario assumptions.

The reference scenario also includes the 2014-2020 cohesion policy program, in particular for the themes concerning regional economic growth, transport network improvements, airport improvements, port improvements and urban renewal. A more elaborate account of how cohesion policies were taken into account can be found in Batista e Silva et al. (2013). Foreseen road network investments are taken into account through expected improvements in travel time, that subsequently affect accessibility levels, which in turn influence location of residents and activities. To compute the travel times that inform accessibility, a road network from the Trans-Tools transport model is used. Finally, it is expected that the ports and airports in particular regions receive funding, which makes the immediate surroundings of those ports and airports are more attractive for industrial land uses.

Figure 8 presents the regional funds available from the ERDF/CF programme (left) and the map of distance to roads (right). These layers are examples of "factor-maps" employed in LUISA for the allocation of land use/cover classes and of population.

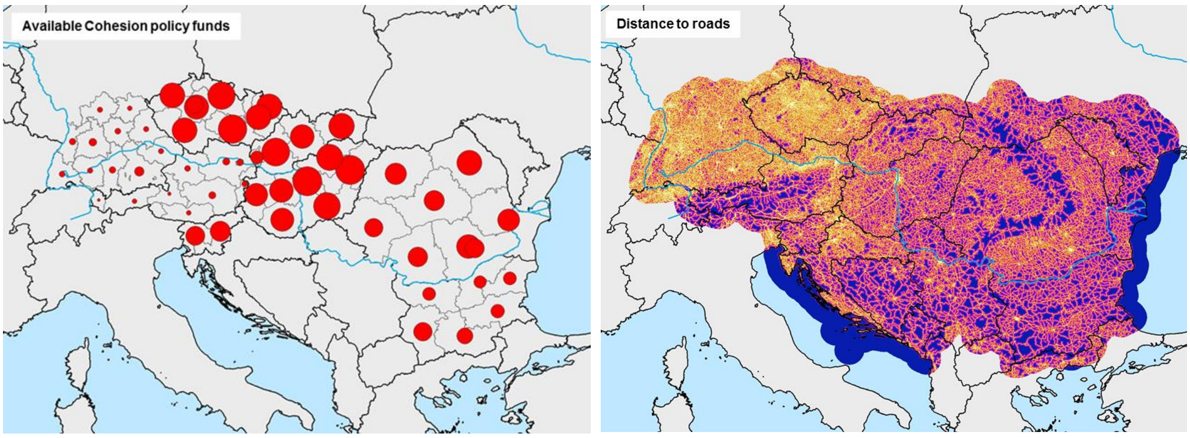


Figure 8 - Left: ERDF/CF funds; Right: Distance to roads.

2.3.3 Example of projected regional indicators

Demographic trends are amongst the main drivers of land use/cover changes, in particular for urban areas. According to the EUROPOP2010 projections, clear patterns of changes in the net population will appear in Europe in the next decades, as shown in Figure 9 for the period 2010-2030 and 2010-2050. A decrease of resident population is predicted to occur in wide central and eastern areas of the European Union. Also, spots of increases are evident in some metropolitan areas, although it is worth remarking that absolute changes as those reported in Figure 9 are necessarily higher in densely populated areas.

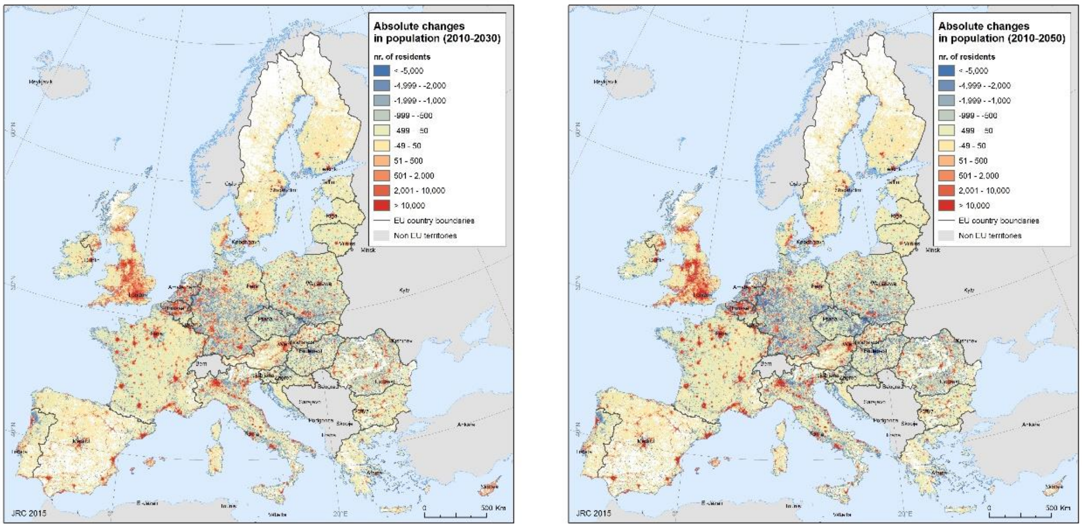


Figure 9 - Changes in resident population in the period 2010 – 2030 (left) and 2010 – 2050 (right).

The indicator of population density (Figure 10, left) is calculated as the total number of inhabitants divided by the land area in m^2 and is used as an ancillary indicator intended to compare the regions based on similar figures. The higher the density, the higher the concentration of population living in a specific region. The number of people is derived from EUROPOP2010 at NUTS 2 level (EC/Eurostat, 2010). The land area corresponds to the total area of the region at NUTS 2 level (EuroBoundaryMap v81 – Eurogeographics, 2014).

The regional trend of GDP is extrapolated from the ECFIN Projections, following an historical trend scenario. GDP per capita is shown in Figure 10, right.

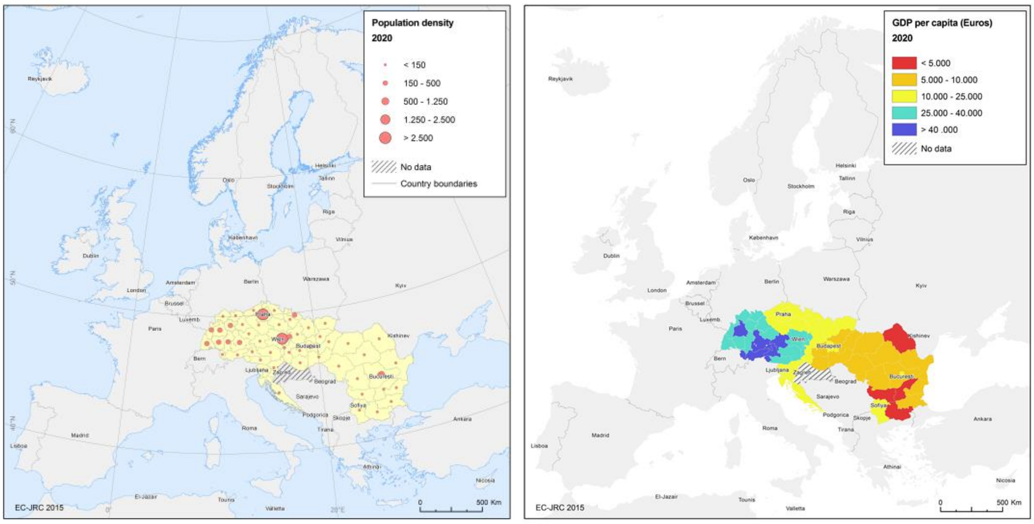


Figure 10 - Left: population density in 2020 in the Danube area. Right: GDP per capita in2020.

When combining population distribution, land use and transport network, a useful indicators is the "Location accessibility" that expresses the travel times to the largest cities in the country or neighbouring countries and the amount of population reached in that time. Figure 11 (left) present the change in 'Location accessibility' between 2010 and 2020. High values of relative changes are indicating that either travelling time has increased (hence a worsening of the transport network) or a decrease in the potential contacts (hence indicating a decrease of regional population).

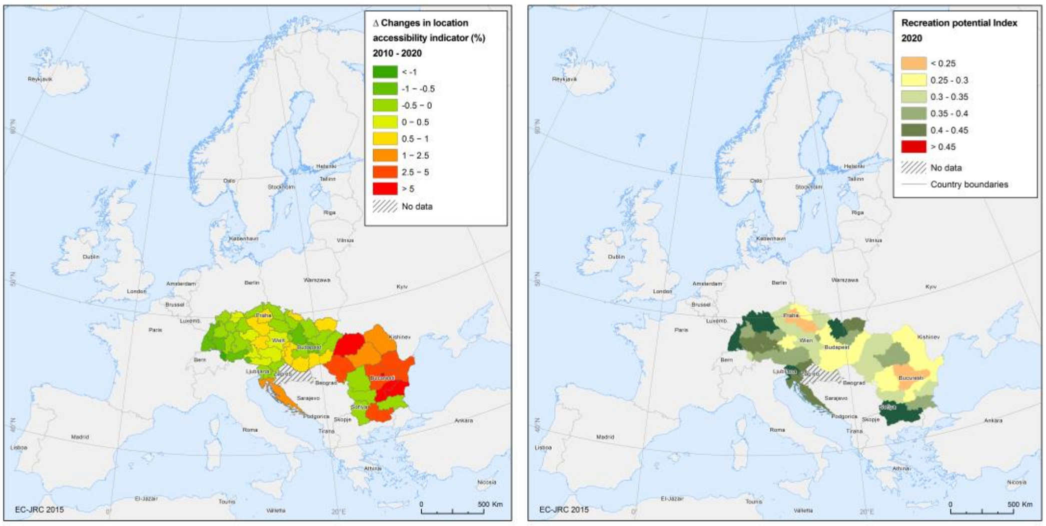


Figure 11 - Left: Changes (%) in the location accessibility; Right: Recreation potential index

The land function provision of leisure refers to the access to recreational services including natural and cultural landscapes. The indicator Recreation Potential (Figure 11, right) reflects the potential opportunities for nature based recreation activities provided from different ecosystems in the Danube area.

2.3.4 Conclusions and next steps for LUISA

This section has illustrated an example of application of advanced land use modelling for the analysis of territorial developments in Europe according to a socio-economic scenario of reference.

The coming years will see much work to improve LUISA as a comprehensive tool for evaluating the effects of various territorial policies. The end goal of LUISA's development should be a modelling framework that closely approximates true economic land-conversions, explicitly modelling all costs and benefits that are internalized in the land use change process, while broadly taking into account both the internal and external costs and benefits of land use changes when evaluating model results.

The frequent use of the LUISA framework in policy consultation presses the need to validate the model's output in terms of accuracy and reliability. In 2013 the JRC began a cross-validation exercise with other national and international institutes that also employs a land use model. It is expected that this validation exercise will yield useful insights into the importance of various model settings and factors that differ between the various models. Furthermore, data to do an empirical validation of the model using historical trends is finally becoming available, in the form of a historical time series of municipal population counts and historical time series land use data . These historical data will be instrumental in empirical validation projects that are planned on the short to medium term.

Lastly, one of the most substantial improvements planned on the medium term is to fully integrate an economic rationale in LUISA – based on true utilities, true costs and true willingness-to-pay data. Feed-back mechanisms with hydrological models, to include water demand, availability and associated costs are being implemented as dynamic elements for the allocation of activities and services.

3. Hydro-economic scenarios for the Danube: competition for water, opportunities and threats

By János Fehér

3.1 Introduction

The Danube River Basin Management Plan - Update 2015 Draft (ICPDR, 2015) states that "Rivers, lakes, transitional and coastal waters, as well as groundwater, are a vital natural resource of the Danube River Basin: they provide drinking water, crucial habitats for many different types of wildlife, and are an important resource for industry, agriculture, transport, energy production and recreation. A significant proportion of this resource is environmentally damaged or under threat. Protecting and improving the waters and environment of the Danube River Basin is substantial for achieving sustainable development and is vital for the long term health, well-being and prosperity for the population of the Danube region."

Based on an extensive Danube Basin analysis update carried out in 2013 the Danube River Basin Management Plan - Update 2015 Draft reaffirms that hydropower generation, physical modification and overexploitation of water bodies and diffuse pollution from agriculture have been identified as significant pressures with cross border impacts. Since the adoption of the 1st DRBM Plan in 2009 required by Water Framework Directive (WFD), additional topics were investigated, such as aspects of sediment quality and quantity, invasive alien species, adaptation to climate change, water scarcity and drought and the sturgeon issue, in order to identify their relevance and significance on the basin-wide scale.

In the period of the first river basin management planning of WFD the European Union Member States (MS) have adopted the European Union Strategy for the Danube Region (EUSDR) in April 2011 within the European Council. The EUSDR was jointly developed by the European Commission together with the Danube Region countries and stakeholders, in order to address common challenges together. The Strategy is defined in a Communication[5], accompanied by a detailed Action Plan[6], which presents the operational objectives and concrete projects and actions of the EUSDR. The Strategy seeks to create synergies and coordination between existing policies and initiatives taking place across the Danube Region.

The Joint Research Centre (JRC) of the European Commission has launched an initiative in 2013 aiming to provide scientific support to the EUSDR. The objective is to gather important scientific expertise and data to help decision-makers and other stakeholders of the Danube Region to identify the policy measures and actions needed for the effective implementation of the Danube Strategy. It is recognised that water is a central issue of the *"Scientific Support to the European Union Strategy for the Danube Region"* programme. Addressing the water challenges posed by the *Blueprint to Safeguard Europe's Water Resources*[7] and the EUSDR requires integrated solutions going beyond sectoral divides and matching the needs of water of the different users in the region. The project called Danube Water-Agriculture-Energy-Ecosystems Nexus (Danube Water

[5] http://files.groupspaces.com/EUStrategyfortheDanubeRegion/files/138422/gtkM4yh5nyvnZC4xjTTE/Communication+of+the+Commission+EUSDR.pdf

[6] http://files.groupspaces.com/EUStrategyfortheDanubeRegion/files/138421/k_VJLxOGVSv3sekq26sr/Action+Plan+EUSDR.pdf

[7] Communication From The Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - A Blueprint to Safeguard Europe's Water Resources. COM(2012) 673 Brussels, 14.11.2012. http://ec.europa.eu/environment/water/blueprint/index_en.htm

Nexus) aims to provide input to decision makers and managers in the region about sustainable futures of water resources use.

The Common Roadmap to the Danube Water Nexus document[8] states that "The 'Danube Water Nexus' flagship cluster will address the environmental and socio-economic consequences of changing agriculture-energy pressures on water. This requires a basin-wide perspective and cooperation with countries in the region taking into account needs of all stakeholders. Allocation of available water across different sectors needs to be integrated into the overall economic strategy of the Danube Region based on optimization concepts in order to maximize growth and minimize the environmental impact. Central to the assessment will be the development and application of an optimisation model linked with dynamic, spatially explicit water quality and quantity bio-physical models allowing the selection of measures affecting water availability and water demand based on environmental and economic considerations, and hydrological extremes such as floods and droughts. Optimization will particularly focus on the competing demand between the energy, agriculture, domestic, transport (e.g. inland navigation) and industrial sectors and ecosystems under a changing environment."

In 2014 the Author of this chapter acted as external expert to the JRC Danube Water Nexus project and carried out scenario studies for specific modelling topics such as desalination, irrigation expansion and efficiency increase, water reuse by industry, treated urban wastewater for irrigation, mini-hydropower and large hydropower. An interim report was produced by the Author for JRC summarizing the outcomes of the studies in three major chapters, namely i) Scenarios identified for Danube Water Nexus modelling; ii) Indicators ideally be included in the Danube Water Nexus Analysis and iii) Overview of scenario studies in the Danube Basin. Using that interim report and combined with another interim report produced by Dr Muerth on water models a JRC Technical Report was published (Fehér and Muerth, 2015).

In 2015 JRC has commissioned the Author to further elaborate the scenario studies focusing on environmental and macro-economic impacts of alternative water allocation across competing sectors in the Danube river basin and discussing hydro-economic scenarios for the Danube highlighting competition for water, opportunities and threats. The work had to give a qualitative discussion of the different scenarios of water allocation and pressures on water and a qualitative discussion of environmental and socioeconomic consequences of the scenarios giving highlights on:

- what are the climatic and land use trends that pose threats to water availability for different usages;

- what are the impacts of different types of water use on rivers and on green water (evapotranspiration), possibly through examples of conflicts happened in the recent past;

- which are the main competitors on water use, possibly through examples of conflicts happened in the recent past; and

- the socio-economic relevance of the water-using sectors, under present conditions and in the "near" future (2030-2050).

3.2 Natural drivers effecting water allocation scenarios: Climate change

More and more studies underline that there will be significant annual average air-temperature increase globally and in Europe, as well. A European Environmental Agency (EEA) report presented that the annual average air-temperature change (increase) will vary from 0.34 °C to 2.47 °C in European territory (Figure 12).

[8] https://ec.europa.eu/jrc/sites/default/files/jrc-danube-water-nexus.pdf

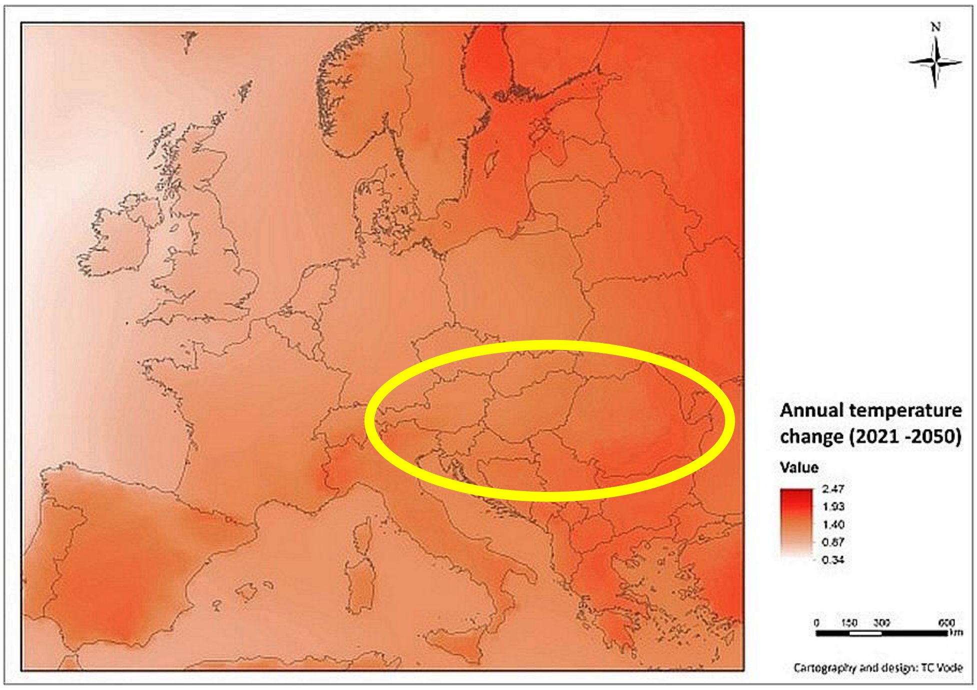


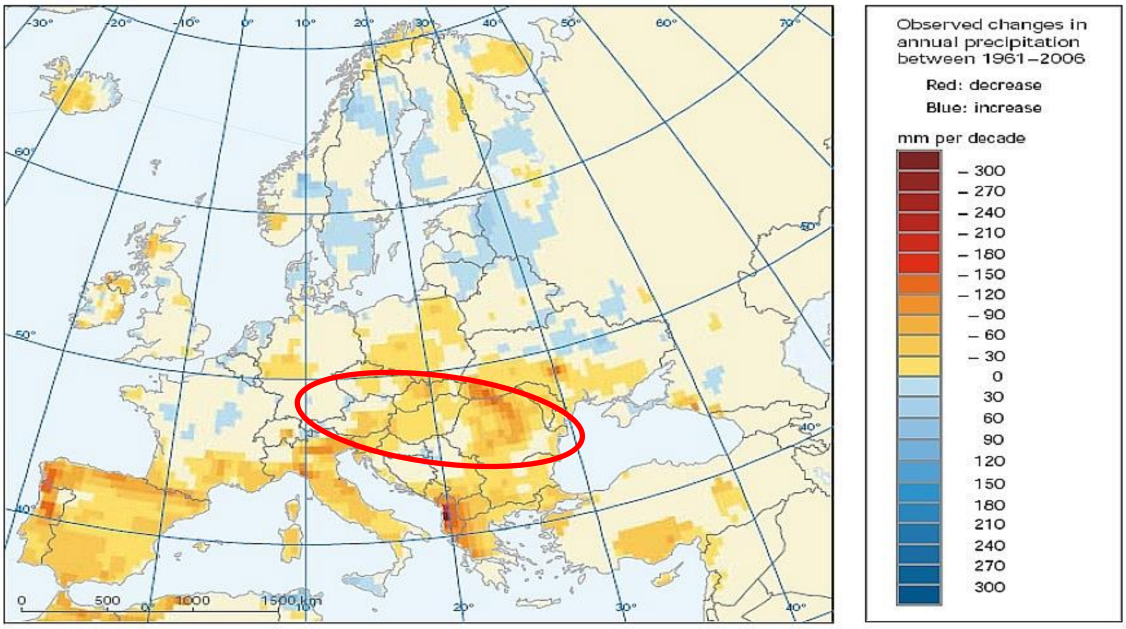
Figure 12 - Predicted long term climate change for Europe[9]

Increasing air-temperature is predicted for the Danube Basin as well with higher than 1 °C temperature increase in the Eastern and South-Eastern part of the basin.

An other EEA study[10] states that in average the available water resources of the European countries exceeds about 8 times the abstracted amount. In yearly average 44% of the abstraction in EU is for energy production (though decreased by 40% during the last 15 years), while 24% is used for agriculture, 21 % is for public water supply, and 11 % is for industrial purposes. However, the report highlights that the balance between demand and availability has reached a critical level in many areas of Europe because among others over-abstraction, prolonged periods of low rainfall or drought. Observed changes in annual precipitation highlights that the southern part of Europe including the Danube Basin is significantly affected (Figure 13). The observed annual precipitation decreased in most part of the Danube Basin, especially in the Carpathian Mountains, which are the dominant recharge area of the groundwater resources in the lower part of the Carpathian Basin.

[9] EEA ETC-ICM Techn. Report (2015); http://forum.eionet.europa.eu/nrc-flis/library/project/tec-icm_wb-follow-rpoject-2015-2016/osce-eea-wb-report/security-implications-future-water-use-western-balkans-2015-09-02/download/en/1/Security%20implications%20of%20future%20water%20use%20in%20Western%20Balkans%20%282015-09-02%29.docx

[10] EEA Report No 2/2009: Water resources across Europe — confronting water scarcity and drought



Note: Data are in mm per decade, blue means an increase, red a decrease. The observations indicate that large decadal scale variability in precipitation amount is superposed on the long time scale trends described above. This variability is partly related to the decadal scale variability in atmospheric circulation anomalies (see Box 5.1). Calculating trends over shorter time periods may therefore lead to different results.

Source: The climate dataset is from the EU-FP6 project ENSEMBLES (http://www.ensembles-eu.org) and the data providers in the ECA&D project (http://eca.knmi.nl).

Figure 13 - Observed changes in annual precipitation between 1961-2006.

Sillmann and Roeckner, 2008 reported that simulation results showed significant increasing trends in maximum number of consecutive dry days for three European regions when different IPPC climate scenarios were applied (Figure 14). For Central Europe, including the Danube Basin, approx. 60% increase is predicted in the maximum number of consecutive dry days.

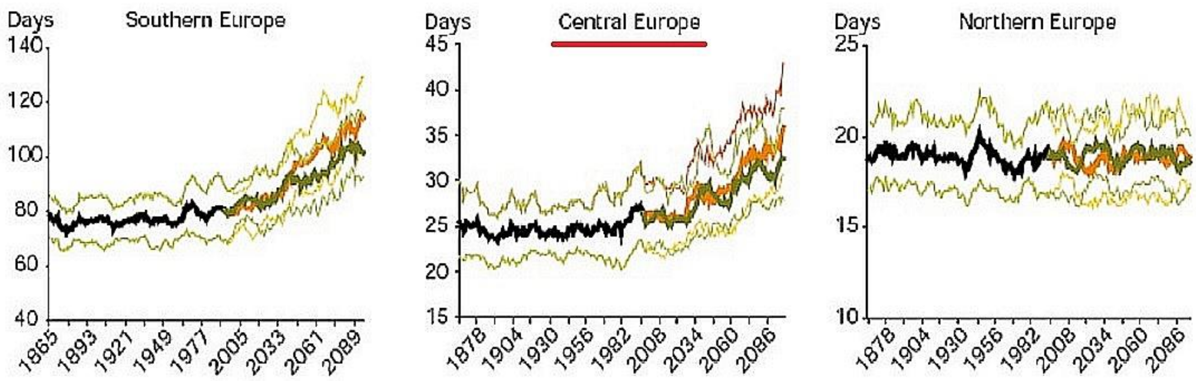


Figure 14 - Maximum number of consecutive dry days in three European regions[11]**.**

Since the Danube region has mostly moderate climate, with a relatively balanced variation of rainfalls, the adverse effects of climate change have so far been only moderate. Based on the findings of the Climate Change Adaptation study for the International Commission for the Protection of the Danube River (ICPDR), the main impacts on water-related sectors are triggered by temperature and precipitation changes, including (a) an increase in air

[11] Sillmann and Roeckner, 2008

temperature with a gradient from northwest to southeast, particularly in summer in the south-eastern Danube region; (b) overall small annual precipitation changes for the whole basin on average, but major seasonal changes in the Danube River basin; (c) changes in the seasonal runoff pattern, triggered by changes in rainfall distribution and reduced snow storage; (d) the likelihood that droughts, low flow situations, and water scarcity will become longer, more intense, and more frequent; and (e) an increase in water temperature and increased pressures on water quality (LMU, 2012).

3.3 Climate change impact on soil water content

This climate change tendency could further impact the actual evapotranspiration of the soil. It will increase the frequency of agricultural droughts and increase the irrigation water demand, while decrease the flow in rivers and creeks, which are the dominant sources of irrigation. Century long meteorological observation highlights the negative tendency in drought situation in the middle part of the Danube Basin. Decreasing trends of annual maximum and minimum values of Palmer drought-index, which can be related with available soil water content, were observed at Debrecen, Hungary (Figure 15).

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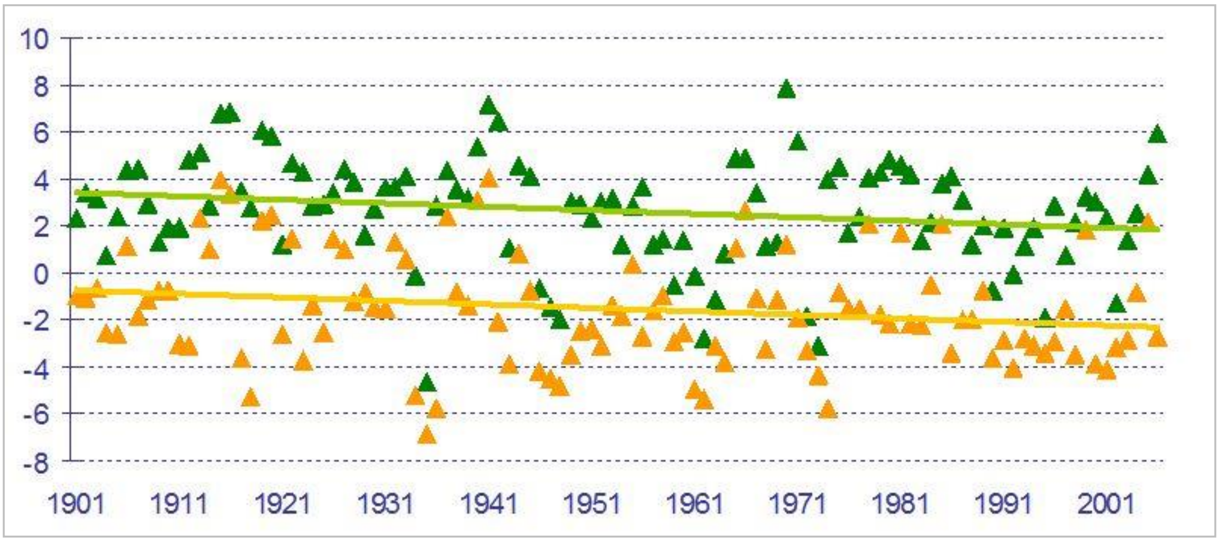

Figure 15 - Trend in annual maximum (green) and minimum (orange) of Palmer droughts-index in 1901-2006 in Debrecen, Hungary[12]

[12] Szalai, 2011

3.4 Climate change impact on surface water temperature

Warming trend in river water temperature also observed in the main rivers of the Danube Basin. Figure 5 shows increasing river temperature trends of Danube and Tisza rivers in their Hungarian sections. Since 1950 average water temperature of both rivers increased by more than 1 °C when considering the linear trend (solid line in Figure 16). The Danube river temperature increased a bit faster than Tisza River, though the Danube moving average curve (dashed line) shows higher fluctuations than the similar Tisza curve.

The warming trend in river water temperature is highlighted by another observation. The date of ice formation on the river surface and the date of final disappearance of ice on the river surface have convergence in long term (Figure 16). This convergence is valid both for the linear trend and moving average line as well. However, it should be noted that deviations in observed dates are high. As water temperature has an increasing trend reflecting the climate change tendency, it can be considered as a scenario that there will be no ice formation during the winters on large parts of the Danube and some of the tributaries within the Danube Water Nexus modelling "near" future (2030-2050) period.

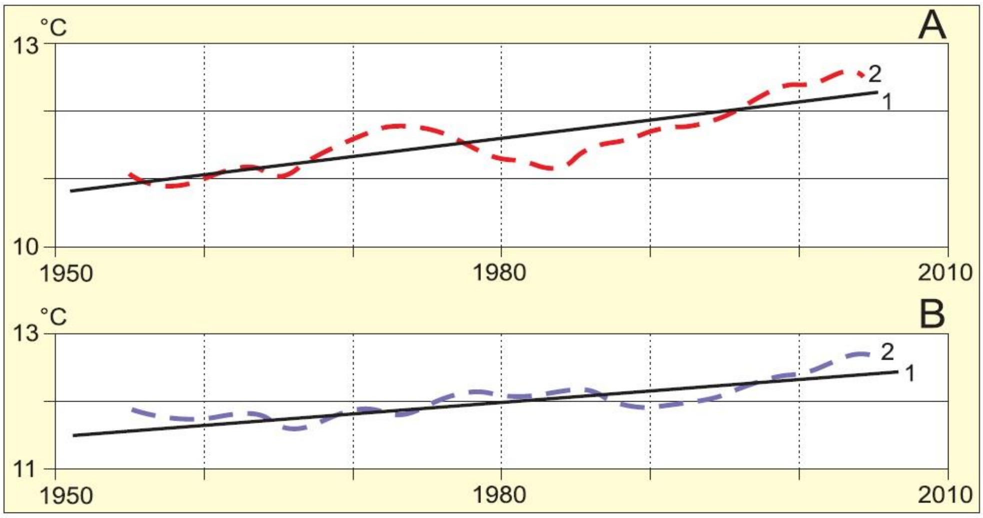

Figure 16 - Water temperature trends of Danube (A) and Tisza Rivers (B) between 1950 and 2010 in Hungary[13]

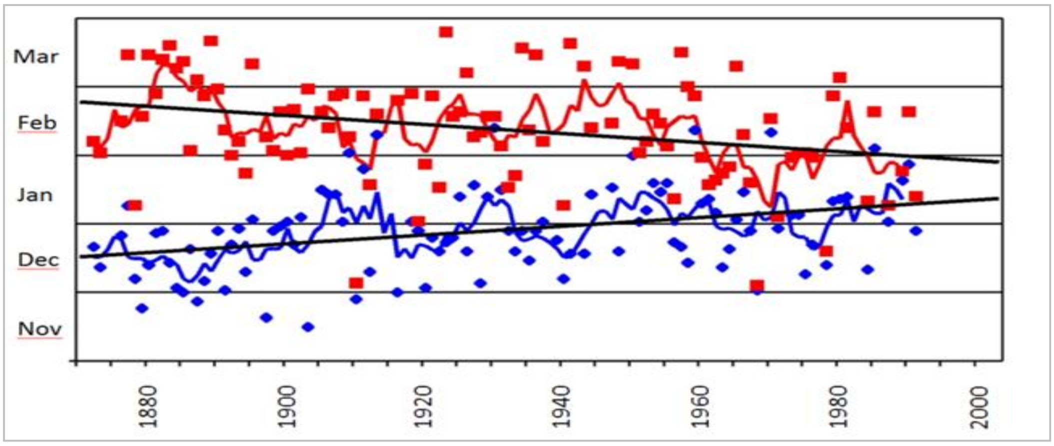

Figure 17- Changes in dates of first ice formation (blue) and final disappearance (red) on the Danube River, at Nagymaros, Hungary[14]

[13] Lovász, 2012.
[14] Takács, 2011

3.5 Recommendation for modelling options

From modelling point of view the followings should be taken into consideration for the Danube Basin for the "near" (2030-2050) period concerning natural drivers:

- increasing air-temperature is predicted for the Danube Basin with higher than 1 °C temperature increase in the Eastern and South-Eastern part of the basin,
- the annual average precipitation will follow a decreasing trend,
- the maximum number of consecutive dry days will increase (in average from 25 days to about 40 days),
- available soil water content will be decreased as a consequence of extended dry periods,
- river water temperature will have further increasing trend,
- within the "near" (2030-2050) period there will be no ice formation during winters on large parts of Danube and some of the tributaries.

3.7 Impacts on water resources

The changes in natural drivers have impacts on water resources, water availability, extreme hydrological event, such as floods and droughts and could influence the different types of water uses and the water quality of water resources and the ecosystem in the Danube River Basin. A climate change adaptation study on the Danube Basin (LMU, 2012) categorised the uncertainties of the long term change of climate elements and their main impacts.

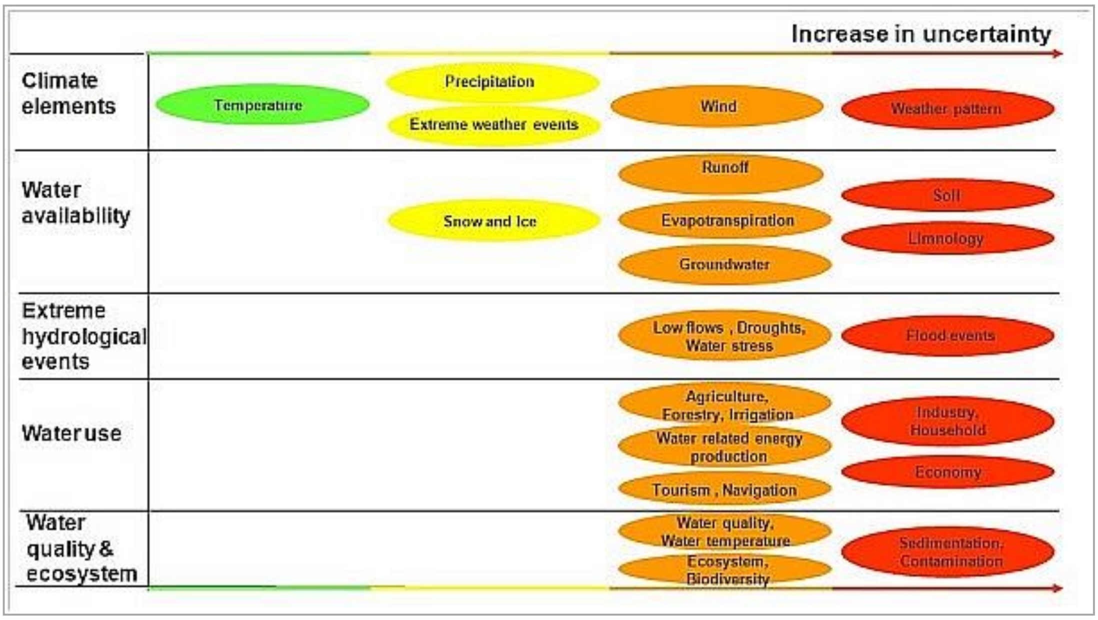

Figure 18 - Uncertainty of climate elements and main impacts in four certainty-categories: very high (green), high (yellow), medium (orange) and low (red)[15].

According to Figure 18 the study considered that changes in temperature in long term trend have very high (green) certainty. Thereby, future increase of both, the mean annual and seasonal temperature, is a hard fact. The certainty of the future development of precipitation is high (yellow), however, less reliable than temperature changes, mainly for

[15] LMU, 2012

spring and autumn. In future, extreme weather events, classified with a high certainty, will show more often variability in quantity, seasonality and space.

Changes in water availability depend largely on precipitation, which might decrease in summer, especially in the southeast of the Danube Basin with a strong tendency to water stress. In annual average, both the precipitation and the total renewable freshwater resources vary significantly among the Danube countries (Figure 19), which situation creates uneven vulnerability for them to climate change.

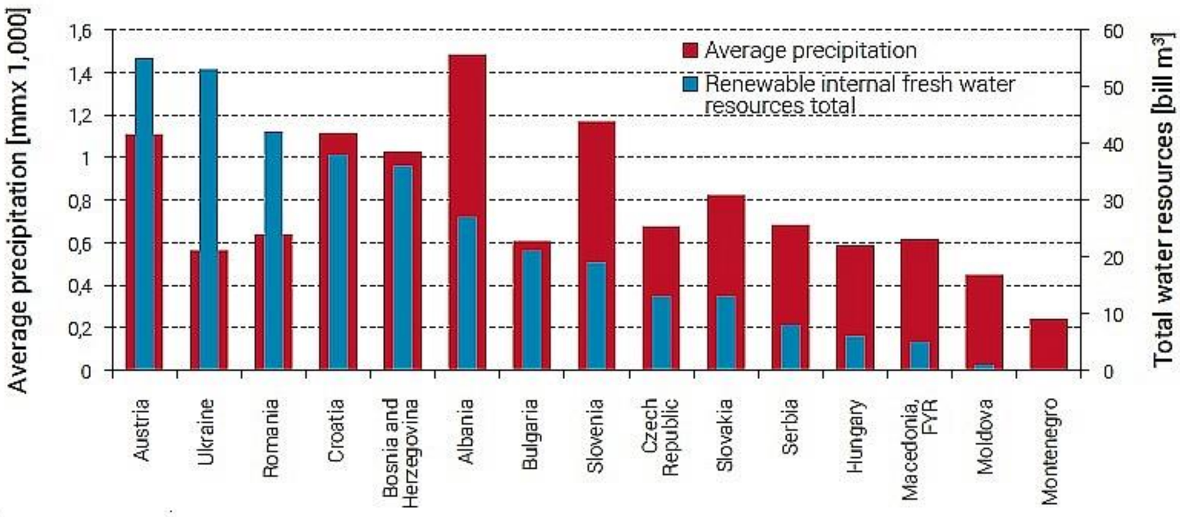

Figure 19 - Annual average precipitation and total renewable internal freshwater resources by countries[16]

Projections of extreme hydrological events are rather uncertain than changes in the mean water availability. Extreme floods occur every 10–12 years in the Danube Basin and are usually caused by a number of factors coming together, such as local storms, unusual areal rainfall patterns, and high soil moisture content. The Danube floods every 2–3 years and in the middle stretch of the river the high to low flow ratio is about five. Its tributaries are more volatile with a ratio of 50 for the Tisza River, which floods every 1.5–2.0 years, and 500 for many small to medium rivers. Coping with floods on the Tisza River and its tributaries causes the river bed to silt, and remedial works to resolve the problems are complex and require the construction of emergency reservoirs and relocating dykes[17].

Although climate change impacts on low flows, droughts and water scarcity are medium. They are more reliable than changes in floods showing a low certainty. Regarding the floods it should be noted that few contradicting statements about changes in flood frequency in different regions exist. The following table highlights in which direction the climate change impacts the river flow regime.

[16] Source: FAO Aquastat; Graph: World Bank, 2015.
[17] GWP, 2015.

Increasing ↑	Decreasing ↓
Evaporation / evapotranspiration	Run-off
Duration of low flow period	Infiltration
Number of temporary rivers / creeks	Time period of ice cover
Depression of groundwater level	
Seasonal water level fluctuation	
More frequent high / extreme floods	

Table 1- Directions of hydrologic change

Regarding the impacts on different fields of water use, most issues are classified with a medium certainty and depend largely on changes in climate elements, water availability and extreme hydrological events. This means their certainty can't be better than of the triggers. The impacts on agriculture for example are investigated to a high degree, but the important future yields for maize and wheat are not uniform. Navigation might benefit in winter due to less icing but in summer shipping will be restricted due to more days with low water conditions. For water related energy production there is a similar assessment, e.g. hydroelectric power generation might possibly increase in winter and decrease in summer. The impacts on industry, household and economy are categorized with low certainty due to little available information. The following table highlights in which direction the climate change impacts on water resources and demands.

Increasing ↑	Decreasing ↓
Public water use / peak usage	Water resources for other users
Cooling water demand	Surface water resources
Irrigation water demand	Water quality
Level of utilization/exploitation and conflict	Hydrological conditions of storage
Illegal water intake	Groundwater resources
Demand for bank-filtered water resources	
Importance of water storage	
Flood risks	Area where irrigation is applicable
Drought and scarcity	Renewable water resources

Table 2 – Anticipated changes on the water demand and supply side

Studies also discuss the climate change impacts on sectors. The next table gives examples on what measures could be considered in modelling for different sectors for mitigation of climate change impacts of these sectors.

Sector	**Mitigation measures to be considered in modelling**
Agriculture	
Increased of drought and scarcity risks. Increased vegetation period.	• New water saving cultivation methods • New, more drought resistant plants to be grown • Modified crop rotations • Water saving irrigation technologies be applied
Paper and pulp industry	
Extreme floods impacts the production	• Flood protection measures to ensure production during flood periods
Forestry	
Extreme climate variability endanger some pine species	• Modification in tree species (modified land cover, water circle)
Inland navigation	
Extended low flow periods	• Regulated water depths in critical sections to be ensured

Table 3 – Mitigation measures to be considered

In case of water quality and ecosystems with a medium certainty, climate change could lead to the fact that water quality deteriorates and water temperature increases. Moreover, vulnerability due to climate change might increase for aquatic ecosystems and biodiversity might decrease with medium certainty. The low certainty of sedimentation and contamination occurs from little available information. However, for all these impacts quantitative, seasonal and spatial changes are not necessarily clear.

3.7 Water resources availability

In general, water resources availability for the Danube countries shows acceptable status when yearly average data are investigated (Table 4).

The total yearly renewable water resources per capita value (Table 4, column 4) exceeds significantly the total yearly water withdrawal per capita (column 5) for all Danube Basin countries. Bulgaria has the highest use rate (but still only 28%) of its total renewable water resources, while Bosnia and Herzegovina, Croatia, and Slovakia use only around 1% of their renewable water resources. Countries dependency on renewable water resources originating from outside of their territory shows considerably different picture. Column 3 (% of internal renewable water resources in the total) highlights that Czech Republic, Bulgaria and Bosnia and Herzegovina practically totally rely on their own renewable water resources, while Serbia, Hungary and Moldova very much dependent on incoming external renewable water resources, thus their vulnerability is relative high as their total water withdrawal is equal or close to their internal renewable water resources.

It has to be noted that Table 4 presents yearly total per capita figures, which does not reflect temporal and spatial variations neither in available water resources nor in withdrawals. Temporal and spatial variations might result in conflicting situations even inside a country with values in column (6). Figure 20 shows the freshwater distribution among three major user categories (domestic, industry and agriculture).

Year 2014	**Total internal renewable water resources per capita (m^3/inhab/year)**	**% of internal renewable water resources in total**	**Total renewable water resources per capita (m3/inhab/year)**	**Total water withdrawal per capita (m3/inhab/year)**	**Freshwater withdrawal as % of total renewable water resources (%)**	**Population (1000 inhab)**
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
Austria	6 451	71	9 113	452	5	8 526
Bosnia and Herzegovina	9 281	95	9 804	**86**	**1**	3 825
Bulgaria	2 930	99	2 972	**841**	**28**	7 168
Croatia	8 825	36	**24 696**	146	**1**	4 272
Czech Rep.	1 224	**100**	**1 224**	173	14	10 740
Germany	1 295	70	1 863	399	21	82 652
Hungary	604	6	10 470	506	5	9 933
Montenegro	No data	N/A	No data	259	N/A	622
Moldova	289	9	3 366	290	9	3 461
Romania	1 995	20	9 792	316	3	21 640
Serbia	888	**5**	17 131	431	3	9 468
Slovakia	2 310	25	9 186	127	**1**	5 454
Slovenia	8 993	59	15 352	452	3	2 076
Ukraine	1 182	38	3 106	412	13	44 941

Table 4 - Renewable water resources and withdrawals in the Danube countries (Data were retrieved from FAO Aquastat database[18] and represent the whole country situation)

[18] http://www.fao.org/nr/water/aquastat/data/query/index.html

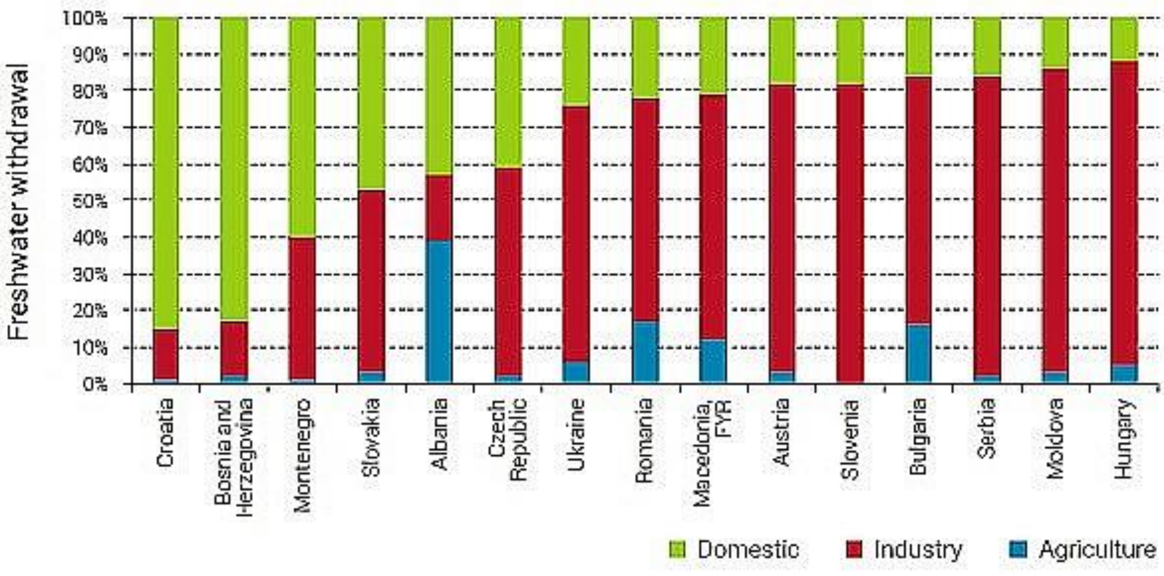

Figure 20 - Freshwater withdrawal distribution per usage[19]

The graph reflects that countries where domestic water use represents high percentage in the total use, such as Croatia, Bosnia and Herzegovina, Montenegro, these are vulnerable to any water shortage situation, because usually the domestic water use is the last one where water use restriction is applied. However, countries within the Danube Basin are already experiencing a population decline (Figure 21) triggered by, in addition to a natural decrease, an outward migration following the opening of borders to the Western European countries.

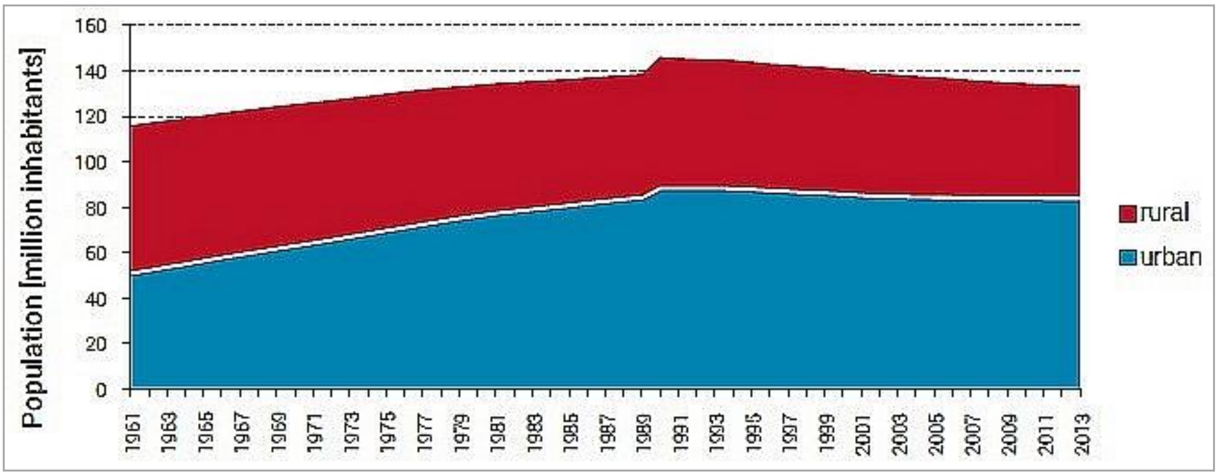

Figure 21 - Trends in total rural and urban population in the Danube Basin (Source: World Bank, 2015)

Although it is mostly rural areas that are depopulating, some of the urban areas have also declined in population numbers, especially those located remotely and isolated from global markets and transport corridors. This has resulted in several cities facing an oversized infrastructure that lacks economies of scale and is costly to maintain and upgrade (World Bank, 2015).

[19] World Bank / IAWD Danube Water Program, 2015.

It can also be stated that agricultural freshwater withdrawal is relatively low in most of the Danube countries, except maybe Albania, where the withdrawal rate is close to 40% of the total (Figure 20). This situation may also reflect that when competition situation occurs the agriculture sector could claim higher portion from the total yearly withdrawal.

3.8 Water use - Urban wastewater treatment

Governments and water professionals in the Danube region are facing a combined challenge of meeting their citizens' demand for universal, good quality, efficient, and financially sound, sustainable sanitation services, while catching up to the environmental requirements of the European Union.

Though urban waterwater treatment is not a direct water use, but it has significant impacts on available water resources, especially on quality of surface water resources. The Danube River Basin Management Plan - Update 2015 document discusses the future development scenarios on urban wastewater sector. The current situation of urban wastewater collection and treatment is presented in Figure 22.

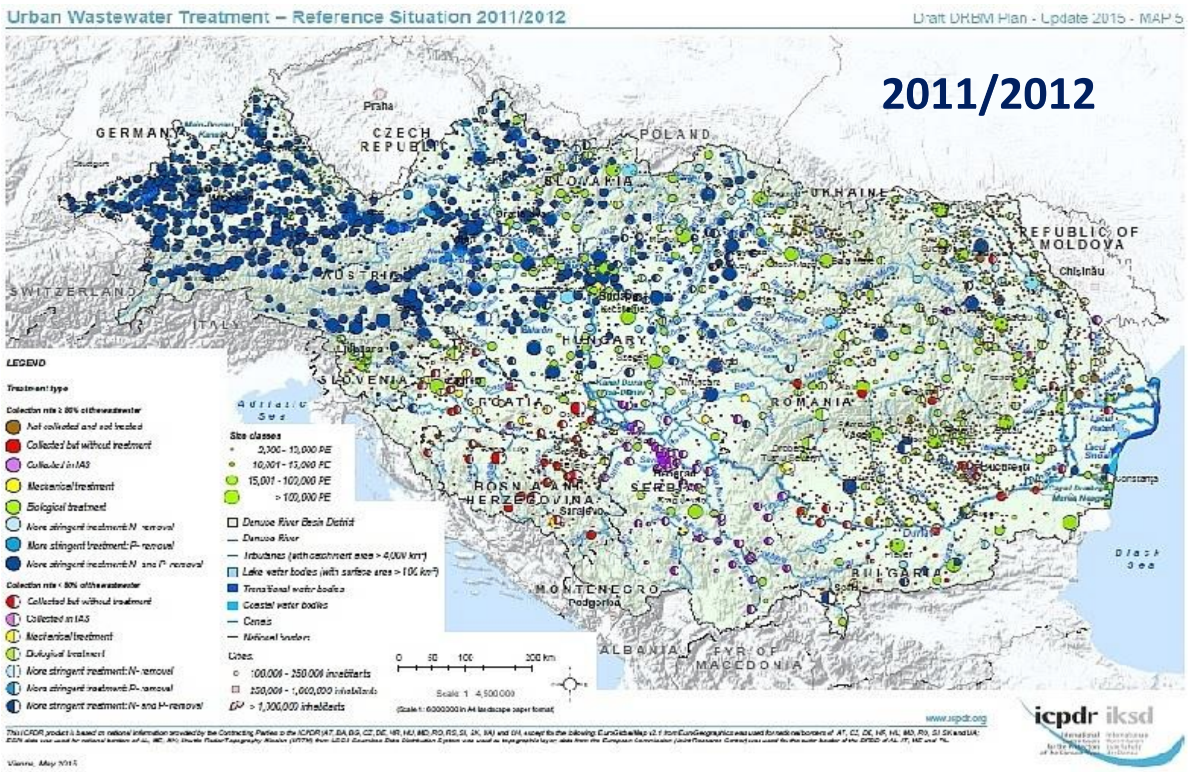

Figure 22 - Current urban wastewater treatment situation in the Danube Basin (Source: ICPDR, 2015)

The DRBMP points out that "further development of the urban waste water sector is needed in the next management cycle. Management activities are legally determined for the EU Member States (EU MS) through several EU directives. The Urban Waste Water Treatment Directive (UWWTD) specifically focuses on the sewer system and waste water system development. EU MS are obliged to establish sewer systems and treatment plants at least with secondary (biological) treatment or equivalent other treatment at all agglomerations with a load higher than 2,000 PE (also for agglomerations smaller than 2,000 PE appropriate treatment must be ensured)". As Figure 22 shows that development stage has not been reach mostly at eastern and southern part of the Danube Basin yet. The plan also drafted a vision scenario for urban wastewater treatment that Danube countries intend to reach in longer term (Figure 23).

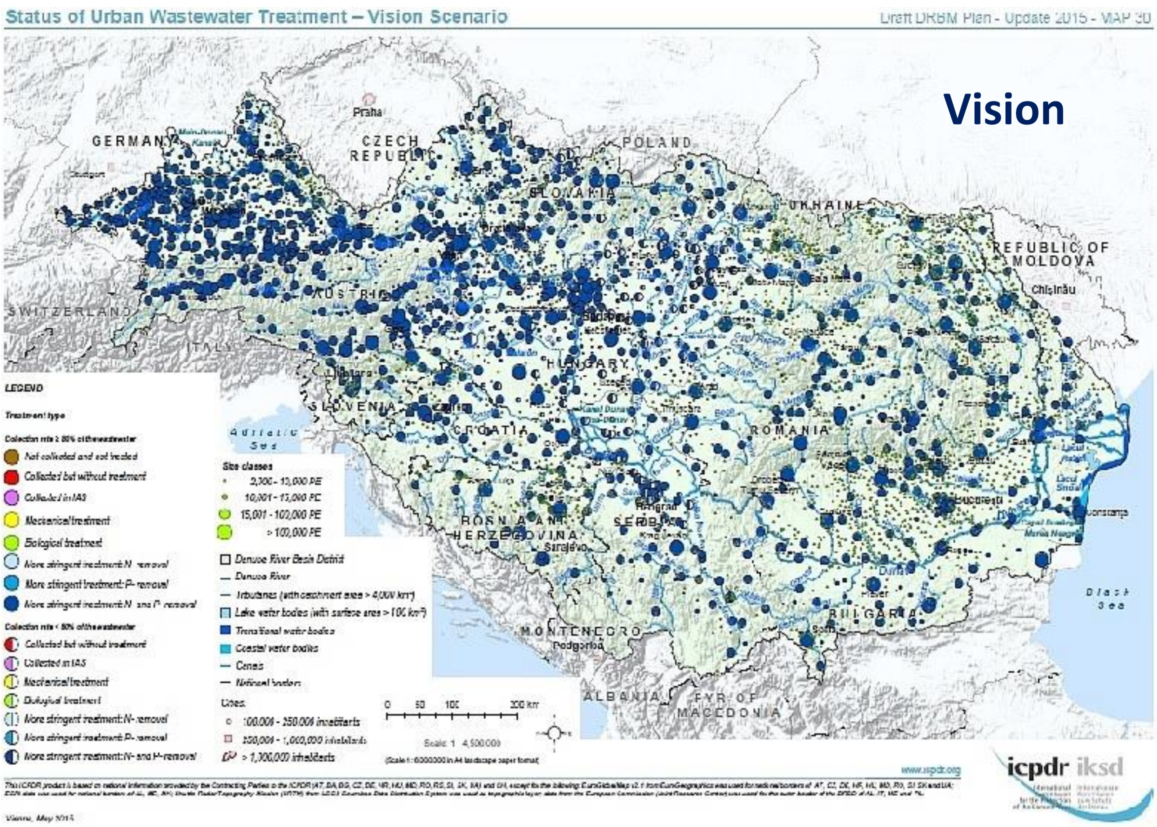

Figure 23 - Vision scenario on urban wastewater treatment for the Danube Basin (Source: ICPDR, 2015)

To reach the development level of the vision scenario huge amount of investments would be needed from dominantly the eastern and southern basin countries. At the same time these countries are the most economically less developed countries which need financial resources for many other societal purposes, as well. Consequently, in the "near" future period, these countries will face significant economic conflicts in their investment policies.

Thus, it is recommended to consider in the Danube Water Nexus modelling to consider alternative scenarios on urban wastewater treatment other than just building expensive sewer networks and construct investment demanding centralized wastewater treatment plans. This version of development may impact negatively the surface water quality at many places where the recipients would not have proper dilution or self-purification capacities.

Some questions that are suggested to consider in the modelling:

- What wastewater treatment technology would be realistic and affordable?
- Would there be enough financial resources in the countries in concern?
- What would be the environmental impacts?
    - What the concentrated loads would cause to recipients?
    - Would the urban wastewater treatment development strategy increase nutrient pollution and if yes, where?
- How the tariffs will change?
    - How the water use will change?
    - What would it result in?

There is some experience from countries that are in advance in the implementation of Urban Wastewater Treatment Directive. For example during the last 15 years Hungary invested significantly (dominantly using EU support) in urban wastewater treatment. The country practically closed the utility gap as in case of ratio of population connected to wastewater treatment plant reached the 99% level. In the mean time tariffs of drinking water which include the cost of wastewater treatment as well increased significantly despite of more modest inflation (Figure 24), while water consumption decreased by 40% (Figure 25).

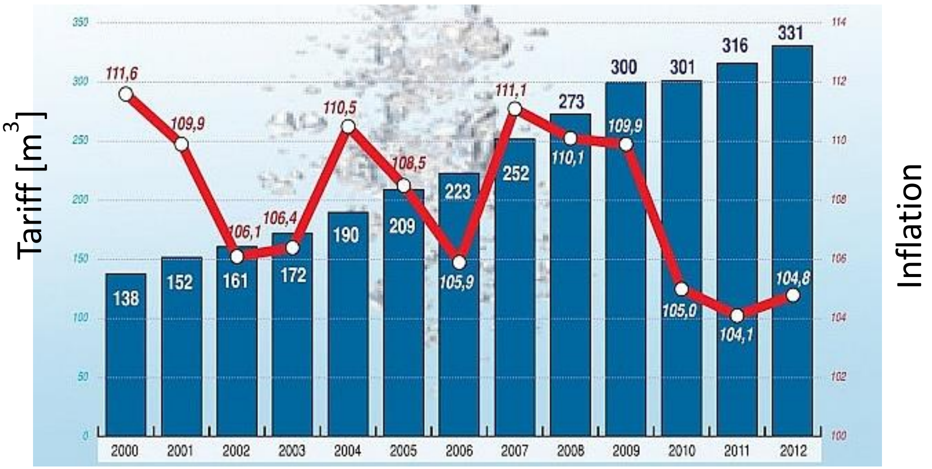

Figure 24 - Water tariffs (blue bar) and inflation (red line) in Hungary (2000-2012). (Source: Hungarian Central Statistical Office)

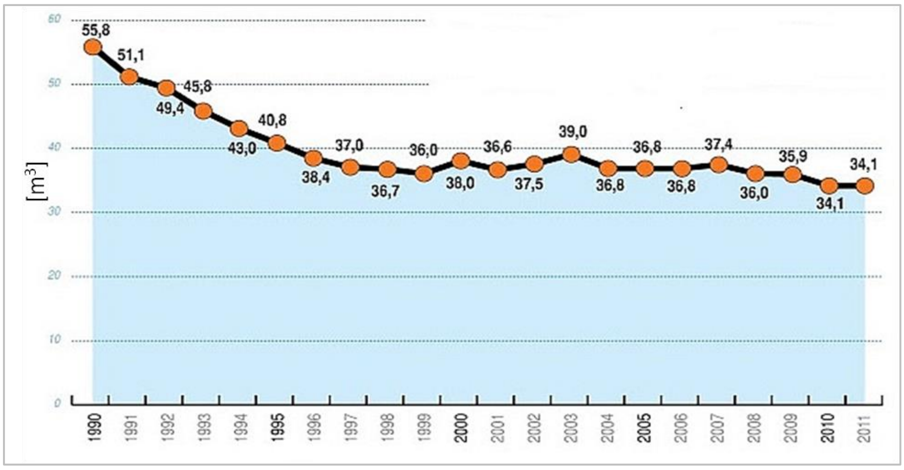

Figure 25 - Water consumption per capita in Hungary (2000-2012). (Source: Hungarian Central Statistical Office)

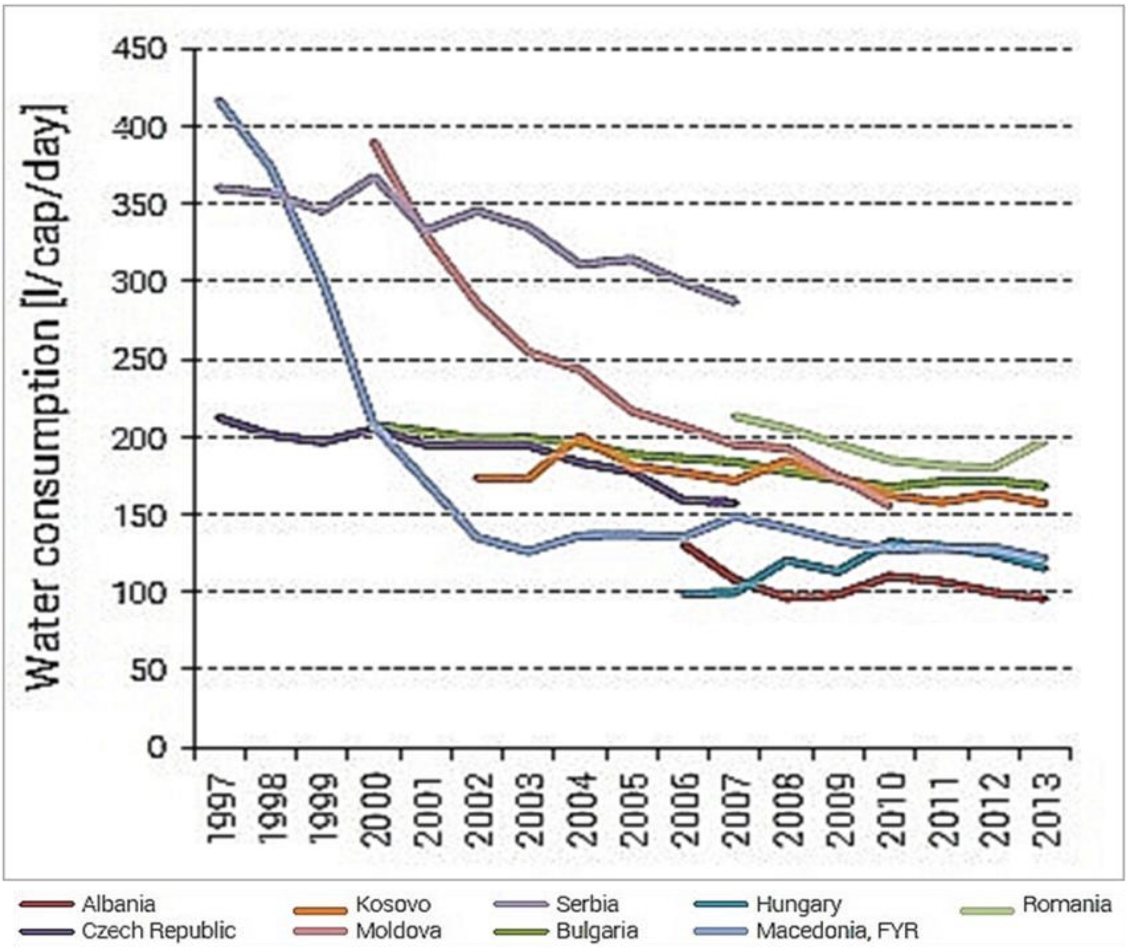

Figure 26 - Per capita water consumption in sample utilities in selected countries in the Danube Basin[20]

Similar water consumption decrease was observed in most other Danube countries (Figure 26). It is expected that the water consumption rate will vary between 100 - 150 m^3/cap/day in longer term.

3.9 Water use - Energy production, hydropower plants

Hydropower development is significant and important natural potential for the developing economies of the Danube Basin, especially for the Western Balkan region. The development of further renewable energy in line with the implementation of the EU Renewable Energy Directive 2009/28/EC31 [21] represents a significant driver for the development of hydropower generation in the countries of the Danube Basin. The ICPDR 2013 report gave a comprehensive overview of the numbers and generated power existing hydropower plants in four power generation categories (Figure 27).

[20] World Bank, 2015.

[21] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:EN:PDF

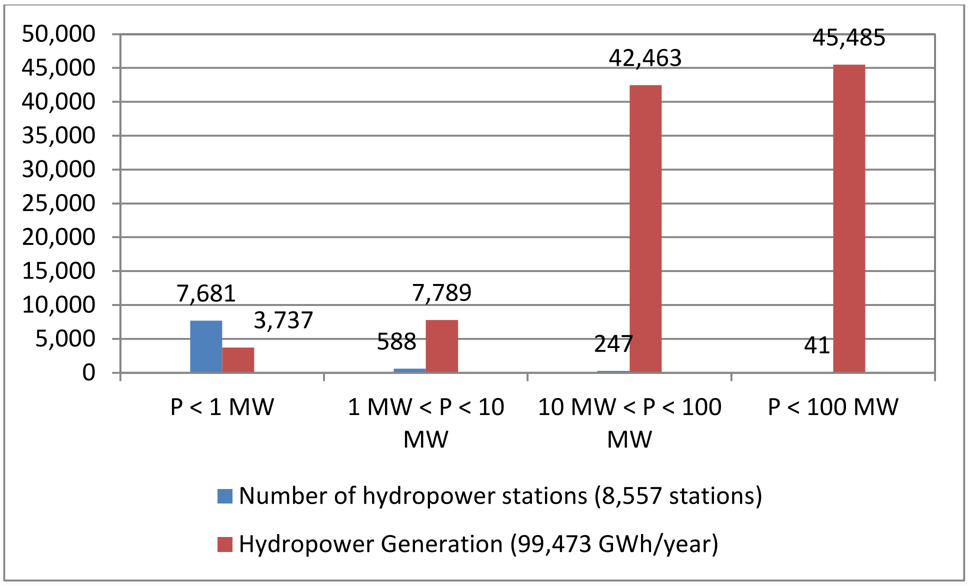

Figure 27 - Contribution of different plant categories to electricity generation from hydropower (Source: ICDPR, 2013)

The large number of hydropower stations (8,557) impacted the hydromorphological status of river water bodies. Austria has the largest percentage of generated electricity based on hydropower (almost two thirds of total electricity generated). The share of hydropower is also relatively high in Croatia, Slovenia, Romania and Serbia (around 30%), and more modest in Germany (although the absolute amount of electricity produced from hydropower is high, compared to other countries in the DRB), the Slovak Republic, and the Czech Republic, where hydropower still plays an important role in the electricity system. However, in most Danube countries (with the exception of DE, HU and MD), hydropower currently represents the most important component of total renewable energy production.

Hydropower is one of the most important energy source for electricity production in most of the South East Europe and therefore it is an energy source with a great strategy importance. However, the existing hydro power plants provide inadequate electricity supply for these countries. It is expected that refurbishment of existing old hydro power plants will improve the power generation output and the economics. Currently the installed capacity of small hydro power in the region is 1 700 MW, but the actual potential is much higher.

Bosnia and Herzegovina has ambitious plans for building several hydro power plants, e.g. on the Neretva (Non-Danube river) and Drina and a cascade on the Bosna River (McGarath et al., 2010).

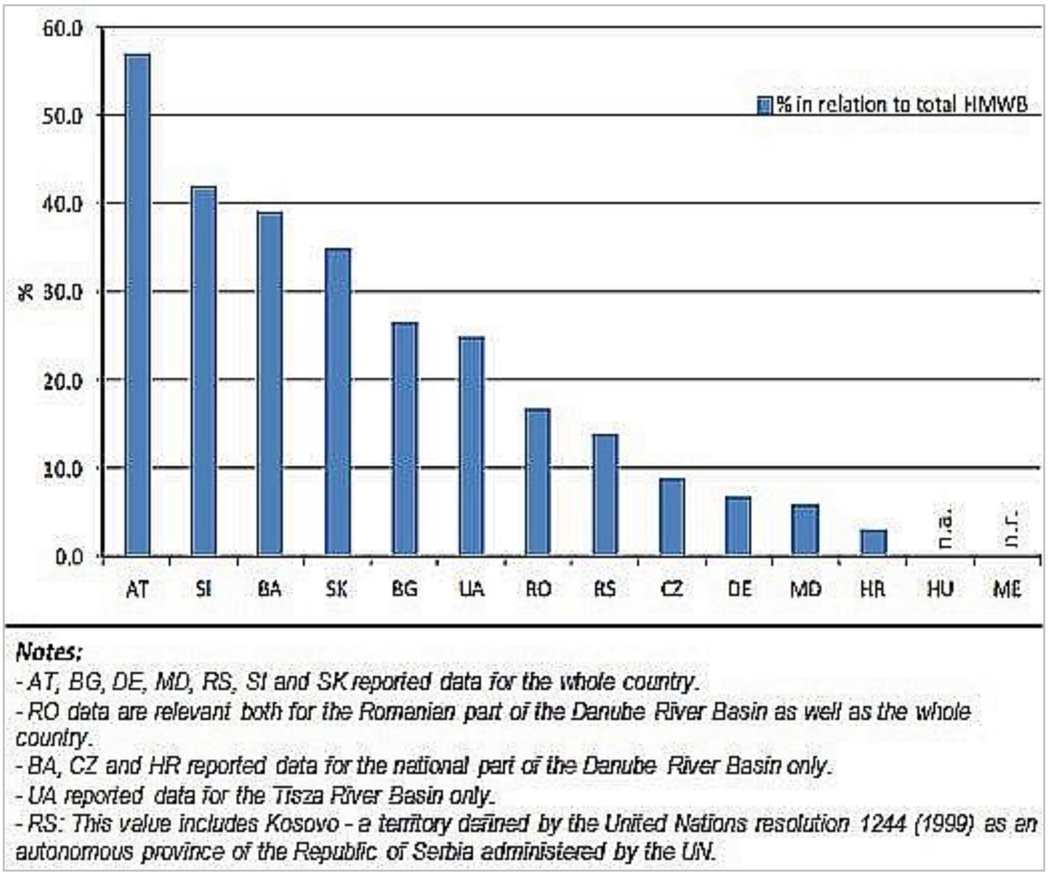

Figure 28 - Percentage of HMWB designated linked to hydropower use in relation to the total number of HMWB

The Croatian government has developed its new energy strategy, which foresees investments in coal, gas, hydropower and possibly nuclear, in spite of the country's lack of coal resources. Renewable energy is marginalised and there is no commitment for an overall increase by 2020 (McGarath et al., 2010).

Hungary has decided to extend the capacity of the Paks Nuclear Power Station. The implementation of the extension may need to construct a new hydropower station at the south section of the Hungarian Danube reach to ensure secure cooling water supply for the extended nuclear power station.

There is a still unrealised, but long time considered plan about a hydropower plant and river barrage at the lower section of the Tisza river.

On other possible future large hydro-engineering construction plan is a long time considered water transfer from the Danube to the Tisza River, called the Danube -Tisza Channel. If that channel will eventually be constructed than some of the elements of the channel system will be used for hydropower generation, as well.

3.10 Governance in case of competition for water

A comprehensive hydro-political gap assessment paper in connection with the trans-boundary water cooperation in the European Union was published by Baranyai, 2015 under EUSDR Priority Area 4 activities[22]. This section highlights and cites the important points of that paper in connection with shared watercourses when competition situation occurs.

22 http://www.danubewaterquality.eu/news/dr-baranyai-gabor-transboundary-waters

"There is internationally accepted recognition that three basic principles should be applied when competition occurs for water in shared water resources. These basic principles are (i) the equitable and reasonable utilisation, (ii) prevention of significant harm (the "no-harm" rule) and the (iii) prior notification of and consultation on planned measures with significant transboundary effects. These principles are clearly expressed in the UN International Watercourses Convention."

"The equitable and reasonable utilisation principle underlines that there is no mandatory priority among competing water uses, but in the case of a conflict between uses special attention must be paid to the "requirements of vital human needs". The "no-harm" rule implies that states utilising their share of the international watercourse must take all necessary measures to prevent causing significant harm to other riparian countries. If such harm is nevertheless caused, all appropriate measures must be taken to eliminate or mitigate it. The Convention also describes the duties of states to cooperate over planned measures that may have a significant negative impact on other riparian countries as well as the related procedures that include prior notification and consultation."

Baranyai, 2015 pointed out that "Water quantity issues are addressed only superficially in EU water law (save groundwater quantity under the WFD and some policy efforts to reduce water demand). The WFD almost completely ignores the quantitative aspects of surface water management. The ecological flow concept ignores the water demand of sectors other than the demand of natural environment."

"Most European basin treaties, including the Danube River Protection Convention[23], have a biased ecological focus. This constitutes a major shortcoming as they leave new hydro-climatic and hydro-political challenges completely unaddressed. Most of the treaties do not even mention water quantity and contain no detailed principles or rules on water allocations. However, a good example is the 2002 Framework Agreement on the Sava River Basin (sub-basin of the Danube River Basin), which lays down important principles on sharing water among the riparian countries."

Europe was largely free from the most common human-induced pressures that could have seriously complicated hydro-politics elsewhere. So far, there were no significant population or urbanisation pressures on most river basins, including the Danube Basin, and upstream countries tend to be environmentally conscious with no unilateral water development agenda. There is also a long history of cooperation in most river basins as well as in the EU, environmental protection is a broadly shared political priority[24]. However, there are still some unsolved qualitative and quantitative issues in the Danube Basin having transboundary aspects, such as the settling of the consequences of the major cyanide pollution occurred in the upper section of the Tisza River or the unsolved water allocation in connection with the Gabcikovo Hydropower Dam.

3.11 Considerations from modelling point of view

EU water policy has a one-sided ecological approach that fails to properly address the quantitative implications of water use and its transboundary impacts. Water allocation issues are completely missing from EU water law and institutional practice. This is particularly problematic as the effects of climate change are primarily expressed in increased variations in river flow. EU law does not contain any norm to guide allocation of water among riparian countries of transboundary water courses. The EU has no legal framework to address in a transboundary context the most important hydrological impact of climate change, such as increased variability of river flows. Variability management is almost completely limited to flood prevention and control. Neither substantive rules, nor procedures are in place to address the impact on freshwater availability of other

[23] https://www.icpdr.org/main/icpdr/danube-river-protection-convention

[24] Mccaffrey, 2015

hydrological extremes whose frequency is expected to increase significantly (Baranyai, 2015).

Consequently, it is difficult to formulate transboundary water allocation rule(s) for rivers shared by more than one country in modelling practice when scenarios might reflect significant water shortages that would require transboundary water management measures.

In case of Danube River Basin modelling practice it is recommended to apply in such cases the individual country water allocation / water restriction regulation. For example the Hungarian Water Law determines[25]: If the amount of utilisable water is reduced to natural or other unavoidable reasons, the use of water - with the exception of subsistence use of water - can be limited, pause, or eliminated without compensation while maintaining safety standards. The limitations can be ordered in the following sequence:

1. Other water use (such as sports, recreation, bathing, tourist purpose, street wash, etc.)
2. Economic water use (industry, agriculture without par. 4 and 5)
3. Nature conservation water use
4. Livestock watering, fish farming,
5. Medical water use and water use of manufacturing and service activities for direct general public interest
6. Public water supply for drinking and sanitation; emergency response water use.

Regional water management institutions as well as public water works keep records on water limitations, but still there is no regular data collection on cases of water limitations. No national or EU statistics are available on where, when, on whom and what extend water limitations were ordered.

3.12 Summary

In this chapter a summary is given about a scenario that might be feasible version for the "near" future (2030-2050) for the Danube Basin and could be applied in the Danube Water Nexus modelling experience.

There is growing consensus in the scientific literature that the climate will change and air-temperature will increase. It seems that a realistic scenario for the Danube Basin is that the air-temperature increase between 1 and 2.5 °C The lower increase is expected in the Western part of the Danube Basin while the highest increase may occur in the South-Eastern region of the basin.

Significant increasing trends in maximum number of consecutive dry days will occur when from the long term average 25 days will increase by the end of modelling period to 35-40 days. This tendency will result in more dry soil during the vegetation period limiting the crop production yields from agriculture.

As a consequence of the air-temperature increase surface water temperature will further increase. Taking into account of the water temperature trends in major rivers an additional 1-1.3 °C water temperature raise is a feasible option. This increasing tendency will further shorten the period of ice cover on surface waters.

Annual average precipitation will follow a decreasing trend, but the rate of change much depends on local geographical conditions. The precipitation pattern, the frequency and the intensities of rainfall events will change. There is a tendency that a shift will occur from wetter spring-summer period to wetter winter and dryer summer.

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[25] http://net.jogtar.hu/jr/gen/hjegy_doc.cgi?docid=99500057.TV&timeshift=20160101 in 15. §.

The DRBMP 2015 Update states that water scarcity and drought are not considered as significant water management issues for the majority of the countries, only a few number of countries consider them as significant water management issues in the national River Basin Management Plans. The main sectors which were reported to be affected by water scarcity and drought include agriculture, water supply, biodiversity, other energy production, hydropower, navigation and public health. Water scarcity and drought was reported to be addressed by a number of Danube countries in their national River Basin Management Plans, whereas specific measures are planned or already under implementation (e.g. increase of irrigation efficiency, reduction of leakages in water distribution networks, drought mapping and forecasting, education of public on water-saving measures, market-based instruments, wastewater recycling and rain water harvesting).

The changing rainfall pattern will influence the intensity of storm events, which will grow as well causing more extreme floods. However, flood management systems in the Danube Basin are well developed, though maintenance is not always satisfactory and the monitoring network needs improving in the eastern part of the basin. Many settlements, railway lines, public roads, industrial plants, and a significant portion of the region's GDP is protected. It is generally believed that constructed civil engineering works reduce the consequences of severe floods, but such events do still occur and cause substantial economic and social damage.

In the Danube Basin the water availability, in general and in annual average terms, shows an acceptable picture. The total yearly renewable water resources exceeds 3 to 100 times of the total yearly water withdrawals. This is valid when the countries as a whole are taken into account. More competition situations might occur locally in case of long dry periods.

The total population of the Danube Basin is in a declining trend. Both the rural and urban population is decreasing, but the rural population is a bit higher rate. This "urbanisation" will follow resulting in higher demand on public utility companies in urbanised areas.

The utility service availability is already high in the Western half of the Danube Basin, while in the Eastern half considerable investment is needed to increase the level of public water supply and sanitation, especially in the West Balkan countries. This situation will create opportunities for new jobs in the construction industry and later in the public utility sector.

Although the needs for investment and development in the utility sector is very significant this situation raises some challenging questions as well: (i) what wastewater treatment technology would be realistic and affordable for these countries?; (ii) would there be enough financial resources in the countries to cover the costs of investment and later the operation and maintenance?; (ii) what would be the environmental impacts of these intensified investments on the water environment?; how the tariffs will change and these be economic and affordable?

The Danube countries are in need in energy, especially electricity. Hydropower is a significant and important potential in the Danube Basin. There are large number of hydropower stations in the Danube Basin, mostly small capacity ones, which have < 1MW capacity and installed dominantly in the western part of the basin.

It is foreseen that hydropower will be used more intensively in the in the West Balkan region, where countries have large hydropower potential and utilisation of them could strongly contribute their economic and social development.

The investment costs of hydropower development is high, thus it is foreseen that economic advantage of investments of hydropower stations will be challenges in about a decade when specific costs of the solar and wind energy production will be much more competitive. Danube Basin countries, and luckily countries in the West Balkan region are good located for solar and wind energy potential as well. Careful planning on selection among the options would be a benefit for these countries.

It is not foreseen that within 15 years large hydropower dam will be constructed on any of the large rivers of the Danube Basin.

In case of governance Danube countries lack to properly address the quantitative implications of water use and its transboundary impacts. This situation stems from the fact that the current EU water policy has a one-sided ecological approach that fails to properly address the quantitative implications of water use and its transboundary impacts. There is no legal framework to address in a transboundary context the most important hydrological impact of climate change, such as increased variability of river flows. Variability management is almost completely limited to flood prevention and control. Neither substantive rules, nor procedures are in place to address the impact on freshwater availability of other hydrological extremes whose frequency is expected to increase significantly. The current JRC Danube Water Nexus scientific work, the developed modelling tools might contribute to elaborate a legal framework on these issues as well.

4. Way forward

The information provided in this report refers to:

- the climate model scenarios being considered by the JRC for the modelling of water resources in the region;

- the LUISA model used to simulate scenarios of land use and related indicators

- some general trends in the availability of water resources in the region as well as dynamics related to their uses.

These elements form, in principle, the starting point of a foresight exercise aimed at identifying socioeconomic and climate scenarios worth being simulated in order to understand their implications for the energy-agriculture-ecosystems-water nexus.

This exercise should involve water stakeholders, professionals and decision makers in the Danube region and should serve to steer future scenario modelling initiatives also in support to the integrated management of the Danube river basin.

A combination of qualitative foresight and quantitative model simulation can be proposed as a practical way to unveil the interconnections among water availability and its use in different sectors, and the drivers of change in the mid- and long-term. Mastering these aspects is the first necessary step to design appropriate management measures aimed at:

- reducing the region's vulnerability to changes and potential conflicts;

- improving its resilience; and

- seizing opportunities for growth, jobs and prosperity related to a wise and sustainable management of water.

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List of abbreviations and definitions

EEA - European Environmental Agency

EU – European Union

EUSDR - European Union Strategy for the Danube Region

DRBMP - Danube River Basin Management Plan

DWN - Danube Water Nexus

ICPDR - International Commission for the Protection of the Danube River

JRC - Joint Research Centre

MS – Member States

WFD – Water Framework Directive

CAPRI - Common Agricultural Policy Regionalised Impact Modelling System

DG ECFIN -Directorate General for Economic and Financial Affairs

EC - European Commission

ERDF/CF – European Regional Development Funds/Cohesion Funds

EURO-CORDEX - Coordinated Downscaling Experiment - European Domain

GDP- gross Domestic Product

LUISA -Land-Use-based Integrated Sustainability Assessment

RCM – Regional Climate Model

RCP – Representative Concentration Pathway

NUTS 2 - Nomenclature of territorial units for statistics, Level 2

UNFCCC – United Nations Framework Convention on Climate Change

UNWTO - United Nations World Tourism Organization

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As the Commission's in-house science service, the Joint Research Centre's mission is to provide EU policies with independent, evidence-based scientific and technical support throughout the whole policy cycle.

Working in close cooperation with policy Directorates-General, the JRC addresses key societal challenges while stimulating innovation through developing new methods, tools and standards, and sharing its know-how with the Member States, the scientific community and international partners.

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