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CAPRI Water 2.0: an upgraded and updated CAPRI water module

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Contents

Abstract

Since 2012 the JRC has been working on the development of a water module in the CAPRI model to allow expanding the analysis of agricultural policy to cover water related issues. This report describes the latest improvements to the module including the change to 2012 base year, the update of the water data used and the spatial coverage, the inclusion of water as a production factor for rain-fed agriculture. In addition, it describes several aspects for further developments of the CAPRI water module, such as: to account for competition between agricultural and non-agricultural water use as well as extending the water module to non-EU regions. The usefulness of the update is shown with two stylized scenarios reflecting impacts of climate change both in terms of less water availability for irrigation and precipitation.

1 Introduction

The main objective of this technical report is to inform and document the latest developments of the Common Agricultural Policy Regional Impact Analysis (CAPRI) water module. Following the assessment of the feasibility to introduce water into CAPRI (Blanco et al, 2012), Blanco et. al. (2015) extended the CAPRI model with a water module consisting of an irrigation sub-module and a water use sub-module in order to make simulations and assess the potential impact of climate change and water availability on agricultural production as well as water use pressures at the regional level. Considering such food-water linkages is necessary in scientific support for designing water-related policies for sustainable water use, including the Common Agricultural Policy (CAP) as well as the Water Framework Directive (WFD) contributing to the Water-Energy-Food-Ecosystems (WEFE) nexus. However, several limitations were identified in the implementation of the water module that required further improvements related to data availability and comprehensive coverage of water as an input of agricultural production. A major issue for the water module was the lack of homogeneous and accurate data at European Union (EU) level for some of the important variables used in the model (irrigation cost, irrigation water use, irrigation efficiency, crop-specific irrigation areas, crop yields of irrigated and rain-fed activities, etc.). Therefore, this report covers a documentation of what data was improved or extended in order to enhance the performance of the CAPRI irrigation sub-module, and the consistency between the regional figures and the different levels of aggregation. In addition, the report covers the new developments in terms of crop-water linkages in rain-fed agriculture. In previous CAPRI modelling, such linkage was limited to irrigated agriculture only. Including water as a production factor in rain-fed agriculture allows for an analysis of impacts on EU agriculture originating from changes in precipitation. Results from test scenarios regarding less precipitation as well as less water availability for irrigation are presented here to illustrate how the model behaves after the latest extensions and developments.

Another major feature of the CAPRI Water 2.0 module is the fact that it is implemented in and is fully compatible with an updated CAPRI model version. In the previous version of the water module, 2008 was used as a base year. However, in the updated version the water module, the CAPRI model was also updated to 2012 as a base. This new baseline includes the 2014-2020 CAP already in the calibration and allows considering UK as a separate market region to account for the outcome of the BREXIT process. In addition, the baseline between the years has been improved and recalibrated to the Mid Term projections published by the European Commission in 2017. Therefore, it would be misleading to compare the simulation results between the two water module versions. Thus, the report focusses on documenting which data was updated and improved and which extensions were done in order to improve the food-water linkages, tested with some scenario runs to check the model behaviour with respect to these improvements.

1.1 The CAPRI model

The CAPRI model is a partial equilibrium, large-scale economic, global multi-commodity, agricultural sector model (Britz and Witzke, 2014). The effects of agricultural, environmental and trade policies on agricultural production, farm prices and income, trade, environmental indicators including water use are analysed in a comparative-static framework where the simulated results are compared to a baseline scenario that is calibrated on the Agricultural Outlook assumptions regarding macroeconomic conditions, the agricultural and trade policy environment, the path of technological change and international market developments, published annually by the European Commission's Directorate-General for Agriculture and Rural Development (DG-AGRI) (European Commission, 2017).

CAPRI consists of a supply module for Europe (with results on the regional, country and aggregated EU level) that interacts with a global market module where bilateral trade and prices for agricultural commodities are computed. The supply module covers more than 50 inputs and outputs which are produced or used in more than 50 crop and livestock activities in about 280 Nomenclature of Territorial Units for Statistics (NUTS) 2 regions within the EU. Technical information on inputs and outputs in the supply module allows using Positive Mathematical Programming (PMP) approach to endogenously compute agricultural production, where water in included as a production factor. The production of 47 primary and processed agricultural products from the supply module is covered by 77 countries in 40 trade blocks in the market model and the two modules interact until equilibrium is reached (Britz and Witzke, 2014).

1.2 Review of the pre-existing water module

The CAPRI water module builds on the irrigation and water use sub-modules. It integrates detailed water considerations in the supply module of CAPRI including irrigated and livestock water use at NUTS 2 level. This is done by modifying the standard CAPRI model in five areas:

1. Land is separated as irrigable (equipped for irrigation) where water input can be supplemented with irrigation and non-irrigable land, which only receives water input from precipitation. Total irrigated land cannot exceed irrigable land at the NUTS 2 level.
2. Crop production activities are split into rain-fed and irrigated variants. Input-output coefficients are estimated for both irrigated and rain-fed crop variants.
3. Water for irrigated crop variants is included as a production factor by considering crop-specific water requirements, irrigation/rain-fed shares, irrigated to rain-fed yield ratio, irrigation efficiency and a price/cost variable in scenarios ([1]).
4. Irrigation water use cannot exceed the potential available water for irrigation at NUTS 2 level.
5. Livestock water use includes both daily drinking and service water requirements. While irrigation water availability is constraint, livestock water is not. Rules of water allocation usually give priority to urban and livestock uses compared to irrigation.

To develop and integrate each of the steps above in the water module, different data sources were used to build the water database.

1. Data on total irrigable and irrigated areas and irrigation methods([2]) at NUTS 2 level originated from the Survey on Agricultural Production Methods (SAPM) 2010 as well as EUROSTAT (2000, 2003, 2005, 2007 and 2010) assessed in the Farm Structure Survey (FSS). As crop-specific irrigated area at NUTS 2 level was only available for 10 crops (durum wheat, maize, potatoes, sugar beet, soya, sunflower, fodder plants, vines, fruit and berry orchards and citrus fruit), for the other crops an estimation procedure is applied to ensure that the sum of irrigated shares match the total irrigated area in the region (Blanco et. al., 2015).
2. The ratios of rain-fed to irrigated yields at NUTS 2 level were derived from biophysical simulations with the World Food Studies (WOFOST) model([3]) for 10 crops (wheat, barley, rye, maize, field beans, sugar beet, rapeseed, potato, sunflower and rice).
3. Since official statistics do not report actual water use per crop, it was approximated through net irrigation requirements (simulated per crop and per

([1]) No data are available on volumetric water prices/costs in the irrigation sector for the base year period. But this parameter enters in the supply module and is intended to be used for simulation purposes reflecting price changes from water pricing policies, increased competition for water with other sectors, increased environmental awareness or improved monitoring of agricultural water use.

([2]) Sprinkler, surface and drip irrigation.

([3]) www.wur.nl/en/Research-Results/Research-Institutes/Environmental-Research/Facilities-Products/Software-and-models/WOFOST.htm.

region with the CROPWAT model(4) and irrigation efficiency coefficients taken from the literature.

4. Data on water availability, abstraction and use at NUTS 2 level for different sectors (irrigation, livestock, domestic, manufacturing and energy) came from the Joint Research Centre - Institute for Environment and Sustainability (JRC-IES) from the Distributed Water Balance and Flood Simulation Model (LISFLOOD) (Burek 2013). Data on water abstraction/use by sector is available also through the Organisation for Economic Co-operation and Development (OECD)/Eurostat Joint Questionnaire.

5. Livestock water use data for each type of animals were based on the literature (Van der Leeden (1990), Steinfield et. al. (2006), Ward and McKague (2007), Lardy et al. (2008), Shroeder (2012) and National Research Council (NRC) (1994-2012)).

However, some of the original data was incomplete at NUTS 2 level or even showed large discrepancies between sources. For example, EUROSTAT-FSS data is incomplete for some countries for any year but 2010. In addition, JRC-IES data and EUROSTAT data on water abstraction/use display large inconsistencies which might affect the quality of the final simulation results and comparability between regions without further action.. As a result, building an irrigation sub-module in CAPRI implied complementing EU data sources with ad hoc assumptions or second choice data as well as using econometric methods to build a technically consistent water database. Therefore it was necessary to update the existing database to enhance the performance of the CAPRI water module, and improve the consistency between the regional figures and data at higher levels of aggregation.

(4) www.fao.org/land-water/databases-and-software/cropwat/en/.

2 Update of the main statistical data sets used in the water module

This section describes which irrigation data were updated as well as extensions in the irrigation sub-module to new regions based on the updated data. Given that the raw data was updated, a new data consolidation and trend projection for irrigated activities was required as well and this section describes the approach taken for the update.

2.1 Data on irrigated areas in the irrigation sub-module

Due to its consistency and comparability, the preferred data source for irrigation areas is that available at EUROSTAT. Data on irrigation were updated to include the new data made available since 2016, this implies including a new year (2013) to the time series used in the first version of the water module in addition to the years previously used (2000, 2003, 2005, 2007, and 2010) (see Table 1).

Table 1. Data sources on irrigation areas (in bold additions to the previous module version).

Variable	**Unit**	**Temporal coverage**	**Spatial coverage**	**Spatial resolution**
Total irrigable area	ha	2000, 2003, 2005, 2007, 2010, **2013**	EU28, Norway and Switzerland	NUTS 0 and 2
Total irrigated area	ha	2000, 2003, 2005, 2007, 2010, **2013**	EU28, Norway and Switzerland	NUTS 0 and 2
Irrigated area by irrigation method	ha	2003		NUTS 0 and 2
Crop-specific irrigated area	ha	2000, 2003, 2005, 2007, 2010, **2013**	EU28, Norway and Switzerland	NUTS 0 and 2

Source: EUROSTAT- FSS, 2018.

Table 2 shows the gaps present in the previous Water Module database in the time series data on irrigable area (area equipped for irrigation) and irrigated area (area irrigated at least once a year) collected from EUROSTAT – FSS. Recall that the 2010 data was complete for all EU Member States, for the other years it may be noticed that no data is available for some countries (Germany, Estonia, Croatia, Ireland) or data is limited to total irrigated area (Czech Republic, Lithuania, Latvia, Poland, Sweden, Norway).

More data points are available for countries where irrigation represents a significant share of total utilized agricultural area (UAA). A few Member States represent more than 80% of total irrigated area in the EU (Spain, Italy, France and Greece) and crop irrigated areas for major crops are available for those countries for the years 2000, 2003, 2005 and 2007 (in the case of France, only from 2003).

However, with the latest 2013 FSS survey available on EUROSTAT the data for all variables were covered and complemented for all EU-28 Member States for 2010, but not the data gaps for previous years listed in Table 2. For 2010, irrigation data is available through the FSS and the SAPM. The SAPM was a one off survey in 2010 to collect farm level data on agri-environmental measures and no updates of this database are available. In addition, with the 2013 FSS survey new data was included for Iceland, Norway, Switzerland and FYR Macedonia and data on total irrigated area for Germany and Estonia.

Table 2. Availability of data on irrigation areas in period 2000-2007.

Country	**VARIABLE**												**Time period**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	
AT - Austria	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y		Y	2003-2007
BE - Belgium	Y	Y		Y	Y	Y			Y	Y			2003-2007
BG - Bulgaria	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y		Y	2003-2007
CY - Cyprus	Y	Y	Y	Y	Y				Y	Y	Y	Y	2003-2007
CZ - Czech Republic	Y	Y											2003-2007
DE - Germany													
DK - Denmark	Y	Y			Y				Y	Y			2003-2007
EE - Estonia													
EL - Greece	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	2000-2007
ES - Spain	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	2000-2007
FI - Finland	Y												
FR - France	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	2003-2007
HR - Croatia													
HU - Hungary	Y	Y		Y	Y	Y	Y	Y	Y	Y		Y	2000-2007
IE - Ireland													
IT - Italy	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	2000-2007

LT - Lithuania	Y	Y											2005 2007
LV - Latvia	Y	Y											2007
MT - Malta	Y	Y			Y			Y		Y	Y	Y	2003-2007
NL - Netherlands	Y	Y		Y	Y	Y		Y	Y	Y			2003-2007
PL - Poland	Y	Y											2003-2007
PT - Portugal	Y	Y	Y	Y	Y	Y	Y		Y	Y	Y	Y	2003-2007
RO - Romania	Y	Y		Y	Y	Y	Y	Y	Y	Y		Y	2003-2007
SE - Sweden	Y	Y											2003-2007
SI - Slovenia	Y	Y		Y	Y	Y			Y	Y			2003-2007
SK - Slovak Republic	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y		Y	2000-2007
UK - United Kingdom	Y	Y											2003-2007
NO - Norway	Y	Y											2005-2007

Variables (measured in ha): 1=Total irrigable area; 2=Total irrigated area; 3=Crop irrigated area (Durum wheat); 4=Crop irrigated area (Maize); 5=Crop irrigated area (Potatoes); 6=Crop irrigated area (Sugar beet); 7=Crop irrigated area (Sunflower); 8=Crop irrigated area (Soya); 9=Crop irrigated area (Fodder plants); 10=Crop irrigated area (Fruit and berry orchards); 11=Crop irrigated area (Citrus fruit); 12=Crop irrigated area (Vines).

Source: EUROSTAT- FSS, 2018.

2.2 Data on water abstraction by sector in the water use sub-module

Data on water abstraction/use by sector was updated through the OECD/EUROSTAT Joint Questionnaire to the latest available year (2015). However, concerns about the comparability and quality of the data still exist, mainly because data are provided by each country without using a common methodology. Moreover, the datasets is very incomplete (see Table 3). Thus, for the current water module it was decided to use the JRC-IES 2006 data as constant for all the years considered in the simulations (2010 to 2050). Therefore, water availability remains constant for the baseline. In addition, with this update it was investigated the possibility for extension to other EU regions that were not part of the previous water module.

Table 3. Data availability on annual freshwater abstraction by source and sector.

Country	Annual water abstraction by sector - data availability (available years)					
	Total	**Domestic**	**Agriculture**	**Agriculture-Irrigation**	**Industry**	**Energy**
AT		2008, 2011	2010	2010	2008	2008
BE	2006-2011	2006-2009	2006-2009, 2014		2006-2009	2006-2009
BG	2006-2015	2006-2015	2006-2015	2006-2015	2006-2015	2006-2015
CY	2006-2015	2006-2015	2006-2015	2006-2015		
CZ	2006-2015	2006-2015	2006-2015	2006-2015	2006-2015	2006-2015
DE	2007, 2010	2007, 2010	2007, 2010	2007, 2010	2007, 2010	2007, 2010
DK	2006-2014	2006-2012	2006-2012	2006-2012	2006-2012	2006-2012
EE	2006-2014	2006-2013	2006-2012	2006, 2007, 2009	2006-2012	2009-2013
EL	2006-2007, 2011-2015	2006, 2007, 2011-2015	2006, 2007, 2011-2015	2006, 2007, 2011-2015	2011-2015	2007, 2010-2015
ES	2006-2012, 2014	2006-2012, 2014	2006-2012, 2014	2006-2012, 2014	2006-2012, 2014	2006-2012, 2014
FI	2006	2006, 2009-2013			2006, 2009, 2010, 2012, 2013	2012, 2013
FR	2006-2012	2006-2012	2006-2012	2006-2012	2006-2012	2006-2012
HR	2008-2015	2006-2015	2006-2010	2006-2010	2006-2015	2008-2015
HU	2006-2012	2006-2015	2006, 2008-2012	2011-2015	2006-2012	2006-2012
IE	2007, 2009	2007, 2009-2015				
IT		2008, 2012				
LT	2006-2011, 2014, 2015	2006-2012, 2014, 2015	2006-2012, 2014, 2015	2006-2012, 2014, 2015	2006-2012, 2014, 2015	2006-2011, 2014, 2015
LV	2006-2009	2007-2009	2006-2009		2006-2009	2006-2009
MT	2006-2015	2006-2015	2006-2015	2006-2015	2006-2015	
NL	2006-2012	2006-2012	2006-2012	2006-2012	2006-2012	2006-2012

PL	2006-2015	2006-2015	2006-2015	2006-2015	2006-2015	2006-2015
PT		2006-2009, 2011, 2012		2009		2009
RO	2006-2015	2006-2015	2006-2015	2006-2015	2006-2015	2006-2015
SE	2006, 2007, 2010	2006, 2007, 2010	2006, 2007, 2010	2006, 2007, 2010	2006, 2007, 2010	2006, 2007, 2010
SI	2006-2015	2006-2015	2006-2015	2006-2015	2006-2015	2006-2015
SK	2006-2015	2006-2015	2007-2015	2006-2015	2006-2015	
UK	2006-2012, 2014	2006-2012, 2014	2006-2012, 2014	2006-2012, 2014	2006-2012, 2014	2006-2011, 2014
NO		2006-2014	2006	2006	2006-2009	
RS	2006-2015	2006-2015	2006-2015	2006-2015	2006-2015	2006-2015
BA	2006-2015	2006-2009, 2011-2015	2006-2009		2014, 2015	
ME						
MK	2006-2009, 2014	2006-2013	2006,2007	2006-2014	2006-2014	2006-2013
AL	2013-2015	2013-2015	2014, 2015			
TUR	2006-2010, 2012, 2014	2006-2012, 2014	2006-2015	2006-2015	2008, 2010, 2012, 2014	2006, 2008, 2010, 2012, 2014
KO	2006-2015		2015	2015	2006-2014	2006-2014

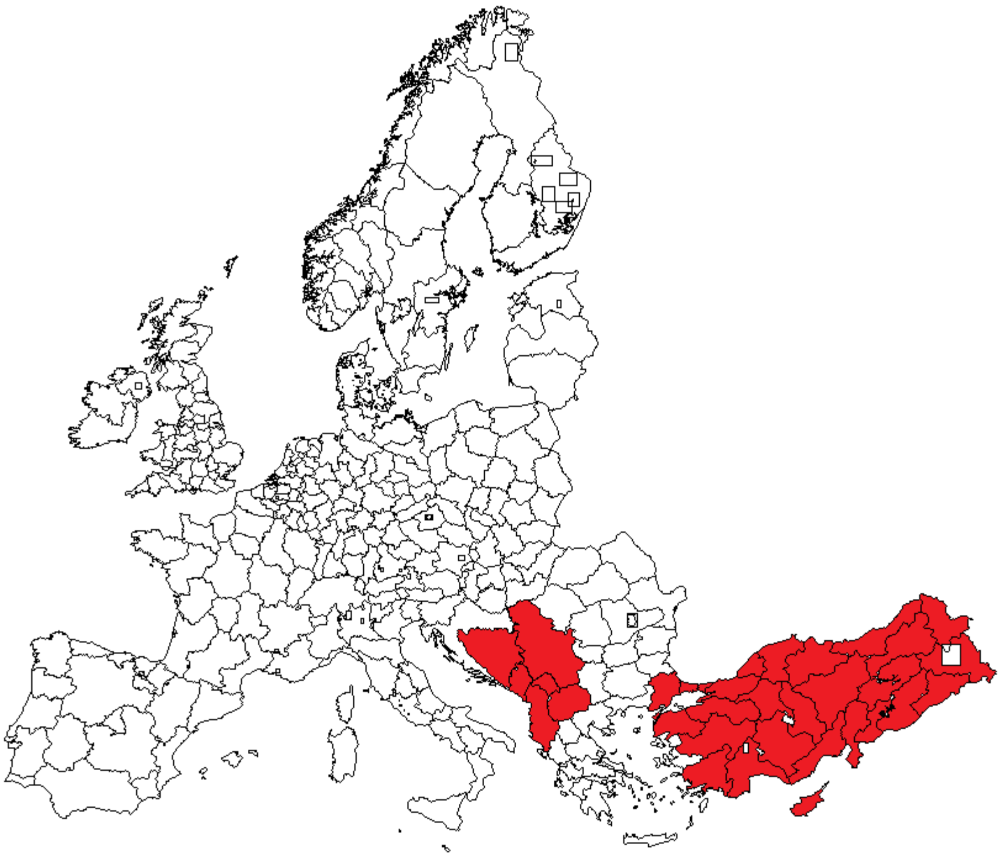
Note: RS – Serbia, BA – Bosnia and Herzegovina, ME – Montenegro, MK – FYR Macedonia, AL – Albania, TUR – Turkey, KO – Kosovo.

Source: EUROSTAT, 2018.

2.3 Extension of the irrigation sub-module to other EU regions

From the previous sections it can be noticed that the irrigation sub-module covered those European regions for which agricultural water data was available in EUROSTAT, basically EU-28 Member States plus Norway. However, with new available (JRC-IES 2006) combined with the updated irrigation data (EUROSTAT/FAOSTAT), all non-EU Western Balkan countries (Serbia, Bosnia and Herzegovina, Montenegro, FYR Macedonia, Albania, Kosovo) and Turkey were included (Figure 1). Thus, the new water module covered all regions in the CAPRI supply module.

Figure 1. New regions added in the irrigation sub-module.



Source: own illustration.

Regarding data on irrigation areas the SAPM 2010 provides data for Montenegro but not for Bosnia & Herzegovina and Serbia. Hence, the AQUASTAT database from the Food and Agricultural Organization of the United Nations (FAO) was used as an alternative source. AQUASTAT provides data on irrigable and irrigated land as well as irrigation shares at the country level for some particular years. However, AQUASTAT only provides the total irrigated land and not crop irrigated areas. National statistics will be needed to provide details on crop-specific data.

Regarding water abstraction by sector, data is available from the OECD/EUROSTAT Joint Questionnaire for Bosnia & Herzegovina and Serbia, but not for Montenegro. Therefore the JRC-IES 2006 data was used for Montenegro.

2.4 Consolidation of water data and trends projections

With the update and extension of the irrigation database, a new consolidation and update approach of the irrigation activities, in line with the projections' generator of CAPRI (CAPTRD) was required as well.. A standalone program was run to establish a complete and consistent water database (water_database.gms). Starting from the results of the regional ex-post time series (from module CAPREG) and trends (CAPTRD), this module disaggregates both data and projections to distinguish rain-fed from irrigated production, while keeping consistency between the "CAPRI water" baseline and the "CAPRI standard" baseline. To disaggregate the crop activities into rain-fed and irrigated variants, the following data sources were considered:

- Pre-2003 irrigation data (Estat_FSShist): EUROSTAT farm structure survey data, historical data until 2003 (Table 4, "ef_lu_ofirrig"). Provides irrigation data, including number of farms, areas and equipment by size of farm (UAA) and NUTS

2 regions, but only for the survey years (1990, 1993, 1995, 1997, 2000, 2003). While data at the NUTS2 level is provided, this dataset is not complete for irrigation data. No data is available for Bosnia and Herzegovina, Serbia and Montenegro.

- Post-2003 irrigation data (Estat_FSS): EUROSTAT farm structure survey data, from 2005 on (Table 4, "ef_poirrig"). Comprises irrigation data for the survey years starting in 2005 (2005, 2007, 2010, 2013). For 2010, data matches the Survey on agricultural production methods (SAPM). Data for 2016 is not available yet. No data is available for Bosnia & Herzegovina and Serbia. Data for Montenegro is only available for 2010.
- Irrigation data for non-EU regions (FAOSTAT): FAO data on irrigation areas and shares from 2006-2015. For the EU-28 Member States, data is taken from EUROSTAT and, therefore, the original EUROSTAT datasets are kept.
- Irrigation demand (CROPWAT): Simulations on crop water requirements (integrating rainfall and irrigation water) for major crops at NUTS2 level. Spatial coverage: EU-28, Norway, Turkey, Albania, Bosnia and Herzegovina, Serbia and Montenegro.
- Irrigation development forecast: The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT)([5]): Trends on irrigation areas and irrigation water availability up to 2050.

Table 4. List and location of updated data files.

Dataset	File name	Location in SVN server
FSS 1990-2003	dataFSS_ef_lu_ofirrig.gdx	\dat\water
FSS 2005-2013	dataFSS_ef_poirrig.gdx	\dat\water
FAOSTAT	faostat_irridata.gdx	\dat\water
CROPWAT	watreq_crops.gdx	\dat\water
LISFLOOD([1])	watbal_jrc_2006.gdx	\dat\water

([1]) Although LISFLOOD data was not updated it is included in the table to have the complete list of the irrigation database sources.

Even with the updated datasets, limitations persist and for some water variables, ad hoc assumptions or second choice data had to be used to address the data gaps. The approach to overcome data limitations included the following elements (Figure 2):

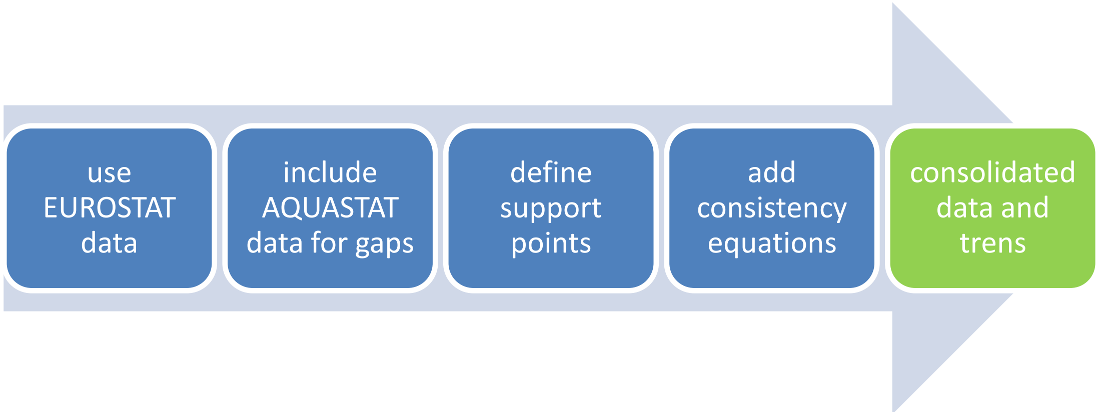
- Make use of all the data points available in EUROSTAT (for some countries data on rain-fed and irrigated areas were available only for a few number of crops and years).
- Fill remaining data gaps with AQUASTAT data or national statistics (whenever possible).
- Develop algorithms to fill persisting data gaps with expected values ("supports") for each variable (rain-fed and irrigated areas by crop and region).
- Include all the additional information in a data consolidation module, which calculates disaggregated time series that minimise the distance to the expected values while satisfying consistency equations (related to crop areas, crop yields and irrigation water use).

([5]) https://www.ifpri.org/program/impact-model

- Include all the additional information in the projection generator, adding consistency equations related to irrigation areas, crop yields and irrigation water use.

The final consolidated data and trends were calculated for the period 1995-2050 and were stored in folder results\capreg and results\baseline respectively.

Figure 2. Approach followed to overcome data limitations.



3 New developments

This section describes which new developments of the water module have been undertaken in order to better represent the crop-water linkages and the role of water in agriculture. The main focus is on how water has been included as a production factor also for rain-fed agriculture.

3.1 Water as a production factor in rain-fed agriculture

In the previous CAPRI Water module version, water has incorporated only in the irrigation sub-module which covered crop irrigation requirements and irrigation water use. However the role of water in rain-fed agriculture was neglected. The new module overcomes this limitation and better represents crop-water linkages, including water as a free (no cost / no price) production input in rain-fed agriculture. This makes it possible to simulate effects of changes in precipitation due to climate change on EU agriculture.

Theoretically there are two options to integrate crop-water linkages into a model such as CAPRI:

- **Crop-water productivity (CWP).** Also known as transpiration efficiency, CWP is the ratio of crop yield to the consumptive water required to produce that yield. CWP is usually measured in kg/m^3 of water. As crop growth models simulate crop yield and consumptive water use these can be used to calculate crop water productivity. Some authors find a close linear relationship between CWP and crop yield, while they report a plateau in CWP as consumptive water increases beyond a limit (Ashraf Vaghefi et al. 2017). For instance, Sadras and Angus (2006) find a maximum CWP for wheat in dry agricultural systems of around 2.2 kg/m^3 (while the current average is around 1.0-1.2 kg/m^3).
- **Crop-water production function**. The crop-water production function depicts the relationship between crop yield and the total volume of water used by the plant through evapotranspiration. Several methods exist to integrate water into the crop production function so as to reflect the yield response to varying levels of water consumption. Accounting for the yield effects of varying temperature and atmospheric CO_2 concentration, implies taking into account not only changes in water but also changes in CWP.

Both methods share similarities and only differ in the parameters used to account for the yield-water linkages. For the implementation of water-yield relationship for rain-fed agriculture, the production function approach was selected because input and output parameters are explicit and, in this way, it is easier to differentiate between rainwater and irrigation water. For the first approach, crop yield-water linkages for rain-fed and irrigated crops depend upon local conditions (soil conditions, weather conditions, etc.). Hence, field experiments or biophysical models are required to estimate the parameters depicting the link between water consumption and crop yields.

3.2 Crop-water production function

A crop-water production function depicts the relationship between crop yield and the total volume of water used by the plant through evapotranspiration. One of the most widely applied function to represent crop-water production functions is the linear evapotranspiration-yield relationship. Doorenbos and Kassam (1979) introduced a yield response factor (k_y), suggesting to use the following linear function:

$$1 - \frac{Y_a}{Y_p} = k_y * (1 - \frac{W_a}{W_p})$$

Where:

- Y_a is the crop actual yield, which is the crop yield achieved under actual conditions.
- Y_p is the potential yield, which is the maximum yield that can be achieved under no water and no input stress.
- W_a is the crop actual evapotranspiration, which is the volume of water actually consumed by the crop under actual conditions.
- W_p is the potential evapotranspiration, which is the maximum amount of water that a crop can use productively under optimum growth conditions (conditions where water, nutrients and pests and diseases do not limit crop growth). Agro-climatic conditions and the crop type are the main factors determining W_p, which is normally expressed in mm/day or mm/period.

Therefore, $1 - Y_a/Y_p$ is the relative crop yield decrease and $1 - W_a/W_p$ is the relative evapotranspiration deficit. The yield response factor is derived for each crop based on the assumption that the relationship between relative yield and relative evapotranspiration is linear. The greater the k_y, the more sensitive is the crop to water deficit. This function is widely used and has also been extended to account for different crop growing stages.

Table 5. Yield response factor for selected crops (k_y).

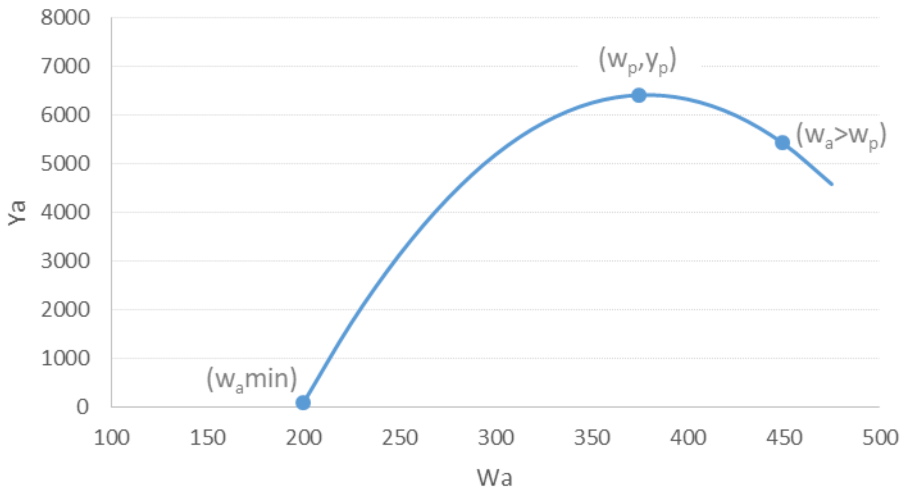
Crop	$\boldsymbol{K_y}$	**Crop**	$\boldsymbol{K_y}$
Alfalfa	0.7 - 1.1	Potato	1.1
Banana	1.2 - 1.35	Safflower	0.8
Bean	1.15	Sorghum	0.9
Cabbage	0.95	Soybean	0.85
Citrus	0.8 - 1.1	Sugar beet	0.7-1.1
Cotton	0.85	Sugarcane	1.2
Grape	0.85	Sunflower	0.95
Groundnut	0.7	Tobacco	0.9
Maize	1.25	Tomato	1.05
Onion	1.1	Water melon	1.1
Pea	1.15	Wheat (winter)	1.0
Pepper	1.1	Wheat (spring)	1.15

Source: AquaCrop

This is the approach used by the AquaCrop model (Raes et al., 2009). AquaCrop is a water-driven simulation model that requires a relatively low number of parameters and input data to simulate the yield response to water of most of the major field and vegetable crops cultivated worldwide.

However, the linear function does not represent adequately the conditions of extreme water stress or surplus. Other authors suggest using a quadratic function which can take into account that a minimum evapotranspiration is needed for a crop to start yield production (Figure 3 shows an example). English (1990) suggests that, as consumptive water increases, crop yield increases linearly, at least up to about 50% of the crop water requirement (for low volumes of water, transpiration efficiency is generally high). Above that level, the function takes a curvilinear shape. After the total crop water requirement is reached, more water may imply a decrease in crop yield. Other functional forms have also been used, as shown by Varzi (2016), who reviewed the applicability of several functions used to describe crop water production.

Figure 3. Example of a quadratic crop-water production function.



Source: adapted from English, 1990.

Despite the advantage of introducing a quadratic crop-water production function, the linear form was used mainly due to simplicity, but also data and model availability to estimate the quadratic production function. Conventional approaches to estimate crop-water production functions use crop growth models. Running biophysical models for each crop all over the EU is very data intensive and time-consuming (and exceeds the limits of this project). As mentioned before, water-yield relationships depend upon local conditions (soil type, climate, ...), and aggregation of simulated gridded crop yields to the NUTS2 level presents additional difficulties (Porwollik et al. 2017).

3.3 Technical implementation

3.3.1 Data sources related to crop water use

Time series on crop yields was obtained from official statistics, which only in exceptional cases differentiate between rain-fed and irrigated yields. However, water use by crop is not reported in official statistics (neither green (precipitation) nor blue (freshwater) water).

As consumptive water is not reported in official statistics, estimated values were used instead. Theoretical crop water requirements can be derived from crop-specific water balances at the local or regional level. Various modelling tools have been developed to estimate crop water requirement and the "crop yield response to water". A widespread approach are the FAO guidelines (Doorembos and Kassam 1979), which estimate the crop water requirement (CWR) as the potential crop evapotranspiration (CPET), avoiding the problem of clearly defining optimum growth conditions. This approach, based on the quantification of the cumulative crop evapotranspiration during the crop growing season, has been recently updated in the AquaCrop model (Raes et al. 2009).

In the current CAPRI-Water version, the CROPWAT model has been used to calculate CWR at the NUTS2 level for a set of 12 crops (soft wheat, maize, paddy rice, sunflower, olives, potatoes, sugar beet, tomatoes, apples, citrus fruits, table grapes and wine production). For the CAPRI crops not directly matched to CROPWAT crop simulations, assumptions were used by assuming that the non-modelled crop has the same value as a "similar" crop (see Table 6). CROPWAT distinguish between CRAIN (rainfall-based water or effective rainfall) and CNIR (net irrigation requirement). In the future other approaches could be envisaged to estimate crop-water relationships. Because of its simplicity and robustness, the AquaCrop model could be chosen to estimate crop water requirements, potential yields (non water-limited conditions) and rain-fed yields (standard rain-fed conditions). An alternative option would be to use data from other biophysical modelling tools such as WOFOST or LISFLOOD. As part of the WEFE nexus activities alignment to these last two models should be pursued to assure homogeneity in the way water-yield response is tackled within the nexus modelling in the JRC.

Table 6. Mapping between CAPRI and CROPWAT crops.

CAPRI crop activities	**CROPWAT crop activities**
Soft wheat	Soft wheat
Durum wheat	Soft wheat
Rye	Soft wheat
Barley	Soft wheat
Oats	Soft wheat
Maize	Maize
Other cereals	Soft wheat
Rapeseed	Sunflower
Sunflower	Sunflower
Soya	Sunflower
Fodder maize	Maize
Fodder root crops	Maize
Other fodder crops	Maize
Extensive grass production	Maize
Intensive grass production	Maize
Paddy rice	Paddy rice
Olives for oil	Olives for oil
Pulses	Maize
Potatoes	Potatoes
Sugar beat	Sugar beat

Tobacco	Sugar beat
Tomatoes	Tomatoes
Other vegetables	Tomatoes
Apples	Apples
Other fruits	Apples
Citrus fruits	Citrus fruits
Table grapes	Table grapes
Table olives	Olives for oil
Wine production	Wine production

3.3.2 Crop water requirements

Crops have access to water through rainfall, irrigation and residual soil moisture. The water really consumed by the crop is always less than the total of these three terms due to the losses (deep percolation and surface runoff). To include consumptive water use as a crop specific input, we need to distinguish between rainfall-based water and irrigation water. Several concepts are used to allow for that distinction:

- Crop water requirement (CWR), which is the maximum amount of water that a crop can use productively under optimum growth conditions (conditions where water, nutrients and pests and diseases do not limit crop growth). It is usually measured in millimetres per year.
- Effective precipitation or effective rainfall (CRAIN), which is the crop actual evapotranspiration under rain-fed conditions.
- Net irrigation requirement (CNIR), which is commonly determined as the difference between CWR (i.e. potential crop evapotranspiration) and the actual crop evapotranspiration under rain-fed conditions or effective rainfall (CRAIN).
- Potential yield (YPOT), which is the maximum yield that can be achieved under no water and no input stress.
- Water-limited yield (YLIM), which is the maximum yield that can be achieved under rain-fed conditions (and no input stress).

Therefore, once the crop water requirements (CWR or CPET([6])) are estimated, net irrigation requirement (CNIR) is calculated as the volume of water needed to compensate for the deficit of water over the growing period of the crop:

$$CNIR_{r,c} = CPET_{r,c} - CRAIN_{r,c}$$

Net irrigation requirement is then the total volume of water needed by a certain crop in addition to the rainfall for achieving the potential yield (YPOT). In the absence of irrigation, the maximum yield under rain-fed conditions (YLIM) is determined by the amount of rainfall and its distribution over the growing season. This water-limited yield is equal to the potential yield in the case of sufficient rainfall, and is lower than the potential yield in the case of water deficit.

([6]) Recall that Doorembos and Kassam (1979), estimated the crop water requirement (CWR) as the potential crop evapotranspiration (CPET)

The CROPWAT simulations provided data for on CPET, CRAIN and CNIR for 12 crops and for most regions in the supply module of CAPRI (EU28, Norway, Turkey, Albania, Bosnia and Herzegovina, Serbia and Montenegro). The data is stored under the p_cropwatReq parameter in the watreq_crops.gdx file located in the ...\dat\water folder.

In the current implementation, potential (YPOT) and water-limited (YLIM) yields are available at the NUTS2 level from WOFOST simulations, and were used to calculate the ratio rain-fed to irrigated crop yield. The yield data is stored under the p_wofostYld parameter in the same gdx file as the CROPWAT data and the yield calculations are in the irrigation_factors.gms file in the …/gams/water folder.

The main parameters used to model crop-water relationships in CAPRI are presented in Table 7 and they are loaded into the water module through the water_database.gms file located in the …/gams folder. Later on they are used to derive the yield water relationship described in the next section.

Table 7. Main parameters used to model crop-water relationships in CAPRI.

Topic	Variable	Unit	Code
Water input	Effective rainfall	mm	CRAIN
	Potential evapotranspiration	mm	CPET
	Actual evapotranspiration	mm	CAET
	Crop water requirement	mm	CWR
	Crop net irrigation requirement	mm	CNIR
	Crop net irrigation dose	m^3/ha	CNID
	Water application efficiency	%	IRWAE
	Water transport efficiency	%	IRWTE
	Water use efficiency	%	IRWUE
	Crop gross irrigation dose	m^3/ha	CGID
	Crop irrigation water use	m^3/ha	WIRR
Crop yield	Potential yield	kg/ha	YPOT
	Actual yield	kg/ha	YACT
	Water-limited yield	kg/ha	YLIM
	Water-limited to actual yield ratio		YRATIO

3.3.3 Yield-water relationships

While potential evapotranspiration (CPET or CWR) refers to the maximum evapotranspiration over the growing period of the crop under optimum growth conditions, actual crop evapotranspiration (CAET) refers to the actual level of evapotranspiration, given the available soil water.

Under non water-limited conditions, actual evapotranspiration (CAET) equals potential evapotranspiration (CPET) and the potential crop yield (YPOT) will be reached.

In practice, however, irrigation may be suboptimal or inexistent. In those situations, actual evapotranspiration (CAET) will fall below potential evapotranspiration (CPET) and water stress will adversely affect crop growth. As a result, the actual crop yield (YACT) will be lower than the potential crop yield (YPOT). Under rain-fed conditions, CAET may also fall below CRAIN because input stress([7]).

As CAET is not observed (not available in statistics), and actual irrigation water consumption usually differs from CNIR (maybe lower as in deficit irrigation), assumptions on irrigation intensity were needed to calculate crop net irrigation dose (CNID) where CNID = (CAET – CRAIN) * 10, considering the unit of m^3/ha. Due to the lack of data and for the time being, we assumed full irrigation such that CAET=CPET and CNID=CNIR*10.

Knowing the potential crop yield (YPOT) per region, allowed to define the actual yield (YACT, available from EUROSTAT) as a function of the potential yield and to define the technology variants for the irrigated activities in a way consistent with crop-water relationships.

The ratio water-limited to potential yield, together with the ratio CRAIN to CPET, allowed to define a water-yield relationship, which, in turn, was used as support to calculate the irrigation dose (CNID) as well as rain-fed and irrigated yields that match the observed average yield found in official statistics.

The modelling of the yield water relationships are in the block "yield response function" stored under the p_yieldWaterFun in the water_database.gms file located in the …/gams folder.

([7]) In the absence of a better assumption, CRAIN was used as a proxy for CAET under rain-fed conditions.

4 Scenarios

This section reports the assumptions of the baseline and the two scenario runs that were implemented in the updated version of CAPRI water to test the behaviour of the model regarding the updated data and the new developments. In particular, to assess the performance of the updated module, a test scenario with less irrigation water availability for irrigation in each country (water supply decrease) was designed. In addition to test how the new development related to rain-fed agriculture performs a test scenario with less precipitation in each country (rainfall decrease) was designed. It is important to note that the two simulation scenarios are hypothetical scenarios, designed to test the performance of the module. It is very likely that any future water stress scenario includes changes in water supply and also changes in precipitation.

4.1 Baseline

As explained in the introduction, the first step to evaluate the performance of the Water module 2.0 is to assess the baseline. While improvements to the baseline cannot be compared to the previous version, in this one the CAPRI baseline is successfully calibrated based on the mid-term projections for agricultural markets by DG-AGRI but also long-term projections by other models. The base year is set to 2012 compared to the older version where the base year was 2008. The CAPRI model with the water module replicates the 2012 baseline results without the water module. The relative changes for areas and yields at aggregated level between the models are shown in brackets in Table 9. The time horizon chosen for the simulations is 2030, due to the high degree of uncertainty surrounding long-term macroeconomic projections. Nevertheless, the year 2050 is also available considering the interest for the simulations for the longer term. The key inputs of the baseline run for 2030 may be summarised as follows:

- Database with historical series up to 2015.
- Mid-term projections for agricultural markets based on DG-AGRI's outlook for 2030 (European Commission, 2017). Policy assumptions, as well as the macroeconomic environment, are in line with this outlook.
- Biofuel trends up to 2030 come from the Price-Induced Market Equilibrium System (PRIMES) energy model[8].
- Trends on irrigation areas up to 2030 come from the IMPACT model.
- Explicit coverage of the most recent agricultural policy settings, i.e., CAP 2014-2020, pillars 1 and 2.

The baseline scenario for 2030 defines the reference situation and thus serves as a comparison point for the simulation scenarios defined in the next section. New tables on irrigation have been added to the CAPRI graphical user interface (GUI) in order to show the disaggregation of crop activities into rain-fed/irrigated variants (see Table 8).

([8]) https://ec.europa.eu/clima/policies/strategies/analysis/models_en#PRIMES

Table 8. Rain-fed/irrigated areas and yields for EU-28 in 2030.

	Area [1000 ha]			Yield [kg/ha]		
Crop	**Aggregate**	**Rain-fed crop variant**	**Irrigated crop variant**	**Aggregate**	**Rain-fed crop variant**	**Irrigated crop variant**
Soft wheat	23,603 (0.00%)	22,877	726	6,473 (0.00%)	6,452	7,129
Durum wheat	2,416 (0.00%)	2,029	387	3,879 (0.00%)	3,757	4,517
Barley	11,545 (0.00%)	10,813	732	5,221 (0.00%)	5,226	5,151
Grain Maize	8,792 (0.00%)	7,088	1,705	8,166 (0.00%)	7,138	12,431
Paddy rice	347 (-0.00%)	5	343	6,951 (-0.00%)	763	7,039
Rapeseed	7,912 (0.00%)	7,753	158	3,692 (-0.00%)	3,688	3,901
Sunflower	3,431 (0.00%)	3,289	142	2,177 (-0.00%)	2,103	3,893
Soya	605 (0.00%)	400	206	2,705 (-0.00%)	2,403	3,293
Potatoes	1,233 (0.00%)	1,014	220	39,026 (-0.00%)	34,898	58,035
Sugar Beet	1,555 (0.02%)	1,431	123	77,482 (-0.01%)	75,833	96,623
Tomatoes	233 (0.01%)	92	141	70,601 (-0.01%)	42,571	88,852
Other Vegetables	1,666 (-0.00%)	993	673	31,113 (0.00%)	25,325	39,648
Apples	798 (0.00%)	547	252	23,480 (-0.00%)	19,717	31,644
Other Fruits	1,741 (0.00%)	1,182	559	11,172 (-0.00%)	7,128	19,721
Citrus Fruits	570 (0.00%)	228	342	21,182 (0.00%)	14,029	25,939
Table Grapes	87 (0.00%)	48	39	18,512 (0.00%)	15,469	22,239

Olives for oil	5,460 (-0.00%)	3,808	1,651	2,754 (-0.00%)	1,913	4,692
Table Olives	292 (-0.00%)	202	91	2,908 (0.00%)	1,827	5,306
Wine	2,625 (0.00%)	2,094	531	5,663 (-0.00%)	5,307	7,069

Note: numbers in brackets are the relative changes between the CAPRI model with and without the water module. Only the most important crops in terms of irrigation are displayed here. Note also that irrigated and rain-fed areas are not always located in the same regions, explaining why rain-fed yields may be higher than irrigated yields for EU28 (case of barley).

The rain-fed/irrigated areas of the crop activities could also be aggregated per country (Table 9). What can be noticed is that the share of rain-fed area is dominant in all countries and Spain, Italy, France and Greece represent more than 80% of total irrigated area in EU.

Table 9. Rain-fed/irrigated areas in Europe in 2030.

Country	**Utilized agricultural area (1000 ha)**	**Rain-fed share (%)**	**Irrigated share (%)**	**Irrigated water use (Million m3)**
European Union 28	179,634 (0.00%)	94.5	5.5	43,357
Belgium	1,482 (0.00%)	99.6	0.4	9
Denmark	2,641 (-0.00%)	90.7	9.3	321
Germany	16,707 (0.00%)	99.2	0.8	227
Austria	2,865 (0.00%)	98.6	1.4	123
Netherlands	1,790 (0.00%)	94.9	5.2	192
France	28,546 (0.00%)	95.0	5.0	4,090
Portugal	3,316 (0.00%)	88.4	11.6	2,732
Spain	23,885 (0.00%)	87.5	12.5	18,097
Greece	4,939 (0.00%)	78.4	21.6	6,041
Italy	13,930 (0.01%)	80.6	19.4	8,710

Ireland	4,314 (0.00%)	99.9	0.1	2
Finland	2,249 (0.00%)	99.7	0.3	15
Sweden	3,016 (0.00%)	98.3	1.7	64
United Kingdom	17,010 (0.00%)	99.7	0.3	233
Czech Republic	3,724 (0.00%)	99.7	0.3	25
Estonia	939 (0.00%)	100.0	0.0	0.68
Hungary	5,436 (0.00%)	96.7	3.3	704
Lithuania	2,924 (0.00%)	100.0	0.0	2
Latvia	1,943 (0.00%)	100.0	0.0	0.72
Poland	15,584 (0.00%)	99.7	0.3	102
Slovenia	481 (0.00%)	99.6	0.5	2
Slovak Republic	1,925 (0.00%)	99.0	1.0	92
Croatia	1,346 (0.00%)	99.1	0.9	34
Cyprus	122 (-0.00%)	82.6	17.4	181
Malta	11 (0.00%)	78.9	21.1	19
Bulgaria	5,011 (0.00%)	97.7	2.3	625
Romania	13,498 (0.00%)	98.8	1.2	704
Norway	1,081 (-0.00%)	99.8	0.2	6
Serbia	4,275 (-0.00%)	100.0	0.0	
Montenegro	490 (0.00%)	97.6	2.4	44
Bosnia and Herzegovina	2,199 (0.00%)	99.7	0.3	15

FYR Macedonia	1216.49 (0.00%)	98.6	1.4	72
Albania	1237.13 (0.00%)	84.1	15.9	516
Kosovo	734.3 (0.00%)	99.5	0.5	8
Turkey	38762.98 (0.00%)	86.6	13.4	27,180

Note: numbers in brackets are the relative changes between the CAPRI model with and without the water module.

4.2 Scenario description: less water availability (water supply decrease)

Whereas water scarcity already constrains economic activity in many regions, the expected growth of global population over the coming decades, together with rising prosperity, will increase water demand and thus aggravate these problems. Climate change poses an additional threat to water security because changes in precipitation and other climatic variables may lead to significant changes in water supply and demand in many regions (Schewe et al., 2014). The impacts of climate change on water resources are, however, highly uncertain (IPCC, 2014).

Global climate models project that in Europe annual river flow will decrease in southern and south-eastern Europe and to increase in northern Europe, but quantitative changes remain uncertain (OECD, 2013). Strong changes in seasonality are projected, with lower flows in summer and higher flows in winter. As a consequence, droughts and water stress will increase, particularly in the south and in summer. Moreover, increased evaporation rates are expected to reduce water supplies in many regions. Increased water shortages are expected to increase competition for water between sectors (tourism, agriculture, energy, etc.), particularly in southern Europe where the agricultural demand for water is already high (OECD, 2013).

However, projections on irrigation water availability are not easily available, thus defining a future scenario becomes particularly challenging. A consistent water availability scenario would have to consider the effects of increasing water demand from other sectors as part of the macroeconomic framework, but this aspect is not possible in the current CAPRI water module. It is difficult, therefore, to specify the appropriate change in water availability that should be investigated in this project, however it is part of the developments expected within the JRC's WEFE Nexus project.

As a result, for the purpose of this report a stylized test scenario was run where a **30% decrease in irrigation water availability in 2030 in each country** was implemented. This was done by affecting the 2006 LISFLOOD data base. As soon as input data regarding future water availability is provided by the LISFLOOD model, a real scenario will be implemented. For the moment a simple test scenario has been used instead in order to check the model behaviour.

4.3 Scenario description: less precipitation (rainfall decrease)

The new implemented crop-water production function allows simulating effects of climate change on rain-fed and irrigated agriculture. One approach for doing so will be to calibrate crop-water production functions to yield changes from climate change for all for all crops and regions in the supply module of CAPRI. This approach may be impractical due to the large number of biophysical simulations involved. Therefore, to assess the effects of climate change on rain-fed agriculture it was decided to apply a simplified scenario analysis.

Biophysical simulations under pre-defined climate scenarios were initially decided to be used to derive the effects of climate change on crop evapotranspiration and crop yield. Yet, isolating the effect of change in precipitation on rain-fed agriculture is not straightforward. First, because effective rainfall (CRAIN) depends not only on the rainfall level but also on the distribution over the growing period, soil conditions, etc., which currently is not modelled in CAPRI. Second, because less water may be accompanied by changes in temperature and atmospheric CO_2 concentration, which influence on crop transpiration efficiency. Actually, many authors report beneficial effects of increasing atmospheric CO_2 concentration, which increases photosynthesis and decreases crop transpiration, even more for water stressed than for well-irrigated crops (Manderscheid and Weigel 2007, Karimi et al. 2017). Nevertheless, a hypothetical scenario with **20% decrease in effective rainfall in 2030 for all crops and regions** was run, in order to illustrate the behaviour of the model. The change in precipitation affects the yield ratio which consequently is reflected in the yield response function p_yieldWaterFun.

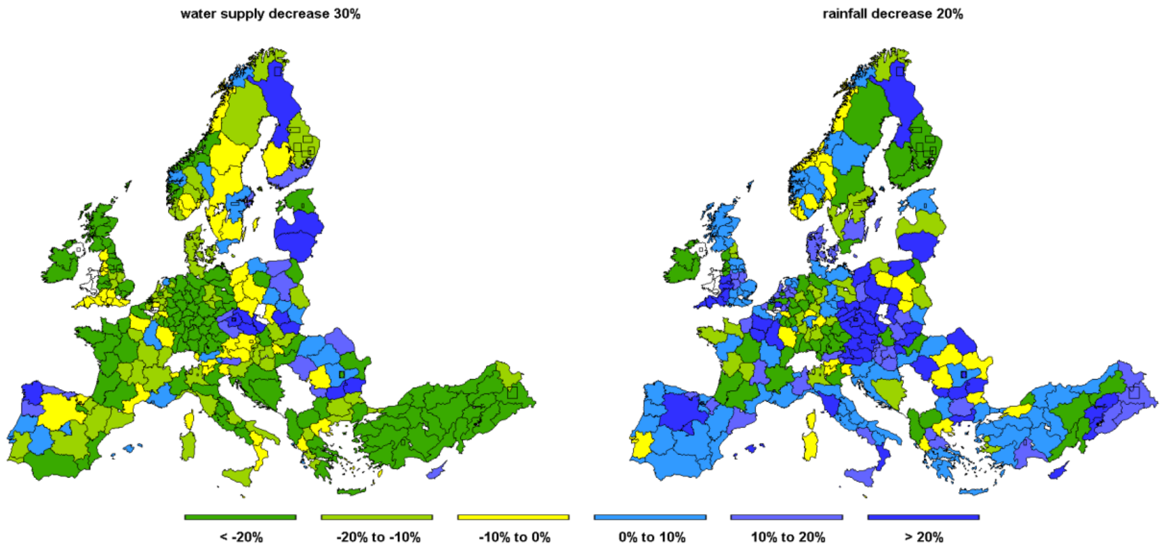
5 Results

In this section the simulation results from both scenarios are presented. The results of the changes in areas, yields, water use, income and prices are analysed at country level for all EU but also at crop level in EU28. Note, that refrain from any comparison of the simulation results between the two water module versions given that the new version uses a different base year (2012) and an updated baseline.

5.1 Country effects

The effects of water stress scenarios (decrease in water supply and decrease in rainfall) on irrigated and rain-fed areas are presented in Figure 4.

Figure 4. Effects on irrigated and rain-fed land in Europe in 2030 under the water supply and rainfall decrease scenarios (relative changes from baseline)([9]).

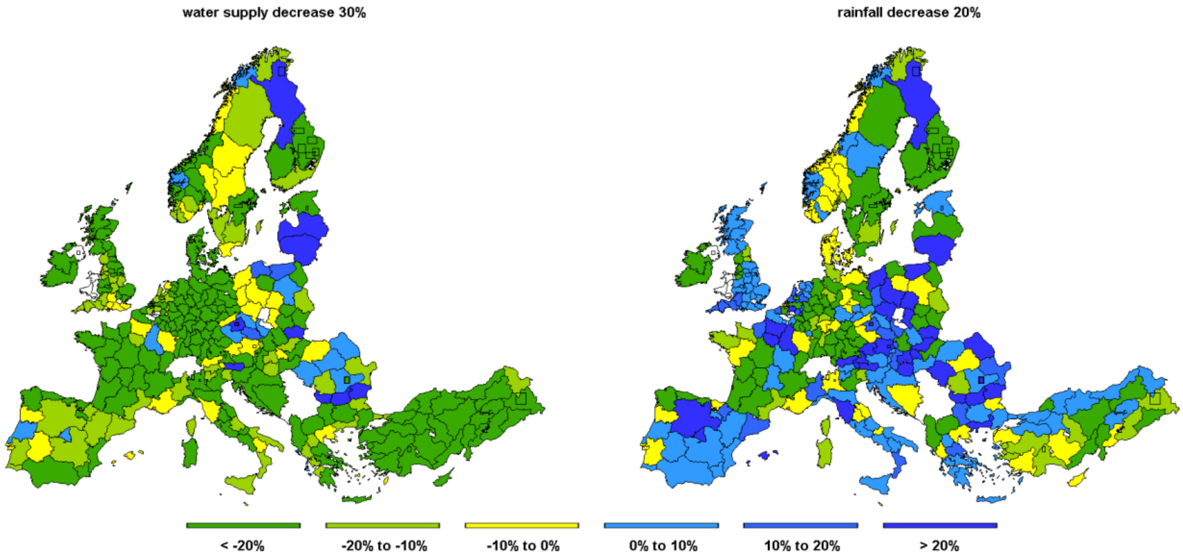


Regional disparities are noticeable but overall it displays that any water supply decrease will induce immediate decline in irrigated areas as a response to climate change. This implies that a decrease in water availability will be compensated by an increase in rain-fed crop variants and a decrease in rainfall will be compensated by increase in irrigated areas (Figure 4, right map).

When a decrease of water supply is considered, the decline in irrigated area will lead to a decline in the irrigated water use across Europe (Figure 5). The highest decline in water use is in countries with high irrigation shares in the baseline such as France, Spain, Greece, Italy, Portugal and Turkey (see Table A1.3 in Annex 1). An initial decline in irrigated areas will result in a decrease in production and supply (Figure 6). Consequently there will be a price increase. This will stimulate additional production from the use of inputs other that water, for example using rain-fed land. Since farms try to stabilize the overall production and income level, an increase in production and supply in rain-fed areas occurs. As water in rain-fed production is a free input, gain in profitability compared to irrigated ones, which together with higher prices supports income. This is particularly visible in countries where agriculture is mainly rain-fed (Belgium, Ireland, Estonia, etc.). On the contrary, in Spain and Greece there is an increase in rain-fed area but production decreases (Figure 6), which combined with lower average rain-fed yields (Table A1.6) will result in a small income decline. Nevertheless, as different price reactions will lead to a similar production level as in the baseline, the average income level in Europe increases by around 1%.

([9]) Absolute changes are provided in Annex 1 in Table A1.1.

Figure 5. Effects on water use (Million m^3) in Europe in 2030 (relative changes from baseline).



On the other hand, when a decrease in rainfall is considered, irrigation particularly rises in those countries where the irrigation shares are already high in the baseline situation as well as facing with water scarcity issues (Spain, Greece, Italy and Portugal) (see Figure 4, right map). This confirms that irrigation plays a role as an adaptation strategy to climate change. The increase in irrigated land will lead to an increase in water use (Figure 5). However, irrigation water availability is limited and thus a situation of water stress will arise in some regions/countries, driving up the opportunity costs for water. The increase in opportunity cost has similar effects to a price increase in water input. Such increase will be translated into higher crop production cost and consequently higher producer prices, stimulating production (Figure 7). As a result, income will increase in most of the countries. But again the average income in Europe will change marginally due to the different price and production reactions.

Figure 6. Effects on production (1000 t), prices (Euro/t) and income (Euro/ha) in Europe (upper) and non-EU countries (lower) in 2030 under the water supply decrease scenario (relative changes from baseline).

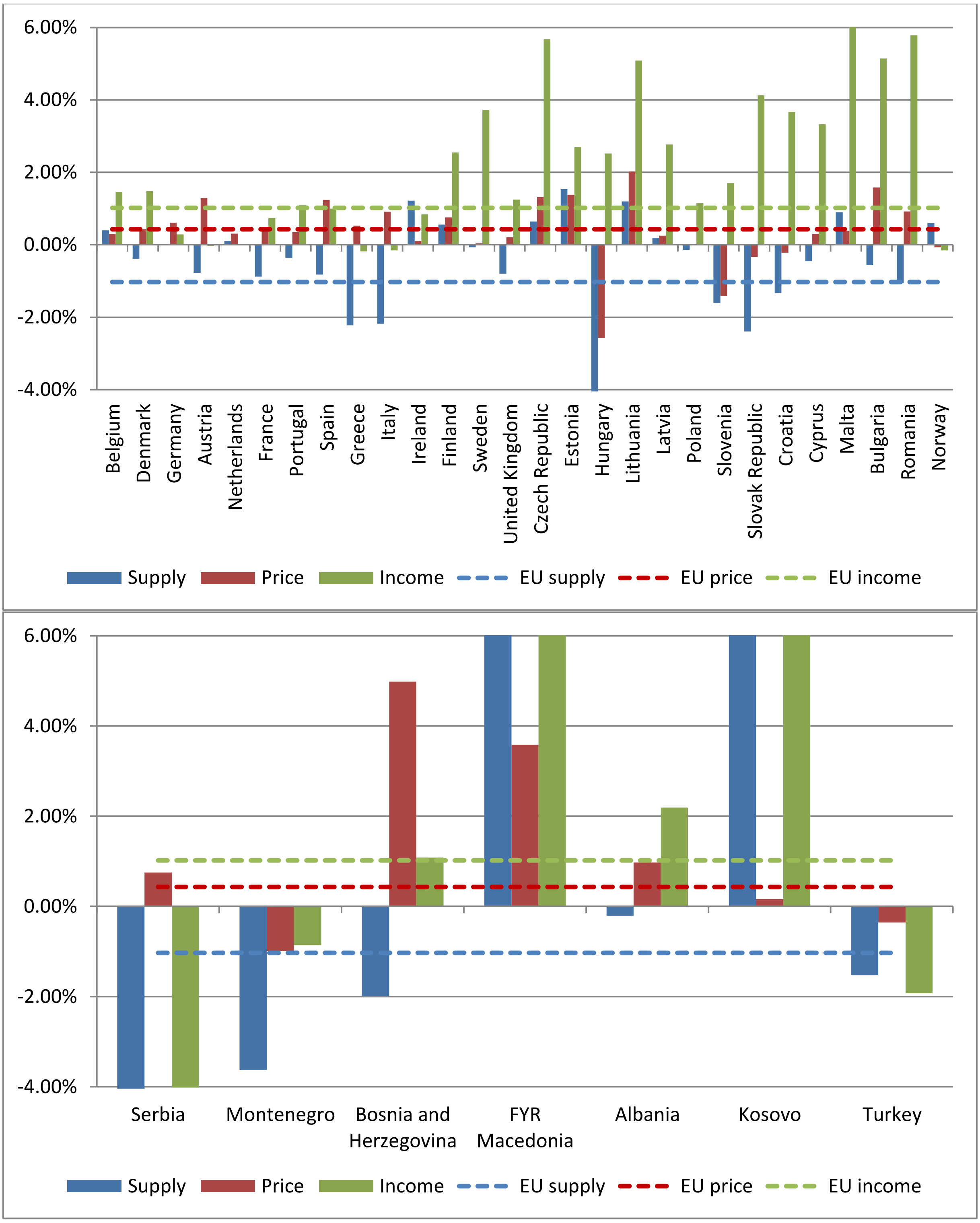
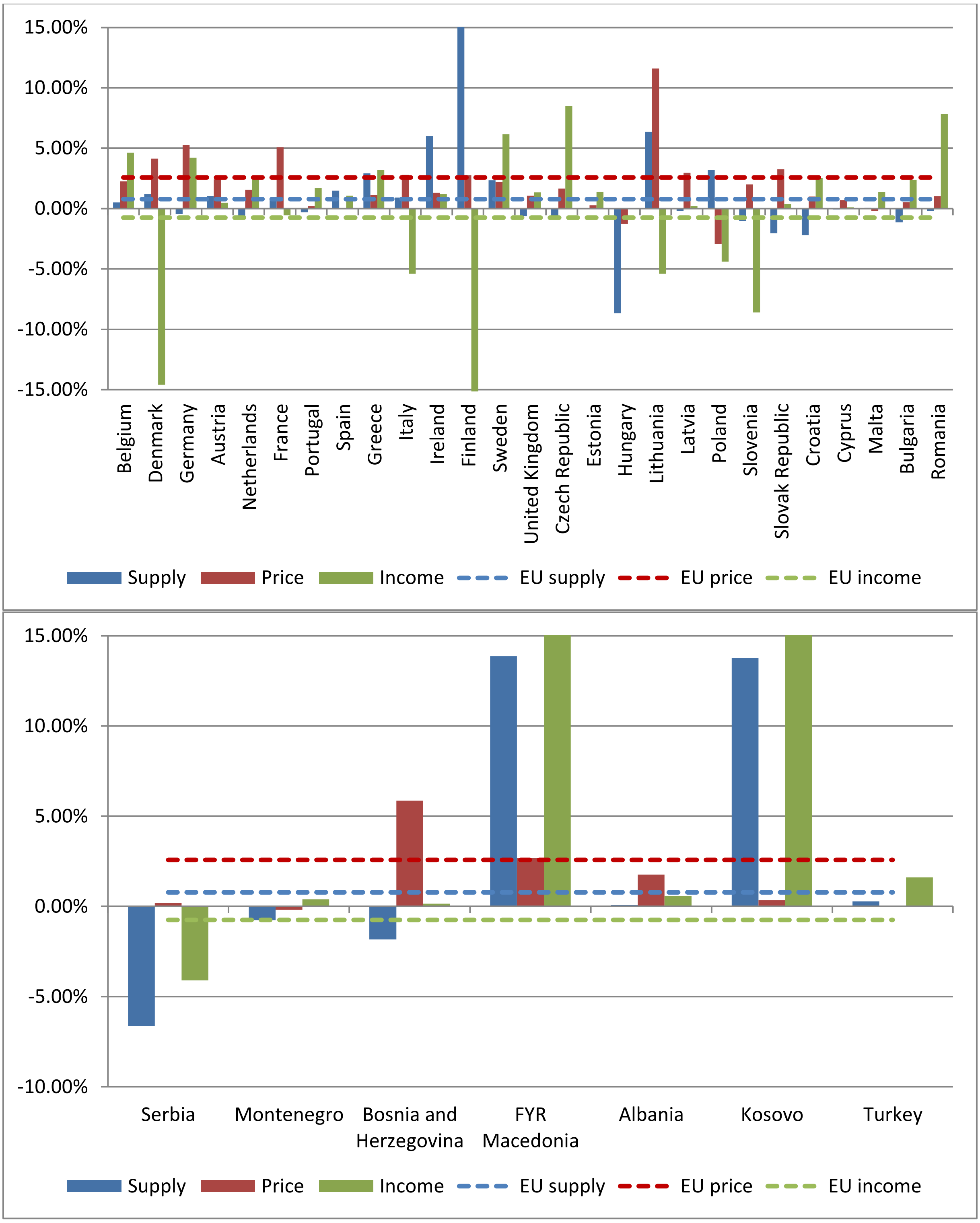


Figure 7. Effects on production (1000 t), prices (Euro/t) and income (Euro/ha) in Europe (upper) and non-EU countries (lower) in 2030 under the rainfall decrease scenario (relative changes from baseline).



5.2 Crop effects in EU28

Figure 8 displays the simulated results in terms of crop changes in EU28. It may be noticed that similar to the results at country level, a water supply decrease will induce a shift from irrigated to rain-fed crops (Figure 8, upper figure). This is especially evident for rice because it depends entirely on irrigation. The most significant decreases in irrigated land are observed for annual crops, while increases are observed for permanent crops. Thus, irrigation area is allocated to high value added crops such as table grapes, table olives and wine. For the other crops (wheat, barley, sugar beet, olives for oil, etc.) the shift to rain-fed area is not as significant as rice because the absolute area moved to rain-fed variant is relatively small compare to the total rain-fed area. Meaning for these crops most of the production is dominated by rain-fed agriculture (Table 8). Thus, even a small decline in the irrigated area will display large relative changes.

Figure 8. Effects of less water availability for irrigation (upper) and less precipitation (lower) on crop areas in EU28 in 2030 (relative changes from baseline).

Some crops such as rapeseed, table grapes and olives and wine display an increase in irrigated area despite the reduced water availability for irrigation. This is because switching entirely the area to rain-fed variant is not enough to offset the income loss from the irrigated crop activities. And rapeseed, grapes and olives are less water intensive that other profitable crops such as fruits and vegetables. The decline in the rain-fed area (supply), which obtains large proportion of total area, will be reflected in higher prices for these products. Because of higher prices and higher yields for irrigated crops (Table 8), a small increase in irrigated area is evident. However, this area is relatively small in absolute terms and even small change displays noticeable relative changes (see Table A1.5 in Annex 1).

Grain maize displays decline in both crop variants in both scenarios. The main reason is that maize is water-intensive crop and decline in water availability/precipitation will not consequently lead to an increase in the rain-fed/irrigated area. Due to the profit maximizing behaviour farms switch to less water-intensive crops such as wheat and barley because yield and consequently income losses from maize are much higher with water deficits either from precipitation or irrigation.

When it comes to rainfall decrease scenario we can observe the same behaviour, i.e. shifting land from rain-fed to irrigated area (Figure 8, lower figure). Such behaviour displays that irrigation plays a role as an adaptation strategy to any climate change effect which will lead to a decline in precipitation. However, this reallocation will come to a cost at the environment (Figure 9). Crops with large share of rain-fed area (cereals, oilseeds, sugar beet, olives and grapes) will put an additional pressure to the already limited water resources. The increase in water use may even be higher compare to the use when there is less water available for irrigation (soft wheat, rapeseed, fruits, wine).

Figure 9. Effects of decline in water supply and rainfall on irrigation water use (Million m^3) in EU28 in 2030 (relative changes from baseline).

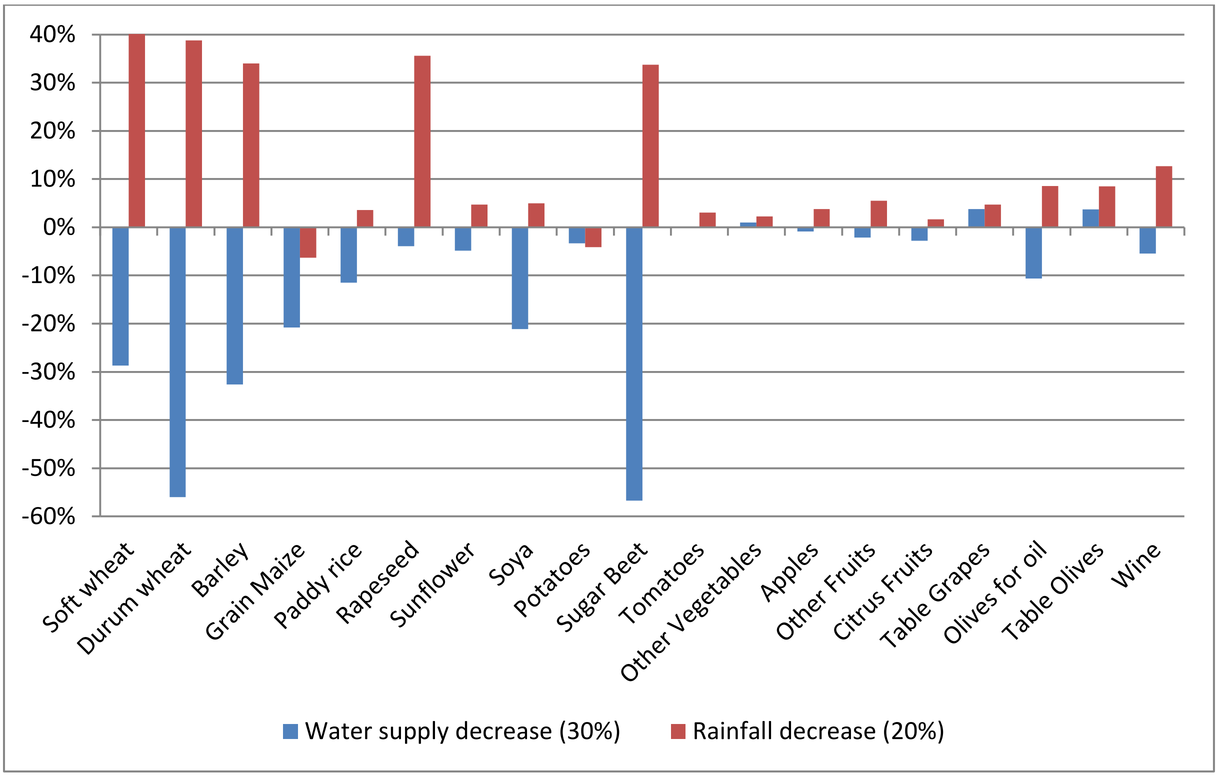
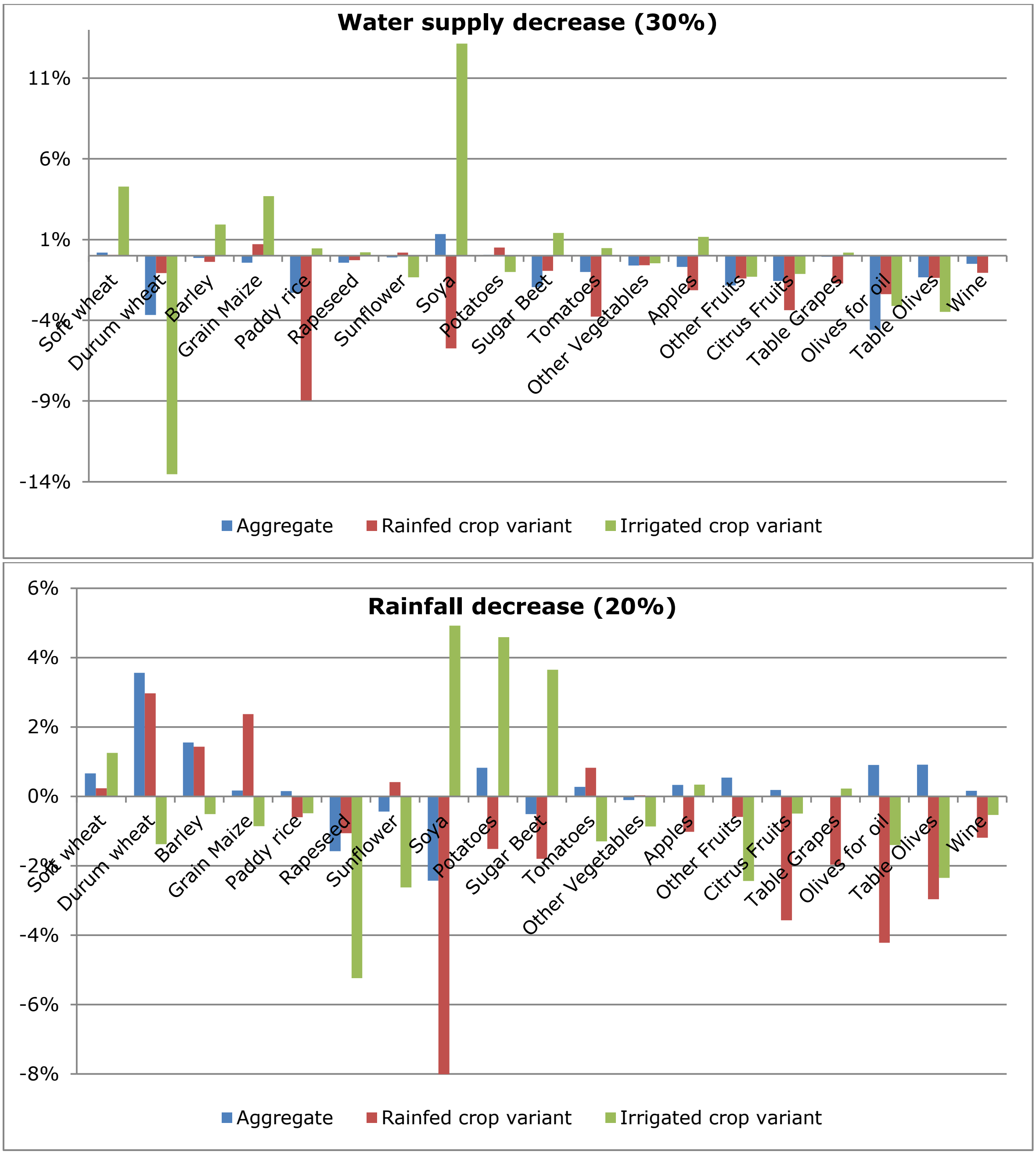


Figure 10 highlights the yield effects at EU level from both scenarios. Overall the results depend on the above described substitution effects between irrigated and rain-fed areas. Meaning less precipitation will directly affect crop growth and consequently results in lower yields for the rain-fed crops. Due to the lower yield, the ratio irrigated to rain-fed yields used to define the technology variants for the irrigated activities will result in higher irrigated area shares. Hence, an increase in irrigated area at EU level will give result in lower average yield (kg/ha) for the irrigated crop variants. Such changes overall are evident in the rainfall decline scenario. When it comes to the water supply decrease scenario, the yields are not affected directly as in the precipitation scenario. Thus, the change in irrigated yields is due to smaller/bigger area shared by similar yield level as in the baseline. The same holds for rain-fed crop variants.

Figure 10. Effects of decrease in water supply (upper) and decrease in rainfall (lower) on yields in EU28 in 2030 (relative changes from baseline).



The overall effect on prices and income is positive compared to the baseline. The decline in areas at aggregated level (see Table A1.5 in Annex 1), is driving up the producer prices and consequently the income (Table 10). But the EU aggregate income level remains similar (+/- 1%) as in the baseline. This is mainly due to the adaptation in the irrigation sector (shifts between rain-fed and irrigated crop variants) as well as adaption by land reallocation across crop activities within the irrigated and rain-fed areas. The reason why in the rainfall decline scenario there is an increase in the rain-fed area by 2%, despite the reduction in precipitation.

Table 10. Effects of decrease in water supply and rainfall on prices (Euro/t) and income (Euro/ha) in EU28 in 2030 (relative changes from baseline)

	Water supply decrease (30%)		**Rainfall decrease (20%)**	
	Income (%)	**Prices (%)**	**Income (%)**	**Prices (%)**
Soft wheat	4.08	1.45	7.69	3.19
Durum wheat	-1.98	1.28	0.95	0.18
Barley	4.16	1.71	5.50	2.94
Grain Maize	12.74	5.63	16.36	7.67
Paddy rice	-1.67	1.48	3.11	1.56
Rapeseed	14.61	5.47	-1.42	0.20
Sunflower	11.84	4.71	1.28	0.20
Soya	13.81	4.67	-3.45	-1.12
Potatoes	7.56	2.83	7.29	0.10
Sugar Beet	-5.00	1.00	145.40	8.19
Tomatoes	0.91	1.76	0.41	0.18
Other Vegetables	0.30	0.83	-0.10	0.13
Apples	0.24	0.84	0.79	0.32
Other Fruits	-0.09	0.07	0.62	0.26
Citrus Fruits	-1.23	0.74	0.21	0.07
Table Grapes	0.01	1.80	0.36	0.10
Olives for oil	13.83	16.40	-0.35	-2.10
Table Olives	4.31	2.31	3.00	0.57
Wine	1.97	1.52	7.99	3.83

6 Further improvements and extensions

This section provides information of possible improvements and extension to the CAPRI Water module 2.0 in order to continue the improvement of its stability as well as improve the representation of the crop-water relationships. Improvements and extensions are described related to the irrigation data base, irrigation costs, role of water surplus on yield crops, competition for water between different economic sectors and introduction of water in the global market module.

6.1 Water database improvements

Despite the significant update in the irrigation database undertaken when developing the CAPRI water module 2.0, there is still room for improvements since the current water database has not overcome all identified deficiencies/gaps. Some of the improvements in the database which would directly translate into an improved simulation behaviour of CAPRI-Water would relate to the following issues:

- Data on crop water requirements and yield response to water (ratio of rain-fed to irrigated yield).
- Effects of both water shortage and water excess on crop yields.
- Data on irrigation efficiency (and on irrigation methods, since they are interrelated).
- Assumptions regarding future water availability for irrigation.
- Assumptions regarding future irrigated area.

Table 11 lists the main suggestions for improvement of the database.

Table 11. Current implementation and suggestions for improvement of the water database.

Variable	Current implementation	Suggestion for improvement
Rain-fed and irrigated crop areas	Data on rain-fed and irrigated areas come from EUROSTAT (FSS + SAPM) for EU28 and Montenegro. Data for Bosnia & Herzegovina and Serbia was not available in EUROSTAT and was taken from AQUASTAT. EUROSTAT data was complete only for 2010. AQUASTAT only provides data on total irrigated area.	Check whether additional datasets are available on: (1) Crop irrigated area or crop irrigated share for additional year (apart from 2010). (2) Integrate FSS-2016 when available (most likely in 2018).
Rain-fed and irrigated crop yields	Data on aggregated yields are part of the CAPRI database. Rain-fed and irrigated yields are derived from biophysical simulations with the World Food Studies (WOFOST) model for 10 major crops within the EU at the NUTS 2 level. Based on these, the ratio irrigated yield to rain-fed yield was calculated. Then, rain-fed and irrigated yields consistent with aggregated	In the framework of the WEFE Nexus project incorporate data on rain-fed and irrigated yields (crop growth simulations) at NUTS 2 level coming from other JRC hosted water models, in particular: (1) For the current list of 10 crops: wheat, barley, rye, maize, field beans, sugar beet, rapeseed, potato, sunflower and

	yields in CAPRI are calculated by considering total production (crop area multiplied by crop yield) equals rain-fed production plus irrigated production.	rice. (2) For additional crops. (3) For additional countries and, in particular, for Bosnia & Herzegovina, Serbia and Montenegro.
Irrigation water requirements	Irrigation water use per crop is not available in official statistics. Thus, these data have been estimated based on theoretical water requirements, efficiency coefficients and actual irrigation water use by region. Net irrigation requirements by crop per region have been calculated using the CropWat model.	In the framework of the WEFE Nexus project incorporate data on water requirements and irrigation requirements by crop at NUTS 2 level coming from other JRC hosted water models.
Water availability, withdrawal and use	Water use by sector comes from JRC-IES datasets, i.e. LISFLOOD simulations at NUTS 2 level for 2006. Water abstraction and use are available for the irrigation, livestock, domestic, manufacturing and energy sectors.	In the framework of the WEFE Nexus project incorporate data on water use by sector at NUTS level coming from other JRC hosted water models, in particular: (1) for recent years (2010, 2012, 2015). (2) for simulated years (projections for 2030 and 2050).
Irrigation efficiency	Current irrigation efficiency is taken from the literature. Projections on irrigation efficiency come from a recent study from OECD, which only reports aggregate values for Europe.	Check whether additional data is available: (1) On current irrigation efficiency at NUTS 2 level. (2) On projections for irrigation efficiency up to 2050.
Irrigation expansion	Projections on future irrigation areas come from the IMPACT model, which provides projections up to 2050.	Check whether additional projections are available on irrigation expansion at the NUTS 2 level.
Future water availability scenarios	Only hypothetical scenarios on future irrigation water availability have been considered so far.	Check whether additional scenarios are available: (1) reporting changes in irrigation water availability by NUTS2 region (up to 2050). (2) reporting effects of climate change on water availability in Europe.

6.2 Irrigation costs

In the current CAPRI water module, water use costs are separated from other costs. However, EU-wide statistics appear to be lacking in the area of irrigation costs. Water is included as a cost item in the European Farm Accounting Data Network (FADN), but this cost component includes only the cost of connection to a water delivery system and the costs of water consumption. Water application costs as well as irrigation investment costs are not reported separately in FADN. The cost of using irrigation equipment is recorded under 'current upkeep of machinery and equipment', 'motor fuels and lubricants' and 'electricity'. Capital cost is recorded under 'investment' and 'depreciation'. As production costs given by FADN are not broken down to the level of agricultural activities, CAPRI uses an econometric procedure to allocate farm input costs to particular agricultural activities (Jansson and Heckelei, 2011). In spite of the difficulties in individualising irrigation costs, FADN data should be used as much as possible for consistency with the input allocation model in CAPRI. Nevertheless, as available data on irrigation costs are very limited, additional data from national statistics should, ideally, be used to fill the gaps in EU-wide statistics.

6.3 Role of excess water on crop production

In the literature one usually finds reference to the effect of water deficit because of the negative impact on crop yields. However, excess/surplus water related to flooding is also an important aspect that has a significant effect on agricultural production. Thus, it is important to consider the effect of excess water on crop production in the CAPRI water module.

For this purpose, the crop-water production function can also be used to simulate effects of excess water on crop production. Similarly to the procedure developed for simulating rain-fed water stress, the effect of excess water can be explored via scenario analysis.

Biophysical simulations are needed to define the effect of excess water on crop yields, which will depend not only on the precipitation level but also on its distribution over the growing period of each crop. Therefore, each scenario run with biophysical models will provide changes in crop yields and evapotranspiration both for rain-fed and irrigated crops.

A stylized approach based on water stress indexes could also be explored. The crop water stress index (CWSI) is commonly measured daily. An average over the growing period or for each stage of growth of the crop could be related to end of the season yield changes. The advantage of this approach is that it could rely on CWSI estimated in other studies.

6.4 Linkage of agricultural water demand to other sectoral demands

6.4.1 Review of modelling approaches

While many local/regional models account for agriculture-water linkages, modelling water balances in national/global agricultural models is not very common. This is partly due to some unique characteristics of water:

- Unlike other farm resources, water is mobile. Water flows through the hydrological cycle, making the availability and use of water very variable over time and space.
- Water is not completely consumed in the course of its "use" in agriculture (and also in other sectors). This means that downstream users are affected by the return flows of upstream users and, therefore, it is important to distinguish between water use and water consumption and to account for return flows when calculating total water availability.

Lack of statistical datasets on the availability and use of water, together with difficulties in modelling water balances at administrative regional level (the river basin level would be preferable in this case), hinders the integration of water balances in the supply module of CAPRI.

To explore the possibility of further developing the water module to account for competition for water between agricultural and non-agricultural sectors, the approaches used by other global agricultural models have been reviewed. Two global partial equilibrium models account for agricultural water use: IMPACT and Global Biomass Optimization Model (GLOBIOM)([10]). IMPACT runs a water allocation model and applies allocation rules in case of water shortages. On the contrary, GLOBIOM focuses on agricultural water use and uses a simplified supply function implying increasing water use costs.

The IMPACT model, developed by the International Food Policy Research Institute (IFPRI) was one of the first global models to integrate a global food projections model with a global water model to jointly analyse water and food supply and demand into the future under various policy scenarios (Cai and Rosegrant 2002). The combined food-water modelling framework has been continuously updated and it is extensively used to analyse water availability, food security, and environmental conservation at basin, country, and global scales (Sulser et al. 2010).

The GLOBIOM is a mathematical programming-based global recursive dynamic partial equilibrium model integrating the agricultural, bio-energy, and forestry sectors (Sauer et al. 2010). Crop production parameters are obtained from international sources and through linkage to biophysical models, EPIC in particular. To account for competition with other water sectors, GLOBIOM incorporates an irrigation water supply function, which is depicted as constant elasticity, upward sloped function. The price elasticity of water supply is based on estimations by Darwin et al. (1995) and equals 0.3 for all regions (Schneider et al. 2011). GLOBIOM accounts for irrigation water consumption (both beneficial water use by the crops and the application efficiency that depends on the irrigation method) but it does not account for irrigation water use in terms of actual water withdrawals from surface water or groundwater.

Both approaches could be applied in CAPRI Water module. Hereafter, we provide a structured procedure (steps, data needs, potential limitations and bottlenecks) to implement each of them.

6.4.1.1 Water supply curve approach

CAPRI already integrates a land supply module, which accounts for land competition between agriculture and other sectors. A similar approach could be envisaged for water. However, unlike for land resources, data on water availability is scarce. Moreover, as seen above, water is a mobile resource and both availability and use are highly variable over time and space.

Therefore, a water supply module will imply a combination with biophysical models able to account for water balances. This approach will be analysed in the next section. Here, we will explore the possibility of applying a simplified version, as a first approximation to modelling competition for water between agriculture and other user sectors.

The idea will be to include in CAPRI Water module an irrigation water supply function, representing the relative water scarcity through an increasing marginal cost. In this "artificial" water supply function, the upper limit on irrigation water availability can be computed by considering the sustainably exploitable internal renewable water resources, together with water demands from other sectors (domestic, industry, livestock and environmental flow).

This modelling approach relies in a number of simplifications:

([10]) http://www.globiom.org/

- A functional form for the irrigation water supply curve needs to be selected; for instance, a constant elasticity, upward sloped function. Parameters for this water supply function will be taken from the literature.
- Calibration of the irrigation water supply curve in the baseline situation will rely on a number of assumptions because no time series on water use by sector are available. An alternative would be to rely on simulated values from other models.
- The wide variety of water conditions within each NUTS2 region of the EU will be summarized in a limited number of parameters.

This approach could be easily implemented in the current structure of CAPRI Water module. It could represent a first step to take into account the competition for the use of water. Nevertheless, the link between water pressures and water availability will be absent or approximate.

6.4.1.2 Water balance approach

Another approach to model competition between agricultural and non-agricultural water use consists of representing water balances at the regional level. Taking into account data availability, additional water using sectors can be considered (domestic, industrial, energy, irrigation and livestock). Sectoral water withdrawal and use can be assessed for each sector. Water use by sector could be computed as a function of water use intensity (e.g. domestic water use per capita) and the driving forces of water use (e.g. population). The main driving forces of water use are population in the domestic sector, industrial production in the industrial sector, irrigated area and climate in the irrigation sector and the number of livestock in the livestock sector. Regarding energy use we can rely on the Dispa-SET power system model([11]) where water use for hydro energy is one of the inputs into the power system modelling. However, will have to only consider final water use which is the one using for colling purposes. The water use for hydro energy only passes through the turbines and may be reused downstream by the other sectors.

Total water supply will be taken from official statistics (EUROSTAT, FAOSTAT) and/or other modelling systems (IMPACT) and will be used to estimate water stress indicators.

For a given water availability, water withdrawal and use in the domestic, industrial, energy, irrigation and livestock sectors may be computed.

For each sector, water withdrawal, total water use and consumptive water use may be distinguished. While water abstraction is the quantity of water taken from any water source, water use is the part of the abstracted water reaching the end user and water consumption is the part of the water actually consumed. The ratio of consumptive water use to water withdrawal is the sectoral water use efficiency.

Water withdrawal and use in the main sectors (domestic, industrial, irrigation and livestock) will be simulated following a balance approach and allocation rules to account for competition between users. In most models, allocation rules give priority first to the domestic sector, then to the livestock and industrial sectors and finally to the irrigation sector. Therefore, water scarcity will mainly affect the irrigation sector. As data on environmental flows is lacking, some assumption will be needed to account for environmental water demands.

In theory, sectoral water withdrawal and use is provided by EUROSTAT at the national level. In practice, few data points are available and, therefore, results from other modelling tools will be needed instead. Water stress indicators, such as the water exploitation index, will be calculated.

Future food-water scenarios may imply changes both in water use intensity and the driving forces of water use and, therefore, may imply changes both in sectoral water

([11]) http://www.dispaset.eu/en/latest/index.html.

demand and water availability. This approach has the advantage of making explicit the link between water pressures and impacts over water sectors.

Implementing this approach also presents some difficulties:

- Taking into account interregional water flows when estimating water availability is not straightforward.
- Making a distinction between water use and water consumption (water depletion) also adds complexity.

A more comprehensive way of representing water competition between agriculture and other water use sectors would be by combining CAPRI with a biophysical/hydrological model. The distributed water balance model LISFLOOD could be one option.

As LISFLOOD and CAPRI use different spatial and temporal scale, linking together these models would not be easy. Nevertheless, both modelling systems could benefit from exchange of information by a soft-linking procedure. LISFLOOD could provide CAPRI with estimates of irrigation water requirements per crop, which are needed to account for irrigation water use. Likewise, CAPRI could provide LISFLOOD with estimates of future cropland allocation under alternative scenarios, which are needed in LISFLOOD to account for future agricultural water demand. This option will be pursued as part of the WEFE Nexus project.

6.5 Irrigation and water use in the CAPRI global market model

While the detailed supply models for EU regions present great advantages for integrating water considerations, the way how the CAPRI market module is presented creates limitation to incorporate crop-water relationships. The main reason why the water module is only available for the supply part is because agricultural production in the market part is modelled through behavioural equations that do not distinguish between an area and a yield response. However, an alternative way is to implement the water relationships similar to the land allocation modelling approach in the CAPRI global market model.

In the current implementation of the land allocation system, land supply and demand are function of the land price. Integration of land demand consists in treating land as a net put in the normalized quadratic profit function of CAPRI. Hence, land demand from agriculture reacts to changes in the land price and output quantities depend on land prices. In order to parameterize the function, information about yield and supply elasticities is used. Land supply is integrated through a land supply curve with exogenous given elasticities.

Irrigation water could be incorporated in the normalized quadratic profit function of CAPRI. Assuming that irrigation water demand depends on water price, changes in irrigation water can be accounted. A specific assumption on the relation between yield and water use will be needed.

Data requirements will include:

1. Data on total irrigation water use for countries / country blocks.
2. Supply elasticities for irrigation water.

Water supply could be integrated through a water supply curve with exogenous given elasticities.

Information needed to parameterize the demand and supply functions could be borrowed from other models and studies, such as the IMPACT and the global freshwater (WATERGAP)([12]) models.

([12]) https://en.wikipedia.org/wiki/WaterGAP

7 Summary

This report provided insights of the latest improvements in the CAPRI water module to improve the model performance in terms of representing the food-water linkages.

1. The water database has been updated and time series on irrigated areas have been incorporated. The water database has been extended to more non-EU countries included in the supply module of CAPRI (such as Western Balkans and Turkey).

Table 12. Update of the water database.

Data source	Previous CAPRI Water version	Current CAPRI Water version
FSS		
Spatial coverage	EU28, Norway	EU28, Norway and Montenegro
Time coverage	2010	1990,1993,1995,1997,2000,2003,2005,2007,2010,2013
LISFLOOD model		
Spatial coverage	EU 28	EU 28
Time coverage	2006	2006
FAOSTAT		
Spatial coverage	--	Western Balkans
Time coverage	--	2006-2015
WOFOST simulations		
Spatial coverage	EU28, Norway and Turkey	EU28, Norway and Turkey
Time coverage	2010 and 2030	2010, 2030 and 2050
CROPWAT model		
Spatial coverage	EU28	EU28, Bosnia & Herzegovina and Serbia
Time coverage	-	-
IMPACT model		
Spatial coverage	EU28	EU28, Bosnia & Herzegovina and Serbia
Time coverage	2030	2030 and 2050

2. Trends on water related variables have been integrated into CAPRI projections. A data consolidation procedure has been used to deal with data gaps.

3. To better represent the role of water in agriculture, water as a production factor in rain-fed agriculture was included. A crop-water production approach has been selected and implemented, using assumptions to overcome data gaps. The combination of the CAPRI model with biophysical models is recommended to account for yield-water relationships in an improved way.
4. The CAPRI-Water version has been aligned with the current CAPRI trunk. As a result, the CAPRI-Water baseline is compatible with the updated base year 2012 and includes the most recent policy setting (CAP 2014-2020 as well as Brexit situation).
5. In order to check model behaviour regarding the new model extensions, two test scenario runs has been performed. One with 30% water availability for irrigation in each country in 2030 and the other with 20% decrease in effective rainfall in 2030 for all crops and regions. The results display that due to less available water farmers will depend more on rain-fed agriculture. However, the decline in production for some crops will be reflected in higher prices and consequently higher farmer income. On the other hand with less precipitation, farmers will depend more on irrigation which will allow maintaining the same income level as before but imposing additional stress to the water resources in some areas.
6. Further improvements in the water data base such as:
    - Rain-fed and irrigated crop yields at NUTS 2 level for current list of 10 crops including additional countries Bosnia and Herzegovina, Serbia and Montenegro.
    - Water requirements and irrigation requirements by crop at NUTS 2 level.
    - Irrigation efficiency and expansion at NUTS 2 level.
    - Current and future water balances (availability, withdrawal and use).
    - Improvements in the database regarding irrigation price/cost
7. An extension of the water module in terms of role of excess water on production was discussed. A crop-water production function approach similar to the one developed for modelling water stress was proposed. Combining the CAPRI model with biophysical models was proposed, which can simulate the biophysical effects under pre-defined simulation scenarios. Those biophysical effects can then be incorporated in CAPRI to assess the impacts on agricultural land use, production and prices.
8. Linkage of agricultural water demand to other sectoral demands was also discussed. In order to take into account the competition between agriculture and other water users, the approaches used by other global partial equilibrium models were reviewed. Two approaches such as the water supply curve and water balance were retained and further examined because they showed potential to be applied in CAPRI.
9. It was suggested to incorporate water in the supply behavioural functions of the CAPRI market module. A proposal was made which will be similar to the land allocation modelling approach in the CAPRI global market model. However, a wealth of data with good quality is necessary which at the moment is difficult to be obtained.
10. Both scenarios were implemented separately, thus effect of reduction in precipitation on water availability for irrigation in the forthcoming year is not considered. A combined scenario should be developed in the next step to see the how agricultural producers will react to such shock. Such effect is expected to occur in the long-run given the climate change effect.

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List of abbreviations and definitions

CAET	Crop Actual Evapotranspiration
CAP	Common Agricultural Policy
CAPRI	Common Agricultural Policy Regional Impact Analysis
CGID	Crop gross irrigation dose
CNID	Net Irrigation Dose
CNIR	Net Irrigation Requirement
CPET	Potential evapotranspiration
CRAIN	Crop Effective Precipitation
CROPWAT	Computer Program for Irrigation Planning and Management (FAO)
CWP	Crop water productivity
CWR	Crop water requirement
CWSI	Crop water stress index
DG-AGIR	Directorate-General for Agriculture and Rural Development
EU	European Union
FADN	European Farm Accounting Data Network
FAO	Food and Agriculture Organization of the United Nations
FSS	Farm Structure Survey
GLOBIOM	Global Biomass Optimisation Model
GMIA	Global Map of Irrigation Areas
GUI	Graphical User Interface
IFPRI	International Food Policy Research Institute
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade
IPCC	Intergovernmental Panel on Climate Change
IRWAE	Water application efficiency
IRWTE	Water transport efficiency
IRWUE	Water use efficiency
JRC	Joint Research Centre
JRC-IES	Joint Research Centre – Institute for Environmental Studies
ky	Yield response factor
LISFLOOD	Distributed Water Balance and Flood Simulation Model
NRC	National Research Council
NUTS	Nomenclature of Units for Territorial Statistics
OECD	Organisation for Economic Co-operation and Development
PMP	Positive Mathematical Programming
PRIMES	Price-Induced Market Equilibrium System
RCP	representative concentration pathway
SAPM	Survey on Agricultural Production Methods

UAA	Utilized Agricultural Area
Wa	Actual Evapotranspiration
WATERGAP	Global freshwater model
WEFE	Water-Energy-Food-Ecosystems
WIRR	Crop irrigation water use
WFD	Water Framework Directive
WOFOST	World Food Studies
Wp	Potential Crop Evapotranspiration
Ya	Actual yield
YACT	Actual yield
YLIM	Water-limited yield
YPOT	Potential yield
Yp	Potential yield
YRATIO	Water-limited to actual yield ratio

List of figures

List of tables

Annexes

Annex 1. Simulation results

Table A1.1. Effects of water supply decrease on irrigated/rain-fed areas (1000 ha) in 2030 (absolute changes from baseline).

Country	Aggregate area	Rain-fed area	Irrigated area
European Union 28	-207.14	1,664.19	-1,879.62
Belgium	0.41	1.53	-1.13
Denmark	2.61	32.48	-30
Germany	10.56	53.5	-43.52
Austria	-6.43	-3.74	-2.44
Netherlands	2.14	17.03	-16.48
France	-20.09	333.99	-354.62
Portugal	-0.23	1.03	-1.29
Spain	53.97	573.42	-519.57
Greece	5.63	222.51	-216.82
Italy	-62.59	518.37	-581.1
Ireland	4.9	5.8	-0.93
Finland	1.24	0.79	0.22
Sweden	-3.13	-5.1	1.73
United Kingdom	-3.47	8.59	-12.56
Czech Republic	2.32	-2.07	4.11
Estonia	3.26	3.2	-0.13
Hungary	-105.73	-65.58	-41.13
Lithuania	8.38	7.92	0.28
Latvia	6.72	6.29	0.16
Poland	12.46	14.06	-2.7
Slovenia	-3.27	-3.29	-0.26
Slovak Republic	-13.43	-7.43	-6.14

Croatia	-10.83	-8.43	-2.47
Cyprus	0.33	-1.88	2.2
Malta	0.01	0.24	-0.23
Bulgaria	-20.29	-5.12	-15.44
Romania	-72.57	-33.92	-39.38
Norway	2.29	2.71	-0.43
Serbia	-92.74	-92.55	
Montenegro	-0.91	1.87	-2.78
Bosnia and Herzegovina	-12.41	-10.25	-2.15
FYR Macedonia	0.12	7.48	-7.35
Albania	-0.82	195.69	-196.5
Kosovo	3.17	4.67	-1.5
Turkey	107.6	2,776.27	-2,668.55

Table A1.2. Effects of rainfall decrease on irrigated/rain-fed areas (1000 ha) in 2030 (absolute changes from baseline).

Country	**Aggregate area**	**Rain-fed area**	**Irrigated area**
European Union 28	3,815.98	3,748.72	66.24
Belgium	-19.44	-19.62	0.22
Denmark	37.15	-6.25	43.4
Germany	133.59	153.66	-19.52
Austria	39.02	26.87	11.85
Netherlands	-24.65	-21.8	-4.42
France	1,056.51	1,446.56	-389.72
Portugal	-5.74	-11.94	6.26
Spain	50.83	-232.69	283.35
Greece	66.34	-81.8	148.1
Italy	779.92	799.97	-19.88
Ireland	76.1	78.3	-2.16
Finland	747.21	749.84	-2.81
Sweden	158.71	172.99	-14.26
United Kingdom	183.4	180.06	3.36
Czech Republic	20.53	15.79	4.74
Estonia	-6.95	-6.99	0.02
Hungary	-106.17	-100.17	-6.17
Lithuania	179.59	179.22	0.45
Latvia	-8.52	-8.41	-0.04
Poland	514.86	511.33	3.33
Slovenia	6.52	6.55	0.11
Slovak Republic	-25.78	-22.7	-3.09
Croatia	-14.83	-15.58	0.76
Cyprus	0.14	-6.11	6.26

Malta	-0.08	0.14	-0.22
Bulgaria	-33.61	-51.44	17.95
Romania	11.33	12.93	-1.58
Norway	1.92	1.93	-0.01
Serbia	-88.73	-88.5	
Montenegro	-2.27	-2.31	0.04
Bosnia and Herzegovina	-24.48	-23.73	-0.71
FYR Macedonia	-13.05	-5.93	-7.12
Albania	-11.2	185.32	-196.5
Kosovo	-1.52	-0.02	-1.5
Turkey	-347.63	267.72	-614.72

Table A1.3. Effects on irrigated water use (Million m^3) in 2030 (relative changes from baseline).

Country	Rainfall decrease (20%) (%)	Water supply decrease (30%) (%)
European Union 28	0.44	-20.73
Belgium	-8.30	-32.78
Denmark	-4.14	-32.90
Germany	-20.21	-38.35
Austria	24.24	-13.03
Netherlands	-8.96	-19.98
France	-36.90	-29.11
Portugal	-5.75	-10.97
Spain	7.90	-19.55
Greece	7.36	-18.36
Italy	-75.92	-33.63
Ireland	-53.57	-22.14
Finland	-49.27	-7.62
Sweden	2.67	-24.69
United Kingdom	11.17	12.32
Czech Republic	3.75	-26.97
Estonia	-0.86	-27.75
Hungary	41.56	28.28
Lithuania	-28.88	63.34
Latvia	4.09	-8.05
Poland	0.77	-26.60
Slovenia	-17.76	-35.82
Slovak Republic	9.48	-21.99
Croatia	-0.23	-23.43
Cyprus	-5.68	-6.29
Malta	10.25	-17.66

Bulgaria	10.65	-14.75
Romania	-5.35	-22.74
Norway		
Serbia	-0.04	-30.03
Montenegro	-7.16	-35.02
Bosnia and Herzegovina	0.44	-20.73
FYR Macedonia	-100	-100
Albania	-100	-100
Kosovo	-100	-100
Turkey	-19.62	-42.22

Table A1.4. Effects of decrease in water supply and decrease in rainfall on production (1000 t), prices (Euro/t) and income (Euro/ha) in 2030 (absolute levels for baseline and relative changes from baseline).

	Production			**Price**			**Income**		
	base	**Rainfall decr. (20%)**	**Water supply decr. (30%)**	**base**	**Rainfall decr. (20%)**	**Water supply decr. (30%)**	**base**	**Rainfall decr. (20%)**	**Water supply decr. (30%)**
European Union 28	239,950	0.78%	-1.03%	144	2.58%	0.42%	934	-0.75%	1.02%
Belgium	4,939	0.51%	0.40%	196	2.25%	0.30%	1,405	4.62%	1.46%
Denmark	4,346	1.18%	-0.39%	159	4.14%	0.43%	1,841	-14.60%	1.48%
Germany	33,205	-0.45%	0.00%	116	5.27%	0.61%	1,224	4.22%	0.29%
Austria	3,691	1.05%	-0.77%	142	2.44%	1.29%	1,229	0.49%	-0.03%
Netherlands	18,450	-0.65%	0.10%	320	1.55%	0.31%	6,41	2.59%	-0.01%
France	43,595	0.73%	-0.88%	147	5.08%	0.47%	938	-0.56%	0.74%
Portugal	3,662	-0.30%	-0.36%	157	0.20%	0.34%	684	1.68%	1.09%
Spain	24,949	1.49%	-0.82%	185	-0.02%	1.24%	802	1.06%	1.00%
Greece	5,929	2.91%	-2.22%	155	1.13%	0.53%	639	3.20%	-0.18%
Italy	30,450	0.92%	-2.18%	263	2.79%	0.91%	1,892	-5.41%	-0.15%
Ireland	2,000	6.02%	1.22%	77	1.32%	0.10%	878	1.19%	0.84%
Finland	1,925	37.61%	0.56%	170	2.75%	0.76%	867	-41.02%	2.55%
Sweden	3,229	2.34%	-0.07%	143	2.20%	0.03%	219	6.17%	3.73%
United Kingdom	13,044	-0.63%	-0.80%	103	1.07%	0.21%	765	1.35%	1.25%
Czech Republic	3,229	-0.72%	0.64%	106	1.68%	1.33%	467	8.51%	5.68%
Estonia	436	-0.03%	1.54%	71	0.28%	1.39%	471	1.39%	2.69%
Hungary	5,344	-8.66%	-8.95%	150	-1.27%	-2.57%	746	0.02%	2.52%
Lithuania	1,833	6.36%	1.20%	78	11.58%	2.02%	568	-5.39%	5.09%
Latvia	889	-0.20%	0.18%	70	2.97%	0.26%	348	0.22%	2.77%
Poland	12,900	3.20%	-0.14%	123	-2.93%	0.00%	627	-4.40%	1.15%
Slovenia	596	-1.04%	-1.60%	214	2.00%	-1.41%	1,835	-8.59%	1.70%
Slovak Republic	1,433	-2.06%	-2.39%	119	3.25%	-0.34%	480	0.38%	4.13%
Croatia	1,617	-2.20%	-1.33%	161	1.00%	-0.22%	964	2.54%	3.67%
Cyprus	324	-0.07%	-0.45%	375	0.70%	0.30%	-481	-0.11%	-3.33%
Malta	45	0.07%	0.90%	414	-0.22%	0.39%	1,036	1.36%	6.36%
Bulgaria	3,227	-1.14%	-0.56%	101	0.53%	1.58%	446	2.38%	5.14%
Romania	11,584	-0.22%	-1.06%	129	1.02%	0.92%	337	7.83%	5.78%
Norway	1,280	0.55%	0.60%	211	0.44%	-0.07%	1,559	0.88%	-0.15%
Serbia	2,834	-6.63%	-7.14%	118	0.19%	0.75%	530	-4.10%	-4.02%
Montenegro	235	-0.75%	-3.63%	131	-0.19%	-0.99%	465	0.39%	-0.86%
Bosnia and Herzegovina	840	-1.83%	-1.99%	146	5.86%	4.98%	445	0.15%	1.08%

FYR Macedonia	733	13.86%	13.07%	129	2.68%	3.58%	473	33.48%	31.07%
Albania	1,208	0.06%	-0.21%	139	1.76%	0.97%	1,303	0.58%	2.19%
Kosovo	32	13.76%	14.08%	190	0.34%	0.16%	365	54.31%	58.21%
Turkey	44,434	0.28%	-1.53%	215	-0.01%	-0.36%	1,516	1.60%	-1.93%

Table A1.5. Effects of decrease in rainfall and decrease in water supply on crop areas (1000 ha) in EU28 in 2030 (absolute changes from baseline).

	Rainfall decrease (20%)			**Water supply decrease (30%)**		
Crop	**Aggregate**	**Rain-fed crop variant**	**Irrigated crop variant**	**Aggregate**	**Rain-fed crop variant**	**Irrigated crop variant**
Soft wheat	462.87	175.05	288.8	276.17	406.49	-131.21
Durum wheat	-185.05	-332.88	147.73	-5.57	188.52	-193.94
Barley	713.2	486.21	227.44	237.97	454.73	-217.29
Grain Maize	-722.02	-461.79	-261.38	-1149.11	-754.45	-397.51
Paddy rice	7.93	-2.8	10.73	-33.81	4.04	-37.84
Rapeseed	89.42	20.12	68.65	-287.16	-323.52	32.57
Sunflower	50.7	48.51	2.54	-123.03	-121.65	-0.32
Soya	16.19	-10.09	26.24	-62.43	-40.73	-21.52
Potatoes	-14.85	-25.82	11.2	-17.41	-13.93	-3.99
Sugar Beet	-47.27	-56.75	9.24	27.89	97.1	-69.03
Tomatoes	-0.81	-3.72	3.18	0.05	1.61	-1.56
Other Vegetables	0.61	-11.34	11.95	5.54	7.04	-1.52
Apples	-3.68	-14.32	10.59	1.14	0.2	0.81
Other Fruits	-12.64	-43.25	30.61	2.8	9.94	-7.15
Citrus Fruits	-1.85	-15.35	13.5	-0.24	-1.7	1.45
Table Grapes	-0.35	-1.98	1.64	0	-1.39	1.39
Olives for oil	-180.52	-316.64	136.09	108.87	195.96	-87.39
Table Olives	-3.6	-11.18	7.59	0.72	-2.61	3.34
Wine	-2.48	-94.72	92.21	5.19	-18.23	23.41

Table A1.6. Effects of decrease in rainfall and decrease in water supply on yields (kg/ha) in EU28 in 2030 (absolute changes from baseline).

	Rainfall decrease (20%)			Water supply decrease (30%)		
Crop	**Aggregate**	**Rain-fed crop variant**	**Irrigated crop variant**	**Aggregate**	**Rain-fed crop variant**	**Irrigated crop variant**
Soft wheat	42.63	14.65	88.85	12.02	3.41	305.83
Durum wheat	137.97	111.54	-62.21	-142.18	-40.05	-611.71
Barley	81.03	74.98	-26.5	-6.87	-19.87	100.07
Grain Maize	14.04	169.29	-106.79	-35.91	51.55	458.31
Paddy rice	10.28	-4.55	-34.58	-160.13	-68.36	31.55
Rapeseed	-58.28	-39.16	-204.38	-16.26	-10.36	8.24
Sunflower	-9.51	8.67	-102.19	-2.31	3.89	-52.21
Soya	-65.62	-192.42	162.06	36.44	-137.84	432.57
Potatoes	319.73	-529.39	2,660.99	20.29	174.09	-580.57
Sugar Beet	-393.61	-1,367.74	3529.2	-1,511.01	-714.05	1,365.82
Tomatoes	193.56	348.87	-1,152.48	-710.87	-1,608.2	425.76
Other Vegetables	-34.31	7.53	-346.41	-188.1	-149.69	-184.5
Apples	76.48	-201.69	107.69	-165.03	-420.67	366.33
Other Fruits	60.78	-41.71	-481.52	-206.81	-99.93	-258.33
Citrus Fruits	37.79	-500.25	-130.63	-332.83	-473.18	-293.12
Table Grapes	1.5	-304.87	48.38	-12.42	-265.73	45.5
Olives for oil	24.81	-80.8	-65.92	-126.67	-45.66	-145.78
Table Olives	26.54	-54.33	-124.88	-38.58	-25.27	-184.93
Wine	8.85	-63.29	-38.41	-28.15	-56.07	-0.84

Table A1.7. Effects of decrease in rainfall and decrease in water supply on irrigation water use (Million m^3) in EU28 in 2030 (absolute changes from baseline).

	Rainfall decrease (20%)	**Water supply decrease (30%)**
Soft wheat	716.76	-505.89
Durum wheat	489.97	-708.55
Barley	1,101.86	-1,058.86
Grain Maize	-406.23	-1,339.37
Paddy rice	82.55	-265.32
Rapeseed	194.08	-21.58
Sunflower	35.59	-36.73
Soya	25.39	-108.64
Potatoes	-31.37	-25.1
Sugar Beet	186.53	-313.84
Tomatoes	27.26	-1.38
Other Vegetables	84.07	37.34
Apples	57.71	-13.81
Other Fruits	177.01	-69.91
Citrus Fruits	28.07	-47.4
Table Grapes	3.45	2.76
Olives for oil	774.01	-963.27
Table Olives	45.21	19.67
Wine	114.22	-49.18

Table A1.8. Effects of decrease in rainfall and decrease in water supply on income (Euro/ha) and prices use (Euro/t) in EU28 in 2030 (absolute changes from baseline).

	Rainfall decrease (20%)		**Water supply decrease (30%)**	
	income	**prices**	**income**	**prices**
Soft wheat	47.37	7.58	25.17	3.45
Durum wheat	6.17	0.54	-12.91	3.84
Barley	23.88	6.54	18.06	3.81
Grain Maize	132.65	18.95	103.33	13.92
Paddy rice	26	4.76	-13.98	4.54
Rapeseed	-10.37	1.06	106.74	29.47
Sunflower	5.6	0.96	51.85	22.85
Soya	-24.76	-5.56	98.99	23.09
Potatoes	155.81	0.19	161.58	5.11
Sugar Beet	115.81	1.96	-3.98	0.24
Tomatoes	87.41	0.7	194.82	6.64
Other Vegetables	-9.66	0.61	30.13	3.76
Apples	47.1	1.34	14.23	3.46
Other Fruits	24.3	3.38	-3.64	0.87
Citrus Fruits	9.31	0.23	-54.77	2.34
Table Grapes	41.8	0.54	0.79	9.77
Olives for oil	-2.06	-5.61	80.55	43.85
Table Olives	36.28	10.63	52.09	42.83
Wine	270.31	44.1	66.77	17.48

Annex 2. Inventory of existing data sources on water

1. Farm Structural Survey (FSS)

The Farm structure survey (FSS) is carried out by all EU Member States using a common methodology provides therefore comparable and representative statistics across countries and time, at regional levels (down to NUTS 3 level). Every 3 or 4 years the FSS is carried out as a sample survey (1997, 2003, 2005, 2007) and once in ten years as a census (2000 and 2010). The 2000 census covers the EU-15 Member States, Latvia, Hungary, Slovenia, Slovakia and Norway, while the 2010 census covers the EU-27 Member States, Croatia, Iceland, Norway, Switzerland, Montenegro and Serbia.

In 2010 a special survey, the Survey on Agricultural Production Methods (SAPM) was carried out. This survey was carried out together with the FSS 2010 census in some countries, where in other countries the survey was carried out as a sample survey.

The latest FSS survey available on Eurostat is for 2013 and covers the EU-28 Member States, Iceland, Norway, Switzerland and FYR Macedonia. While the FSS-2016 is not available yet on Eurostat, data has already been released for some member states in national statistics.

- The FSS reports data on irrigable and irrigated areas:
- Total irrigable area (area covered by irrigation infrastructure) (in total hectares and in number of holdings with irrigable area)
- Total irrigated area (in hectares)
- Crop-specific irrigated area (in hectares) for main irrigated crops (selection of crops varies over time)

In addition, the SAPM 2010 also reports crop-specific data for 10 major crops, data on irrigation methods and volume of water use for irrigation. In the Eurostat online database for agriculture, SAPM data are published in tables together with FSS data.

Main tables

- FSS tables on irrigation (from 2005 onwards): ef_poirrig
- FSS tables on irrigation (1990-2007): ef_lu_ofirrig
- Structure of agricultural holdings 2010: reg_ef_po
- Online database: http://ec.europa.eu/eurostat/web/agriculture/data/database

Strengths

- Available for EU-28 countries (plus Norway and Switzerland) and regularly updated (each 2 or 3 years).
- Additional data on irrigation available for 2010 from SAPM (covering crop irrigated area, irrigation methods employed, source of irrigation water used and the volume of water used for irrigation).
- SAPM 2010 also covers Montenegro.

Weaknesses

- Incomplete datasets on crop irrigated areas for some countries.
- Crop-specific irrigated areas only available for 2010 (from SAPM) for all countries.
- In FSS 2010, the volume of water that has been used for irrigation on the holding during the 12 months prior to the reference date of the survey, regardless of the source, is provided using data estimation, imputation, or modelling methods. This might affect comparability across countries.

2. Water coverage in EUROSTAT statistics

The development of European environmental accounts is set out in the multi-annual European Strategy for Environmental Accounts, the latest of which covers the period 2014-2018. Within this framework, EUROSTAT has plans to develop ecosystem accounts and water accounts, but no data are available yet for publication.

Eurostat provides water statistics that cover:

- water resources (per year, long-term average)
- abstractions from water resources by origin (fresh surface water & groundwater, other sources) and purpose
- water use by supply scheme and by economic activity group
- connection rates to wastewater treatment by type and level of treatment
- wastewater treatment infrastructure
- generation and disposal of sewage sludge
- generation of aquatic pollution by source and its discharge by type of treatment.

Water statistics are also used in indicator exercises, e.g. the resource efficiency scoreboard and the sustainable development indicators. Eurostat and the OECD jointly administer a questionnaire on inland waters designed to collect data from EU countries and prospective EU members. In line with the Water Framework Directive, data is also collected at regional level, to develop a smaller data set on NUTS2 regions and River Basin Districts (regions defined in terms of hydrology – individual or grouped river catchments).

Main tables

- Water statistics on national level (env_nwat)
- Renewable freshwater resources (env_wat_res)
- Annual freshwater abstraction by source and sector (env_wat_abs)
- Water made available for use (env_wat_use)
- Population connected to public water supply (env_wat_pop)
- Water use by supply category and economical sector (env_wat_cat)
- Water use balance (env_wat_bal)
- Water statistics by NUTS 2 regions (env_rwat_n2)
- Freshwater resources by NUTS 2 regions (env_watres_r2)
- Water abstraction by NUTS 2 regions (env_watabs_r2)
- Water use by NUTS 2 regions (env_watuse_r2)
- Population connected to public water supply by NUTS 2 regions (env_watpop_r2)

Strengths

- Availability of time-series of water abstraction by sector and water source at national level.
- Availability of data on irrigation water (as part of water abstraction for agriculture).

Weaknesses

As collecting data is voluntary for the data providers (data collected at national level), the resulting data sets are incomplete to varying degrees (regarding both temporal and spatial coverage), which limits their usability. In addition, since the data collection procedure differs by country, data quality and comparability are not guaranteed.

An initiative to establish a legal framework for water statistics is under way.

3. AQUASTAT

The AQUASTAT database from FAO (www.fao.org/nr/aquastat) provides information on water and agriculture by country since the 1970s. Main variables of interest for CAPRI-Water are:

- Total area equipped for irrigation, measured in share in Agricultural area (%) => since 1961 for some countries (since 2006 for Bosnia and Herzegovina, Serbia and Montenegro).
- Agricultural area actually irrigated (thousand ha) and Agricultural area (thousand ha) => since 1961 for some countries (since 2006 for Bosnia & Herzegovina, Serbia and Montenegro).
- Percentage of arable land equipped for irrigation (%) (3-year average) => data available for the period 2005-2014.
- Water withdrawal for agricultural use, in % of total water withdrawal.

AQUASTAT also provides data at the subnational level for 2005 through the Global Map of Irrigation Areas (GMIA)([13]). The map shows the amount of area equipped for irrigation around the year 2005 in percentage of the total area on a raster with a resolution of 5 minutes. Additional map layers show the percentage of the area equipped for irrigation that was actually used for irrigation and the percentages of the area equipped for irrigation that was irrigated with groundwater, surface water or non-conventional sources of water. This dataset was developed by combining sub-national irrigation statistics with geospatial information and applying modelling procedures.

Strengths

- Data available for most countries. Data available for Bosnia and Herzegovina, Serbia and Montenegro since the year 2006.
- Availability of time series make this database suitable for assessing trends.

Weaknesses

- Data are only provided at a national level (apart from the estimated GMIA for 2005 at subnational level).
- Only data on total irrigated area is available, no data on crop-specific irrigated areas and yields.
- Time series are incomplete.
- For EU28, data comes from EUROSTAT-FSS and no other additional data is available.

References

FAO. 2016. AQUASTAT Main Database, Food and Agriculture Organization of the United Nations (FAO). Website accessed on [20/05/2018]. http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en

([13]) Stefan Siebert, Verena Henrich, Karen Frenken and Jacob Burke (2013). Global Map of Irrigation Areas version 5. Rheinische Friedrich-Wilhelms-University, Bonn, Germany / Food and Agriculture Organization of the United Nations, Rome, Italy.

4. OECD/Eurostat Joint Questionnaire on Inland Waters

This dataset is released every second year and provides information on annual water abstraction per sector. Data are provided by national or local authorities.

Main tables

- Annual freshwater abstraction by source and sector [env_wat_abs]

Strengths

- Availability of time-series of water abstraction by sector and water source at national level.
- Availability of data on irrigation water (as part of water abstraction for agriculture).

Weaknesses

- Data collected at national level.
- Datasets are very incomplete regarding both temporal and spatial coverage.
- No consistency on the data collection procedure, which differs by country. Data quality and comparability are not guaranteed.

5. JRC simulations with WOFOST

Rain-fed and irrigated yields

Results of crop yield simulations on Representative Concentrations Pathway (RCP) aggregated at NUTS 2 level for EU28 with Norway and Switzerland.

List of crops: wheat, barley, rye, maize, field beans, sugar beet, rapeseed, potato, sunflower and rice.

Crop growth models: WOFOST and WARM (only for rice).

Time frame: 1960-2060.

Global Circulation Model: Hadgem2, IPLS. MIROC.

Representative Concentration Pathway: RCP 4.5 and RCP 8.5.

References

JRC (2014). Crop yield simulations on RCP. http://agri4cast.jrc.ec.europa.eu/DataPortal/Index.aspx

6. JRC data portal

Several datasets are available in the JRC Data Portal: Water Portal: http://water.jrc.ec.europa.eu/waterportal.

While some of those datasets are available at NUTS2 level, most of them are only available as maps.

Main datasets available in the Data Portal at NUTS spatial level (Mari Rivero et al. 2015) are:

- LF312 - Water Productivity (LUISA Platform REF2014). The file contains the projected water productivity maps from 2010 to 2050. The data is stored in .csv format.
- LF311 - Water Consumption (LUISA Platform REF2014). The indicator Water consumption is the result of the water use model which allocates sectorial statistical data on freshwater consumption. The level of detail of this indicator is per NUTS0 and NUTS2.

Datasets not available in the website at NUTS2 spatial level:

Map of costs of water abstraction for irrigation	abscost	Map shows the average cost in a country for farmers to abstract water for irrigation (incudes license and pumping costs). The resolution of the map is 5x5km
Map of comparative price level	comppric	Map of the comparative price level for each country
Map of price elasticity for domestic water	elasdoms	Map of price elasticity for the domestic sector
Map with the price of water for the domestic sector	watprdom	Map shows the average price in a country that citizens pay for domestic water use. The resolution of the map is 5x5km
Map with the price of water for industry	watprind	Map shows the average cost in a country of water for industrial purposes. The resolution of the map is 5x5km
Map of comparative price level	comppric	Map of the comparative price level for each country
Annual water availability for 1991-2010	Yr_Runof	Map shows the simulated average annual water availability between 1990 and 2010 forced by gridded meteorological observations of JRC. The resolution of the map is 5x5km
Annual precipitation for 1991-2010	Yr_Prec	Map shows the observed average annual precipitation between 1990 and 2010 obtained interpolation of the meteorological observations available at JRC. The resolution of the map is 5x5km
Water Exploitation Index + map (WEI+, based on net consumption) 2006 (excluding interbasin water transfers)	nuts0wus	WEI+ map shows the total water consumption as a fraction of available water in 2006 on an annual basis, averaged per country. The resolution of the map is 5x5km
Water Exploitation Index map (WEI, based on abstraction) 2006 (excluding interbasin water transfers)	nuts0wab	WEI map shows the total water abstraction as a fraction of available water in 2006 on an annual basis, averaged per country. The resolution of the map is 5x5km

References

Mari Rivero, I., Vandecasteele, I. and Lavalle, C. (2015): LF312 - Water Productivity (LUISA Platform REF2014). European Commission, Joint Research Centre (JRC) [Dataset] PID: http://data.europa.eu/89h/jrc-luisa-lf312-water-productivity-ref-2014.

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