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Projected freshwater needs of the energy sector in the European Union and the UK

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Contents

Foreword

Increasing water stress will intensify competition between water uses. A lack or an excess of water may undermine the functioning of the energy and food production sectors with societal and economic effects. Energy and water are inextricably linked: we need “water for energy” for cooling thermal power plants, energy storage, biofuels production, hydropower, enhanced oil recovery, etc., and we need “energy for water” to pump, treat and desalinate. Without energy and water, we cannot satisfy basic human needs, produce food for a rapidly growing population and achieve economic growth. Producing more crops per drop to meet present and future food demands means developing new water governance approaches.

The Water Energy Food and Ecosystem Nexus (WEFE Nexus) flagship project addresses in an integrated way the interdependencies and interactions between water, energy, agriculture, as well as household demand. These interactions have been so far largely underappreciated. The WEFE-Nexus can be depicted as a way to overcome stakeholders’ view of resources as individual assets by developing an understanding of the broader system. It is the realization that acting from the perspective of individual sectors cannot help tackle future societal challenges.

The overall objective of the Water-Energy-Food-Ecosystems Nexus flagship project (WEFE-Nexus) is to help in a systemic way the design and implementation of European policies with water dependency. By combining expertise and data from across the JRC it will inform cross-sectoral policy making on how to improve the resilience of water-using sectors such as energy, agriculture and ecosystems.

WEFE-NEXUS objectives

- Analyse the most significant interdependencies by testing strategies, policy options and technological solutions under different socio-economic scenarios for Europe and beyond.
- Evaluate the impacts of changing availability of water due to climate change, land use, urbanization, demography in Europe and geographical areas of strategic interest for the EU.
- Deliver country and regional scale reports, outlooks on anomalies in water availability, a toolbox for scenario-based decision making, and science-policy briefs connecting the project’s recommendations to the policy process.

How is the analysis done?

JRC experts use a broad range of models and sources to ensure a robust analysis. This includes water resources and climate models to understand current and future availability of water resources, and energy models and scenario employed to understand and forecast current and future energy demands and the related water footprint of the energy sector.

The results from these models are expected to provide i) understanding the impacts of water resources on the operation of the energy system, and vice versa, ii) spatial analysis and projection of water and energy requirements of agricultural and urban areas in different regions, iii) producing insights for a better management of water and energy resources.

What is this report about?

The aim of this technical report is to provide projections of future freshwater demands of the energy sector (primary energy supply and transformation in power plants and oil refineries) in the EU and the United Kingdom. The projections are estimated by the combination of water withdrawal and consumption factors for different energy technologies under six energy scenarios. The national projections are disaggregated at NUTS2 level.

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Abstract

Since 1990 the European energy system has been reducing its water requirements, mainly due to the penetration of wind and solar energy and the closure of thermal power plants (European Environment Agency, 2019), and at the same time water reservoirs have increased its relevance as providers of flexibility to the European power systems (Huertas-Hernando et al., 2017). Despite that positive evolution, changes in the availability of freshwater resources due to heatwaves and droughts affect the operation of the energy system across Europe, in particular reducing the output of power plants during some periods of time. The frequency and the intensity of these episodes is expected to increase in the coming decades due to the effects of climate change. The goal of this study is to estimate plausible projections of the long-term freshwater needs of the energy industries (that is, primary energy production and energy transformation in refineries and power plants) in all the EU Member States and the UK until 2050, according to the six energy scenarios publicly available[1] when the analysis was carried out, namely:

- The EU Energy Reference Scenario 2016
- The EUCO3232.5
- The GECO 2018 reference scenario
- The GECO 2018 2 °C scenario
- The GECO 2018 1.5 °C scenario
- The POTEnCIA Central scenario.

This study follows up a previous JRC analysis (Medarac, Magagna, and Hidalgo Gonzalez, 2018) carried out in the framework of the Water-Energy-Food-Ecosystem Nexus Project (WEFE). The projections are disaggregated at NUTS2 level for further analysis within the WEFE project. They are intended to be used in combination with other estimations of the freshwater requirements of other sectors (e.g. agriculture, public water supply) to assess the overall stress of water resources, and also in energy modelling analyses supporting the design of energy and environmental policies.

This analysis shows that, during 2015, the water withdrawn by the energy sector in the EU and the UK was in the range 63-69 billion m^3, depending on the energy scenario considered, in line with similar studies available in the scientific literature. This amount exceeds withdrawals for public water supply and agriculture (Magagna et al., 2019). The water withdrawals are expected to decrease by 26%-51% in 2050, down to 31-48 billion m^3, as a result of the increasing penetration of renewable energy sources and the phase out of coal and nuclear power plants. Throughout the 2015-2050 period, most of this water (approximately 97%) would be used for cooling thermal power plants.

However, the total decrease in water consumption across the EU and the UK would be more moderate, from 7-8 billion m^3 in 2015 (approximately 11% of the withdrawals) to 6-7 billion m^3 in 2050 (15%-18% of the withdrawals, depending on the scenario). Evaporation from water reservoirs would account for around half of the water consumed by the energy industry.

The overall decrease in the use of freshwater resources across the EU and the UK may conceal problems at lower geographical scales, especially in those areas where water-intensive energy technologies are used until 2050 according to the energy scenario. For this reason, this study breaks down the projections at national and regional (NUTS2[2]) level.

At national scale, water withdrawals would be concentrated in Germany, France, Spain, Poland and Bulgaria (on average among all scenarios, 73% of the EU total in 2015 and 64% in 2050). Depending on the scenario, some countries would drastically reduce withdrawals (like Spain or Belgium), while others (notably Hungary and Romania) would experience the opposite trend. Most water consumption would occur in Czechia, Germany, Spain, France, Poland, Sweden and the United Kingdom (70% of EU consumption in 2015 on average among all scenarios, and 65% in 2050).

[1] The time series of the scenarios considered in the European Commission Long Term Strategy (European Commission, 2018; European Commission, 2018) are not publicly available at country level. Thus, none of the projections used in this study consider the possible impact on freshwater resources of a fully decarbonised scenario for the EU and the UK in 2050.

[2] Nomenclature Of Territorial Units For Statistics; https://ec.europa.eu/eurostat/web/nuts/background.

In 2015 there were 13 regions with significant nuclear and coal-fired power generation capacity and coal mining, where withdrawals were above 3% of the total in all scenarios (for the EU and UK): FRK2 (Rhône-Alpes), DE11 (Stuttgart), ES43 (Extremadura), ES51 (Cataluña), DEF0 (Schleswig-Holstein), BG31 (Severozapaden), HU23 (Dél-Dunántúl), BE33 (Prov. Liège), DE92 (Hannover), DE12 (Karlsruhe), RO22 (Sud-Est), FRF1 (Alsace), and PL72 (Świętokrzyskie). By 2050 the regions with withdrawals above 3% of the total would be: FRK2 (Rhône-Alpes), DE11 (Stuttgart), HU23 (Dél-Dunántúl), RO22 (Sud-Est), BG31 (Severozapaden), PL72 (Świętokrzyskie), ES43 (Extremadura), ES51 (Cataluña), and SI03 (Vzhodna Slovenija).

As regards consumption, only two regions in all scenarios reached 3% of the total in 2015: FRB0 (Centre — Val de Loire) and FRK2 (Rhône-Alpes). By 2050 the regions with highest consumption would be DE11 (Stuttgart), ES61 (Andalucía), FRB0 (Centre — Val de Loire), ES43 (Extremadura), FRK2 (Rhône-Alpes), FI1D (Pohjois- ja Itä-Suomi), CZ03 (Jihozápad) and SK02 (Západné Slovensko).

Some of the low-carbon energy sources that could bring significant CO_2 emission reductions to the energy industry are also highly water-intensive. Higher biomass production could increase consumptive freshwater needs by 21% in 2050, up to 1.59 billion m^3 (EUCO32325 and POTENCIA CS scenarios). In the six energy scenarios considered, the penetration of hydrogen could increase consumptive freshwater demand by 0.02-0.05 billion m^3 in 2050 (REF2016, EUCO32325 and POTENCIA CS scenarios), but this impact could be much higher under more ambitious scenarios such us those considered in the European Commission Long Term Strategy, where hydrogen could account for up to 16-20 % of the total EU energy share, which would consume 1.2-1.4 billion m^3 of freshwater, equal to a third of the total water consumed in the energy sector today. By far the highest impact on water resources would be produced by the penetration of carbon capture and sequestration technologies from 2040 onwards. The additional water withdrawal needs for power generation with CCS would be 6% to 58% higher, or 2.5-25 billion m^3, depending of the scenario. The impact on water consumption would be higher, growing by 22%-225% in 2050, or 1.4-16 billion m^3.

The complete set of projections described in the rest of this report are available at the JRC Data Catalogue under the WEFE Collection[3].

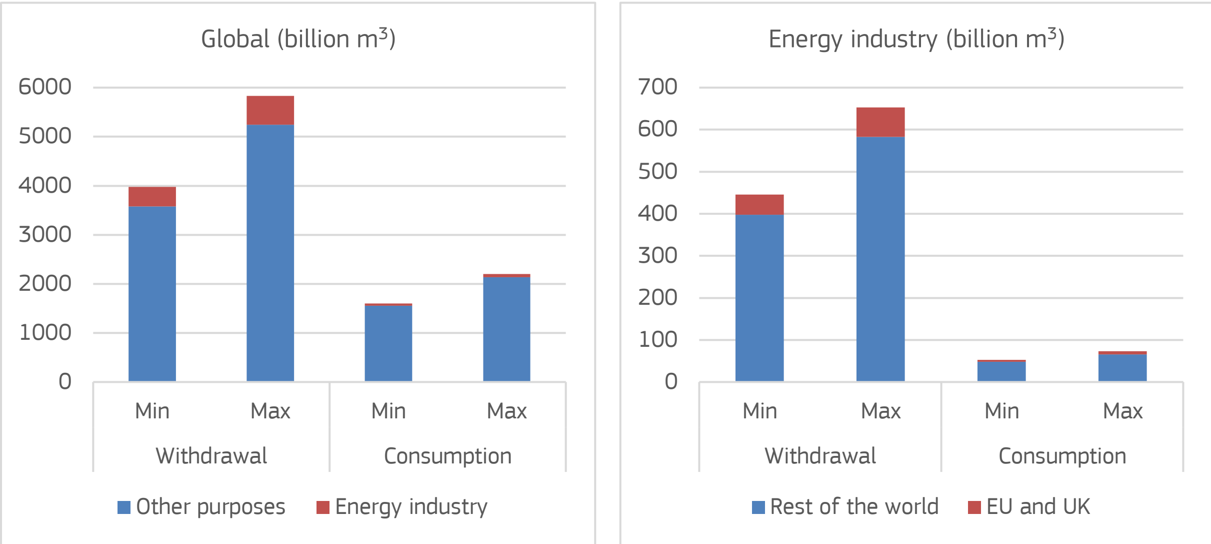
[3] https://data.jrc.ec.europa.eu/collection/id-00134

1 Introduction

Water is used throughout the energy industry, especially for the production of primary energy and for transforming it in power plants and oil refineries. Water resources are essential for hydropower, a major carbon-free power generation source that provides key flexibility services to the energy system, helps to balance intermittent generation (e.g. from wind and solar) and changes in demand, and accounts for virtually all the current energy storage capacity of the power system. On the other hand, the water system needs energy for collecting, pumping, treating and desalinising water.

Global freshwater withdrawals[4] during the 2010-2014 period ranged between 3582 and 5247 billion m^3 per year. Energy-related water withdrawals during those years ranged between 398 and 583 billion m^3 per year, around 10 % of total water abstraction for all purposes) and consumption[5] ranged between 48 and 66 billion m^3 (3 % of the global water consumption), while the total energy consumption of the water sector was approximately 1 % of the world's total (IEA, 2018). In the period 2010-2014 the EU and the UK accounted for 12 % of energy-related withdrawals (48-70 billion m^3 per year) and 10 % of consumption at the global level (5-7 billion m^3 per year), while the water demand from the energy sector accounted for 42 % of the total water abstraction in the EU and the UK (IEA, 2018).

Figure 1. Annual freshwater use in the period 2010-2014



Source: (IEA, 2018)

Water-related problems have recently produced several generation adequacy problems in power systems across Europe. In July 2019, several nuclear power plants were temporarily closed due to high water temperatures, and hydropower output and stocks were also affected in France, Spain, the Balkans and Scandinavia (Paulger, 2019).

As our energy demand is predicted to increase, scientists see the rising temperatures as a threat to the proper functioning of our energy and water systems (Byers et al., 2020). According to the latest IPCC Assessment Report, water availability will be affected by climate change (Jiménez Cisneros et al., 2014) and land use and water consumption changes (Forzieri et al., 2017; Füssel et al., 2017; Bisselink et al., 2018). Changes in water quantities and temperature will have consequences on the energy sector, which will have to cope with impacts similar to those described above. The in-depth analysis in support of the communication from the European Commission "A clean planet for all: a European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy" (European Commission, 2018), warns that:

> *Thermoelectric generation will be under more pressure in Southern European regions where their water cooling needs may no longer be met: they may generate up to 20 % less under a 3 ºC scenario;*

[4] Water withdrawal: amount of water removed from the ground or diverted from a water source for use in any energy process.

[5] Water consumption: amount of water withdrawn that is not returned to the source; defined as the amount of water that is evaporated, transpired, incorporated into product or crops, or otherwise removed from the immediate water environment.

15 % less in a 2 ºC world. Thermal electricity generation may suffer most from water stress in the near term in the Mediterranean, France, Germany and Poland.

While the magnitude of these impacts is not expected to jeopardise Europe's long-term decarbonisation path, it may entail higher costs and different regional energy mixes, unless adaptive measures are deployed, such as increased plant efficiencies, replacement of cooling systems and fuel switches. Private stakeholders in the energy system and EU and national policies should reinforce the right market framework to ensure that the climate impacts do not jeopardise the EU's stability and security of energy supply. Transitions in the electricity sector should encompass both mitigation and adaptation planning, if they are to sustain and secure a sustainable water–energy nexus in the next few decades.

The EU has ambitious decarbonisation goals for the future, which could be very difficult to achieve if the European water system becomes too stressed or if they rely on highly water-intensive energy technologies such as biofuels, carbon capture, or nuclear power.

This technical report presents estimations of the projected freshwater used by the energy sector in the EU and the UK, for the period 2015-2050, derived from six energy scenarios. The projections are disaggregated at NUTS2 level for further analysis within the WEFE project. They are intended to be used in combination with other estimations of the water requirements of other sectors to assess the overall stress of water resources, and also in energy modelling analyses supporting the design of energy and environmental policies. They are derived from the following six publicly available energy projections (none of which considers a fully decarbonised scenario for the EU and the UK in 2050):

— **EU Energy Reference Scenario 2016** (hereafter *REF 2016*) (Capros et al., 2016): the EU Reference Scenario is one of the European Commission's key analysis tools in the areas of energy, transport and climate action. It focuses on the EU energy system, transport and greenhouse gas (GHG) emission developments, including specific sections on emission trends not related to energy, and on the various interactions among policies in these sectors. Its time horizon as in the 2013 version is up to 2050 and it includes all EU Member States and the UK individually. The scenario provides a model-derived simulation of one of its possible future states given certain conditions. It starts from the assumption that the legally binding GHG and RES targets for 2020 will be achieved and that the policies agreed at EU and Member State level until December 2014 will be implemented.

— **EUCO3232.5** (hereafter EUCO32325) (European Commission, 2020): this scenario estimates the potential impact of achieving an energy efficiency target of 32.5% and a renewable energy target of 32%, as agreed in the Clean energy for all Europeans package (European Commission, 2019). This scenario was used to support the Commission's June 2019 assessment of the draft national energy and climate plans (NECPs), submitted by Member States.

— **GECO 2018 Reference Scenario** (hereafter GECO REF) (Keramidas, K., Tchung-Ming et al., 2018): this scenario corresponds to a world where no additional policies are implemented compared to what was legislated as of the end of 2017; energy and emissions projections are driven by market forces and technological learning.

— **GECO 2018 2 °C** (hereafter GECO 2.0 C) (Keramidas, K., Tchung-Ming et al., 2018): this projection is a global mitigation pathway in which the immediate strengthening of climate action from 2018 reduces emissions to levels consistent with a likely chance of meeting the long-term goal of a temperature increase over pre-industrial times below 2°C. It reflects the need for a global transition towards a low-emission economy development pattern. The global mean surface temperature would have an overall 64% probability of staying below 2 °C throughout the century.

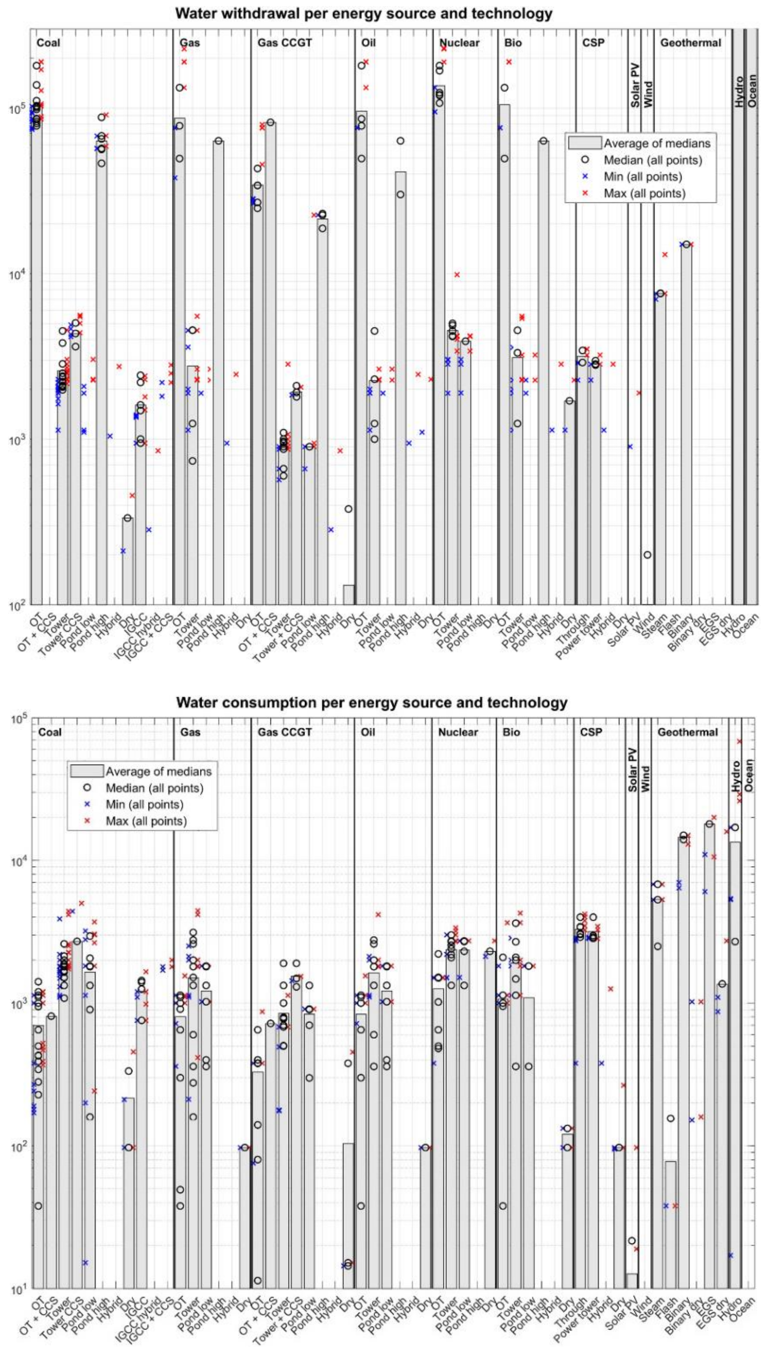
— **GECO 2018 1.5 °C** (hereafter GECO 1.5 C) (Keramidas, K., Tchung-Ming et al., 2018): this scenario is defined with the same parameters as the central 2°C scenario but aims at more aggressively GHG emissions reductions in order to achieve a lower temperature change at the end of the century, with a 2011–2100 carbon budget compatible with a 50% chance of achieving that objective according to MAGICC 6 of 500 GtCO_2. In this scenario, the temperature peaks at about 1.7°C around the middle of the century and decreases to 1.5°C by 2100 (with 50% probability).

— **POTEnCIA Central Scenario** (hereafter POTENCIA CS) (Mantzos et al., 2019): this projection describes the evolution of the EU energy system until the year 2050 under the assumption that no further policies and measures are introduced beyond the end of 2017. The results show that both the energy and the carbon intensity of the European economy remain on a declining path in the 'Central' scenario set-up, but will miss mid-century targets. This evolution is driven by the continued impact of policies that are already in place in combination with technology progress, as well as by structural changes and the development of the prices of fossil fuels and of the CO_2 allowances under the EU Emissions Trading System. The EU target to reduce GHG emissions by at least 40% from 1990 levels in 2030 will not be met under the assumptions of the scenario, confirming the need for additional policies and measures.

2 Overall trends at continental level

The estimations of the freshwater needs of the energy industry are obtained by the combination of the projections from the energy scenarios listed in section Introduction with the available data of the specific water withdrawal and consumption requirements of the different energy technologies according to the methodology followed in a previous JRC estimation of the freshwater requirements of the energy industry according to the Energy Reference Scenario 2016 (Medarac, Magagna, and Hidalgo Gonzalez, 2018). The freshwater projections described in this report are based on the data used in that study (Medarac, Magagna, and Hidalgo Gonzalez, 2018) updated with the most recent values found in the literature (Larsen and Drews, 2019; Vanham et al., 2019).

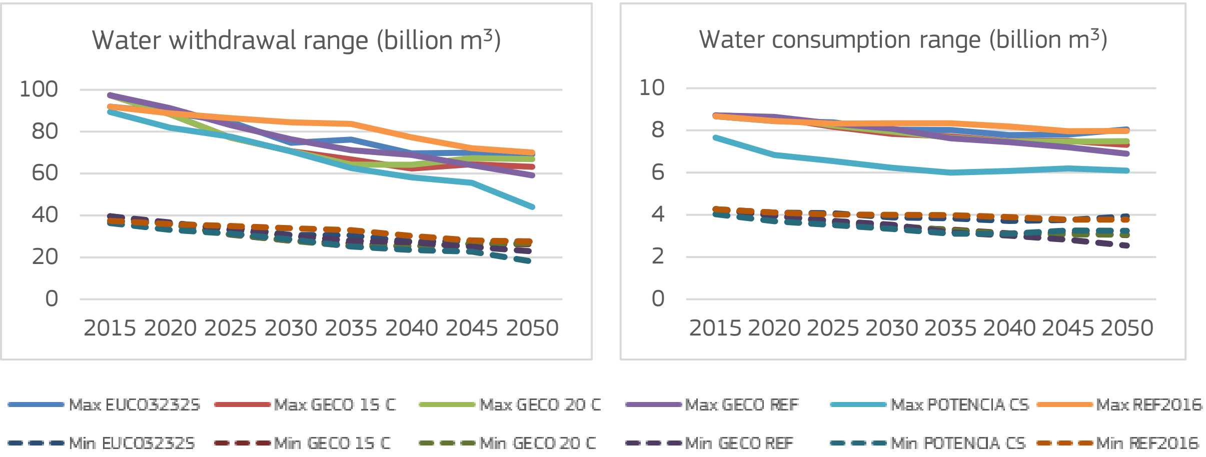
Figure 2. Example of water withdrawal and consumption factors



Source: reproduced from figures 1 and 2 in (Larsen and Drews, 2019)

However, the reported water requirements available from scientific sources show huge variations for most technologies, due to variations across natural, geographical, technological, hydro-climatic conditions and differences in definitions as shown in Figure 2. Using maximum and minimum values of water withdrawal and consumption factors, total water withdrawal in the EU and the UK would change from 36-97 billion m^3 in 2015[6] to 18-70 billion m^3 in 2050. Similarly, total water consumption would decrease from 4-9 billion m^3 in 2015 to 3-8 billion m^3 in 2050.

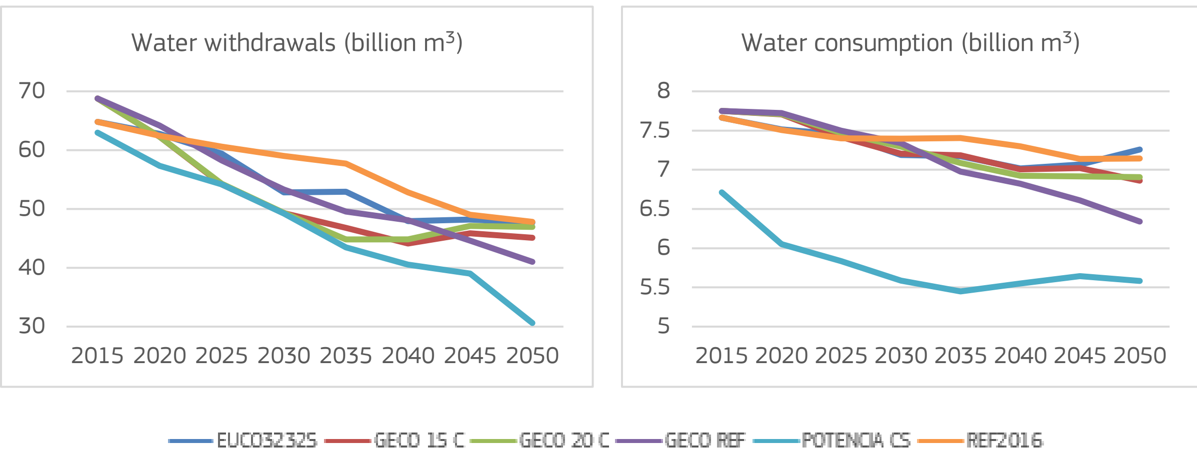
Figure 3. Water withdrawal and consumption ranges based on maximum and minimum water factors



Source: JRC, 2020

The projections of freshwater requirements described hereafter in this report are based on the median water withdrawal and consumption factors. Using those values, the freshwater withdrawn by the energy sector in the EU and the UK during 2015 was estimated to lie in the range 63-69 billion m^3, depending on the energy scenario considered. This amount exceeds 2015 withdrawals for public water supply and agriculture (Magagna et al., 2019). The water withdrawals are expected to decrease by 26%-51% in 2050, down to 31-48 billion m^3 (respectively in the POTENCIA CS and the REF2016 scenarios), as a result of the increasing penetration of renewable energy sources and the decrease of coal and nuclear power generation. None of these projections consirder a fully decarbonised energy system for the EU and the UK in 2050. The closest scenario to that goal would be the GECO 15 C, that would require 45 billion m^3 in 2050.

Figure 4. Water withdrawal and consumption ranges based on median water factors



Source: JRC, 2020

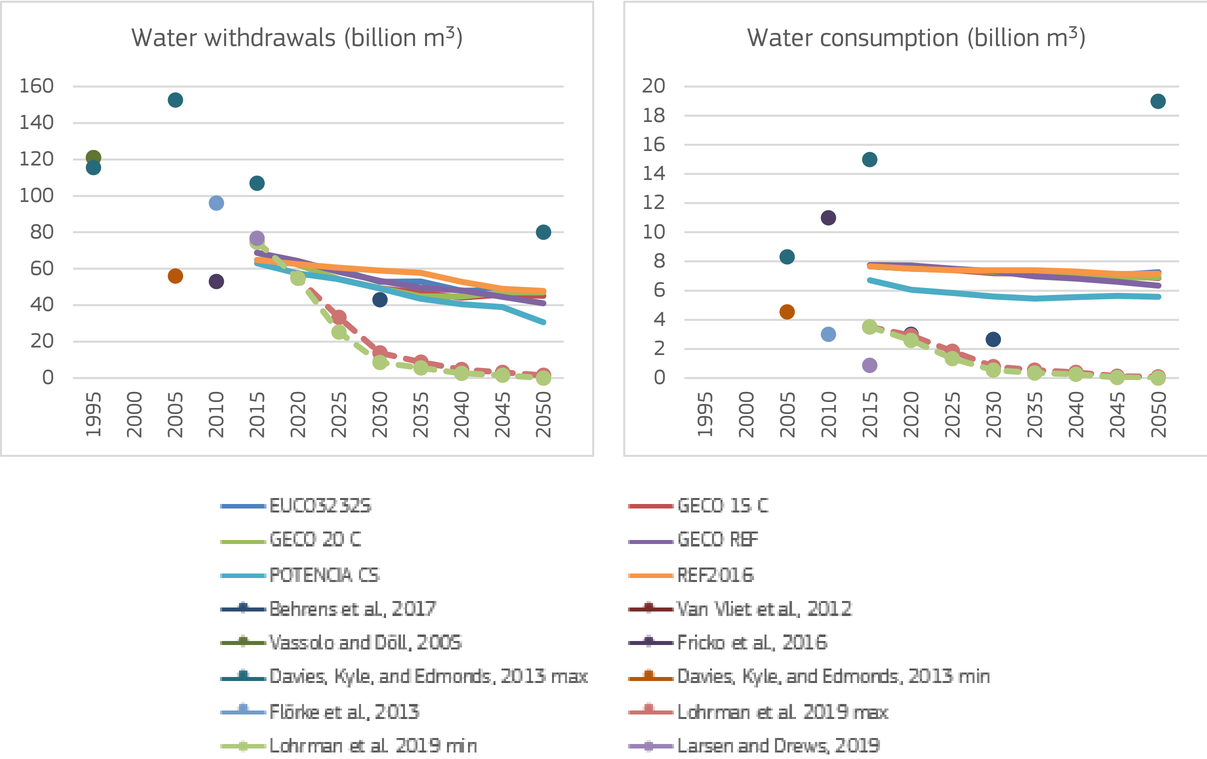
[6] Note that due to differences between the energy scenarios in 2015, particularly in electricity generation, there is a range of estimated freshwater requirements for that year rather than a single value. Thus, in the POTENCIA CS scenario there is more electricity generated from the least water-intensive technologies (gas and hydro) and less from the most water-intensive ones (coal and nuclear). As a result the overall withdrawal and consumption of freshwater in POTENCIA CS are lower than in the other scenarios.

However, the decrease in water consumption would be more moderate, changing from 7-8 billion m^3 in 2015 (approximately 11% of the withdrawals) to 6-7 billion m^3 in 2050 (15%-18% of the withdrawals, depending on the scenario). Evaporation from water reservoirs would account for around half of the water consumption.

The projections described in this report have been compared with other available studies. They differ with respect to this study, in terms of geographical and sectoral scope, as well as in terms of the methodologies and data employed. Despite that, the overall values and trends for the EU and the UK presented in this study are rather in line with the available research (Figure 5) as explained below:

- (Behrens et al., 2017): this is an EU-wide assessment (including the UK) of the climate impacts for 1326 thermoelectric plants across 818 water basins in 2020 and 2030. Water withdrawal would reduce from approximately 55 billion m^3 in 2020 to 43 billion m^3 in 2030, while consumption would drop from around 3 billion m^3 to 2.65 billion m^3 in the same period. This analysis concludes that despite policy goals and a decrease in electricity-related water withdrawal, the number of regions experiencing some reduction in power availability due to water stress rises up to 2030. The majority of vulnerable basins lie in the Mediterranean region, with further basins in France, Germany and Poland.
- (Van Vliet et al., 2012): this is a study on the vulnerability of the US and European (EU, UK, and other non-EU countries in Eastern Europe) electricity supply to climate change. The results estimate that freshwater withdrawals for cooling of coal-, gas and nuclear-fuelled power plants amounted to 121 billion m^3 for Europe in 1995, in line with previous analyses (Vassolo and Döll, 2005).
- (Fricko et al., 2016) assess the impact on freshwater sustainability derived from the required transition of the energy systems resulting from a 2 °C climate policy. For continental Europe (including Turkey and excluding the Baltic EU Member States) in 2010 the withdrawal and consumption of freshwater would amount respectively to 53 billion m^3 and 11 billion m^3.
- (Davies, Kyle, and Edmonds, 2013): this is an assessment of the global and regional water demands for electricity generation until 2095. The water withdrawals for cooling of thermal power plants in continental Europe (including Turkey) were estimated to be in the range 56-152.6 billion m^3 in 2005 while the consumption would be in the range 4.54-8.31 billion m^3. The water withdrawals would decrease to 107 billion m^3 in 2015 and 80 billion m^3 in 2050. On the contrary, water consumption would grow to 15 billion m^3 in 2015 and 19 billion m^3 in 2050.
- (Flörke et al., 2013) simulate the global domestic and industrial water use since 1950, in 2010 water withdrawals amounted to 94 billion m^3 while the consumption was 3 billion m^3.
- (Lohrmann et al., 2019) is another global assessment of the water needs of the electricity sector. Water withdrawal and consumption in continental Europe were estimated respectively at 76.4 billion m^3 and 2.5 billion m^3 in 2015. The water use would be drastically reduced, to 9 billion m^3 in 2030 and 2 billion m^3 in 2050 in the case of withdrawal, and to 0.6 billion m^3 in 2030 and 0.1 billion m^3 in 2050.
- (Larsen and Drews, 2019) provides estimations of water withdrawal and consumption in Europe in 2015 amounting to 86 billion m^3 0.9 billion m^3 respectively.

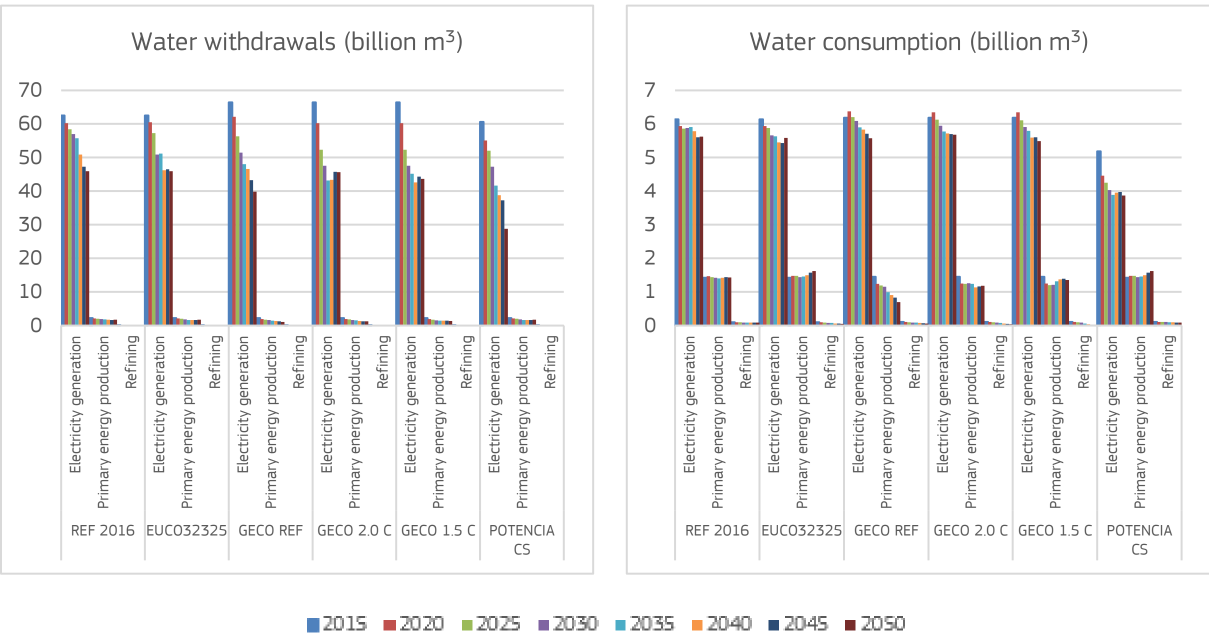
Figure 5. Comparison with other estimations



Source: JRC, 2020

Throughout the 2015-2050 period, most of the freshwater (approximately 97%) would be used in the power system (Figure 6). A significant part of that water is consumed by cooling devices in thermal power plants and evaporated in water reservoirs used for hydropower. A much smaller fraction is used for primary energy production (biomass production, coal mining coal and extraction of oil and gas), while the freshwater needs of oil refineries are negligible in comparison.

Figure 6. Freshwater needs by energy sub-sector



Source: JRC, 2020

3 Detailed results at country and regional levels

At country level all scenarios agree that water withdrawal would be concentrated mainly in Germany, France, Spain, Poland and Bulgaria (Figure 7)[7]. On average among the six scenarios those countries would account for 73% of the EU total freshwater withdrawals in 2015, and 64% in 2050. Germany would pass from withdrawing 19 billion m^3 on average in 2015 to 11 billion m3 in 2050, while France would change from 13 billion m^3 to 7.2 billion m^3. Poland would roughly halve withdrawals as well, from 5.7 to 2.9 billion m^3, while in Bulgaria the reduction would be on avereage 25%, from 4.2 to 3.2 billion m^3. Depending on the scenario, some countries would drastically reduce withdrawals. That would occur for example in Spain (where the withdrawals would decrease from 7 billion m^3 in 2015 to 0.4 billion m^3 (REF2016) or 6.2 billion m^3 (GECO 2.0 C) in 2050), or in Belgium (where the withdrawals would change from 3.8 billion m^3 in 2015 to 0.08 (GECO 1.5 C) or 0.9 (REF2016) billion m^3 by 2050). Other countries, mainly Hungary and Romania, would experience the opposite trend. In Hungary the witdrawal could grow from 3 billion m^3 in 2015 to 5.7 billion m^3 by 2050 under the EUCO32325 scenario, only in the GECO REF scenario the witdrawal would decrease to 2.5 billion m^3.

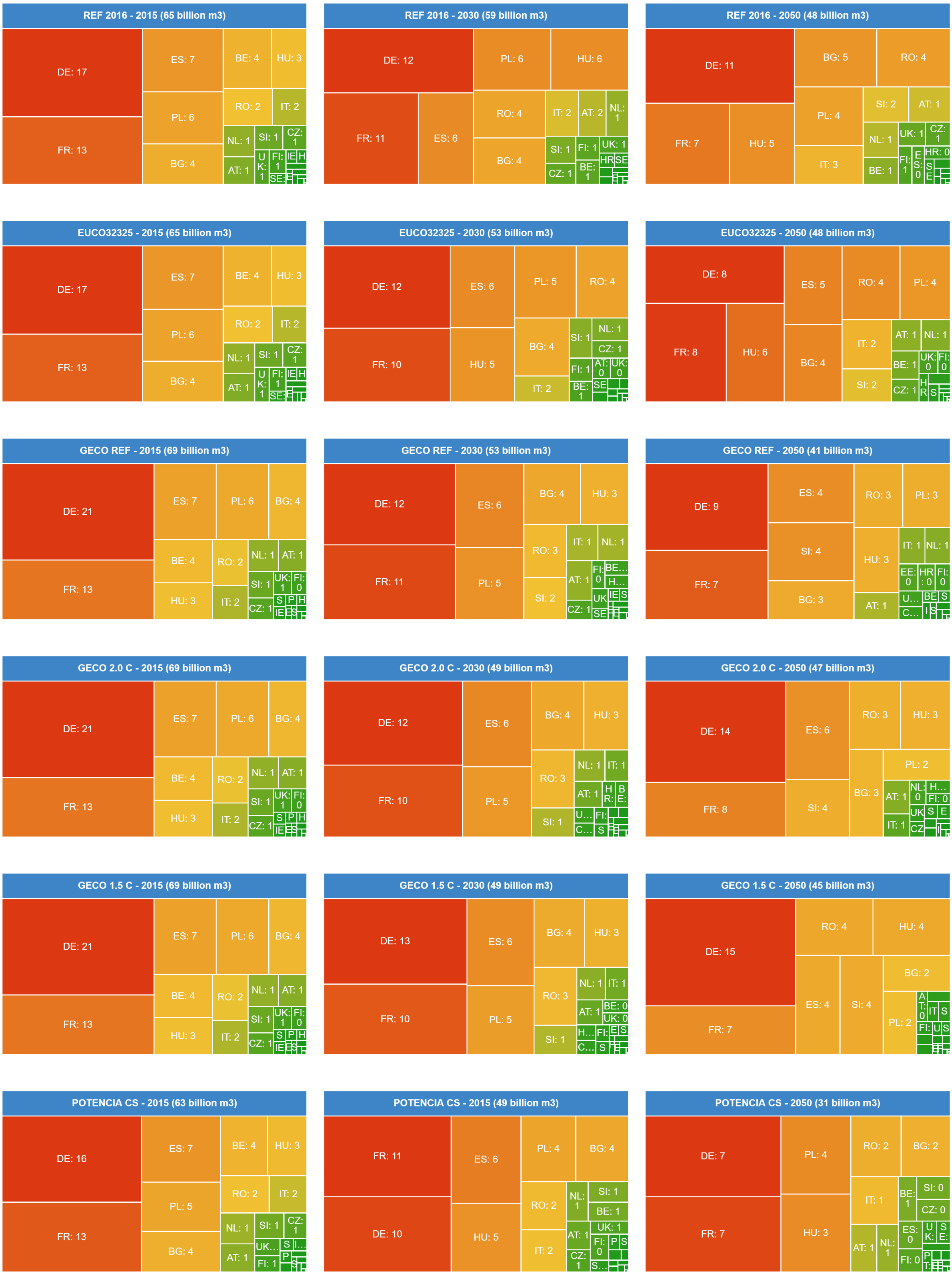
The consumption of freshwater would be more fragmented (Figure 8). In all scenarios most water consumption would occur in Czechia, Germany, Spain, France, Poland, Sweden and the United Kingdom. These countries would account, on average among all scenarios, for 70% of the total consumption in the EU and the UK in 2015, and 65% in 2050. Germany would reduce its consumption from 0.9 billion m^3 on average in 2015 to 0.43 billion m^3 in 2050. The reduction would be significant as well in France, changing from 0.7 billion m^3 to 0.4 billion m^3 in 2050, and in Poland, from 0.35 to 0.2 billion m^3. On the contrary, consumption would grow in Spain from 0.29 billion m^3 to 0.44 billion m^3 in 2050.

Water withdrawal and consumption at regional level are shown respectively in Figure 9 and Figure 10. In 2015 there were 13 regions with significant nuclear and coal-fired power generation capacity and coal mining where withdrawals were above 3% of the total for the EU and UK: FRK2 (Rhône-Alpes, 9.2 billion m^3 on average among all scenarios), DE11 (Stuttgart, 5.9 billion m^3), ES43 (Extremadura, 2.7 billion m^3), ES51 (Cataluña, 2.7 billion m^3), DEF0 (Schleswig-Holstein, 2.6 billion m^3), BG31 (Severozapaden, 2.6 billion m^3), HU23 (Dél-Dunántúl, 2.6 billion m^3), BE33 (Prov. Liège, 2.2 billion m^3), DE92 (Hannover, 2.2 billion m^3), DE12 (Karlsruhe, 2.3 billion m^3), RO22 (Sud-Est, 2.0 billion m^3), FRF1 (Alsace, 2.0 billion m^3), and PL72 (Świętokrzyskie, 1.8 billion m^3). All the scenarios agree that by 2050 the regions with withdrawals above 3% of the total in the EU and the UK would be: FRK2 (Rhône-Alpes, 5.2 billion m^3), DE11 (Stuttgart, 6.9 billion m^3), HU23 (Dél-Dunántúl, 3.7 billion m^3), RO22 (Sud-Est, 3.3 billion m^3), BG31 (Severozapaden, 2.5 billion m^3), PL72 (Świętokrzyskie 1.7 billion m^3), ES43 (Extremadura, 1.5 billion m^3), ES51 (Cataluña, 1.4 billion m^3), and SI03 (Vzhodna Slovenija, 2.6 billion m^3). The worst trends would take place in HU23, SI03, DE11, and RO22.

As regards consumption, only two regions reached 3% of the total in 2015: FRB0 (Centre — Val de Loire, 0.2 billion m^3) and FRK2 (Rhône-Alpes, 0.16 billion m^3). By 2050 the regions with the highest consumption would be DE11 (Stuttgart, 0.07 billion m^3), ES61 (Andalucía, 0.15 billion m^3), FRB0 (Centre — Val de Loire, 0.12 billion m^3), ES43 (Extremadura, 0.13 billion m^3), FRK2 (Rhône-Alpes, 0.09 billion m^3), FI1D (Pohjois- ja Itä-Suomi, 0.09 billon m^3), CZ03 (Jihozápad, 0.07 billion m^3) and SK02 (Západné Slovensko, 0.07 billion m^3. ES61, ES43, CZ03 and SK02 would be regions experiencing the highest growth in consumption from 2015 to 2050.

[7] Figures 7, 8, 9, and 10 are A3-sized.

Figure 7. Water withdrawal per country and scenario in selected years (2015, 2030 and 2050)



Source: JRC, 2020

2-letter codes: EUROSTAT country codes (https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Country_codes)
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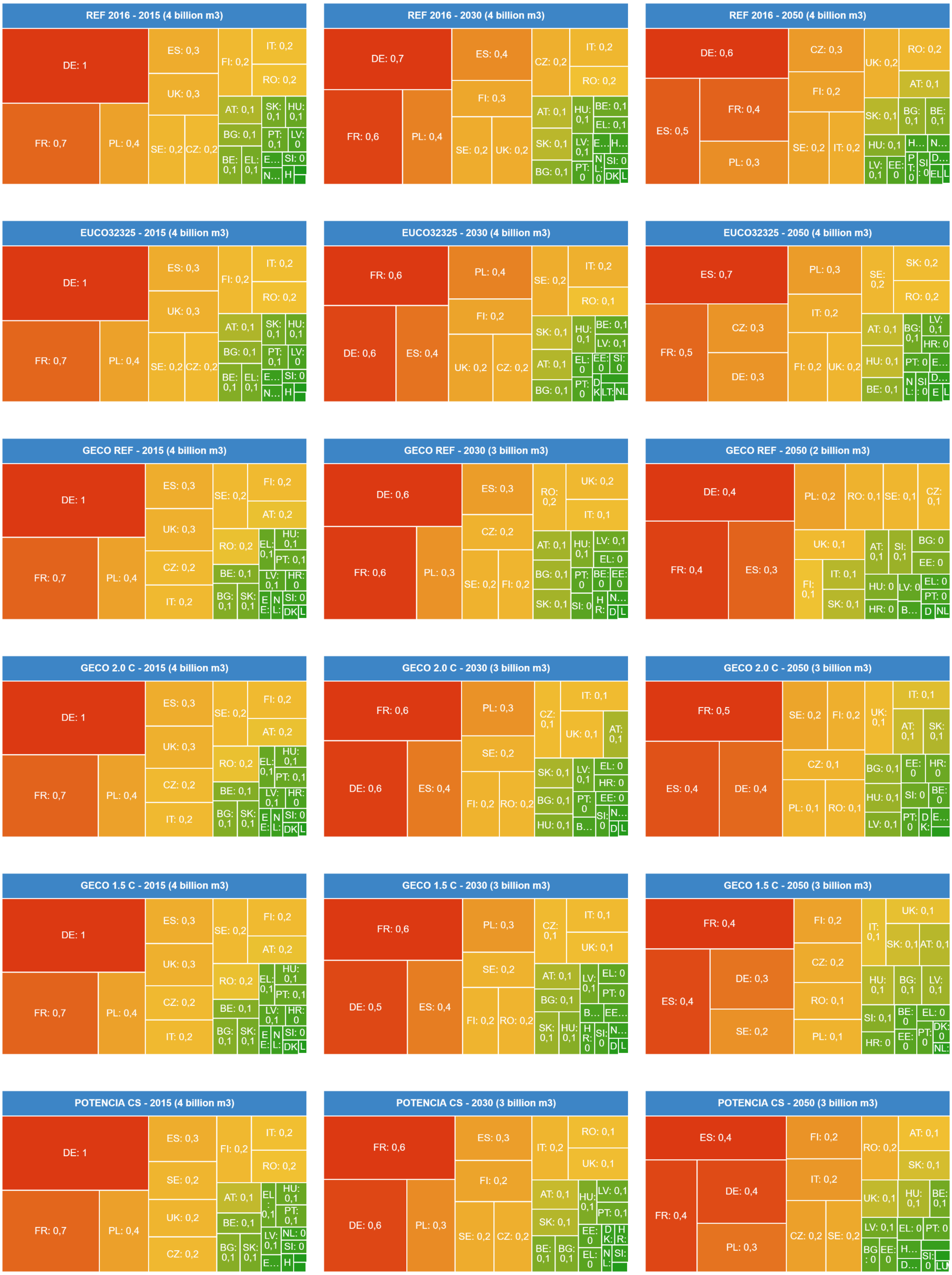
Figure 8. Water consumption per country and scenario in selected years (2015, 2030 and 2050)



Source: JRC, 2020

2-letter codes: EUROSTAT country codes (https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Country_codes)
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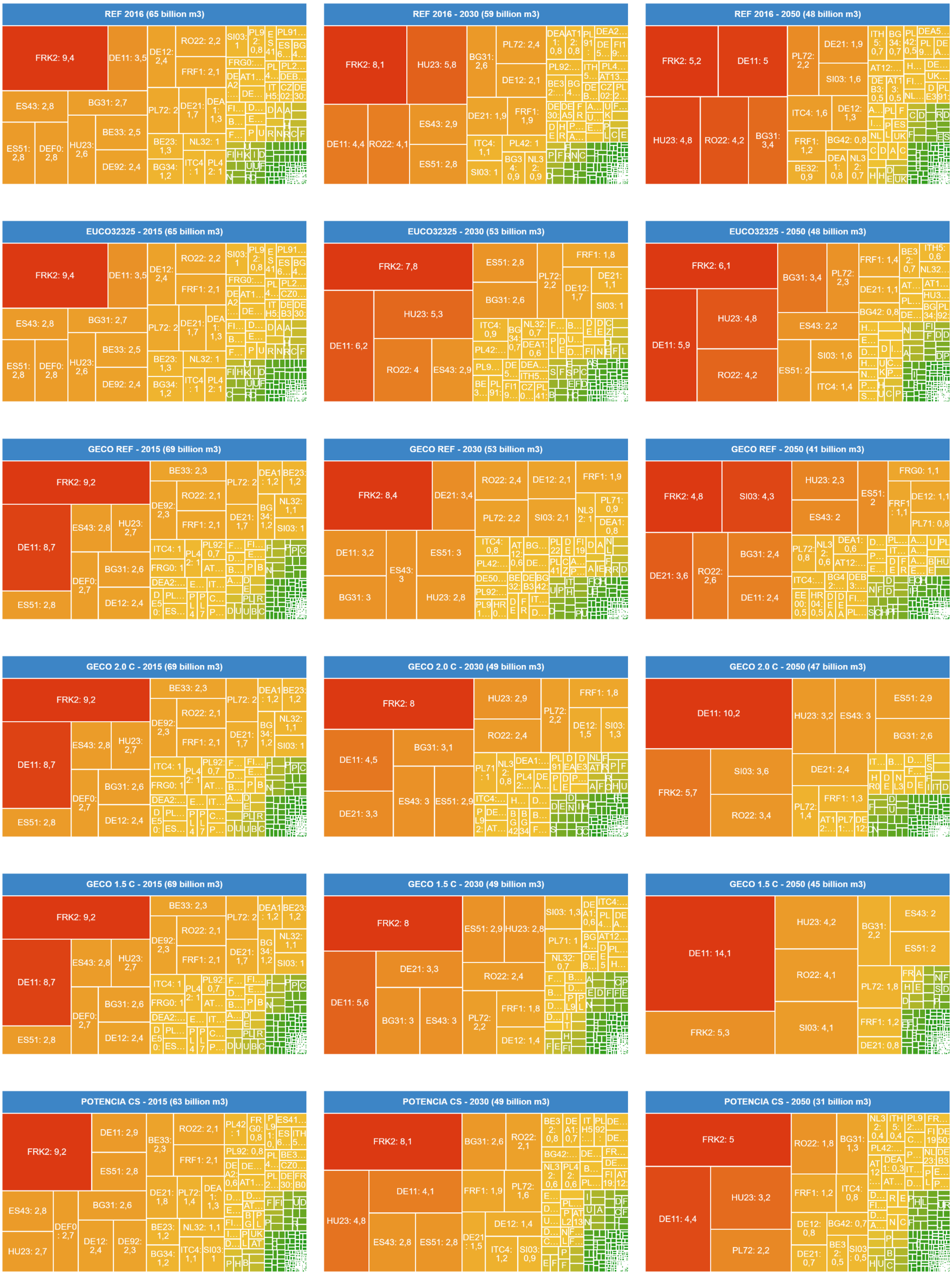
Figure 9. Water withdrawal per NUTS2 region and scenario in selected years (2015, 2030 and 2050)



Source: JRC, 2020

2-letter codes: EUROSTAT NUTS2 codes (https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Country_codes)
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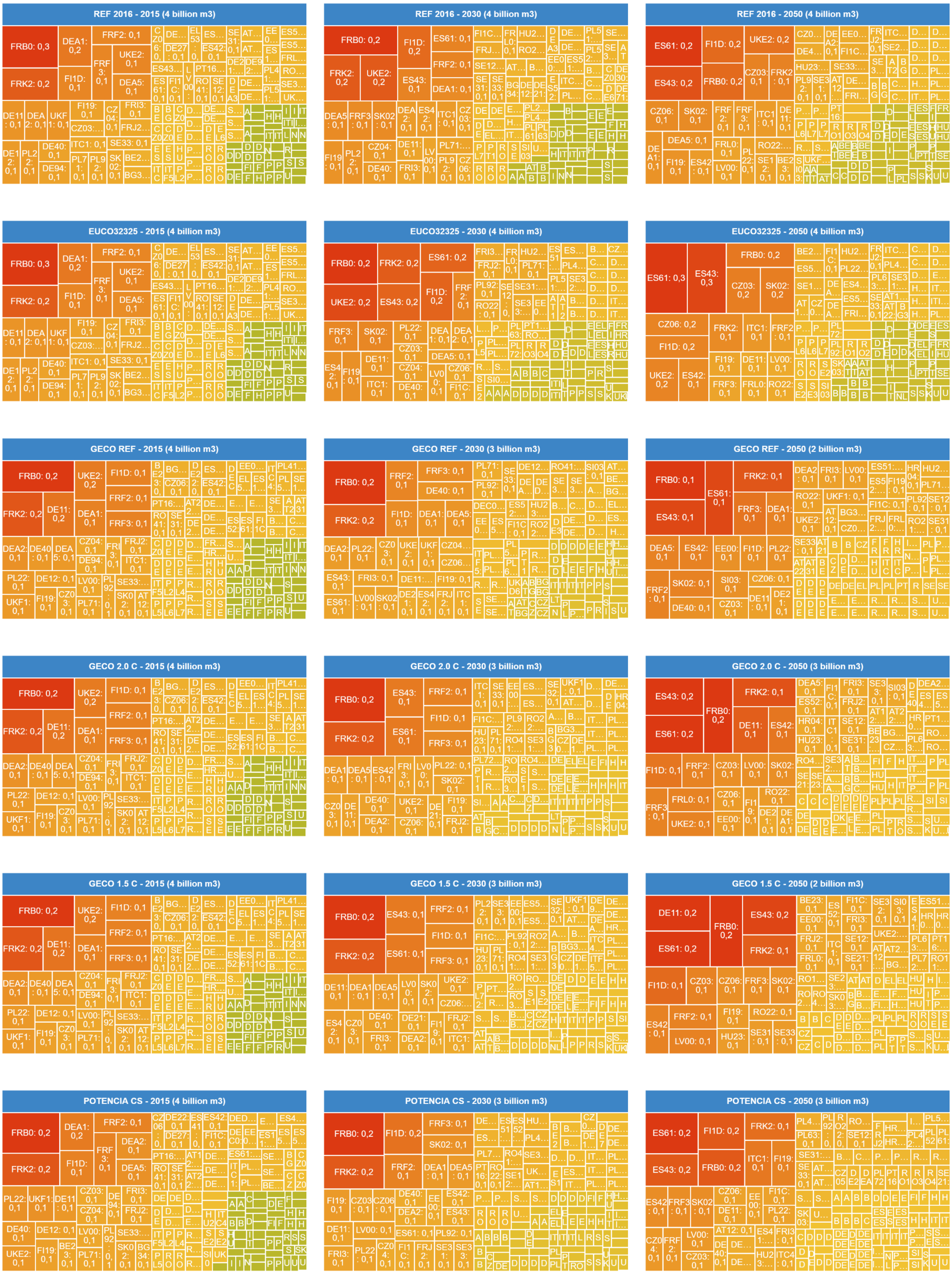
Figure 10. Water consumption per NUTS2 region and scenario in selected years (2015, 2030 and 2050)



Source: JRC, 2020

2-letter codes: EUROSTAT NUTS2 codes (https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Country_codes)
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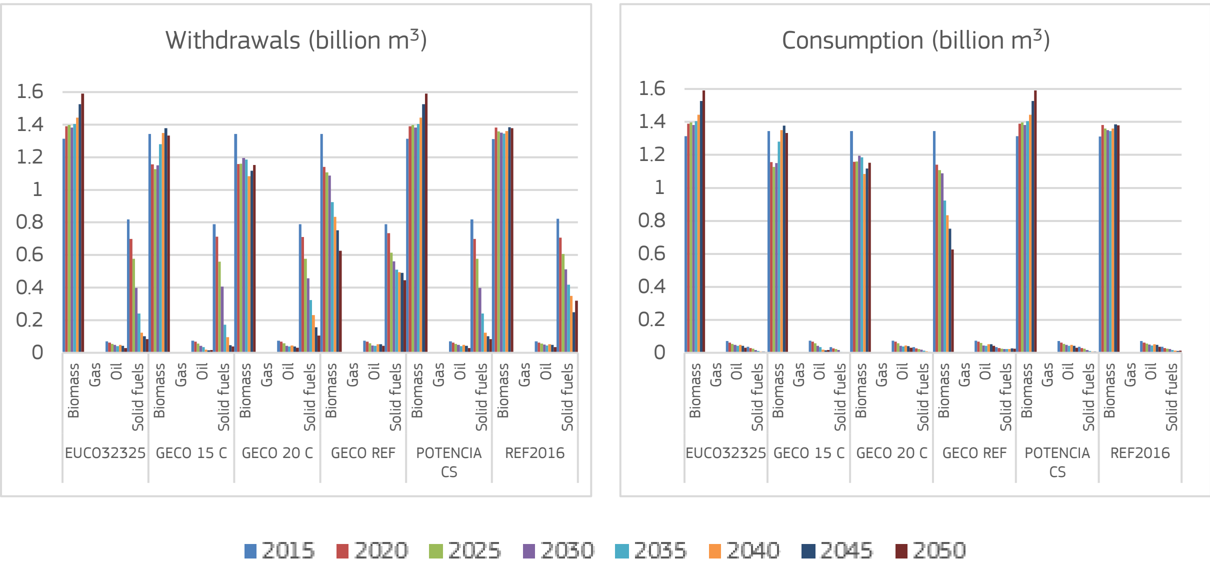
4 Low-carbon energy sources

Some of the low-carbon energy sources that could bring significant CO_2 emission reductions to the energy industry are also highly water-intensive. Therefore, the quantification of the impact on freshwater resources of the penetration of these technologies can help to understand the consequences of the different decarbonisation options. This section discusses the estimated freshwater needs of biomass production, hydrogen production, carbon capture and sequestration, and hydropower. The results are shown for the whole EU and the UK since it is not possible to disaggregate them at lower geographical scales due to the lack of information in the energy scenarios particularly as regards the location of future energy facilities.

4.1 Biomass

The production of biomass (assumed to be mostly fuelwood) accounted for approximately 60% of the water withdrawals for primary energy production in 2015, ranging from 1.31 to 1.34 billion m^3 in the different scenarios By 2050, the production of biomass would require 56%-96% of the withdrawals needed for primary energy production. However the scenarios do not agree on the extent of future biomass production and therefore withdrawals would range from 0.62 billion m^3 in the GECO REF scenario (a 53% reduction with respect to 2015), to 1.59 billion m^3 in EUCO32325 (a 21% increase with respect to 2015). According to the literature, virtually all the water withdrawn for biomass production is actually consumed.

Figure 11. Water use for primary energy production

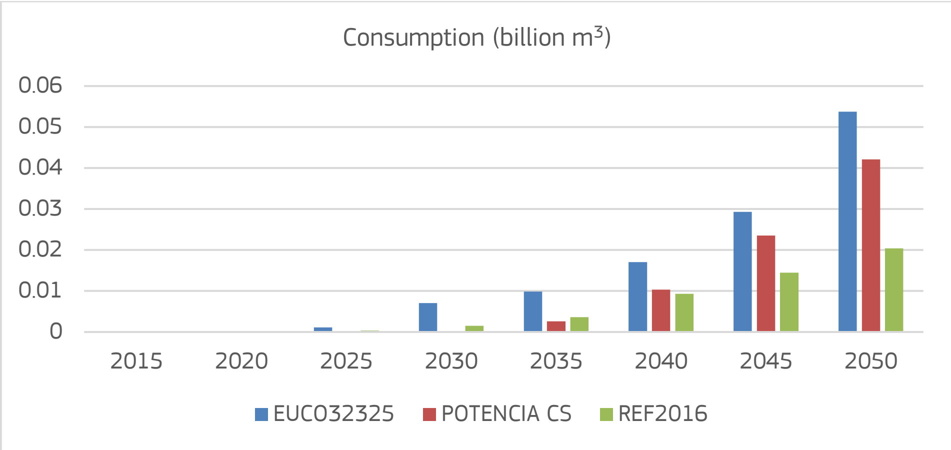


Source: JRC, 2020

4.2 Hydrogen production

Hydrogen is one the main options considered to decarbonise the energy system but only three of the six energy scenarios (REF2016, EUCO32325, and POTENCIA CS) provide detailed figures of the expected hydrogen production. The production of hydrogen requires the use of purified water, which would be accounted as water consumption. The water source could be either desalinated seawater or freshwater. Assuming that all hydrogen is produced from freshwater resources, the water consumption would grow from virtually 0 in 2015 to 0.02-0.05 billion m^3 in 2050 (0.29%-0.75% of the total water consumption of the energy sector).

Figure 12. Water consumption for hydrogen production



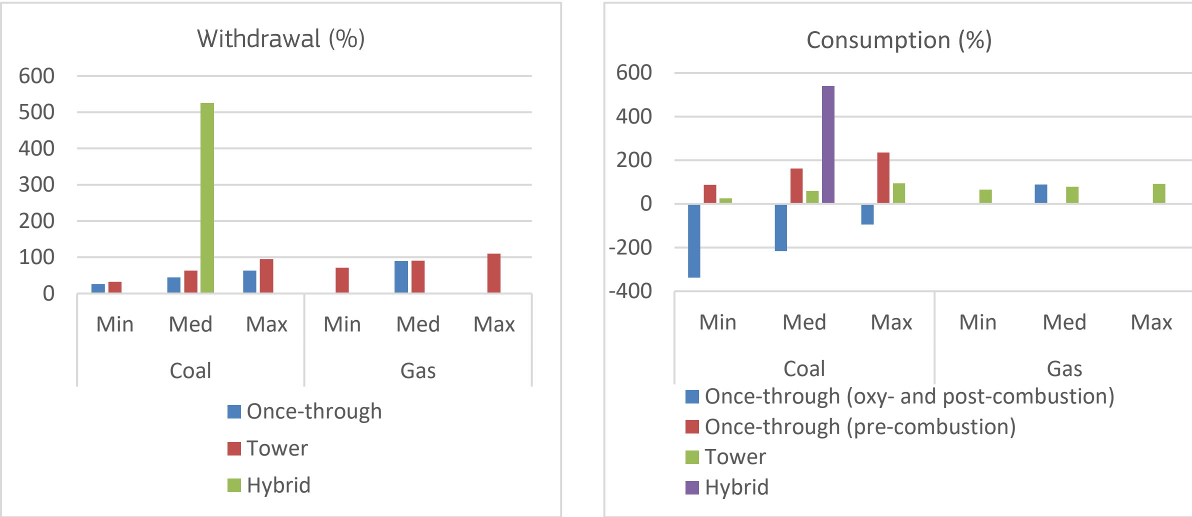
Source: JRC, 2020

The impact of hydrogen production on water resources could be several orders of magnitude higher in scenarios with much more ambitious decarbonisation goals. For instance, in the European Commission Long Term Strategy (European Commission, 2018; European Commission, 2018), hydrogen could account for up to 16-20 % of the total EU energy share, mostly in the residential and transport sectors, and could provide additional solutions for long term energy storage. Supplying the equivalent of 1600-2300 TWh of hydrogen would consume 1.2-1.4 billion m^3 of freshwater, equal to a third of the total water consumed in the energy sector today (Moya et al., 2019).

4.3 Carbon capture and sequestration

Fitting carbon capture and sequestration (CCS) devices in power plants is another technological alternative to decarbonise the energy indutry, but those power plants would use water for cooling, emission scrubbing, and make-up in larger amounts than similar conventional plants (Larsen and Drews, 2019; Magneschi, Zhang, and Munson, 2017; Eldardiry and Habib, 2018). Thus, the large-scale deployment of CCS technologies is expected to significantly introduce additional stress on the sustainability of water systems (Byers et al., 2015). Water use estimates cannot be generalized since they are very dependent on the power plant type, the CO_2 capture technology and the cooling system used. Exception to that are some cases of oxy-combustion and post-combustion in power plants with once-through cooling systems, which may generate water (Kapetaki et al., 2019).

Figure 13. Changes in water needs of CCS-power plants



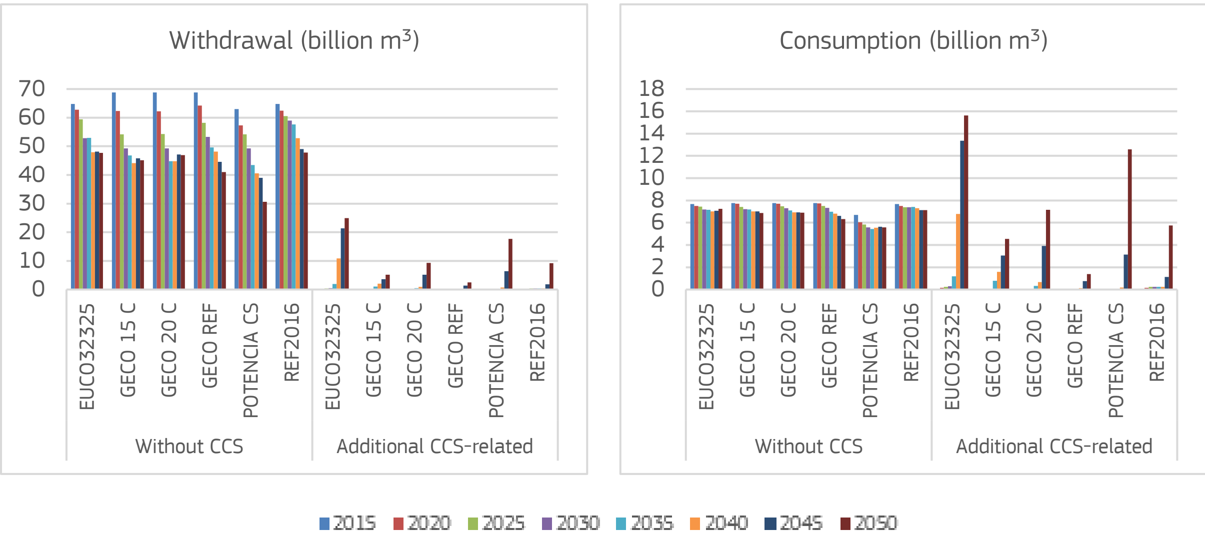
Source: (Kapetaki et al., 2019)

Source: JRC, 2020

In all scenarios CCS starts playing a significant role from 2040 onwards, especially in the EUCO32325 and POTENCIA CS scenarios. By 2050 additional water withdrawal needs for power generation with CCS would be 6% to 58% higher, or 2.5-25 billion m^3, depending of the scenario. The impact on water consumption would be higher, growing by 22%-225% in 2050, or 1.4-16 billion m^3.

In the scenarios considered by the European Commission Long Term Strategy (European Commission, 2018; European Commission, 2018), the role of CCS for power generation in 2050 would be very limited as competitive wind and solar, as well as biogas, hydrogen, batteries and biomass would be available in large quantities. CCS would play a noticeable role by 2050 only in the 1.5TECH scenario, where CCS would reach 5% of the total net electricity generation, while in other scenarios the share of CCS in net electricity generation would be in the range 0.1-0.5%. The additional freshwater needs of the 1.5TECH scenario in 2050 due to CCS would be very similar to those of the REF2016 scenario (withdrawal: 10.5 billion m^3, consumption: 6.6 billion m^3).

Figure 14. Additional water needs due to the use of CCS technologies in power plants



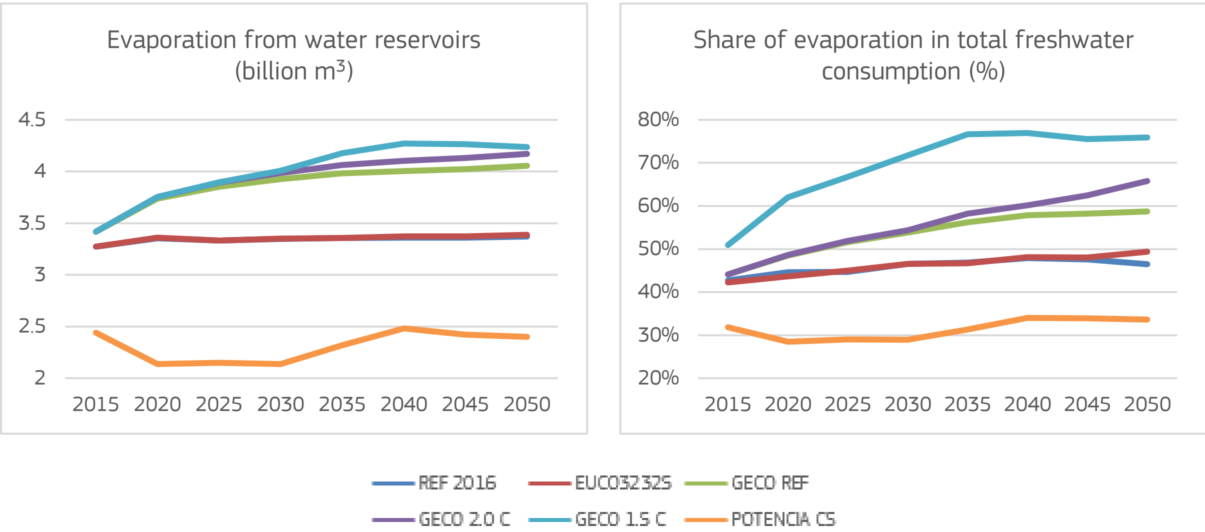
Source: JRC, 2020

4.4 Hydropower

Freshwater resources are also needed for hydropower generation. Water stored in reservoirs is consumed due to evaporation, but reservoirs are usually multipurpose and there is no agreed method neither to estimate total evaporation nor to allocate it to the different uses of the reservoir (energy, irrigation, water supply, etc.) (Vanham, Gawlik, and Bidoglio, 2017) (Bakken, Killingtveit, and Alfredsen, 2017).

Evaporative consumption due to hydropower generation is estimated according to the water factors found in the available literature (Medarac, Magagna, and Hidalgo Gonzalez, 2018; Larsen and Drews, 2019; Vanham et al., 2019). The results ranged between 2.4 and 3.4 billion m^3 in 2015 (32%-51% of the total), similar to the figures found in the scientific literature (Hogeboom, Knook, and Hoekstra, 2018), which allocates total evaporation from water reservoirs to purposes according to their economic value. By 2050 evaporation would be between 2.4 and 4.2 billion m^3 (34%-76% of the total).

Figure 15. Water needs of hydropower production



Source: JRC, 2020

5 Conclusions

During the last years, changes in the availability of freshwater resources due to heatwaves and droughts have affected the operation of the energy system across Europe, in particular reducing the output of power plants during some periods of time. The frequency and the intensity of these episodes are expected to increase in the coming decades due to the effects of climate change. As our energy demand is predicted to increase, scientists see the rising temperatures as a threat to the proper functioning of our energy and water systems and therefore the quantification of the impact of the projected freshwater requirements of the energy sector is key to understand the consequences of the different technological options to decarbonise the European energy system.

This study estimates plausible projections of the long-term freshwater needs of the energy industries (that is, primary energy production and energy transformation in refineries and power plants) in the EU and the UK until 2050, according to six of the energy scenarios used by the European Commission to support different energy and climate policies. It is worth noting that none of these scenarios envisages a fully decarbonised energy system in the EU and the UK by 2050.

The results of this analysis show that the decarbonisation of the energy industry, and the power system in particular, could have a very positive impact on freshwater resources across the EU and the UK, reducing water withdrawal to 31-48 billion m^3 and water consumption to 6-7 billion m^3 in 2050, depending on the scenario).

The overall decrease in the use of freshwater resources across the EU and the UK may conceal problems at lower geographical scales, especially in those areas where water-intensive energy technologies are used until 2050 according to the energy scenarios. The disaggregation of the frehswater projections at national and regional levels allows the identification of the areas where a majority of the scenarios agree in the expected evolution of the pressure on water resources.

At national scale, Germany, France, Spain, Poland, and Bulgaria would account for most of the freshwater needs of the energy system throughout the 2015-2050 period, but while the decarbonisation of the energy system would reduce significantly the water needs of countries like Spain or Belgium, countries such as Hungary or Romania would keep or increase the pressure of water resources.

Most of the regions with withdrawals above 3% of the total (for the EU and UK) in 2015 are mainly areas with significant nuclear and coal-fired power generation capacity and coal mining: FRK2 (Rhône-Alpes), DE11 (Stuttgart), ES43 (Extremadura), ES51 (Cataluña), DEF0 (Schleswig-Holstein), BG31 (Severozapaden), HU23 (Dél-Dunántúl), BE33 (Prov. Liège), DE92 (Hannover), DE12 (Karlsruhe), RO22 (Sud-Est), FRF1 (Alsace), and PL72 (Świętokrzyskie)) will continue using significant amounts of freshwater in 2050. In 2015 only two French regions had freshwater consumption levels above 3% of the total but in 2050 that would occur in eight regions (DE11 (Stuttgart), ES61 (Andalucía), FRB0 (Centre — Val de Loire), ES43 (Extremadura), FRK2 (Rhône-Alpes), FI1D (Pohjois- ja Itä-Suomi), CZ03 (Jihozápad) and SK02 (Západné Slovensko).

This study also quantifies in aggregated terms, due to the lack of information in the energy scenarios over the location of future energy facilities, the impact on freshwater use of the penetration of the most important low-carbon energy sources considered in the energy scenarios. The conclusion of this simplified analysis is that any increment in the use of those energy sources (particularly hydrogen, and CCS) would impact negatively on water resources.

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