EUCALC

Explore sustainable European futures

WP4 – Water module documentation

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Main authors	Alexandre Bouchet
Partner in charge	EPFL
Contributing partners	University of East Anglia, Imperial College London
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Short Description
This report describes the Water module, and in particular: - *the sources and hypotheses used to build the historical database;* - *the calculation logic and scope of the module;* - *the lever choices and ambition levels.*

Quality check	
Name of reviewer	**Date**

Statement of originality:
This deliverable contains original unpublished work except where clearly indicated otherwise. Acknowledgement of previously published material and of the work of others has been made through appropriate citation, quotation or both.

Table of Contents

List of abbreviations

BAU – Business as Usual

EEA – European Environment Agency

EFI – Environmental Flow Indicator

EU – European Union

EU-28 – The 28 EU Member States as of 1 July 2013

EU28+1 - The 28 EU Member States as of 1 July 2013, plus Switzerland

EUCalc – European Calculator

GVA – Gross Value Added

JRC – Joint Research Center

LSU – Livestock Unit

RCP – Representative Concentration Pathway

WFD – Water Framework Directive

WFN – Water Footprint Network

Glossary

Cooling water: Water used to regulate the temperature of a process.

Drought: temporary decrease of the average water availability.

Fresh water: Water with low concentration of salts.

Groundwater: Water held underground in the soil or in pores and crevices in rock.

Local water availability: Refers to internal renewable water resources, excluding upstream inflows from neighbouring countries.

Surface water: Fresh water you can see as overland flow, rivers and lakes excluding sea water.

Water consumption: Water use that permanently withdraws water from its source; water that is no longer available because it has evaporated, been transpired by plants, incorporated into products or crops, consumed by people or livestock, or otherwise removed from the immediate water environment (Vickers, 1999).

Water Exploitation Index normal (WEI-normal): One of the indicators used to measure water stress. It corresponds to the ratio between total water consumption and local water availability within a specific area.

Water footprint: Indicator that assesses the contribution over of the system under study to water impact on the environment.

Water footprint (blue): Used and defined by the Water Footprint Network (WFN). It can be defined as water that has been sourced from surface or groundwater resources and is either evaporated, incorporated into a product or taken from one body of water and returned to another, or returned at a different time (Hoekstra, 2011). Irrigated agriculture, industry and domestic water use can each have a blue water footprint.

Water footprint (green): Used and defined by the Water Footprint Network (WFN). This is the water from precipitation that is stored in the root zone of the soil and evaporated, transpired or incorporated by plants (Hoekstra, 2011). The green water is particularly relevant for agricultural, horticultural and forestry products.

Water footprint (grey): Used and defined by the Water Footprint Network (WFN). This is the amount of fresh water required to assimilate pollutants to meet specific water quality standards (Hoekstra, 2011).

Water resources: Water from natural resources that can potentially be used, and is either renewable or non-renewable. Renewable water resources represent the long-term average annual flow of rivers and groundwater, while non-renewable water resources are groundwater bodies that have a negligible rate of recharge at the human time-scale (FAO)[1]. This term often directly refers to renewable water resources, which are either internal (generated from endogenous precipitation) or external (upstream inflow from neighbouring countries).

Water scarcity: refers to long-term water imbalances, combining low water availability with a level of water demand exceeding the supply capacity of the natural system.

Water stress: occurs when the demand for water exceeds the available amount during a certain period or when poor quality restricts its use. Water stress causes deterioration of fresh water resources in terms of quantity (aquifer over-exploitation, dry rivers, etc.) and quality (eutrophication, organic matter pollution, saline intrusion, etc.). Usually, we use the Water Exploitation Index (WEI) to refer to water stress.

Water use: generic term used to describe an anthropogenic activity that involves water resources.

Water withdrawals: Water diverted or withdrawn from a surface water or groundwater source (Vickers, 1999).

[1] http://www.fao.org/3/Y4473E/y4473e06.htm

1 Introduction

Water is a vital substance for human life but also a critical input for agriculture, industries, energy production and households. A reduction in water availability can for instance have a significant impact on food production and cooling of power stations, thus jeopardizing the proper functioning of our societies.

In EUCalc, we explore pathways that would allow EU countries to mitigate their impacts on climate and aim for low-carbon societies. Reaching ambitious low-carbon objectives can have important benefits regarding water security since climate change is projected to extend water shortage periods and increase the frequency and intensity of extraordinary events such as droughts or floods. Rise in water demand is also likely to continue, putting even more pressure on these changing water resources. Assessing the water impacts of these pathways is then crucial to help policy makers make the right adjustments in order to keep European countries on a sustainable path.

The objective of this report is to provide a structured, documented and transparent view of water flows in all sectors as well as water stress levels in Europe until 2050. Water flows include water withdrawal and water consumption, respectively defined as the temporary or permanent removal of water from any water body, and the permanent removal of water that is not returned to the environment (see extended definitions in Glossary). The calculation method is thoroughly explained, by detailing the scope and the influence of a multitude of external factors. This report also identifies a set of levers that could further influence water flows in the future.

In this report, we first analyse the trends and evolutions of the water uses and resources. Then we introduce the questions addressed by the module and the calculation logic behind the model. Finally, we describe the potential levers and list the different resources used to build the model.

2 Trends and evolutions of the water uses and resources

This section gives a short overview of the context and current trends in water availability and water demand.

2.1 Water availability

Water availability (or water resources) refers to the freshwater available for use in a territory and include surface waters (lakes, rivers and streams) and groundwater.[2] Renewable water resources are calculated as the sum of internal flow (which is precipitation minus actual evapotranspiration) and external inflow. Freshwater availability in a country is primarily determined by climate conditions and transboundary water flows (in other words, external flows).

Large spatial and temporal differences in the amount of water available are observed across Europe.[3] Water availability problems appear in areas with low rainfall, high population density, intensive irrigation and/or industrial activity.

Recent studies have shown that water resources are increasingly stressed by population growth and climate change, thus contributing to higher scarcity risks (Gosling et al., 2016). Water scarcity emerges when a low water availability is combined with water demand levels exceeding the supply capacity of the natural system. Figure 1 illustrates the high variability of water resources in response to climate change.

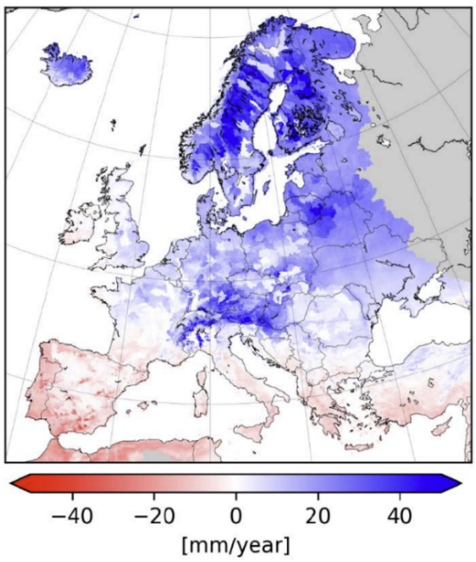

Figure 1 - Impact of 2 degrees climate change on groundwater recharge, as compared to the 1981-2010 climate [Bisselink et al., 2018]

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[2] Eurostat, Water statistics. Direct link: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Water_statistics&oldid=421073#Water_as_a_resource

[3] European Commission, Environment. Direct link: http://ec.europa.eu/environment/water/quantity/about.htm

These changes in water availability have an impact not only on food security (Rijsberman, 2006) but also on power generation cooling capacities (Tobin et al., 2018). Figure 2 shows spatial and temporal impacts of water scarcity.

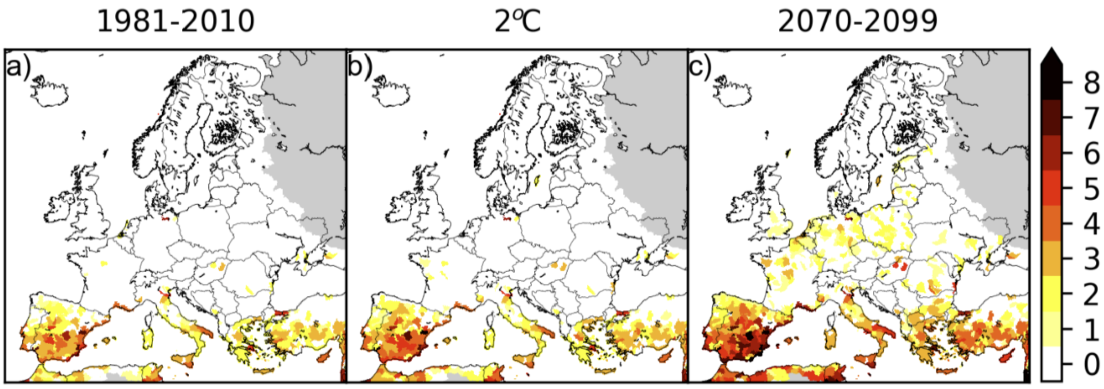

Figure 2 - Number of months in a year with high scarcity risk for different projections [Bisselink et al., 2018]

2.2Water demand

During the last century, worldwide water demand has been largely driven by population and economic growth. However, water efficiency improvements, structural change and increasing water supply costs slightly decoupled water use from population and income increase (Duarte et al., 2014). Generally, water demand is divided as follows:

- Agriculture water demand which includes livestock water use and irrigation.
- Industry water demand which includes industrial manufacturing water use and electricity production cooling demand.
- Domestic water demand which includes household water use and other water uses related to services (hotels, restaurants, hospitals, schools, …).

In EU countries, the European Environmental Agency (EEA) estimated that in 2015 the most water intensive sector was agriculture (with around 40% of all withdrawals), followed by electricity production (28%), mining and manufacturing (18%) and households domestic use (11%) (EEA, 2018a). Figure 3 illustrates the percentage distribution of water withdrawals by sector for each European country.

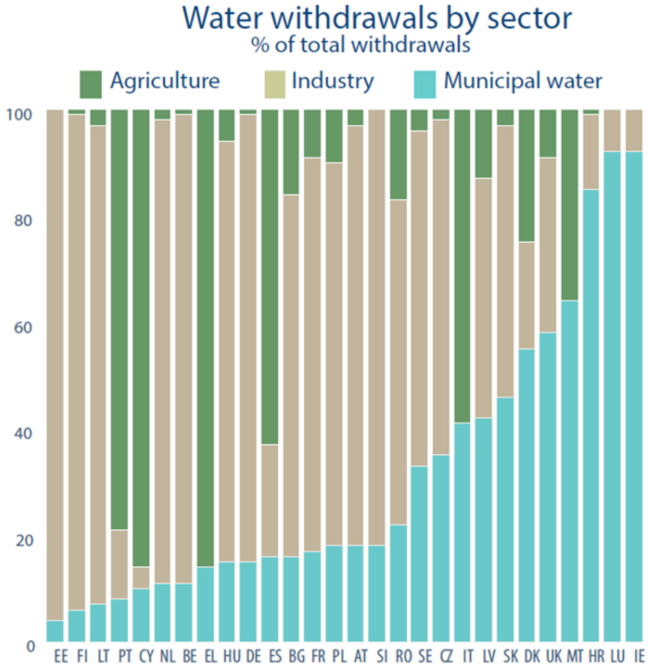

Figure 3 – Water withdrawals in Europe by sector (Source: EPRS, 2016)

More specifically, Figure 4 and Figure 5 show respectively the economic sub-sectors that have withdrawn and consumed most water in the EU over the period 1990-2011. On the one hand, the most water intensive sub-sectors are mainly the electricity productions from coal, nuclear, gas and petroleum, which are abstracting substantial amounts of water for cooling purposes.

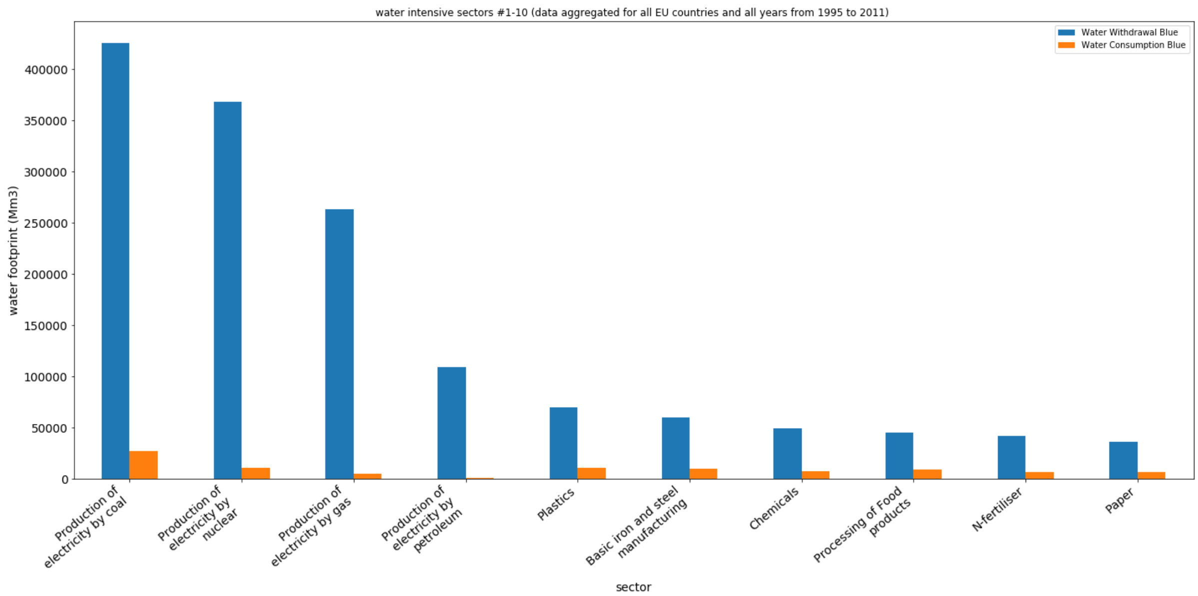

Figure 4 – Water flows from the most water withdrawing sub-sectors in EU over the period 1990-2011 (based on EXIOBASE data[4])

[4] Exiobase data download: https://www.exiobase.eu/index.php/data-download/exiobase3mon

On the other hand, the most water consumptive items are typically related to agriculture, such as the cultivation of fruits and vegetables, cereal grains and crops, due to irrigation needs.

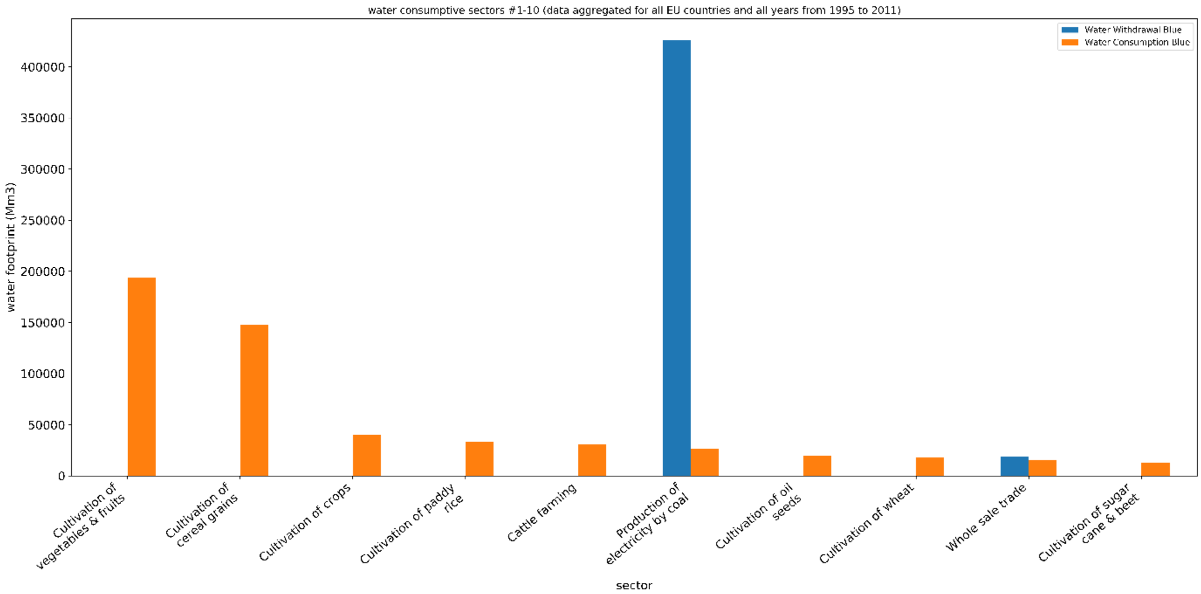

Figure 5 – Water flows from the most water consumptive sub-sectors in EU over the period 1990-2011 (based on EXIOBASE data[3])

The trends from 1990 to 2000 highlight a stunning 18-fold increase in industry and domestic water withdrawals, versus a mere five-fold increase in agriculture water withdrawal (Davies et al., 2012). Similar trends were also observed in water consumptions. Indeed, as pointed out by Duarte et al. (2014), EU countries increasingly relied on agricultural imports, thus gradually substituting internal agricultural water use. This suggests that percentage distributions of water withdrawals and consumptions among sectors might evolve in the future. We can imagine a contraction in water demand for agriculture as irrigated land expansion stalls (Bruinsma J., 2009) and efforts are made to improve irrigation efficiencies (Gleick P.H., 2003), and a rapid increase in domestic and industrial water demands due to their close relation to population growth (Flörke et al., 2012).

3 Questions addressed by the module

The goal of EUCalc Water module is to quantify various impacts of the EU28+1 (including Switzerland) water demands on the local water resources in different scenarios. The objective of this section is therefore to clarify the ambitions of the module by providing an overview of the questions addressed by the module.

The water module considers different types of water impacts: water withdrawal, water consumption and water stress (see Glossary). Water withdrawal and water consumption are derived from the water demand, which is inferred from the inputs given by different EUCalc sectors, namely lifestyle, production & manufacturing, energy supply and agriculture & land-use. As a main outcome, the water module computes the water stress. In other words, a particular focus is put on water quantity instead of quality. Indeed, water quality issues are outside the scope of this analysis because of limited data availability and the fair complexity of modelling processes such as nutrient pollution (Wan et al., 2018). Moreover, there does not exist a commonly accepted definition of water quality (Sutadian et al., 2016), thus hampering the design of reliable water quality indicators. Finally, modelling water treatment and reuse would create feedback loops (in particular with the Energy supply module) which would prevent us from achieving the objective of real-time computation. Nonetheless, these aspects might be introduced in future developments of the module. Figure 6 illustrates the schematic view of the module.

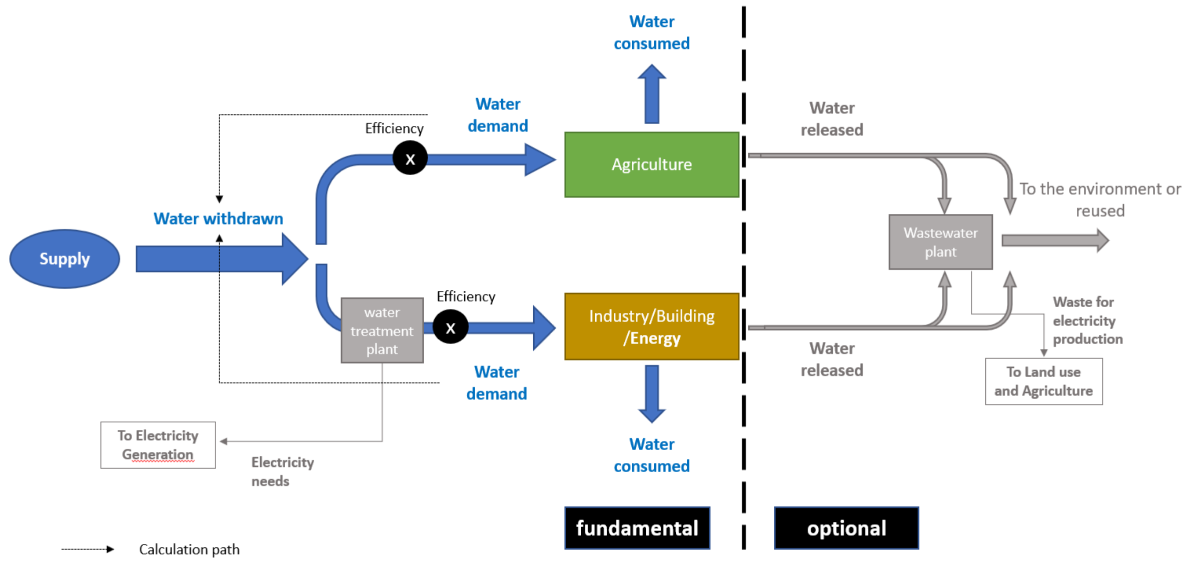

Figure 6 – Scope of the water module

In terms of decarbonisation scenarios, the module does not integrate any particular decarbonising solution but rather flags whether the chosen pathway puts pressure on water resources or not. Solutions to lower water impacts that are not directly related to decarbonisation are not integrated in the module.

Table 1 lists the questions by theme, and describes if the question is tackled in the module or not.

Table 1 – Main questions addressed in the agriculture and land-use modules

Theme	Questions		Ambition	Progress
What are the types of impacts we want to take into account in the model?	Products And Materials	• Assessing the water demand and water flows for each sector and sub-categories of materials or products	Yes	Done
	Energy	• Assessing the impacts of energy production through power plant cooling requirements	Yes	Done
	Resources	• Assessing the impacts of climate change on local water availabilities	Yes	Done
	Economy	• Assessing the economic impacts of different water uses	No	No
	Other	• Assessing the impacts of allocating flows for biodiversity, namely e-flows	No	No
What are the existing solutions to lower water impacts?	Avoid	• Avoiding water misuse	No	No
	Shift	• Moving towards more sustainable water abstractions	No	No
	Improve	• Improving efficiency of the current and new water use practices	No	No
		• Assessing degree of achievements of the Water Framework Directive	No	No
Can we identify some potential breakthrough (technologies or societal) that could have an impact?	Technology & practices	• Assessing the potential of water desalination for regions prone to water scarcity	No	No
What are the impacts of water on the other sectors?	All sectors	• Warning about scarcity risks when water demand is too high and water availability is low	Yes	Done
What are the impacts of other sectors on water?	All sectors	• Changing water demands according to chosen decarbonization pathway	Yes	Done
	Climate	• Changing water resources according to chosen climate scenario	Yes	Done

4 Calculation logic and scope of module

4.1 Overall logic

The water module is based on a bottom-up approach to compute water demand from the different water intensive sectors described in the EU calculator, as well as water resources by region.

The main outputs of the water module are:

- The water demand for each main sector in each country.
- The local surface and groundwater resources available in each country based on specific climate scenarios.
- The water stress (or Water Exploitation Index normal) derived from water demand and water resources, based on specific climate scenarios.

The fundamental calculation logic consists in: (1) estimating water flows from each sector (households & services, livestock, irrigation, electricity supply, industrial manufacturing); (2) computing the water resources available. Thereafter, the Water Exploitation Index normal (WEI-normal) in each region is derived by dividing water consumption by water availability (see definition in the Glossary). Figure 7 presents the general calculation logic of the water module.

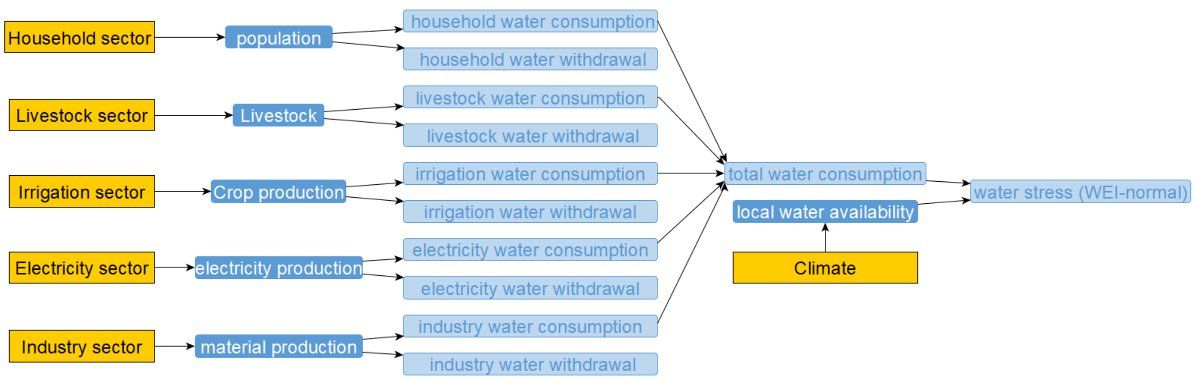

Figure 7 – Overall calculation logic of the water module

As water issues are due to an uneven distribution of water resources across space and time (Postel et al., 1996), water stress values might vary within a country and at yearly temporal scale. Thus, a finer granularity is implemented to highlight regions where risks of water shortage are the highest:

- 6 countries are divided in sub-regions to capture the spatial variability of water shortage, namely Spain, Italy, Greece, France, UK, Germany.
- Two semesters are distinguished each year to capture the temporal variability of water shortage: "winter" which spans from October to March, and "summer" which spans from April to September.

This choice in regional and temporal granularity is the result of a trade-off between appropriately representing water issues while ensuring a fast computation time, which is a key objective of the model to ensure users' friendliness. The decision was made thanks to expert consultation, in particular during a workshop on resource use, and feedback from the Joint Research Center (JRC).

The following sections delve deeper into the water resources (supply) sub-module and the calculation logic associated with the water demand sub-module.

4.2 Scope definition

4.2.1 Water resources (supply)

Water resources are mostly driven by precipitation which is dependent on climate (Bisselink et al., 2018). In EUCalc, climate scenarios are determined by a lever that allows the user to set climate ambition for Europe. We obtain water availability scenarios thanks to the JRC team, who shared with us their most up-to-date simulations of local water availability for all relevant European regions with a monthly time-step. Their historical datasets cover the period 1981-2010, while their projections run up to 2100. These projections were simulated for both the RCP 4.5 and RCP 8.5 scenarios.

The data received is then aggregated to obtain the granularity defined in section 4.1., and matched to the levels given by the Climate lever (see Table 2).

Table 2 – Description of datasets used for future water resources according to the level of the Climate lever

Climate lever	Water resources data description
Level 1	RCP 8.5 dataset
Level 2	RCP 4.5 dataset
Level 3	RCP 4.5 dataset with static value from 2048 to 2050
Level 4	RCP 4.5 dataset with static value from 2030 to 2050

4.2.2 Water demand

According to the data granularity provided by other modules, water demand per sector is disaggregated into the main water intensive industries and products, as detailed in Figure 8. In this model, we exclusively focus on domestic water demands.

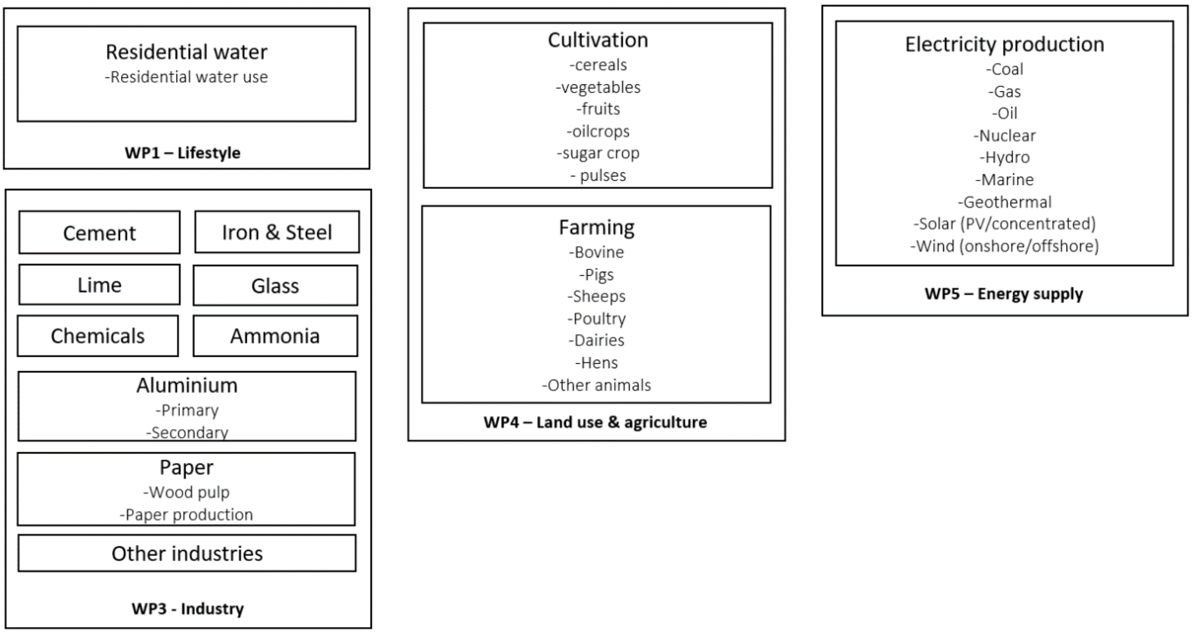

Figure 8 – sectors and products considered in the water module

In the literature, the water demand is split into several categories, depending on if the water comes from natural resources or rain. More precisely, the following terminology is often adopted: blue, green and grey water footprints (see definitions in the Glossary).

Actually, Studies on water demand usually make the distinction between blue water and green water, whereas grey water is less tackled. Blue water and green water cannot be summed but both contribute to water potentialities of a country:[5]

- Blue water is the source of supply. It is equivalent to the natural water resources (surface and groundwater runoff).
- Green water is the rainwater directly used and evaporated by non-irrigated agriculture, pastures and forests.

We consider here that blue water represents the impact on local resources, which is why we are often referring to this value in our calculations.

As already seen in the section on trends in water uses, consumptive use might have a bigger impact on water resources (i.e. blue water availability) whereas water withdrawn will only be partly consumed, thus returning a substantial amount of the water to the environment. Hence the relevance of analysing both water withdrawal and water consumption stemming from this water demand.

[5] FAO concepts and definitions: http://www.fao.org/3/Y4473E/y4473e06.htm

4.3 Interactions with other modules

The water module takes as inputs from other modules several production values demands in their original unit (tons, kWh, etc.). These values are then converted into water demand using water intensities (See section 4.4). The subsequent output is the total water demand from the considered sector, which is then shown in the Pathway Explorer. Interactions with the water module are summarised in Figure 9.

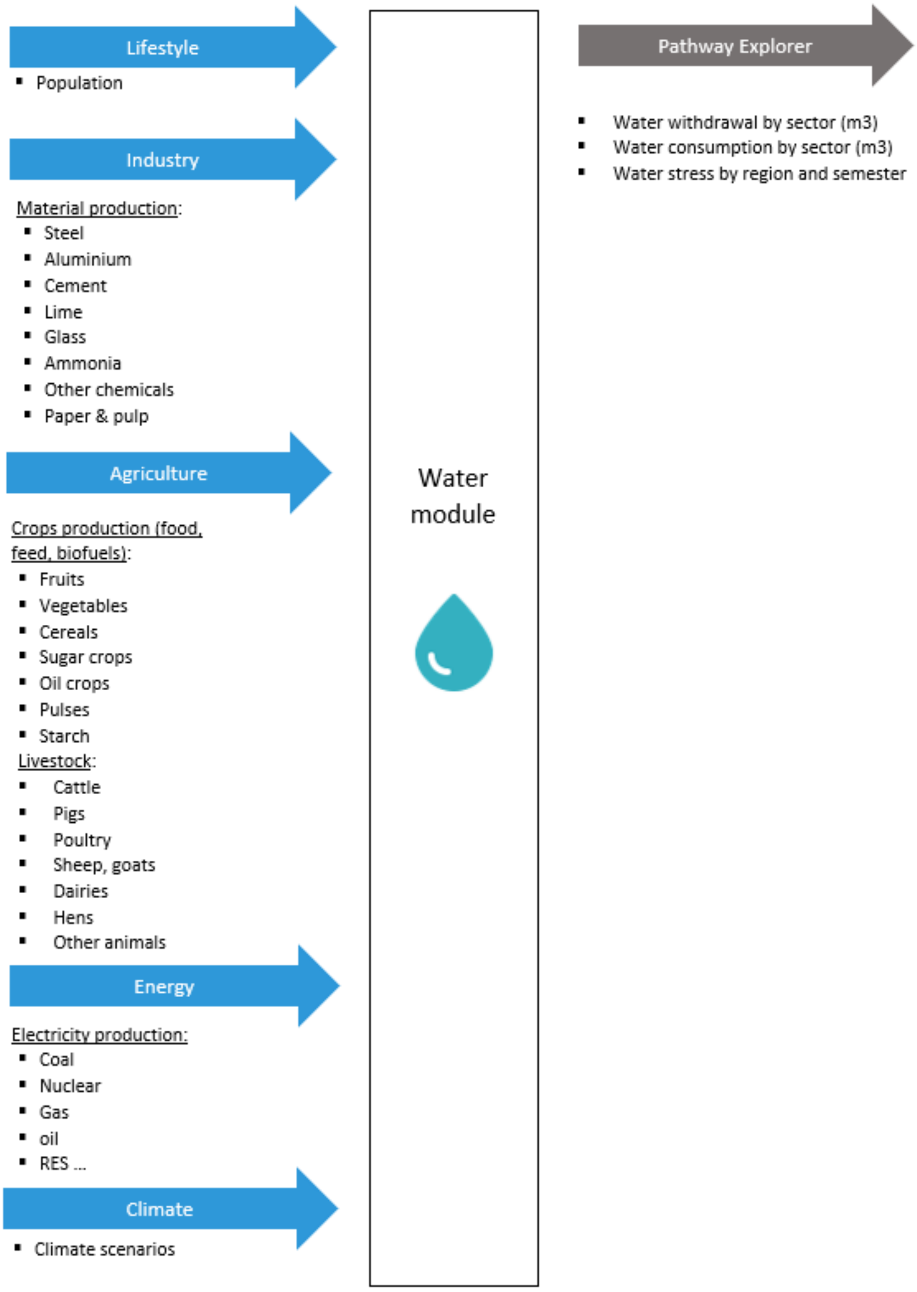

Figure 9 – Overview of the water module interactions

4.3.1 Inputs

4.3.1.1 Lifestyle

The lifestyle module provides the water module with demands for water in households & services through population counts in inhabitants (see Table 3).

4.3.1.2 Industry

The production & manufacturing module provides the water module with domestic material production and manufacturing of products in megatons. (see Table 3)

4.3.1.3 Agriculture / Land use

The agriculture/land-use module provides the water module with domestic production of crops for food, animal feed and bioenergy in kilo calories. It also provides the livestock counts in livestock units (see Table 3).

4.3.1.4 Energy supply

The energy supply module provides the water module with electricity production through various energy vectors in terawatt hours. This electricity production will be transformed into water demand for cooling of power plants. Water for oil & gas extraction and refining is not considered. (see Table 3)

4.3.1.5 Climate

The climate module provides the water module with the water availability dataset corresponding to the level chosen by the climate lever. (see Table 3)

Table 3 – List of inputs from other modules to the water module

Module	Variable
Lifestyle	lfs_pop_population[inhabitants]
Industry	ind_material-production_steel[Mt]
	ind_material-production_cement[Mt]
	ind_material-production_paper[Mt]
	ind_material-production_chem[Mt]
	ind_material-production_ammonia[Mt]
	ind_material-production_aluminium_prim[Mt]
	ind_material-production_aluminium_sec[Mt]
	ind_material-production_lime[Mt]
	ind_material-production_glass[Mt]
Agriculture/Land use	agr_liv-population_meat_poultry[lsu]

	agr_liv-population_meat_bovine[lsu] agr_liv-population_meat_pig[lsu] agr_liv-population_meat_oth-animals[lsu] agr_liv-population_abp_dairy-milk[lsu] agr_liv-population_abp_hens-egg[lsu] agr_liv-population_meat_sheep[lsu] agr_domestic-production_afw_cereal[kcal] agr_domestic-production_afw_oilcrop[kcal] agr_domestic-production_afw_pulse[kcal] agr_domestic-production_afw_fruit[kcal] agr_domestic-production_afw_veg[kcal] agr_domestic-production_afw_starch[kcal] agr_domestic-production_afw_sugarcrop[kcal]
Energy supply	elc_energy-production_electricity_pv_solar-power[TWh] elc_energy-production_electricity_biomass[TWh] elc_energy-production_electricity_concentrated_solar-power[TWh] elc_energy-production_electricity_hydro[TWh] elc_energy-production_electricity_marine[TWh] elc_energy-production_electricity_geothermal[TWh] elc_energy-production_electricity_coal[TWh] elc_energy-production_electricity_oil[TWh] elc_energy-production_electricity_gas[TWh] elc_energy-production_electricity_uranium[TWh] elc_energy-production_electricity_onshore_wind[TWh] elc_energy-production_electricity_offshore_wind[TWh]
Climate	wat_water-availability[m3]

4.3.2 Outputs

4.3.2.1 Pathway Explorer

The water module provides the Pathway Explorer with water consumption and water withdrawal for all relevant sectors (households, industrial manufacturing, electricity generation, agriculture), as well as water stress levels displayed on a map of Europe. Figure 10 shows an example of graphs displayed by the pathway explorer, and Figure 11 gives an idea of what the water stress map will look like.

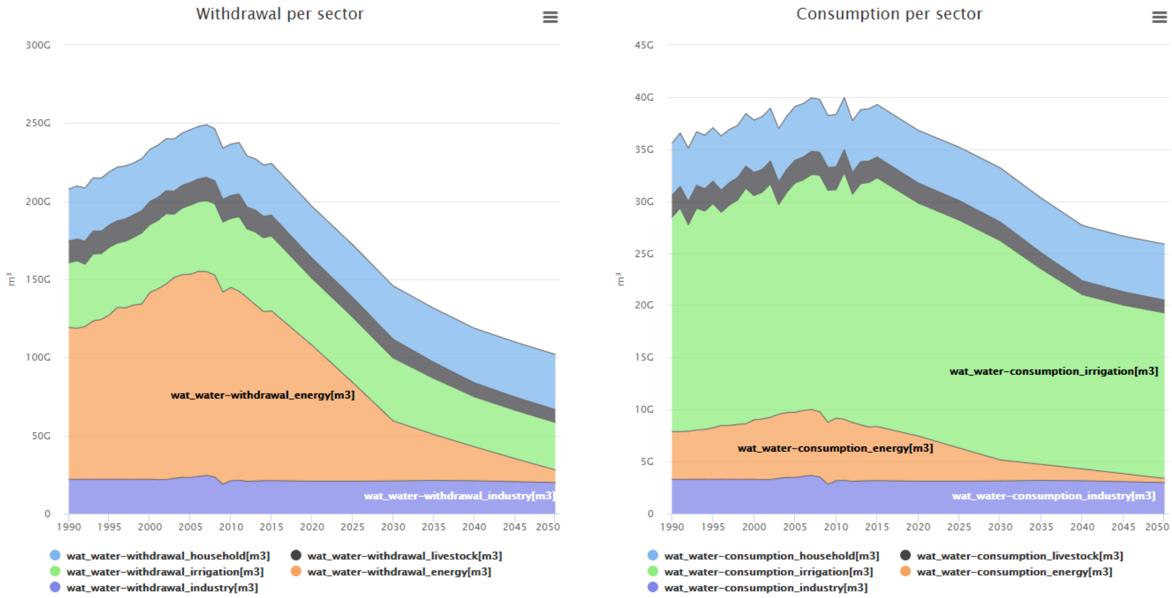

Figure 10 – Visual representation on the Pathway Explorer of water withdrawals and water consumptions in Europe

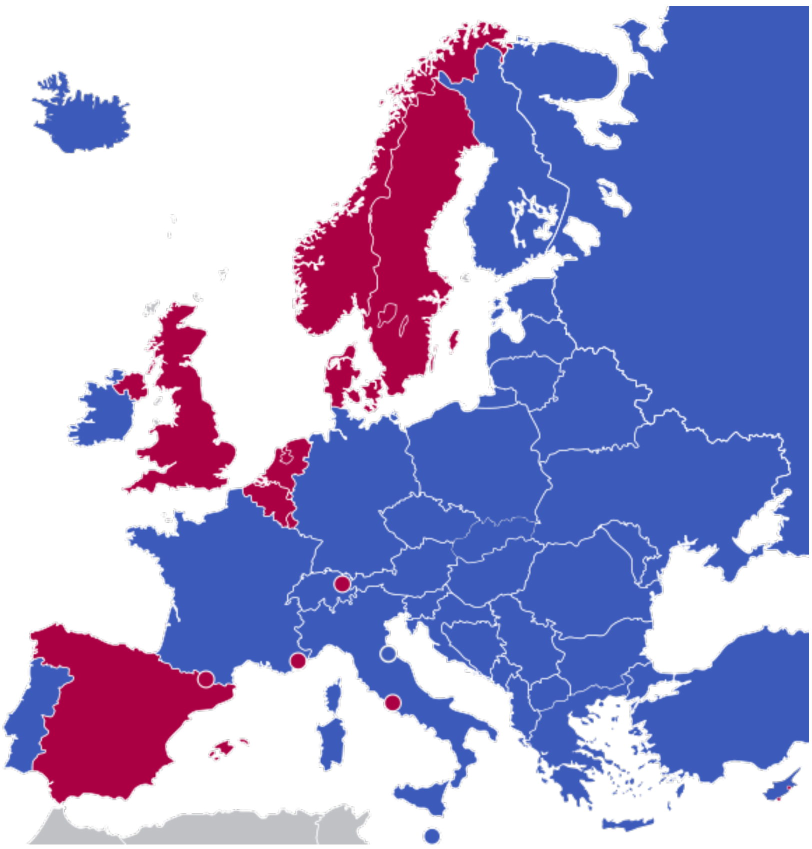

Figure 11 – Example of visual representation for water stress values, with red regions under water stress (image licensed under the Creative Commons)

4.4 Detailed calculation trees

The following sections presents the calculation breakdown of the module. The first part describes the calculation processes for the different water demands, whereas the second part focuses on the calculation path to obtain water stress values.

4.4.1 Water demand

Using the tons of material per sector, kWh produced by energy supply vector, etc., as well as water intensity values based on historical data, we can derive as outputs the water demands per region and per sector. From these demands two types of water flows are derived: water withdrawals and water consumptions.

Water demands and subsequent water flows have been computed for 5 major sectors: households & services, industrial manufacturing, electricity generation, irrigation and livestock. Irrigation and livestock represent the agricultural sector. Only domestic water demands covered by internal water resources are considered. The sectoral calculations are described below.

4.4.1.1 Households & services

The goal of this step is to compute consumption and withdrawal water flows from the water demand for households & services. This sector covers water uses from households and other services (hotels, restaurants, hospitals, schools, …). Figure 12 illustrates the calculation tree for households & services water flows. For greater readability, the term "households & services" will be shortened to "household".

Figure 12 – Calculation tree for household water demand and flows

First, the household water demand is computed by multiplying the population counts with an average water use per capita (Equation 1). This basic approach is similar to the methodology applied in the WaterGAP model (Flörke et al., 2012).

Equation 1: $\text{household water demand [m3]} = \text{Population [\#inhabitants]} * \text{water use per capita [m3/capita]}$

Historical values for household water use per capita are taken from Reynaud (2015) and reported in the Appendix, Table 6. In this study, household water use is defined as "the quantity of water used to cover the household and related utility needs of the population through the water supply industry and self-supply". The author strived to remove water use from other types of consumers (small industrial and commercial entities) that are already computed in our industrial manufacturing calculation tree, thus avoiding double counting issues.

From household water demand we then compute the household water withdrawal:

Equation 2: $Household\ water\ withdrawal\ [m3] = \ Household\ water\ demand[m3]\ /\ (1 - water\ losses[\%])$

Equation 2 outputs water withdrawn from freshwater resources by considering the water losses due to the various efficiencies of public water supply network. The historical efficiency values for EU28 were provided by JRC and are available in the Appendix,

Table 7. The value for Switzerland was extracted from the report from the SKAT foundation (Saladin, 2002).

Similarly, household water consumption is derived from household water demand as follows:

Equation 3: $Household\ water\ consumption[m3] = \ Household\ water\ demand[m3] * consumptive\ use\ [\%]$

We assume that consumptive use for households is 20% of the water demand, implying that 80% flows back to the environment as waste water (Bisselink et al., 2018).

Further improvement could integrate the percentage of population connected to public water supply prior to calculating households water demand. Due to a high range of missing data on the EUROSTAT database[6], we made the rather coarse assumption that every EU28+1 inhabitant have access to public water. The calibration process adjusts our calculated values in order to mitigate our approximation. As in the WaterGAP model, future iterations of the calculator could include changes in household water use intensity (m3/capita/year) due to structural and technological changes (Alcamo et al., 2003).

4.4.1.2 Electricity generation

The objective is to compute consumption and withdrawal water flows from the electricity generation cooling water demand. Figure 13 illustrates the calculation tree for electricity generation water flows.

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[6] EUROSTAT, Population connected to public water supply (%), direct link: https://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&language=en&pcode=ten00012&plugin=1

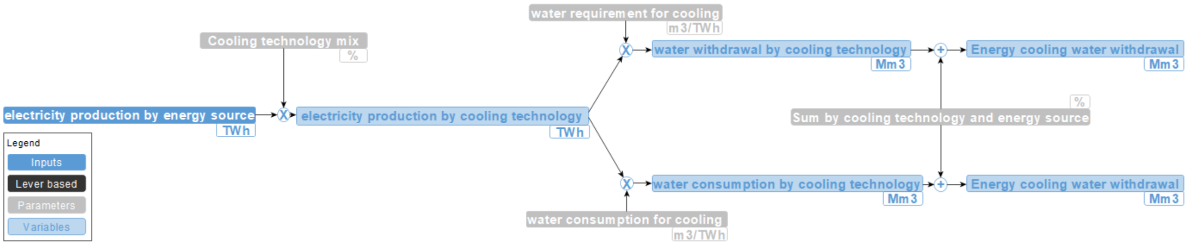

Figure 13– Calculation tree for electricity generation water demand and flows

The first calculation step is to split the electricity production input (in TWh) by cooling technologies. We use the assumed cooling system shares for thermoelectric generation technologies reported in the paper from Davies et al. (2013) to split coal, oil, gas, nuclear and biomass-based electricity productions. Cooling system technologies considered in our model include once-through cooling (open-loop cooling), wet recirculating cooling (evaporative towers) and dry cooling (air-cooled condensing) (Macknick et al., 2012).

Then we multiply these values with water requirements for cooling (in m3/TWh) found in literature (Davies et al., 2013; Fricko et al., 2016). Literature provides distinct values per cooling technology for water consumption and for water withdrawal, as presented in Equations 4 and 5:

Equation 4: $$\text{Electricity generation water withdrawal}[m3] = \text{Electricity production by energy source}[TWh] * \text{water withdrawal for cooling}[m3/TWh]$$

Equation 5: $$\text{Electricity generation water consumption}[m3] = \text{Electricity production by energy source}[TWh] * \text{water consumption for cooling}[m3/TWh]$$

Once water flows are calculated by cooling technology, these are summed to obtain total cooling water consumption and withdrawal.

Further improvements could include a future shift from once-through to recirculating cooling systems over time. This feature was not relevant in this model since future power-plants constructions plans for which different cooling technologies could be applied are low, thus not really impacting our modelling results.

4.4.1.3 Industrial manufacturing

The goal is to compute consumption and withdrawal water flows from the industrial manufacturing water demand. Figure 14 illustrates the calculation tree for industrial manufacturing water flows.

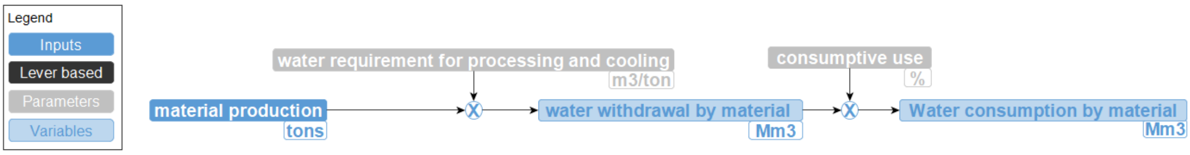

Figure 14 – Calculation tree for industrial manufacturing water demand and flows

The water demand from this sector excludes water demands for oil and gas production and coal mining, as well as the indirect water demand for producing the energy used in industrial processes. Our definition differs from the "industrial water withdrawals" used in FAO Aquastat[7] since the latter includes electric power generation, which is not the case in our model. Similarly to Bisselink et al. (2018), we separate water demand for energy and cooling from manufacturing water demand.

Our procedure consists in using water requirements for industrial processing and cooling (m3/ton) and multiplying them with specific material production (tons) to derive water withdrawal by material type. The corresponding equation is the following:

Equation 6: $$\text{Material water withdrawal}[m3] = \text{Material production}[tons] * \text{water requirement for processing and cooling}[m3/ton]$$

As water requirement values are not available for all industrial productions covered in EUCalc, we introduce a specific sub-sector labelled "other-industries" which is calibrated to match historical water demands for the whole industrial sector. For other industrial sub-sectors from EUCalc, water requirements for industrial processing and cooling (m3/ton) are defined as follows:

- For **steel**, we use a combination of the blue water footprints of "Chromium-nickel unalloyed steel" and "Unalloyed steel" from (Gerbens-Leenes et al., 2018) weighted by the steel quality shares in Europe in 2017 (EUROFER, 2018).
- For **cement**, we use a combination of the blue water footprints of "Portland Cement" (CEMI) and "Portland composite cement" (CEMII) from (Gerbens-Leenes et al., 2018) weighted by the cement shares by process in Europe in 2015 (European Commission, 2018).
- For **glass**, we use the blue water footprint of "Soda-lime float glass" from (Gerbens-Leenes et al., 2018).
- For **lime**, we assume that the water requirement of the transformation step in the cement process that transforms limestone into lime and which requires washing (Gerbens-Leenes et al., 2018).

[7] FAO Aquastat database, direct link: http://www.fao.org/nr/water/aquastat/data/query/index.html

- For **paper** (woodpulp and recycled), we use the estimation of the water footprint of paper products in industrial stage for the USA industry from (Van Oel, P. R., & Hoekstra, A. Y., 2010).
- For **aluminium** (primary and secondary), we use the values provided in the Environmental Profile Report from European Aluminium (European Aluminium, 2018) We apply the water supply value for an aluminium sheet production for primary aluminium, and the total water supply value after scrap remelting for secondary aluminium.
- For **ammonia**, we use an average value between blue water footprints of "Nitrogen-phosphorus-potassium (NPK) fertilizer (12:32)" and "Nitrogen-phosphorus-potassium (NPK) fertilizer (10:26)" given in the Tata Industrial Water Footprint Assessment report (Unger et al., 2013).
- For **other chemicals**, we assume that the production is mainly related to the demand of plastic packs from the Lifestyle module. Consequently, we decide to use the average water footprint of plastics found by Li et al. in their report on the water footprint of Tetra Pak carton (Li et al., 2010).

These water requirements are presented in Table 4.

Table 4 – List of material water requirements for industrial processing and cooling used in the water module

Material production	Water requirement (m3/ton)	Source / *Adapted from
Steel	65,2	*Gerbens-Leenes et al., 2018
Cement	3,2	*Gerbens-Leenes et al., 2018
Glass	5,9	Gerbens-Leenes et al., 2018
Lime	0,19	Gerbens-Leenes et al., 2018
Paper (pulp & recycled)	5,5	Van Oel, P. R., & Hoekstra, A. Y., 2010
Aluminium (primary)	3,9	European Aluminium, 2018
Aluminium (secondary)	6,8	European Aluminium, 2018
Ammonia	4,96	*Unger et al., 2013
Other chemicals	13,7	Li et al., 2010

Water consumption is then derived by multiplying water withdrawal with an average consumptive use of 15% (Bisselink et al., 2018) (see Equation 7).

Equation 7: $Material\ water\ consumption[m3] = Material\ water\ withdrawal[m3] * consumptive\ use[\%]$

Usually, industrial water uses are approximated by using the ratio of water abstracted over the manufacturing gross value added (GVA) (Flörke et al., 2013). However, given that these GVA values are only available at aggregated level, this large scale approach did not suit our sub-sectoral approach. Furthermore, using GVA values as inputs would create loops with other modules that could compromise the objective of real-time computation.

4.4.1.4 Livestock

The objective is to compute consumption and withdrawal water flows from the livestock drinking water demand. Figure 15 – Calculation tree for livestock drinking water demand and flowsFigure 15 illustrates the calculation tree for livestock drinking water flows.

Figure 15 – Calculation tree for livestock drinking water demand and flows

The water footprint of animals includes the indirect water footprint of ingested feed which is considered in the irrigation section, and the direct water footprint associated with drinking and servicing which is tackled in this section. Drinking water mainly comes from blue water sources whereas water in feed may come from blue or green water sources depending on irrigation practices to produce feed. The outflows correspond to respiration, perspiration, excreta as manure and urine, and water incorporated into livestock products (milk, meat, wool, etc.) (FAO, 2018). We then assimilate the consumptive use of livestock to the respiration and perspiration processes, which account for 17% of water intakes for lactating Holstein dairy cow (Khelil-Arfa et al., 2012) and is rounded for all animals to 15% of livestock water demand by the JRC (Bisselink et al., 2018).

In this section, we use the Livestock Unit (LSU) which is defined by Eurostat as *a reference unit which facilitates the aggregation of livestock from various species and age as per convention, via the use of specific coefficients established initially on the basis of the nutritional or feed requirement of each type of animal.*[8]

As shown in Equation 8, the first step of calculation consists in multiplying livestock counts per year (LSU) by the water requirement (m3/LSU) to obtain livestock water demand in m3.

Equation 8: $\textit{Livestock water demand[m3]} = \textit{Livestock[LSU]} * \textit{water requirement per LSU[m3/LSU]}$

[8] Eurostat glossary link: https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Livestock_unit_(LSU)

The water requirements per LSU are pre-calculated using the average annual water footprint per animal presented in Mekonnen & Hoekstra (2012) and the unit conversion factors to transform animals counts into LSU.[9] Complementary water footprint values were found in Tschudin et al. (2011).

The second step is to select the share of livestock water demand related to drinking and other services. According to Mekonnen & Hoekstra (2012), the largest water footprint for animals come from their feed which is tantamount to 98% of the total water footprint, while drinking and other services only represent 2% of the total water footprint. Consequently, we multiply the livestock water demand by the drinking use share (approximately 2%), as shown in Equation 9:

Equation 9: $Livestock\ drinking\ water\ demand[m3] = Livestock\ water\ demand[m3] * livestock\ drinking\ use\ share[\%]$

We assume in our model that *livestock drinking water demand* corresponds to the water withdrawal for livestock drinking so that no water loss is accounted.

Finally, the water consumption for livestock drinking is calculated in Equation 10 by multiplying the "livestock drinking water withdrawal" with the livestock consumptive use from JRC (equal to 15%) (Bisselink et al., 2018).

Equation 10: $Livestock\ drinking\ water\ consumption[m3] = Livestock\ drinking\ water\ withdrawal[m3] * livestock\ consumptive\ use[\%]$

4.4.1.5 Irrigation

The goal is to compute consumption and withdrawal water flows from the irrigation water demand. Figure 16 illustrates the calculation tree for irrigation water flows.

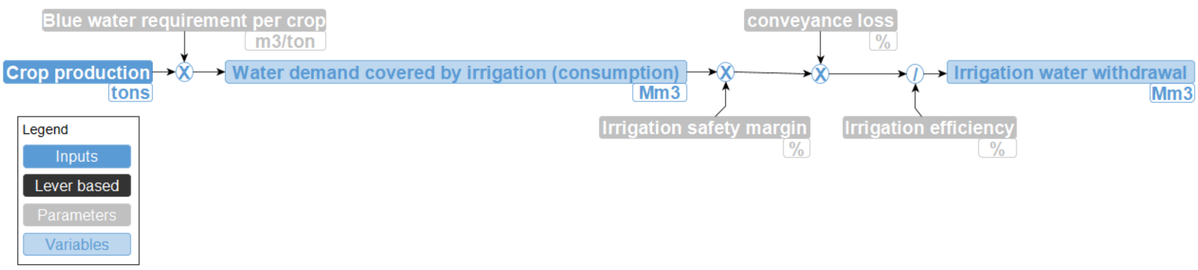

Figure 16 – Calculation tree for irrigation water demand and flows

First, we compute in Equation 11 the irrigation water demand by using blue water footprints from Mekonnen & Hoekstra (2011):

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[9] https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Livestock_unit_(LSU)

Equation 11: $Irrigation\ water\ demand[m3] = crop\ production[tons] * blue\ water\ requirement\ per\ crop[m3/ton]$

In this case, irrigation water demand corresponds to the irrigation water consumption since we assume that water poured onto fields is entirely consumed by plants for growth.

Water withdrawals for irrigation are derived from net irrigation consumption by counting efficiency losses, 20% of conveyance losses, and another 20% of safety margin (we irrigate more than needed to prevent soil salination):

Equation 12: $Irrigation\ water\ withdrawal[m3] = Irrigation\ water\ demand[m3] * irrigation\ safety\ margin[\%] * conveyance\ losses[\%] / irrigation\ efficiency[\%]$

Irrigation efficiencies have been provided by JRC, as well as irrigation safety margin and conveyance losses.

4.4.2 Water stress (WEI)

This section describes the procedure to calculate the water stress, considered as the most common warning sign regarding water scarcity (Rijsberman, 2006).

We use the Water Exploitation Index "normal" (WEI-normal), defined as the ratio between water consumption versus local water availability (see Equation 13). This indicator is derived from the WEI+, which was defined by EU member states in the Water Scarcity and Droughts Working Group in 2011 as the total consumption of water divided by the renewable freshwater resources (Faergemann, 2012).

As explained in section 4.1, we decided to increase spatial and temporal granularity to better reflect the regions prone to water shortage and the periods when water scarcity is more acute.

This increment in granularity posed a modelling challenge since the water module is the only piece of the calculator that integrates this feature. Indeed, where other sectors use country level and yearly data, we decided to use finer spatial and temporal scales so as to obtain more reliable results. Consequently, the first step prior to the calculation introduced in Equation 13 is to adapt our aggregated output from the water demand section to the granularity given by the local water availability data. The local water availability dataset used in the calculation is defined by the climate lever input which is described in Table 2, section 4.2.1.

Equation 13: $WEI\text{-}normal[-] = total\ water\ consumption[m3] / local\ water\ availability[m3]$

Note that WEI-normal uses local water availability which does not take into account upstream inflow.

4.5 Calibration

The calibration process is introduced in the cross sectoral model documentation.

4.5.1 Sources

In the water module, we calibrate water demand for each sector, i.e. households, electricity generation, industrial manufacturing, irrigation and livestock. The source for water demand calibration is the data computed by JRC (Bisselink et al., 2018). The water flows provided by JRC for calibration are:

- Water demand public sector [m3] (for region in month)
- Water demand livestock sector [m3] (for region in month)
- Water demand energy sector [m3] (for region in month)
- Water demand industry sector [m3] (for region in month)
- Irrigation water consumption[m3] (for region in month)

The granularity of these data is the same as the one used in the water availability data (with sub-regions for countries prone to water scarcity).

4.5.2 Module improvement through calibration

Calibration allows to flag incorrect data or hypotheses in the model and to change them in order to improve the quality of the model.

The calibration process took place at two different scales. We first check at the European scale (EU28 + Switzerland) if the sum for all European countries matched the calibration data, before doing the same exercise at the national level.

Countries with robust data result in calibration rates close to 1 whereas countries for which data is scarce or less precise produce calibration rates rather out of scope.

4.5.3 Current calibration rates

Not applicable in the current version of the module.

5 Description of levers and ambition levels

This section presents the different lever suggestions that have been explored during the workshop on resource use lead by Imperial College in London. None of these levers was implemented so far. Among other reasons:

- no carbon trade-off could be foreseen through these levers.
- some levers were tackling water quality rather than quantity, which is out of scope for the current version of the module.
- historical data justifying ambition levels were either insufficient or missing.

5.1 Lever list and description

The objective would be to introduce a water management lever that includes several practices described as sub-levers.

Table 5 summarizes the proposed sub-levers for a water management lever.

Table 5 – List of possible sub-levers for the water management lever in the water module

Lever		**Sub-Lever**	**Short description**
Water Management	1.	Water use efficiency [%]	This lever sets the percentage of current water loss avoided. It will impact the total water demand
	2.	Sustainable water abstraction [%]	This lever sets the percentage of water sustainably abstracted. It will impact the total water demand.
	3.	Water framework Directive (WFD) ambitions [%]	This lever sets the percentage of water bodies (rivers, groundwater) achieving good status defined by the WFD.
	4.	Sea water desalination [Mm3]	This lever sets the amount of seawater in Mm3 that is desalinated to meet water demand in EU. It will impact the quantity in Mm3 of readily available water resources.

	5.	Waste water treatment and reuse [%]	This lever sets the percentage of waste water treated and reused in EU. It will impact the quantity in Mm3 of readily available water resources.

5.2 Definition of ambition levels

5.2.1 1, 2, 3, 4

The list here under describes the 4 ambition levels used in EUCalc.

Level 1	**Business as usual** This level contains projections that are aligned and coherent with the observed trends.
Level 2	**Ambitious but achievable** This level is an intermediate scenario, more ambitious than business as usual but not reaching the full potential of available solutions.
Level 3	**Very ambitious but achievable** This level is considered very ambitious but realistic, given the current technology evolutions and the best practices observed in some geographical areas.
Level 4	**Transformational breakthrough** This level is considered as transformational and requires additional breakthrough and efforts such as a very fast market uptake of deep measures, an extended deployment of infrastructures, major technological advances, or strong societal changes, etc.

5.2.2 A, B, C, D

This type of ambition levels should only be used for levers that cannot be adapted to the 1,2,3,4 logic.

Definition of ambition levels and list of levers with that kind of ambition levels.

5.3 Lever specification

5.3.1 Lever rationale

The European Commission estimated that in 2007, more than 16% of EU total population had been affected by water scarcity and droughts (European Commission, 2007). Although spatial and temporal distribution of water resources were considered as an outstanding reason to this situation, Europe wastes more than 20% of its water due to inefficiency. Moreover, the EEA evaluated that respectively 40% of reported water bodies were under hydromorphological pressure and 18% were under point source pollution pressure (EEA, 2018b). These figures reveal a tremendous potential for water saving and ecological status improvement of water bodies. Consequently, a water management lever would enable the user to act upon several parameters such as water efficiency, sustainable water abstraction or ecological status improvement of water bodies. The main objective of such a lever would be to reduce pressure caused by water demand on water bodies, especially for areas sensitive to droughts.

5.3.2 Sub-levers description

5.3.2.1 Water efficiency

Water efficiency can be achieved through water use reduction, water recycling and technological advances in efficiency. This lever would be modelled as the percentage of water loss avoided through water use reduction, water recycling and technological advances in efficiency. As stated during the workshop on Land-use, biodiversity and water (deliverable 4.3), water efficiency improvements may not impact much on expected negative effects of climate change. However, this point was not considered strong enough reason not to include it, reflecting that changes in practices and new practices may be required to meet climate targets. Practically, the different levels of ambition could be based on the measures for managing water in Europe proposed by EEA, which include: water restrictions and rationing in periods of acute shortage, network leakage reduction, use of water efficient devices in buildings and houses, or else consumer awareness campaigns (Ecologic, 2017).

5.3.2.2 Sustainable water abstraction

Another suggestion for a lever was the degree of sustainable abstraction, i.e. the degree of water use in line with annual recharge in order to reduce water stress and over abstraction. This lever would be modelled as the percentage of water sustainably abstracted. With climate change, we expect less groundwater recharge and larger seasonal variations in river flow as well as changes to when and how extended dry periods occur. Therefore, sustainable water abstraction appears to be essential to ensure that river flows and groundwater levels support ecology and natural resilience to climate change and human activities. In order to achieve the goals of sustainable abstraction, the Environment Agency in UK for instance will focus on abstraction licenses having the greatest impact and act now to reduce future risks. They will review licenses by adjusting them as necessary to make sure they do not allow environmental damage now or in the future, or revoke licenses that have been shown unused (EEA, 2018b). Some data sets from JRC could be used to model this and it will be followed up directly with JRC scientist on a separate meeting.

5.3.2.3 *Water Framework Directive (WFD) ambitions*

This lever would set the proportion of water bodies achieving Water Framework Directive (WFD) good status. This was suggested during the "Expert consultation workshop on the biodiversity and water impacts of biomass provision for food, feed, energy and materials in the EUCalc" since this is already a target that Europe has set and is legally binding. For rivers in England, the Environment Agency uses the 'Environmental Flow Indicator' (EFI) to indicate where abstraction, or flow regulation, may start to have an undesirable impact on river habitats and species. The Environment Agency interprets surface water bodies with flow greater than the EFI as supporting Good Ecological Status under the EU Water Framework Directive (WFD). For groundwater abstraction, the Environment Agency uses 4 quantitative tests that aim to protect surface water flows, groundwater levels, spring discharges and water quality. The Environment Agency interprets groundwater bodies that meet those 4 tests as being at good status for groundwater quantity under the WFD (Priestley et al., 2018). Several other metrics, that have not been previously mentioned, are taken into account in WFD to determine the status of water bodies in EU.

5.3.2.4 *Sea Water Desalination*

Water desalination could either be used as a buffer in case of lack of freshwater supply or as a lever that would enable the user to choose among four scenarios (A-D) for water desalination use. So far, it is a very energy intense process and is critical as long as it is not solar driven and made carbon neutral. For instance, The H2020 project "Revived water" focuses on developing several new low energy electro dialysis systems to support future sea water desalination projects.[10] As water desalination requires energy use, we should be careful about a possible feedback with energy demand. A solution is to add a dedicated sub-module within the energy module.

[10] Revived water H 2020 project : https://revivedwater.eu

5.3.2.5 Waste Water Treatment and Reuse

The degree of wastewater treatment, through the percentage of wastewater that is treated to certain standards has also been suggested. From the EUCalc perspective, this lever would be modelled as the percentage of wastewater treated and reused. Indeed, there is a huge potential in reusing treated wastewater while ensuring a reasonable return flow to the environment. However, reuse of treated wastewater seems still politically sensitive in EU as mentioned during the "Expert consultation workshop on the biodiversity and water impacts of biomass provision for food, feed, energy and materials in the EUCalc". Similarly to the water desalination sub-lever, waste water treatment requires energy use and we should be careful about a possible feedback with energy demand.

6 Description of constant or static parameters

6.1 Constant list

This section presents the list of constants used in the water module:

- Cooling consumption water factors (Davies et al., 2013 ; Fricko et al., 2016)
- Cooling withdrawal water factors (Davies et al., 2013 ; Fricko et al., 2016)
- Households consumptive use: 20% (Bisselink et al., 2018)
- Industry consumptive use: 15% (Bisselink et al., 2018)
- Irrigation conveyance losses: 20% (Bisselink et al., 2018)
- Irrigation margin factor: 20% (Bisselink et al., 2018)
- Livestock drinking use: 2% (Bisselink et al., 2018)
- Livestock consumptive use: 15% (Bisselink et al., 2018)

6.2 Static parameters

This section presents the list of static parameters used in the water module:

- Cooling technology shares per energy vector (Davies et al., 2013)
- Household water leakage factors (JRC data)
- Industry water factors (see Table 4, section 4.4.1.3)
- Irrigation efficiencies (JRC data)

7 Historical Databases

Describes each historical dataset that is needed for the model, its sources, quality and the hypotheses needed to fill the data gaps

Dataset	**Description**	**Main sources**	**Data quality check**	**Hypotheses**
Household water use [m3/capita/year]	Average household water use per inhabitant within a year	[Reynaud A., 2015]	Good quality data from reliable, coherent and credible source (JRC) However data is not available for all years	We extrapolate missing "in-between" data, or keep last value constant.
Blue water footprints for crops [m3/ton]	Average water from freshwater resources consumed by crops	[Mekonnen & Hoekstra, 2011]	Thorough data from reliable, coherent and credible sources However the values are worldwide average	We keep these values constant for every country and every year
Livestock water requirements [m3/animal/year]	Water required by livestock over a year	[Mekonnen & Hoekstra, 2012]; [Tschudin et al., 2011]	Good quality data from reliable, coherent and credible sources However the values are worldwide average	We keep these values constant for every country and every year

8 References

(Abbaspour et al., 2015) Abbaspour, K. C., Rouholahnejad, E., Vaghefi, S., Srinivasan, R., Yang, H., & Kløve, B. (2015). A continental-scale hydrology and water quality model for Europe: Calibration and uncertainty of a high-resolution large-scale SWAT model. Journal of Hydrology, 524, 733-752.

(Alcamo et al., 2003) Alcamo, J., Döll, P., Henrichs, T., Kaspar, F., Lehner, B., Rösch, T., & Siebert, S. (2003). Development and testing of the WaterGAP 2 global model of water use and availability. Hydrological Sciences Journal, 48(3), 317-337.

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

(Bruinsma J., 2009) Bruinsma, J. (2009, June). The resource outlook to 2050: by how much do land, water and crop yields need to increase by 2050. In Expert meeting on how to feed the world in (Vol. 2050, pp. 24-26).

(Davies et al., 2013) Davies, E. G., Kyle, P., & Edmonds, J. A. (2013). An integrated assessment of global and regional water demands for electricity generation to 2095. Advances in Water Resources, 52, 296-313.

(Duarte et al., 2014) Rosa Duarte, Vicente Pinilla & Ana Serrano (2014) Looking backward to look forward: water use and economic growth from a long-term perspective, Applied Economics, 46:2, 212-224

(Ecologic, 2017) Ecologic (2017). Pricing and non-pricing measures for managing water demand in Europe, Service Contract No 3415/B2015/EEA.56130 for the European Environment Agency. Link: https://forum.eionet.europa.eu/nrc-eionet-freshwater/library/other-reports-and-assessments/water-management-europe-price-and-non-price-approaches-water-conservation/water-management-europe-price-and-non-price-approaches-water-conservation-1

(EEA, 2018a) European Environment Agency (2018). Water use in Europe — Quantity and quality face big challenges. Link: https://www.eea.europa.eu/signals/signals-2018-content-list/articles/water-use-in-europe-2014

(EEA, 2018b) European Environment Agency (2018). European waters Assessment of status and pressures 2018, European Environment Agency Report, ISSN 1977-8449. Link: https://www.eea.europa.eu/publications/state-of-water

(EPRS, 2016) European Parliamentary Research Service (2016). Water use in the EU, EPRS Briefings. Link: http://www.europarl.europa.eu/RegData/etudes/BRIE/2016/581983/EPRS_BRI(2016)581983_EN.pdf

(EUROFER, 2018) EUROFER (2018) European Steel in Figures 2018. Link: http://www.eurofer.org/News%26Events/News/European%20Steel%20in%20Figures%202018.fhtml

(European Aluminium, 2018) European Aluminium (2018). Life-Cycle inventory data for aluminium production and transformation processes in Europe.

(European Commission, 2007) European Commission (2007). Addressing the challenge of water scarcity and droughts in the European Union. Link: http://ec.europa.eu/environment/water/quantity/pdf/comm_droughts/ia_summary_en.pdf

(European Commission, 2018) European Commission (2018). Competitiveness of the European cement and lime sectors. Link: https://publications.europa.eu/en/publication-detail/-/publication/07d18924-07ce-11e8-b8f5-01aa75ed71a1/language-en/format-PDF/source-65040600

(FAO, 2018) FAO. 2018. Water use of livestock production systems and supply chains – Guidelines for assessment (Draft for public review). Livestock Environmental Assessment and Performance (LEAP) Partnership. FAO, Rome, Italy.

(FAO Aquastat) FAO. 2016. AQUASTAT Main Database, Food and Agriculture Organization of the United Nations (FAO). Link: http://www.fao.org/faostat/en/#home

(Faergemann, 2012) Faergemann H. (2012). Update on Water Scarcity and Droughts indicator development, European Commission.

(Flörke et al., 2013) Flörke, M., Kynast, E., Bärlund, I., Eisner, S., Wimmer, F., & Alcamo, J. (2013). Domestic and industrial water uses of the past 60 years as a mirror of socio-economic development: A global simulation study. Global Environmental Change, 23(1), 144-156.

(Fricko et al., 2016) Fricko, O., Parkinson, S. C., Johnson, N., Strubegger, M., van Vliet, M. T., & Riahi, K. (2016). Energy sector water use implications of a 2 C climate policy. Environmental Research Letters, 11(3), 034011.

(Gerbens-Leenes et al., 2018) Gerbens-Leenes, P. W., Hoekstra, A. Y., & Bosman, R. (2018). The blue and grey water footprint of construction materials: Steel, cement and glass. Water resources and industry, 19, 1-12.

(Gleick P.H., 2003) Gleick, P. H. (2003). Global freshwater resources: soft-path solutions for the 21st century. Science, 302(5650), 1524-1528.

(Gosling et al., 2016) Gosling, S. N., & Arnell, N. W. (2016). A global assessment of the impact of climate change on water scarcity. Climatic Change, 134(3), 371-385.

(Hoekstra, 2011) Hoekstra, A.Y. (2011). The Water Footprint Assessment Manual, Water Footprint Network – WFN.

(Khelil-Arfa et al., 2012) Khelil-Arfa, H., Boudon, A., Maxin, G., & Faverdin, P. (2012). Prediction of water intake and excretion flows in Holstein dairy cows under thermoneutral conditions. Animal, 6(10), 1662-1676.

(Li et al., 2010) Li, C., & Nwokoli, S. (2010). Investigating the water footprint of Tetra Pak Carton Economy's beverage portfolio.

(Macknick et al., 2012) Macknick, J., Newmark, R., Heath, G., & Hallett, K. C. (2012). Operational water consumption and withdrawal factors for electricity generating technologies: a review of existing literature. Environmental Research Letters, 7(4), 045802.

(Mekonnen & Hoekstra, 2011) Mekonnen, M. M., & Hoekstra, A. Y. (2011). The green, blue and grey water footprint of crops and derived crop products. Hydrology and Earth System Sciences, 15(5), 1577-1600.

(Mekonnen & Hoekstra, 2012) Mekonnen, M. M., & Hoekstra, A. Y. (2012). A global assessment of the water footprint of farm animal products. Ecosystems, 15(3), 401-415.

(Postel et al., 1996) Postel, S.L., Daily, G.C., Ehrlich, P.R., 1996. Human appropriation of renewable fresh water. Science 271, 785.

(Priestley et al., 2018) Priestley, S., Barton, C. (2018). Water Framework Directive: achieving good status of water bodies, briefing paper number CBP 7246, House of Commons Library

(Reynaud A., 2015) Reynaud A. (2015). "Modelling Household Water Demand in Europe". JRC Technical Reports.

(Rjisberman, 2006) Rijsberman, F. R. (2006). Water scarcity: fact or fiction?. Agricultural water management, 80(1-3), 5-22.

(Saladin, 2002) Saladin M. (2002). Community water supply in Switzerland – What can we learn from a century of successful operation?. Skat Foundation.

(Sutadian et al., 2016) Sutadian, A. D., Muttil, N., Yilmaz, A. G., & Perera, B. J. C. (2016). Development of river water quality indices—a review. Environmental monitoring and assessment, 188(1), 58.

(Tobin et al., 2018) Tobin, I., Greuell, W., Jerez, S., Ludwig, F., Vautard, R., Van Vliet, M. T. H., & Breón, F. M. (2018). Vulnerabilities and resilience of European power generation to 1.5 C, 2 C and 3 C warming. Environmental Research Letters, 13(4), 044024.

(Tschudin et al., 2011) Tschudin, A., Clauss, M., Codron, D., Liesegang, A., & Hatt, J. M. (2011). Water intake in domestic rabbits (Oryctolagus cuniculus) from open dishes and nipple drinkers under different water and feeding regimes. Journal of animal physiology and animal nutrition, 95(4), 499-511.

(Unger et al., 2013) Unger, K., Zhang, G. and Mathews, R. (2013). Water Footprint Assessment Results and Learning: Tata Chemicals, Tata Motors, Tata Power, Tata Steel, Tata Quality Management Services, International Finance Corporation, and Water Footprint Network. Link: https://waterfootprint.org/media/downloads/WFN_2013.Tata_Industrial_Water_Footprint_Assessment.pdf

(Van Oel, P. R., & Hoekstra, A. Y., 2010) Van Oel, P. R., & Hoekstra, A. Y. (2010). The green and blue water footprint of paper products. Value of Water Research Report Series, 46.

(Vickers, 1999) Vickers, A.L. (1999). "Handbook of water use and conservation". United States.

(Wan et al., 2018) Wan, D., & Zeng, H. (2018, July). Water environment mathematical model mathematical algorithm. In IOP Conference Series: Earth and Environmental Science (Vol. 170, No. 3, p. 032133). IOP Publishing.

9 Appendix

Table 6 – Historical values for water use per capita in m3/year/cap. (from Reynaud. A, 2015)

Country	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Austria																				48.093	47.955	47.503				
Belgium																		54.746	53.649	53.070						
Bulgaria															32.548				31.890			30.279				
Croatia															44.666			43.938			43.682					
Cyprus											41.030	39.198	40.073	41.589	39.045	38.958	38.829	39.281	37.832	37.645	35.766	35.861				
Czech Republic												34.979	33.045	35.003	34.393	33.998	35.464	36.892	36.335	36.476	35.864					
Denmark											103.259	100.521	99.281	101.738	101.045											
Estonia																	35.344	35.595	34.146	33.597	32.554	32.239				
Finland															63.824	62.187	59.785	57.196	56.182	54.377	52.442	51.629				
France																			63.126	54.275	49.513	49.071				
Germany						70.210	73.945	66.786	62.877	70.191	69.020	82.680	88.782	91.605	94.643	99.255	98.136	96.337	79.456	87.005	98.987	94.723	91.330			
Greece		78.395	77.146	75.067	71.558	69.826	69.769	62.090	50.355	44.467	41.367	38.595	36.885	35.961	34.635	44.639	35.690	38.004	40.520	34.290	33.808	40.100	34.359			
Hungary												27.395	25.553	25.366	26.005	26.483	28.171	25.814	25.354	24.324	24.134	24.974	24.847			
Ireland																					44.557	47.633	46.713			
Italy																					81.908					
Latvia																						49.255				
Lithuania											77.552	78.498	76.413	74.917	73.367	72.543	71.951	69.940	69.219	68.465	66.830	64.245				
Luxembourg																								58.618		
Malta																					51.186					
Netherlands						32.204	34.794	36.875	27.975	29.217	29.621	28.988	30.989	31.560	31.887	27.605	26.564	27.413	27.234	27.347	25.825					
Poland														36.908	35.775	35.509	35.598	34.983	35.318	34.781	34.546	34.655	34.618	34.380		
Portugal																	50.431	54.355	59.693	63.523						
Romania											105.047	94.234	77.763	68.632	66.883	60.157	60.866	61.151	60.987	57.285	55.803	54.371	55.253			
Slovakia													48.179	50.360	47.437	46.352	46.933	47.973	47.929	45.912	44.809	44.505	45.139			
Slovenia												42.536	41.746	39.617	35.900	35.450	32.832	33.801	33.407	30.899	30.128	29.592				
Spain																						66.457				
Sweden						69.751					69.608					62.038					61.137					
Switzerland																							59.13			
United Kingdom													55.044	57.138	55.692	55.156	54.620	53.954	53.632	53.767						

Table 7 - Public water supply network efficiencies (from JRC)

MS	NUTS Name	Current Efficiency [estimate]
AT	Austria	0,7973
BE	Belgium	0,8
BG	Bulgaria	0,7973
CY	Cyprus	0,76
CZ	Czech Republic	0,83
DE	Germany	0,94
DK	Denmark	0,92
EE	Estonia	0,7973
GR	Greece	0,7973
ES	Spain	0,71
FI	Finland	0,81
FR	France	0,79
HR	Croatia	0,7973
HU	Hungary	0,8
IE	Ireland	0,52
IT	Italy	0,62
LT	Lithuania	0,7973
LU	Luxembourg	0,7973
LV	Latvia	0,7973
MT	Malta	0,58
NL	Netherlands	0,95
PL	Poland	0,85
PT	Portugal	0,77
RO	Romania	0,61
SE	Sweden	0,82
SK	Slovakia	0,72
SI	Slovenia	0,71
GB	United Kingdom	0,76
UE 28		0,7826