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An analysis of water consumption in Europe’s energy production sector

The potential impact of the EU Energy Reference Scenario 2013 (LUISA configuration 2014)

Ine Vandecasteele, Claudia Baranzelli, Carolina Perpiña, Chris Jacobs-Crisioni, Jean-Philippe Aurambout, Carlo Lavalle

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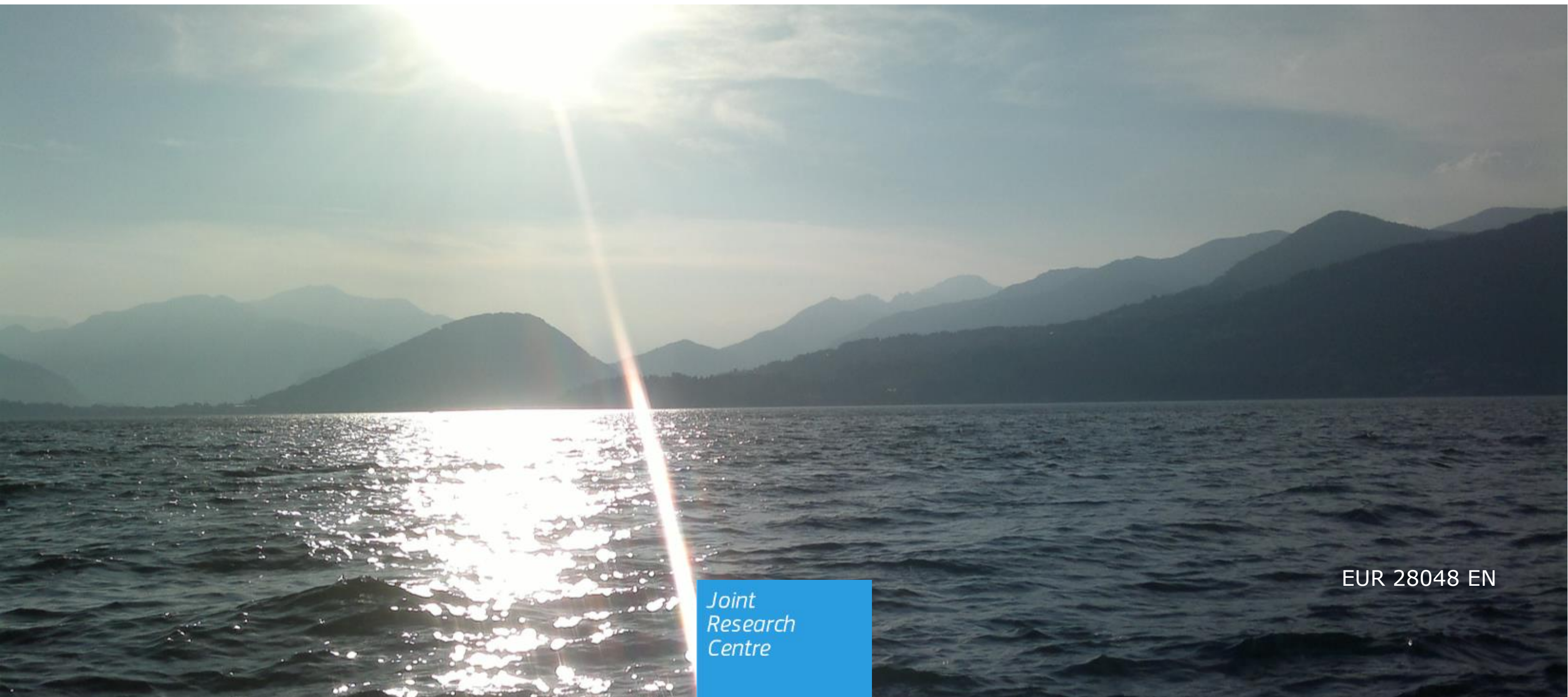

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Abstract

This report presents the outcome of a study carried out in the frame of a wider assessment performed with the LUISA (Land Use-based Integrated Sustainability Assessment) modelling platform, configured in compliance with the "EU Energy, Transport and GHG emissions trends until 2050" (EU Energy Reference Scenario 2013).

A new methodology has been implemented to estimate and map water requirements for energy production in Europe. In this study, the category of dedicated energy crops (ENCR) played an important role. These crops are expected to emerge as additional fuel sources within the EU28 by 2020. Water requirements in the remaining energy sectors have also been estimated in order to assess whether the introduction of these ENCR may, in any way, compete with the existing water requirements for energy production. More specifically, the study tackles the following questions:

- Where and to what extent will there be potential competition with cooling water required for electricity generation related to the introduction of these crops?
- How will these trends evolve over time?
- How will the introduction of energy crops affect the overall water consumption trends in Europe?

The analysis indicates that high irrigation requirements for ENCR are foreseen in France, Poland, Spain, eastern Germany, and regions of Italy and the UK. Substantial increases in requirements are seen for several regions from 2020 to 2030. ENCR are absent in Finland, Denmark, Greece, Malta, Cyprus and Croatia for the whole simulation period.

Water consumption for cooling in electricity production has been quantified for the years 2020 and 2030 for 2 scenarios with a minimum and a maximum value. There is notable variation in overall water consumption, both over time and between the scenarios. There is an increase in cooling water consumption for most regions in both scenarios over the period 2020 to 2030, which is especially high in France for the minimum scenario. The values given by the two scenarios vary greatly due to the wide range in water consumption between the different cooling technologies assumed in the two cases. In some regions there is even up to a factor 10 difference in total consumption for cooling.

As for any modelling exercise, the study presents a level of uncertainty due to the number of external models giving input and to the assumptions made. In the case of the cooling water mapping, a possible range of minimum/maximum values has been used to reflect the large variation due to the type of cooling system used by each power plant. For the energy crop water requirements we relied on estimates found in the literature. Nevertheless, the study presents an overall continental scale analysis of the potential impacts of the 2013 Energy Reference scenario, covering many of the involved sectors and provides the framework for further refinements and improvements.

1 Introduction

We present a new methodology to estimate and map water requirements for energy production in Europe. An important role is played, in this study, by the category of non-food crops well-known as dedicated energy crops (ENCR). These crops are expected to emerge as additional fuel sources within the EU28. Water requirements in the remaining energy sectors have also been estimated to assess whether the introduction of these ENCR may, in any way, compete with the existing requirements for energy production. More specifically, we aim to answer the following questions:

- Where and to what extent will there be potential competition with cooling water required for electricity generation related to the introduction of these crops?
- How will these trends evolve over time?
- How will the introduction of energy crops affect the overall water consumption trends in Europe?

In order to assess the overall impact of the introduction of ENCR on competing water uses, we use the LUISA (Land Use-based Integrated Sustainability Assessment) modelling platform (Lavalle et al., 2011) and several recent applications thereof. The platform simulates land use scenarios for the EU-28 countries at 100m resolution, using a range of driving factors derived from exogenous models (eg. CAPRI, GEM-E3, EUROPOP). The results of the LUISA run configured in compliance with the "EU Energy, Transport and GHG emissions trends until 2050" (EU Energy Reference Scenario 2013) were used in this study.

The LUISA model has numerous applications, and in this analysis we build further on several previous and continuing pieces of work involving the model framework. More specifically, we use the results of the following 3 projects as inputs towards our analysis:

Contribution to the Blueprint to Safeguard Europe's Waters

In the context of the Blueprint to Safeguard Europe's Waters, published in 2012, we developed a model to map water withdrawals and consumption per sector at the European scale (De Roo et al., 2012). Specifically, we looked at the public, industrial, energy, and agricultural (irrigation and livestock) sectors. The mapping of water consumption for cooling presented in this report builds further on the initial work done to map water consumption in the energy sector. The water consumption maps from this model for the public, industrial and agricultural sectors were used to produce Figure 10. An overview of the model is given in Annex 1.

Assessment and mapping of dedicated energy crops in Europe

This previous work presents the main drivers, policies and methods used in the LUISA modelling platform to allocate land dedicated to energy crop (ENCR) production and assess to what extent such allocation might cause adverse land-use impacts up to 2050 (Perpiña et al., 2014; Perpiña et al., 2015). In LUISA, lignocellulosic crops, both woody and herbaceous, are simulated as one unique class (dedicated energy crops, ENCR). Land demand for this class is derived from the CAPRI model, entering in competition with other land-use classes (for instance, land devoted to food and feed production or forest sector) through the simulation exercises. Along with the land demands, other technical components take important relevance such as the availability and suitability of the land, the recuperation of degraded and contamination lands and other sustainability criteria for energy purposes.

EREBILAND project

The JRC Exploratory Project EREBILAND (European Regional Energy Balance and Innovation Landscape) analyses energy supply and demand in Europe at regional (sub-national) scale (Baranzelli et al., 2016). Its approach is based on the territorial disaggregation of information, and the development of optimisation scenarios at the regional scale. It makes use of the Land Use-based Integrated Sustainability Assessment (LUISA) modelling platform for the assessment of policies and investments that have spatial impacts. It also incorporates interactions with (1) the JRC-EU-TIMES model – a bottom-up, technology-rich model representing the EU28+ energy system – and (2) the RHOMOLO model that integrates economic and social dimensions of regional development. EREBILAND provides an overview of the current trends of energy production and consumption patterns, at the regional scale.

The water requirements estimated in this study for the electricity generation sector are derived from the projected regional disaggregation of electricity production produced by the EREBILAND project for the years 2020 and 2030.

**Note that in the context of this study, we use the term “water demand” to mean the overall requirement of water for a specific purpose, in this case for irrigation or cooling purposes. Furthermore, we assess only the share of this total amount of water demand that is actually consumed in each case – ie. evaporated, polluted or otherwise lost to the direct environment. This is consistent with the choice of indicator used in the Blueprint work (ie. the Water Exploitation Index plus, WEI+, which is equal to (abstractions-returns)/renewable water resources). The analysis of consumption values rather than total water demand gives us a better idea of the actual environmental impacts associated with the removal of water from the direct environment. For a more detailed overview of the terminology relating to the use of water please see Annex 1.

We assume that all irrigation water used is consumed, so that the water demand for irrigation is equivalent to the water consumption. The actual share consumed may vary depending on the type of technology used and local conditions, but since we lack sufficient data at the EU level on this, we consider that the assumption holds. The results of this study therefore reflect a maximum impact of energy crops in terms of water consumption and competition with other sectors.

2 Methodology

2.1 Water demands for energy crops

2.1.1 Modelling dedicated energy crops in LUISA

Energy crops are expected to become increasingly widespread in the EU Member States. Here we focus on the impact of the expansion of dedicated energy crops over the time period 2020 - 2030 in terms of water demands for a successful growing. This report follows on the mapping of ENCR as described in detail in Perpiña et al. (2015). This exercise assessed and mapped the potential suitability of land to grow the herbaceous energy crops and the potential land-use impacts. Herbaceous energy crops (perennial grasses) considered are: Miscanthus (Miscanthus spp.), Switchgrass (Panicum virgatum), Reed canary (Phalaris arundinacea), Giant reed (Arundo donax) and Cardoom (Cynara cardunculus). Woody energy crops (fast growing) considered are: Willow (Salix spp.), Poplar (Populus spp.) and Eucaliptus (Eucaliptus spp.).

Energy crops in Europe were modelled under a specific policy context and the current LUISA configuration. Under these premises, biophysical and environmental information for each of the aforementioned energy crops was required in order to identify the most suitable location for a successful development, according to their adaptability to different regions of Europe. In terms of ecological demands, a number of relevant factors were determined according to topographical aspects, quality of the soil (physical and chemical characteristics) and climate conditions. Eight biophysical suitability maps were created using a multi-criteria GIS environment which represented the degree of suitability of the land fore each energy crop across Europe.

The CAPRI model drives the demand for energy crops at a regional scale, whilst the actual (high resolution) allocation is performed in LUISA. The first energy crop productions are foreseen to appear in Europe from the year 2020 onward according to the demand for bio-energy derived from the EU Energy Reference Scenario 2013. For some countries, energy crops are absent for the whole simulation period (2020-2050), such as in Denmark, Greece, Malta, Cyprus and Croatia, while for others, as in Italy, Portugal, Romania, Bulgaria and Finland, fluctuations are forecasted.

2.1.2 Estimation of irrigation demands

The LUISA projected energy crop maps can be disaggregated to give proportional maps of each individual energy crop (eight main species). Using the mean water demands per crop type and the proportion of each energy crop species per pixel we can assign a total irrigation water demand. In a final step, this map is corrected with the mean rainfall for that pixel for that year, to better estimate the actual irrigation water demand.

For the estimation of the irrigation maps, the main input data used were the following:

- Allocated land for energy crops (100m resolution) from LUISA simulation for the years 2020 and 2030.
- Energy crops suitability maps (100m resolution; eight species) from Perpiña et al. (2015).
- Average water demand per energy crop species (Table 1).
- Mean annual rainfall[1] (100m resolution) derived from E-OBS (2014) and Dosio and Paruolo (2011) aggregated at country level from 2010 to 2050 (Figure 1).

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[1] The mean annual rainfall was considered a dynamic factor since it was projected to future time up to 2050. Two different datasets were needed: one for 2010 that reflected observed precipitation values from the European Climate Assessment and Dataset (E-OBS; http://eca.knmi.nl/; Haylock et al., 2008) and another for the remaining time slices (2020, 2030, 2040, 2050) that considered projections related to five regional climatic models (RCM) derived from the ENSEMBLE project (Christensen et al., 2010; van der Linden and Mitchell, 2009) and

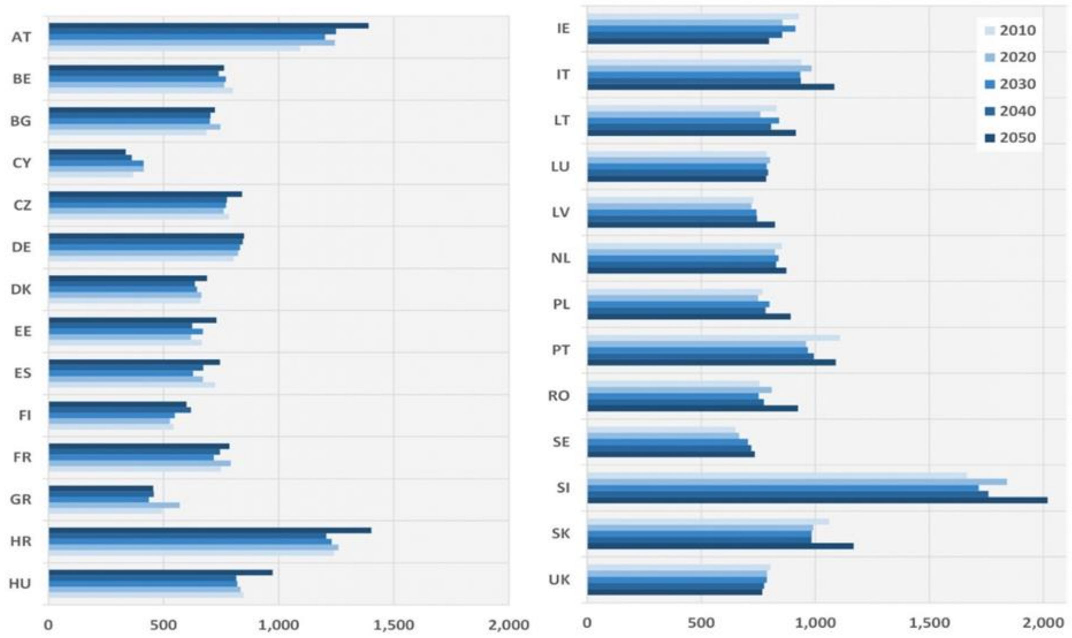

Figure 1. Future precipitation projections averaged at country level for the years 2010 to 2050 in mm/year. Own elaboration computed from E-OBS (2014) and Dosio and Paruolo (2011).

Table 1. Estimated average water demands for the growth of the selected energy crops. High, medium and low categories represent the qualitative water demand for each energy crop for a successful growth (4F-crop project, 2010).

Energy Crop	Water demand (mm/year)	Category
Willow	1125	HIGH
Poplar	825	MEDIUM
Eucalyptus	1117.5	HIGH
Miscanthus	1200	HIGH
Switch grass	675	MEDIUM
Cardoon	450	LOW
Reed Canary Grass	1087.5	HIGH
Giant Reed	825	MEDIUM

Figure 2 gives an overview of methodology framework taking into account the input data used and the intermediate calculation steps necessary to estimate both the total water demand and the actual average annual irrigation demand for energy crops. The computation of the Total Annual Irrigation demands for dedicated energy crops involved the following steps:

1) In a first step, the share of each crop type within the total area allocated to was calculated based on the relative suitability for each crop (eight main species), rescaled to add up to 100% for each pixel.
2) The estimated water demand per crop species was then assigned based on the amounts given in Table 1 and the individual percentage share crop maps (eight in total).

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later, corrected by biases (Dosio and Paruolo, 2011). The five RCM used were: RCA3, RM5, HIRHAM5, CLM and RCA, all of them under the scenario A1B. The starting year was assigned 2010 and, to compute the projected years, the increments between the base year and the projected years was added to the base year 2010.

3) The total water demand for energy crops was calculated as the sum of these eight maps of water demands per species.
4) The total irrigation demand per pixel was estimated by subtracting the average rainfall received from this total water demand per pixel. Where the amount of rainfall received was greater than the water required, the irrigation demand was set to zero. This final map represents the actual irrigation demand per pixel.

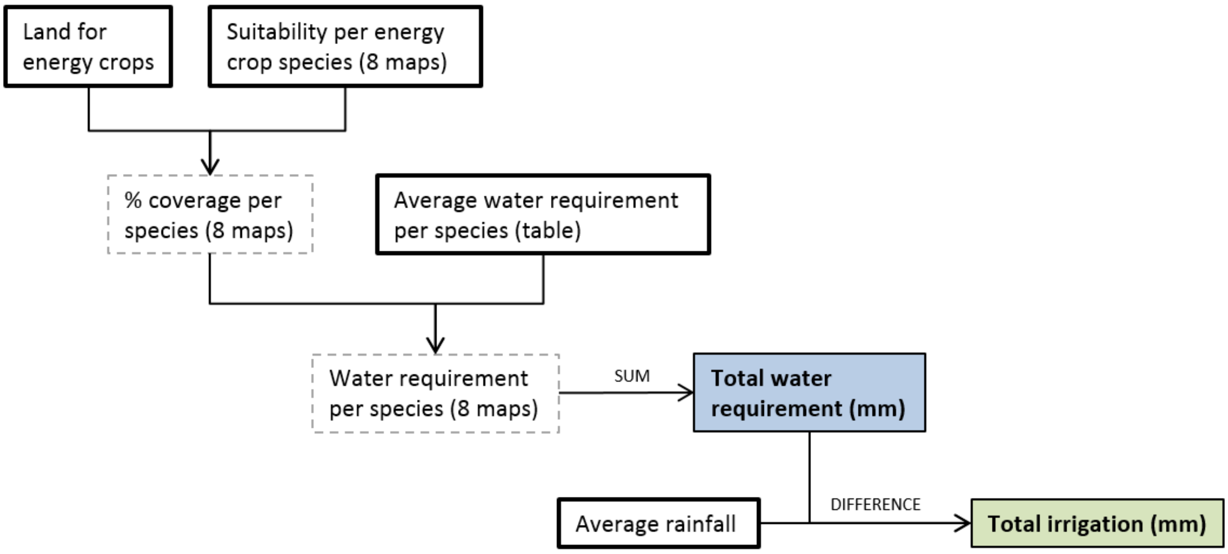

Figure 2. Overview of input data and calculation steps required to estimate the total annual irrigation demand for energy crops.

2.2 Water demands for electricity production

2.2.1 Review of demands per fuel type

Water for electricity production is mainly used for cooling, and to a much lesser extent for scrubbing and general operation of power plants (Mielke et al., 2010). The actual amount required therefore varies greatly not only by the fuel or generation typology (ie. specific method used), but also the cooling technology used in each case.

In what follows we give an overview of the demands per fuel type and per cooling method. For the purposes of this report, however, we use only the range of possible consumption values to calculate an overall minimum and maximum water consumption scenario.

Thermoelectric power generation

Electricity is mostly generated by steam turning turbines within a magnetic field. The fuel used to produce the steam may be of several typologies, including fossil fuels, biomass, nuclear and concentrating solar. A large amount of water is generally required for cooling during and after this process; the amount of which depends on the technology used (Cooley et al., 2011; Halstead et al., 2014; Williams and Simmons, 2013). The water demands for these types of energy production are therefore given per cooling method in Figure 3.

Once-through cooling (O) - Water is run through the system and used to condense the steam from the turbine, and is then returned to the original source (e.g., the river) at a higher temperature. There is low net water consumption (often only between 1 and

5%), but high throughput volumes are required and potentially impacts on aquatic life at intake and discharge points.

Closed-loop tower cooling (T) - Cooling water exits the condenser, goes through cooling tower, and is then returned to the condenser. This requires relatively low water withdrawals, but water consumption at the power plant is significantly higher (ie. some 60-85%).

Dry cooling (D) - Towers are cooled only by air, in theory eliminating the need for water, although what little water that is used is usually completely consumed, however.

Other methods of power generation

Solar PV and Wind - In both these cases, water is mainly required for washing and general maintenance, and therefore much less is required than for more conventional electricity production. There is also much less variation in the quantity of water consumed, and the same value was used for both scenarios.

Geothermal - The demands can vary greatly depending on the technology used. Large quantities of water are usually used to pump into geothermal bodies and extract heat. In many cases, however, water that is unsuitable for other purposes is used, and therefore this has little anthropogenic impact. For the purposes of this study, the water consumption for this type of electricity consumption was taken as negligible.

An overview of the estimated water withdrawals and consumption per fuel type are given in Figure 3. The actual values used in the definition of the minimum and maximum cooling water consumption scenarios are given in **Table 2**.

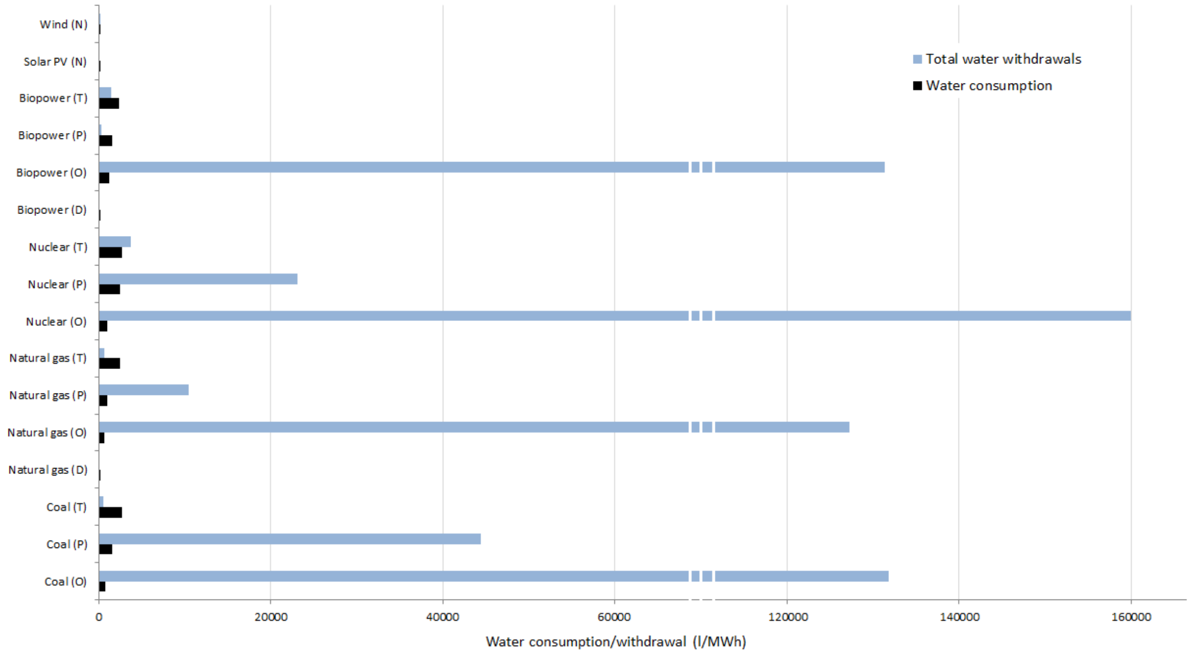

Figure 3. Overview of estimated total water withdrawals and consumption per energy production type. *(D) = Dry; (O) = Once-through; (T) = Tower/closed-loop; (P) = Pond cooling system.*

Table 2. Water consumption in l/MWh for the different electricity generating technologies mapped for the Minimum (MIN) and Maximum (MAX) cooling water consumption scenarios (based on Mielke et al., 2010 and Cooley et al., 2011). The assumed cooling technologies are also given where relevant: (D) = Dry; (O) = Once-through; (T) = Tower/closed-loop.

Fuel type	MIN	MAX
Coal	721 (O)	2684 (T)
Biopower	132 (D)	2272 (T)
Natural gas	8 (D)	2461 (T)
Nuclear	947 (O)	2699 (T)
Solar (PV)	180	180
Wind	22	22

2.2.2 Mapping of estimated water demands

The EREBILAND Exploratory Project (Baranzelli et al., 2016) aims at supporting efficient patterns of regional energy supply and demand in Europe. The overall approach is based on territorial disaggregation of information, and the development of optimisation scenarios at regional scale. It is centred around the Land Use-based Integrated Sustainability Assessment (LUISA) modelling platform for the assessment of policies and investments that have spatial impacts, in interaction with the JRC-EU-TIMES model – a bottom-up, technology-rich model representing the EU28+ energy system – and the model RHOMOLO that integrates economic and some social dimensions of regional development.

In particular for what concerns electricity generation, the EREBILAND project developed a methodology to disaggregate projections of generated electricity from national to regional scale. The methodology combines information from different sources: on technologies and operating characteristics of the power plants from the UDI World Electric Power Plants Data Base (WEPP; PLATTS, 2015) and the Worldwide Wind Farms Database (The Wind Power, 2015); on projected run load hours and total electricity generation from the JRC-EU-TIMES model. The main output of the methodology is estimated electricity generation at plant level. This information on electricity generation, for the years 2020 and 2030, was then combined with water consumption figures form Table 2 to estimate water needs.

An overview of the calculations performed to estimate water consumption of energy plants is given in Figure 4. Due to the wide range of values found in the literature, and the especially large variation in water consumption per cooling technology used, we present the results as 2 scenarios, giving the minimum and maximum possible values. The minimum scenario takes into account the lowest possible water consumption value per energy production type, that is usually the consumption associated to through-flow or dry (air) cooling systems. The maximum scenario, on the other hand, assumes all plants will employ the highest water consuming cooling technology, usually closed-loop cooling.

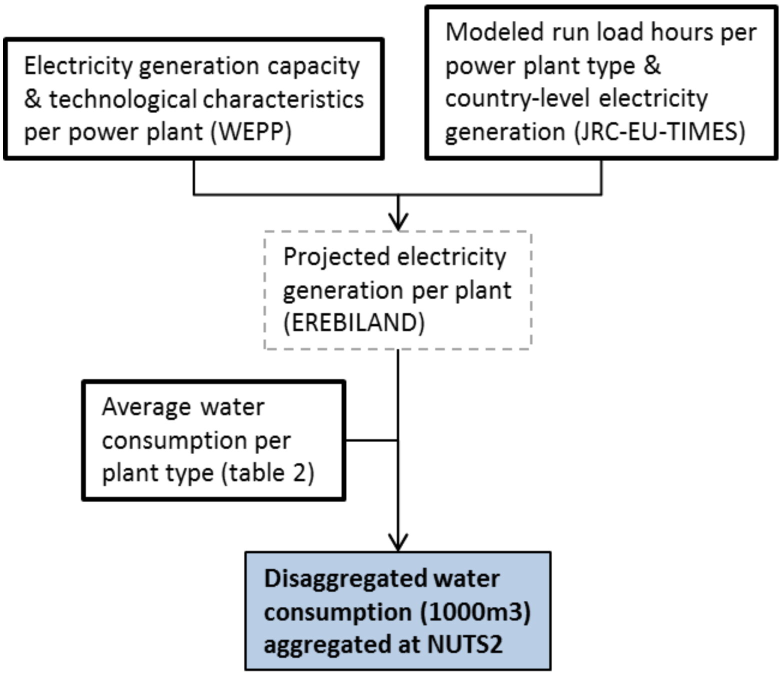

Figure 4. Overview of calculations to estimate the disaggregated water demand for electricity generation.

2.3 Assessing the overall impact of ENCR

In a final step we compared the amount of water foreseen to be consumed for the growth of dedicated energy crops to that consumed in the potentially competing sectors (energy production and crop irrigation), and to the consumption of water in all sectors as a whole.
Maps were prepared at NUTS2 level showing the relative proportion of ENCR irrigation in the consumption of water for the years 2020 and 2030, and where relevant also for the different cooling water scenarios.

For the energy sector comparison we used the water consumption as explained in section 2.2, so maps are given for the years 2020 and 2030 for both the minimum and maximum cooling scenarios.

The comparison to the total irrigation sector uses the results of a disaggregation exercise of the country-level total irrigation demands (based on EUROSTAT data) to the crop groups as defined and modelled in LUISA. This is explained in more detail in Annex 1. These shares are given for the years 2020 and 2030.

Lastly, the water consumed for ENCR was compared to the overall water consumption in all sectors. The total consumption was calculated based on the irrigation, livestock, public and industry sectors calculated using the Water Use Model methodology (see Annex 1). The energy sector was represented by the cooling water scenarios as explained in section 2.2, meaning that in this case 4 maps are shown – for the years 2020 and 2030 and in each case the minimum and maximum scenario.

3 Results and Discussion

3.1 Water consumption for energy crops

Figure 5 shows the total amount of land dedicated to the growth of energy crops, and the share of available land taken up by energy crops per NUTS2 region in the EU28 in 2020 and 2050. According to LUISA outputs, ENCR occupy 4,733 kha in 2020 and 13,549 kha in 2050, which represent, on average, 1.3% and 3.6% of Europe’s total available land. Poland, France, Germany, Spain, Romania and the United Kingdom are the largest ENCR producer countries, accounting all together for 83% of the total European acreage. At regional level, the European average of ENCR is approximately 3.2% and 7.5% of the total available land in 2020 and 2050 respectively.

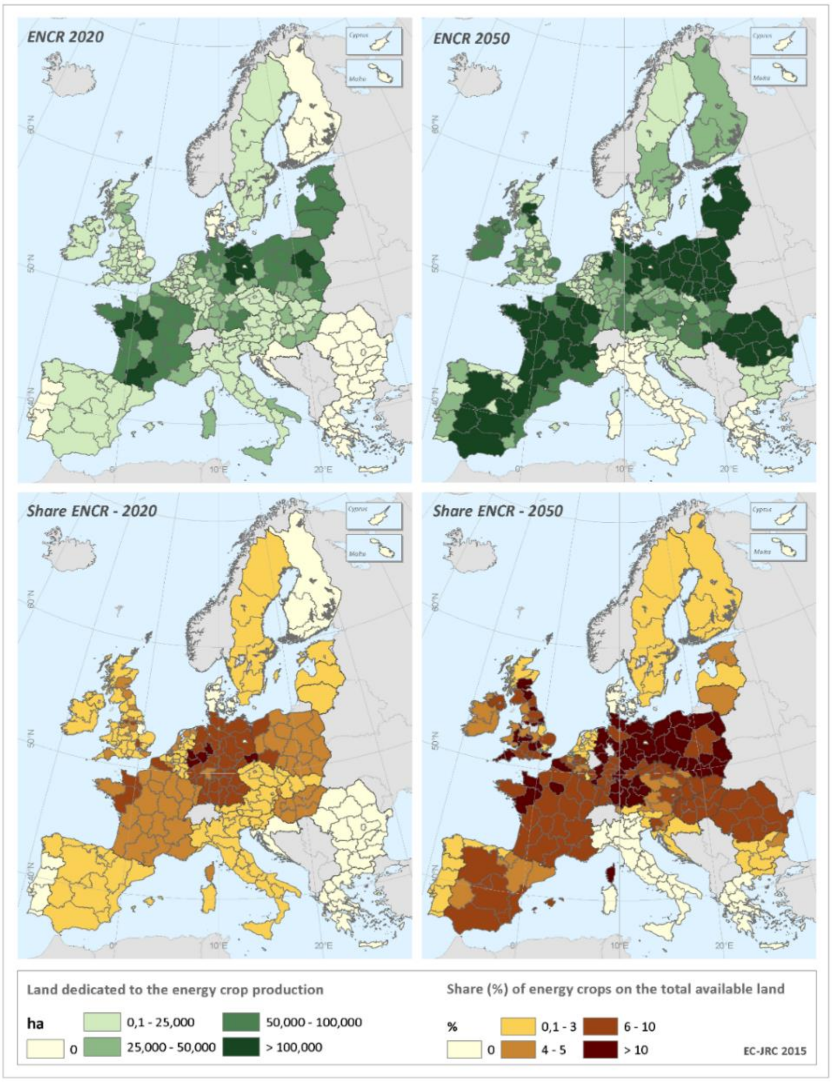

Figure 5. Expansion of dedicated energy crops between 2020 and 2050 at NUTS 2 level in the EU28. The first-upper two maps (green colours) represent the ENCR allocation measured in ha while the bottom two maps (orange colours) report the percentage of energy crop on the total available land. Source: Perpiña et al. (2014)

The calculated total water demand and actual irrigation demand for these crops is given in thousands of m^3 per NUTS2 region in **Figure 6** for the years 2020 and 2030.

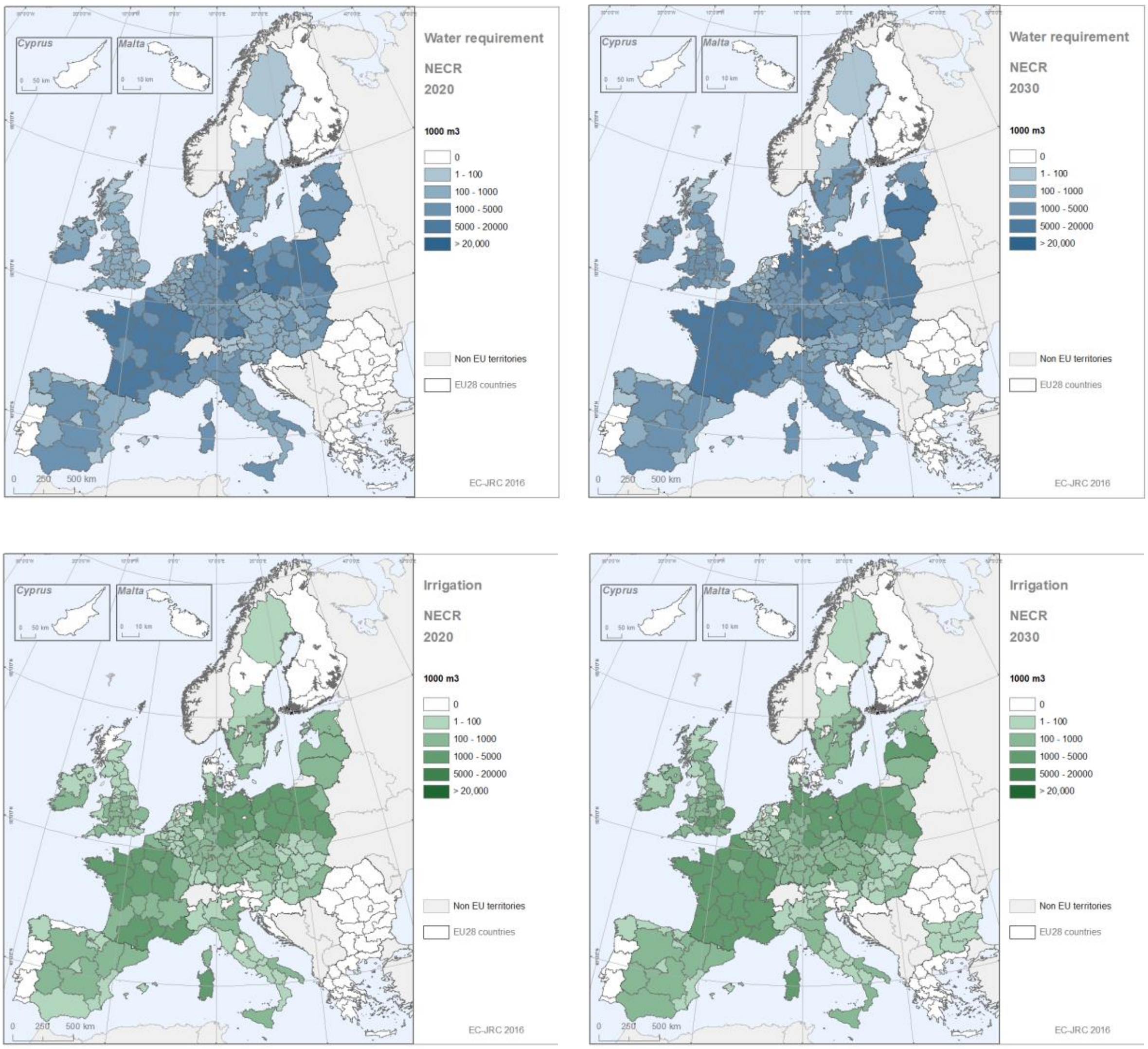

Figure 6. Total water demands (first-upper two maps, colored in blue hues) and total irrigation demands (second-bottom two maps, colored in green hues) in thousands of m^3 per NUTS2 region for the simulated years 2020 and 2030.

Water demand maps rely on the suitability energy crops maps, the estimated average water demands for each specie (Table 1) and land dedicated to energy crops (spatial allocation). Since the first-two factors are considered statics through the time, the total water demands are subjected to the increase on the energy crop production. The expansion of energy crops occurs mainly, between 2020 and 2030, in France and Poland while regions belonging to other countries (Germany, United Kingdom, Czech Republic, Slovakia, Hungary and Bulgaria) undergo a more modest increase. This effect is reflected on the total water demands substantially increase in some regions, especially more than 50% in Austria, Czech Republic, Poland, Slovenia, Slovakia and United Kingdom. On the contrary, some regions in The Netherlands, Belgium and Luxemburg reduce drastically the water demands (more than 100%).

Irrigation maps include, on top of the water demand maps, the average annual rainfall. Substantial increases are seen in demands for several regions from 2020 to 2030. Especially, high irrigation demands are foreseen in France, Poland, Spain, eastern Germany, and regions of Italy and the United Kingdom. Except for Spain, the remaining countries mentioned receive moderate annual precipitation (600 – 1,000 mm/year). However, the energy crop species more suitable for these countries are, in turn, more water demanding (for instance, Miscanthus and Willow). According to the rainfall projections patterns (Figure 1), France, United Kingdom and Spain will undergo a decrease on rainfall from 2020 to 2030, which will provoke a higher need for irrigation. On the other hand, rainfall is expected to slightly increase in Germany and Poland but, in turn, those countries are the higher energy crop producer, and, therefore, irrigation demands will increase. It should be mentioned that there is absent of energy crop plantations in Finland, Denmark, Greece, Malta, Cyprus and Croatia for the whole simulation period and, in particular, in Romania and Bulgaria for 2020 and/or 2030.Therefore, it is not expected water demands for this particular propose thus, in these countries, the water competition decrease among the other energy sectors.

3.2 Water consumption for cooling in electricity production

For the years 2020 and 2030, 2 scenarios were mapped, showing the possible range of total water consumption in cooling, from a minimum to a maximum value. Figure 7 shows the resulting total ranges for the scenarios in 2020 and 2030 at NUTS2 level.

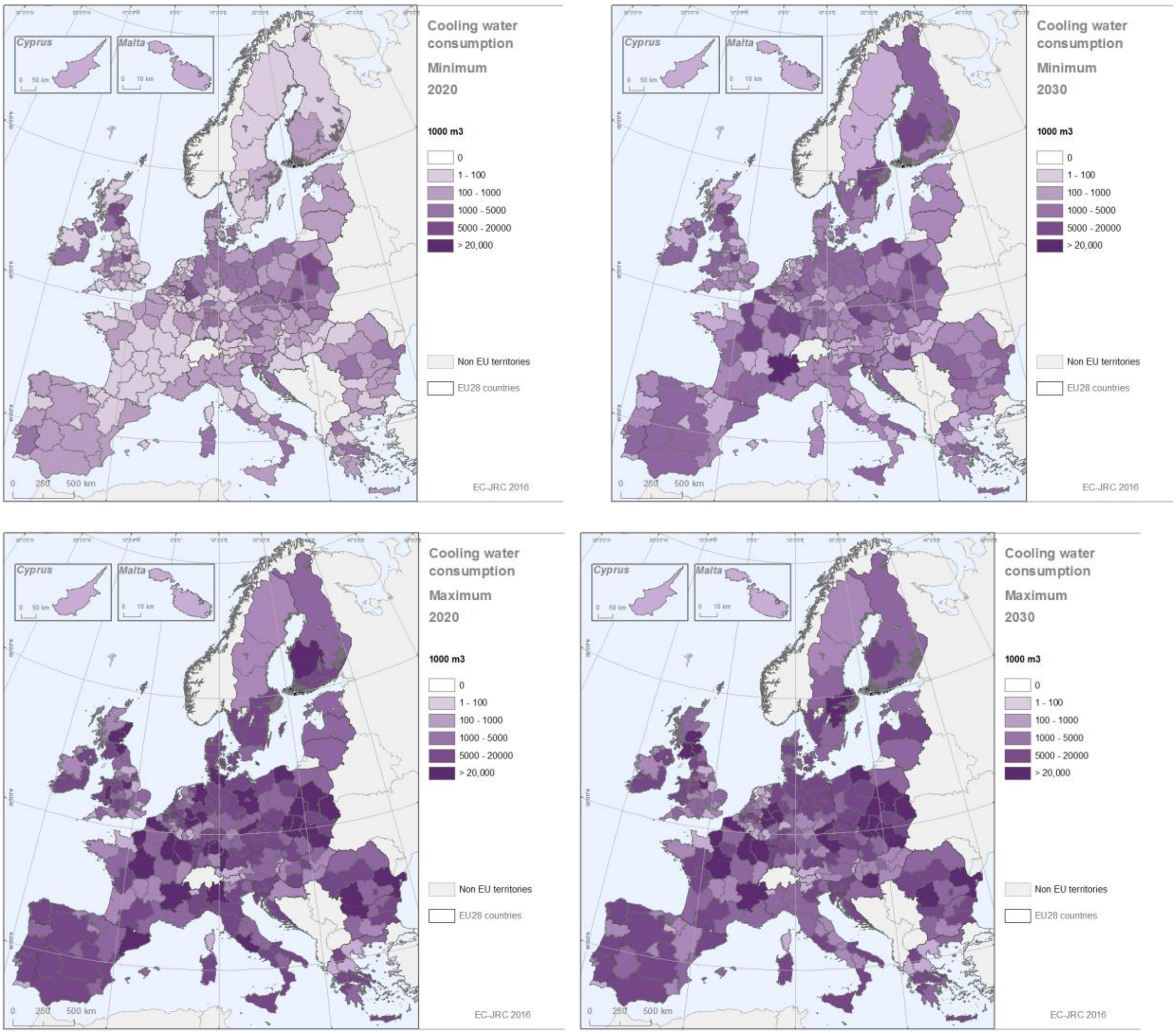

Figure 7. Total water consumption in thousands of m^3 per NUTS2 region for the simulated years 2020 and 2030, Min and Max scenarios.

There is notable variation in overall water consumption, both over time and between the scenarios. There is an increase in cooling water consumption for most regions in both scenarios over the period 2020 to 2030, which is especially high in France for the minimum scenario. The values given by the two scenarios vary greatly, in the case of some regions even up to a factor 10 difference in total consumption for cooling.

The individual maps computed per fuel type are given in Annex 2.

3.3 Quantifying the additional impact of ENCR

To try to quantify the potential impacts the additional water consumption in irrigating NECR may have, we calculated the percentage share this consumption would have in:

1) the overall water consumption for energy production (all cooling water consumption as calculated in this analysis, 2020 and 2030, minimum and maximum scenarios) - *Figure 8*
2) irrigation of all crops for the years 2020 and 2030 - *Figure 9*
3) the overall water consumption in all sectors (2020 and 2030, minimum and maximum cooling scenarios – the methodology used is further explained in Annex 1.) - *Figure 10*

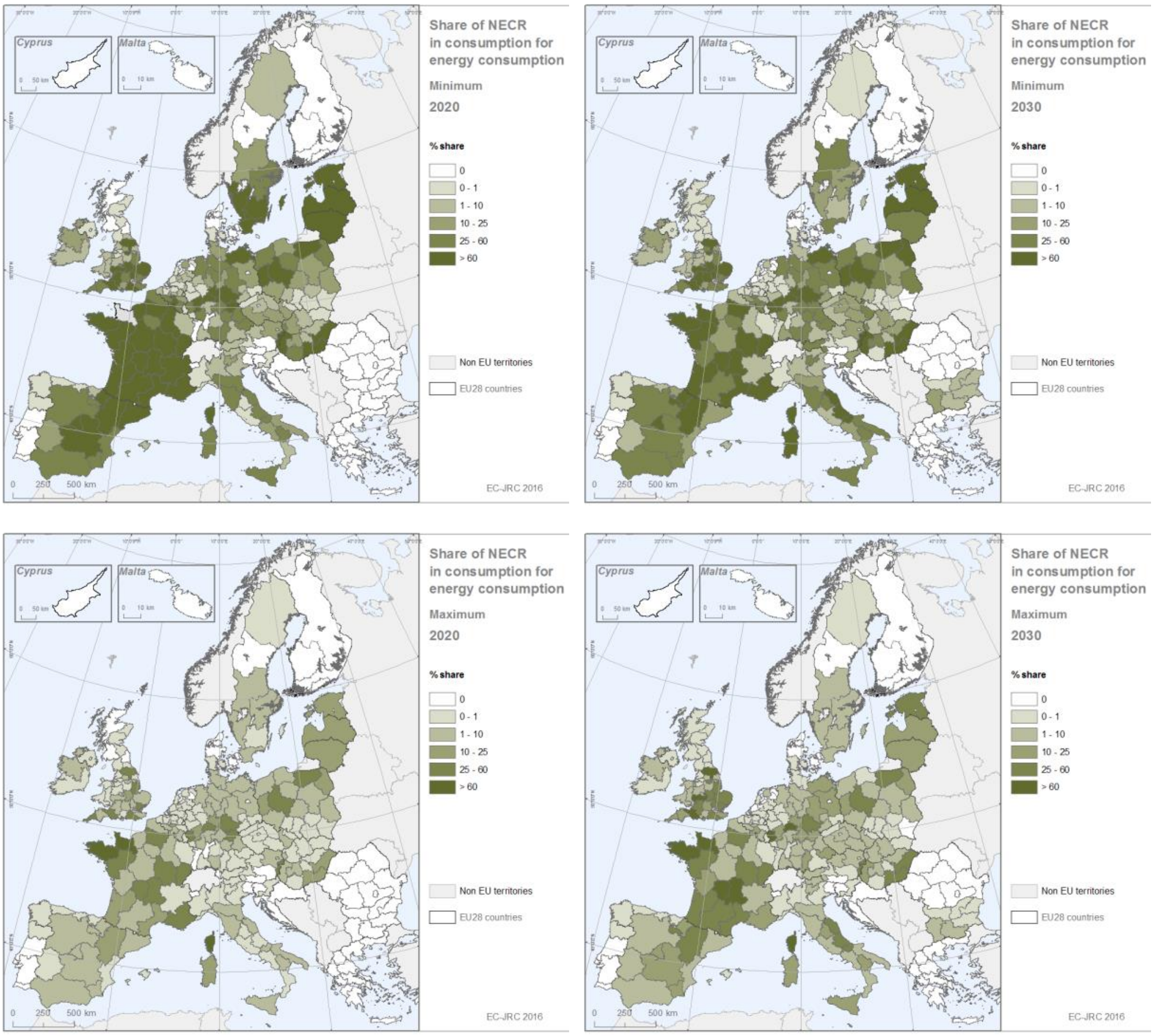

Figure 8. Total water consumption in the irrigation of new energy crops as a share of the total estimated consumption in the use of cooling water for energy production, given in thousands of m^3 per NUTS2 region for the simulated years 2020 and 2030, Min and Max scenarios.

ENCR account for more than 65% of total water consumption in the minimum cooling water consumption scenario in Latvia, Lithuania, Estonia, most of France, and several regions in Hungary, Poland, Germany, Italy, Spain and the UK. In the maximum scenario, the share is much lower, with ENCR irrigation accounting for under 5% of the total in the majority of regions.

Although some variation is seen over time, the main differences seen are between scenarios. Most regions remain constant, or see a slight increase in the share of ENCR irrigation over time. Notable, however, is that the share is seen to reduce significantly in several regions in France over the period 2020 – 2030 for the minimum scenario. This means that electricity production by the most water-consuming fuel types is increasing to a greater extent than the energy crops in those regions (see figure 7).

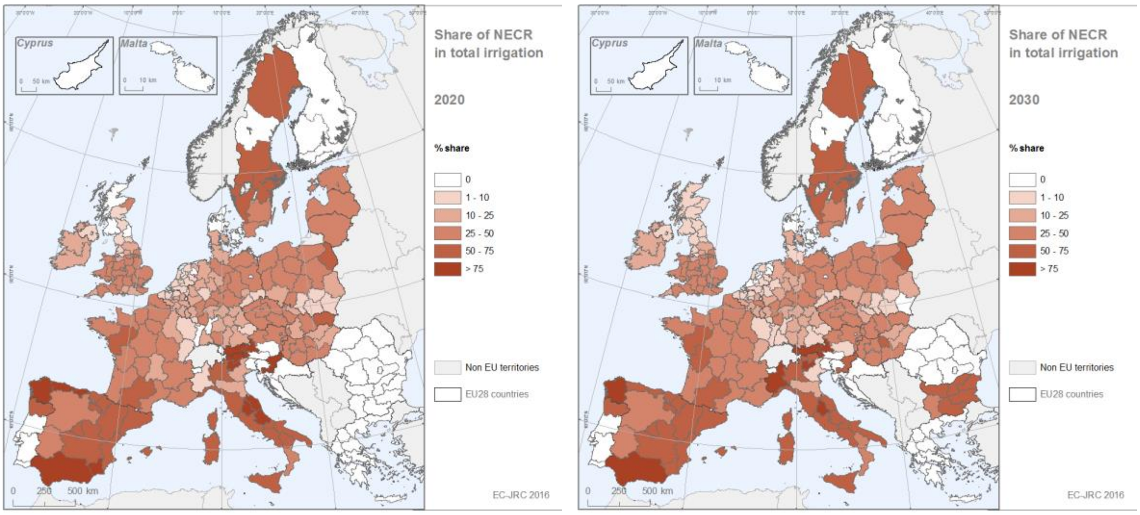

Figure 9. Total water consumption in the irrigation of new energy crops as a share of the total estimated consumption in irrigation as a whole, given in thousands of m^3 per NUTS2 region for the simulated years 2020 and 2030, Min and Max scenarios.

The share of ENCR irrigation in the total irrigation consumption is seen to vary only slightly over the period 2020 to 2030. They are expected to make up an especially high share of overall irrigation (ie. over 50%) in southern Spain, most of Italy, Sweden, and in 2030 Bulgaria.

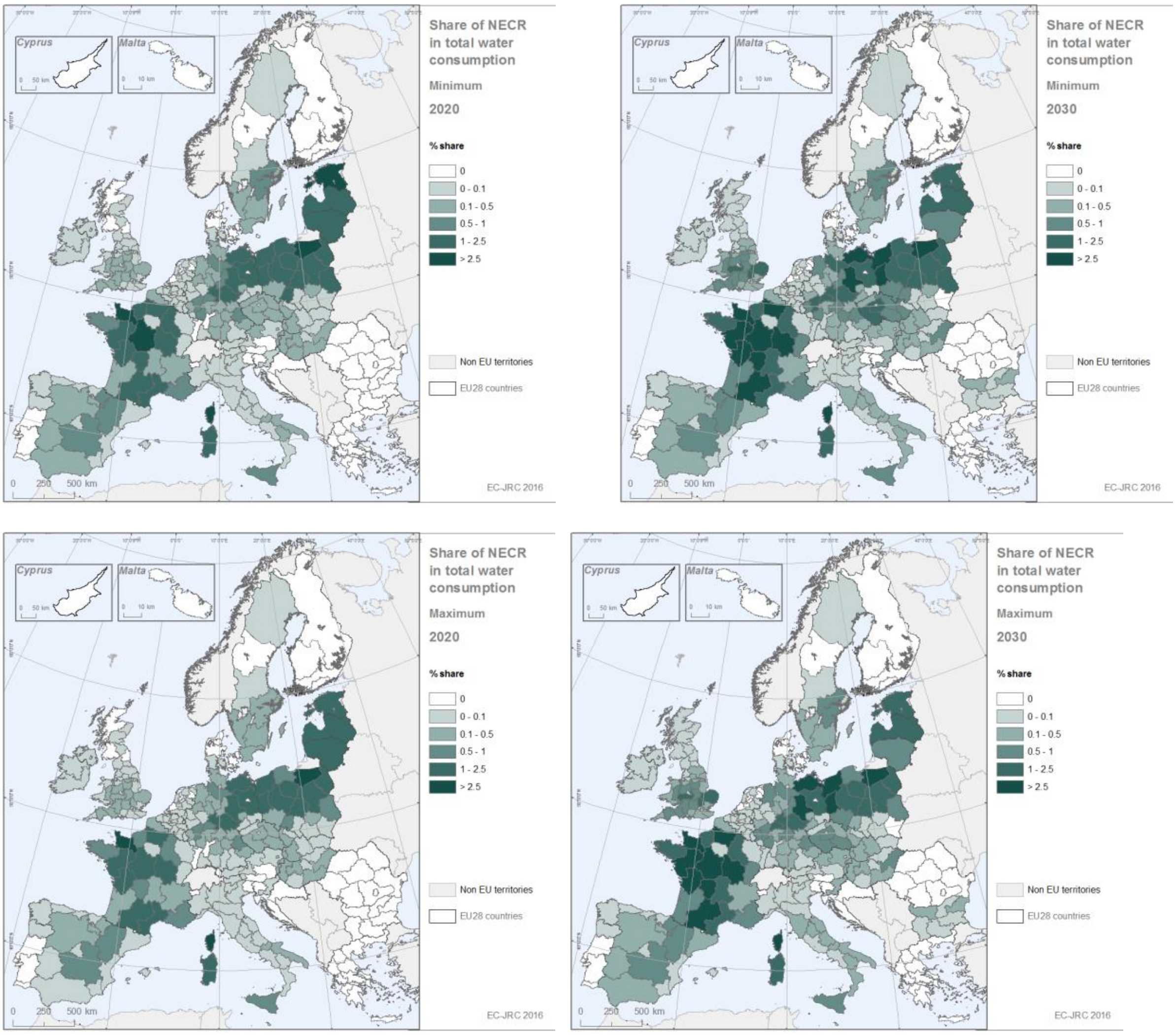

Figure 10. Total water consumption in the irrigation of new energy crops as a share of the total estimated consumption of water in all sectors, given in thousands of m^3 per country for the simulated years 2020 and 2030, Min and Max scenarios.

Although there is great spatial variation, the impact of irrigation demands for energy crops as compared to the total consumption of water for all sectors is expected to be significant in some regions. In some parts of France, Germany and Poland, for example, the contribution of NECR irrigation is expected to be more than 2.5% of the total water consumption.

Table 3 summarizes the mean percentage shares of NECR irrigation in each case. The mean share as compared to the total water consumption for energy production ranges from 5.9% (MAX 2020) to 24.8% (MIN 2020). The share of NECR irrigation in total irrigation water is 25.7% in 2020, increasing slightly to 26.2% in 2030. As compared to all sectoral water consumption, NECR irrigation accounts for between 0.27% (MAX 2020) and 0.5% (MIN 2030). The maximal share is about 5%, which is reached in the MIN 2030 scenario.

Table 3. Overview of maximum and mean percentage shares of ENCR irrigation as compared to the total consumption in the energy production sector, total irrigation, and total consumption in all sectors within the EU28.

ENCR water consumption as share of that for:	Mean (%)
Energy production MAX 2020	5.9
Energy production MAX 2030	10.1
Energy production MIN 2020	24.8
Energy production MIN 2030	23.4
Total irrigation 2020	25.7
Total irrigation 2030	26.2
Total water consumption MAX 2020	0.27
Total water consumption MAX 2030	0.45
Total water consumption MIN 2020	0.32
Total water consumption MIN 2030	0.50

4 Conclusion & Discussion

We looked at the impact that the introduction of dedicated energy crops may have in Europe as compared to the other water demands in the energy sector, and on water consumption as a whole. Specifically, we aimed to answer the following questions:

Where and to what extent will there be potential competition with cooling water required for electricity generation related to the introduction of these crops?

The impact could be greatly significant, depending on the region. For some regions of France, for example, water consumed in the irrigation of ENCR make up over 90% of the overall water consumption for energy production. Although the impacts vary greatly between the two scenarios, and especially spatially, the water consumed for ENCR is foreseen to increase and consistently account for a substantial share of the overall water consumption in the energy sector.

Quite some variation is seen between cooling water consumption scenarios, however, so the overall additional impact of ENCR would also depend on the cooling technology used in the other energy production methods.

How will these trends evolve over time?

The general trend is towards an increase in energy crops over time. Since the water consumption in the remaining and competing sectors is also mostly foreseen to increase, the impacts vary greatly.

How will the introduction of energy crops affect the overall water consumption trends in Europe?

Water consumption for the growth of ENCR is foreseen to account for an average share of about 26% of the total for the irrigation sector.

As compared to all sectoral water consumption, NECR irrigation accounts for between 0.27% (MAX 2020) and 0.5% (MIN 2030). In some parts of Europe the contribution of NECR irrigation is expected to be more than 2.5% of the total water consumption.

There are several limitations to this modelling excercise. There is a level of uncertainty due to the number of external models giving input. There are also numerous assumptions made due to a lack of sufficient data. In the case of the cooling water mapping, we needed to look at a possible range of values due to a lack of detailed data on the type of cooling system used by each power plant. For the energy crop water demands we rely on estimates found in the literature.

For the purposes of this study we assessed the consumption of water, rather than the total water withdrawals per sector. This gives us a better picture of the overall impact on the availability of freshwater, but includes the additional assumption of an average percentage share of water being consumed per sector over the whole of Europe (see table A.1), whereas there is likely to be great variation in the actual proportion consumed per region.

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List of abbreviations and definitions

CAPRI	Common Agricultural Policy Regionalized Impact model
ENCR	Dedicated energy crops
EREBILAND	European Regional Energy Balance and Innovation Landscape (Exploratory Project)
EU28	The 28 European Union Member States
LUISA	Land Use-based Integrated Sustainability Assessment modelling platform
NUTS2	Nomenclature of Units for Territorial Statistics level 2
WEPP	World Electric Power Plants Data Base

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ANNEX 1. Overview of the Water Use Model

In what follows we give a brief overview of the calculations made to produce the total sectoral water consumption maps for the EU28, as described in Vandecasteele et al. (2013, 2014).

The model works by disaggregating country-level statistics on water withdrawals to the pixel level by means of land use and proxy data. It covers the following sectors:

- Industry (manufacturing)
- Public (domestic/residential)
- Energy (cooling water)
- Agriculture (irrigation and livestock)

Figure A.1. gives an overview of the terminology used in the model. For the purposes of the model we assumed the water withdrawals to be equal to the water demand (ie. No limitations on water availability), and that the consumption would be an average share of the withdrawals per sector.

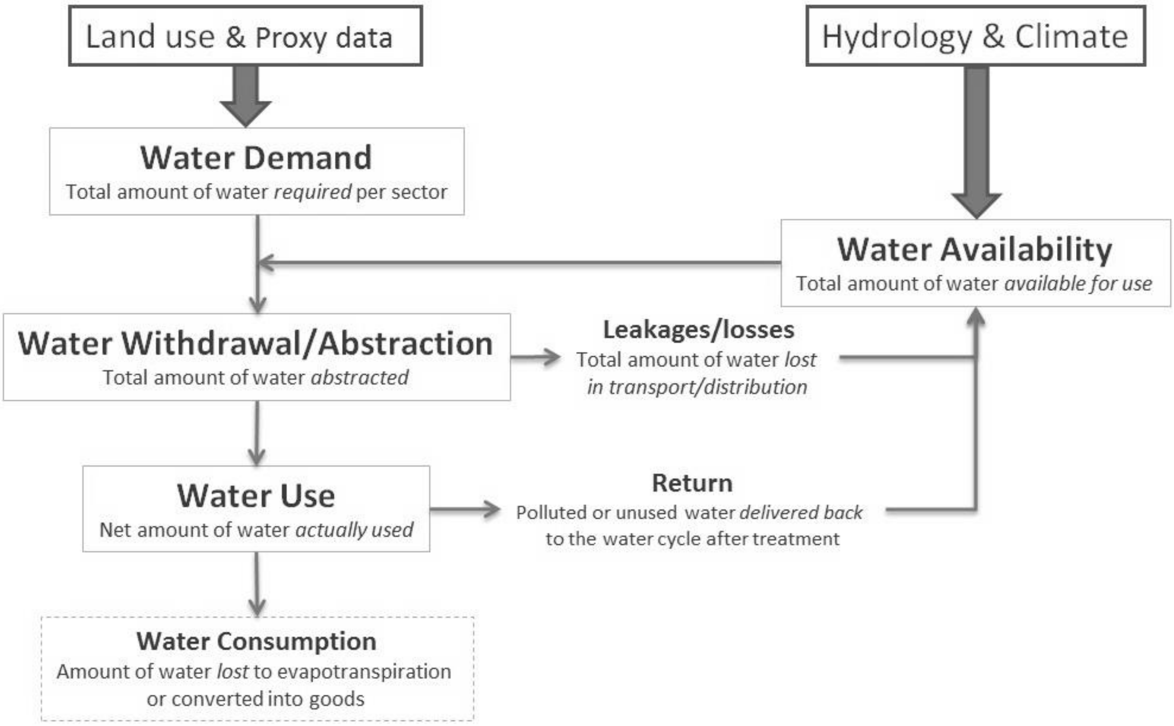

Figure A.1.1. Overview of the terminology used to describe water flows in the context of this report.

In the context of this study, we use the term "water demand" to mean the overall requirement for water, in this case for irrigation purposes. For irrigation, we assume all of this required water to be consumed (ie. Completely evaporated or infiltrated into the ground). For the remaining sectors we assume consumption to be an average proportion of the water withdrawal.

Calculations per sector

Data used

The annual freshwater abstraction by sector was used for the base year 2006. Statistics were derived from the OECD/EUROSTAT Joint Questionnaire on Inland Water (Nagy et al., 2007), and supplemented where data was incomplete or missing with the average annual withdrawal from FAO – AQUASTAT (2011).

Industrial water withdrawals

All water used for industry (manufacturing purposes) was assumed to be withdrawn within designated industrial areas. The water withdrawals were therefore disaggregated to the modeled 'industry' class in LUISA. In order to calculate water withdrawals for 2030, we first computed a "change factor" per country. We assumed the driving force for industrial water withdrawals in time to be the GVA for industry (%increase/year, for EU25, from GEM-E3, 2012). The average (decreasing) trend in total industrial water withdrawals for 2000-2006 was taken as an "efficiency factor" (-1.33 %/year) to correct for technological improvements over time:

Country change factor (%/yr) = Δ GVA for industry (%/yr) – efficiency factor (%/yr)

The country-level total withdrawal in 2030 was first calculated in this way, and then disaggregated to the projected industrial land as modeled by LUISA.

Public water withdrawals

Public water withdrawals were assumed to be those made by residents and tourists in urban areas, so that the spatial distribution of the withdrawals was assumed to be directly related to the combined population and tourist density. Since tourists tend to have a higher water-use than residents, the tourist density maps were given a greater weight when assigning the water withdrawals (a ratio of 300/160; Gössling et al., 2012). Population density maps were available for 2006 at 100m resolution (Batista e Silva et al., 2013). Tourist density maps were created using the regional number of nights spent by non-residents, and the number of bedplaces (EUROSTAT). The total number of tourists per month at regional level for each country was disaggregated to the appropriate CORINE Land Cover classes (urban fabric, green urban areas, and sport and leisure facilities). The number of nights spent abroad by residents was also calculated and subtracted from the population density maps. The final map, to which the country-level public water withdrawal statistics were disaggregated, was then calculated as:

*Weighted number of "users" per pixel = Population density map 2006 – outbound tourism map (quarterly) + 300/160*inbound tourism density map (monthly)*

A population density map for 2030 was computed, using population projections from EUROSTAT, and projected land use maps for 2030 from LUISA. Both the tourist density maps and the nights spent abroad maps were multiplied by a specific predicted annual growth factor taken from the Tourism vision 2020 projections (WTO, 2000). The temporal (monthly) and spatial distribution of tourism was kept constant. The public water withdrawal per capita was also kept constant, so that the total public water withdrawals for 2030 directly reflect the projected population and tourism densities.

Agricultural water withdrawals

Irrigation water withdrawals were estimated based on the country-level total irrigation water withdrawals from EUROSTAT, the distributed land use of each crop group modelled by LUISA (maize, root crops, cereals, permanent crops, and other crops), and the estimated relative water requirements between the crop groups to give a weighted allocation of irrigation. The calculated irrigation per crop type per pixel was kept constant at the base year (2006) value, so that the forecasted maps to 2020 and 2030 reflect the variance in amount and spatial distribution of each crop as modelled in LUISA.

Livestock water withdrawals were calculated based on the specific water requirements and spatial distribution of each type of livestock. The Food and Agriculture Organization of the United Nations (FAO) livestock density maps for 2005 (described in Robinson et al 2007), actual livestock figures for 2005 made available through the Common Agricultural Policy Regionalized Impact Modeling System (CAPRI, 2012) are used to refine the livestock density maps. A series of water requirements per livestock type data is taken from the literature in order to compute water requirements per livestock type on a daily basis.

Sectoral water consumption

Of the total water withdrawn for each sector, a portion is 'consumed', that is to say removed from the direct environment through evapotranspiration, conversion into a product or otherwise. The remaining water is returned to the environment either directly, or after use, so having an altered quality level. For each sector we assumed a percentage of the total withdrawals to be fully consumed. Table A.1.1. shows these figures, originating from available literature (UN WWDR, 2009) and expert opinion. These average values were then used to compute maps of water consumption (by multiplying this sector-specific value with the water withdrawal maps).

Table A.1.1. Consumption factors used per water withdrawal sector to calculate the overall total water consumption

Water withdrawal sector	Assumed water consumption (%)
Public	*20*
Industry	*15*
Energy	*2.5*
Irrigation	*100*
Livestock	*15*

ANNEX 2. Maps of water consumption per fuel type for the years 2020 and 2030, MIN and MAX scenarios.

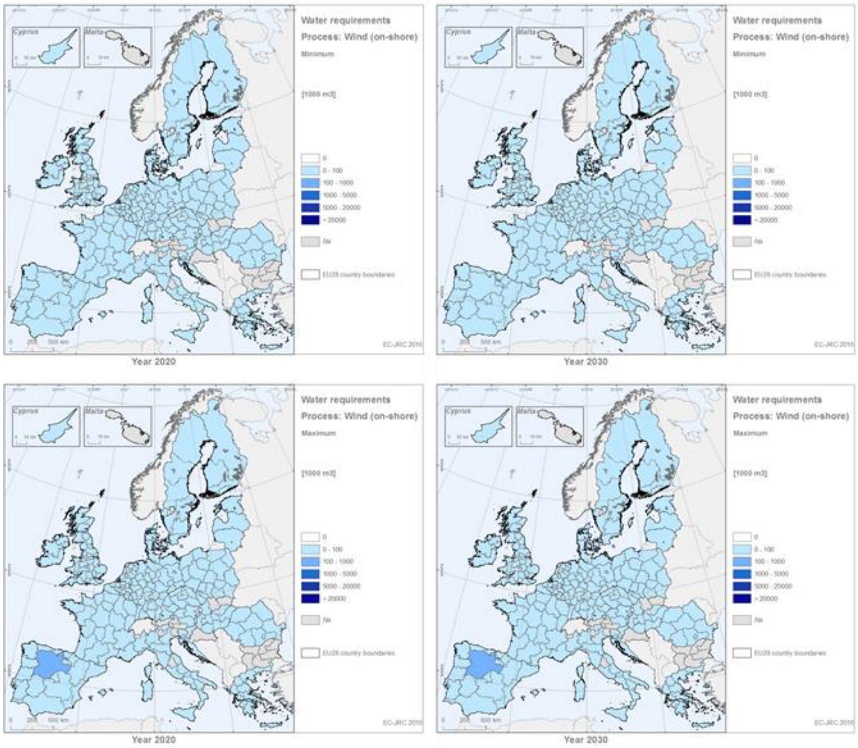

Figure A.2.1. Water consumption in electricity generation by wind (on-shore) for the years 2020 and 2030, minimum and maximum scenarios

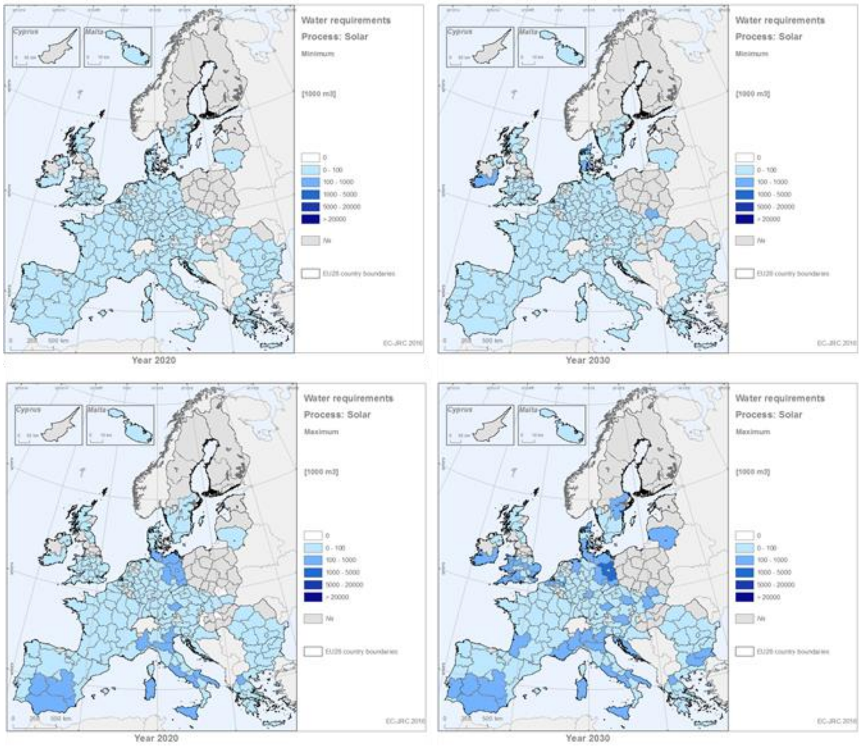

Figure A.2.2. Water consumption in solar electricity generation for the years 2020 and 2030, minimum and maximum scenarios

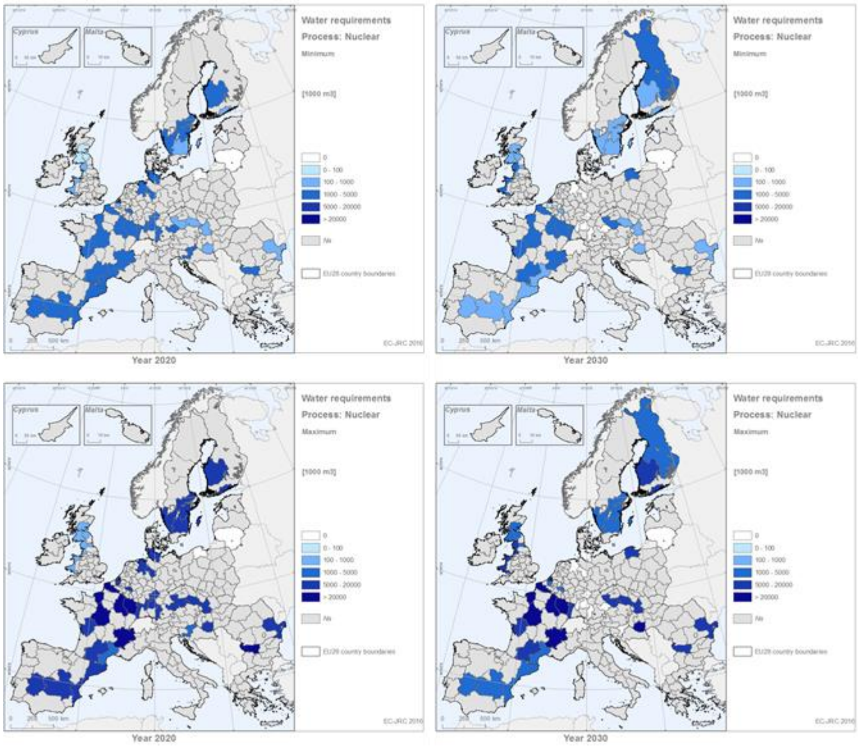

Figure A.2.3. Water consumption in nuclear electricity generation for the years 2020 and 2030, minimum and maximum scenarios

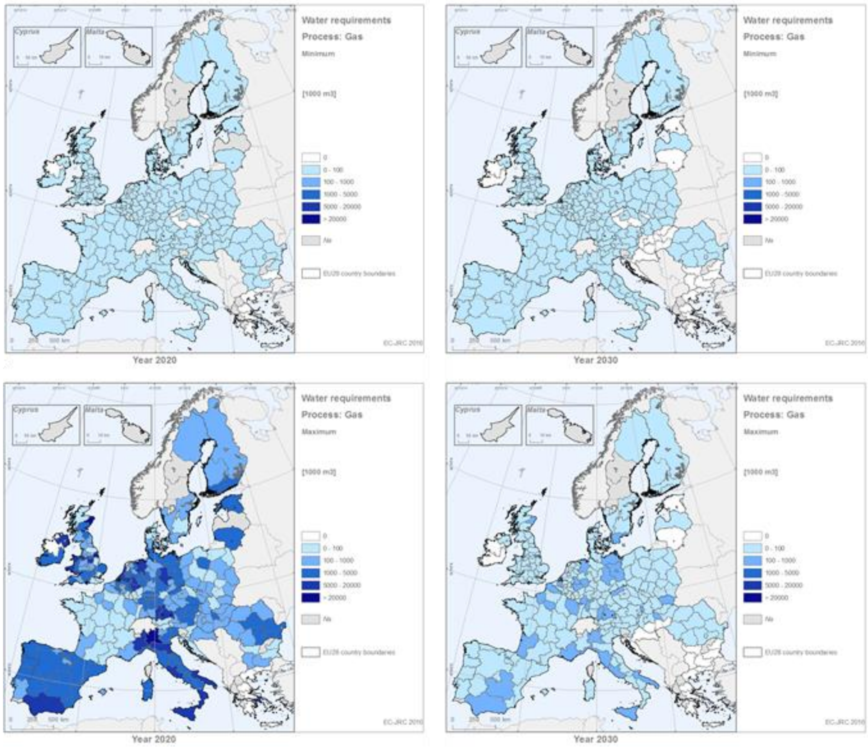

Figure A.2.4. Water consumption in electricity generation by gas for the years 2020 and 2030, minimum and maximum scenarios

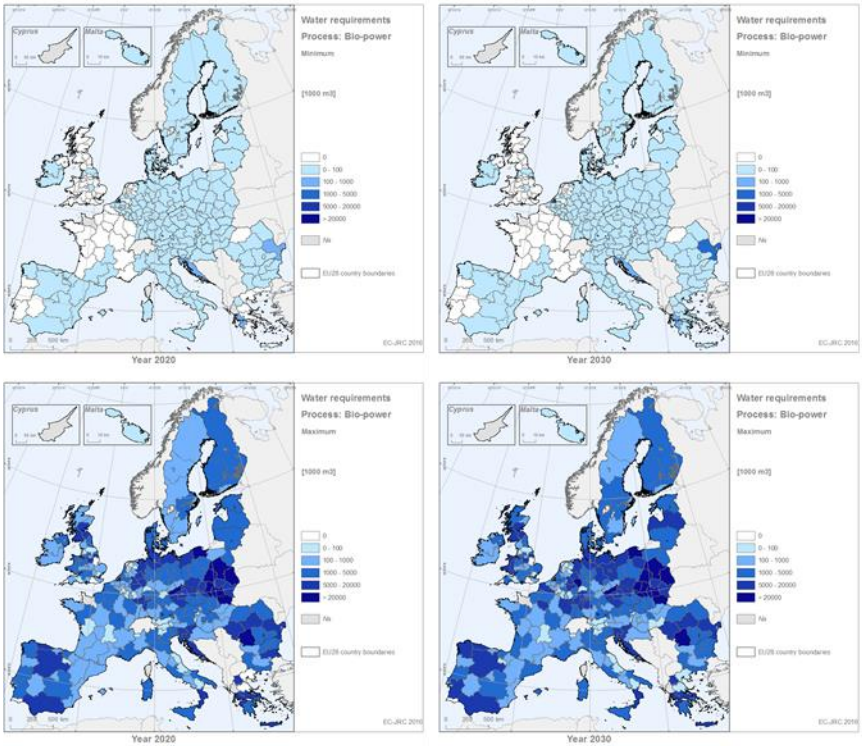

Figure A.2.5. Water consumption in electricity generation by bio-power for the years 2020 and 2030, minimum and maximum scenarios

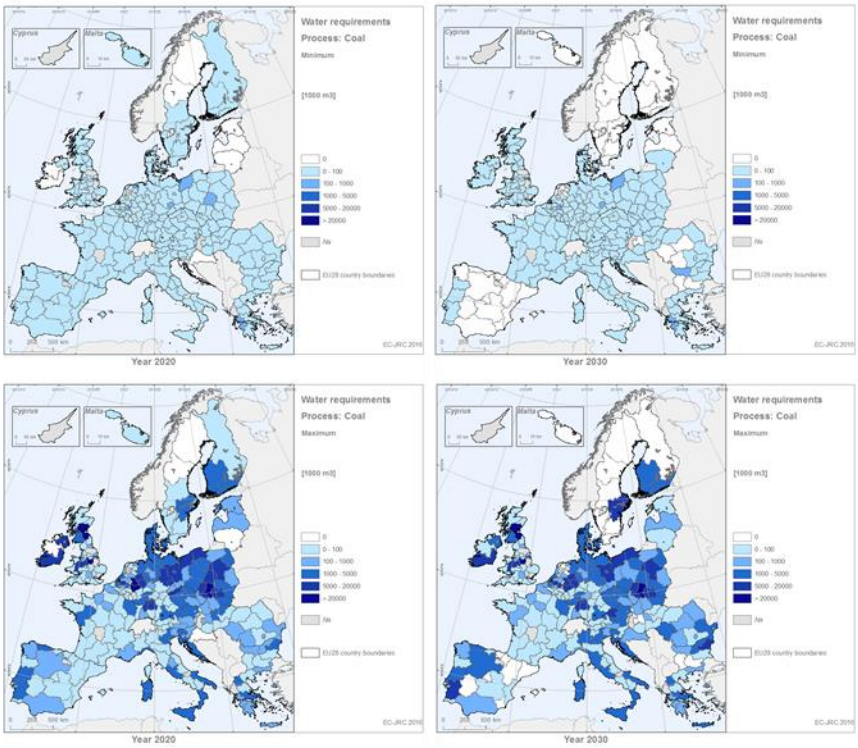

Figure A.2.6. Water consumption in electricity generation by coal for the years 2020 and 2030, minimum and maximum scenario

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