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Water resources across Europe - confronting water stress-II

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List of abbreviations

7th EAP	Seventh Environment Action Programme
AWB	Artificial water body
CAP	Common agricultural policy
CCA	Climate change adaptation
CDI	Combined Drought Indicator
CDS	Climate data store
CIS	Common implementation strategy
Climate-ADAPT	The European Adaptation Platform
CLIMATE-KIC	Knowledge and Innovation Communities for Climate
CMEF	Common Monitoring and Evaluation Framework
CMIP	Coupled Model Intercomparison Project
CSI	Core Set of Indicators (EEA's indicators system)
DG ENV	Directorate-General for Environment (European Commission)
DG JRC	Directorate-General - Joint Research Centre
DMP	Drought management plan
DRR	Disaster risk reduction
DSS	Decision Support System
EAFRD	European Agricultural Fund for Rural Development
EAGF	European Agricultural Guarantee Fund
EbA	Ecosystem Based Adaptation
ECA	European Court of Auditors
ECA&D	European Climate Assessment and Dataset
ECMWF	European Centre for Medium-Range Weather Forecasts
ECRINS	European Catchments and Rivers Network System
EDO	European Drought Observatory
EEA	European Environment Agency
EEA38+UK	The 32 member countries, the United Kingdom and 6 cooperating countries of the European Environment Agency
EIP	Water European Innovation Partnership on Water
E-OBS	Daily gridded observational dataset under the ENSEMBLES project
EP	European parliament
EQS	Environmental quality standards
ESTAT/EUROSTAT	Directorate-General of the European Commission responsible for statistical information
ETC/ICM	European Topic Centre on Inland, Coastal and Marine Waters
EU	European Union
EU27	The 27 Member States of the European Union
EU27+UK	The 27 Member States of the European Union plus the United Kingdom
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
FAO	Food and Agriculture Organization of the United Nations
FAO-Adapt	FAO's programme on climate change adaptation
FRBD	Functional River Basin District (ECRINS spatial reference scale)
FRMP	Flood Risk Management Plan
GACSA	Global Alliance for Climate-Smart Agriculture
GAEC	Good Agriculture and Environmental condition
GCM's	Global Circulation Models
GDP	Gross domestic product
GEM	General Equilibrium Models
GFDRR	Global Facility for Disaster Reduction and Recovery
GFS	Global Forecast System

GHG	Greenhouse gases
GHMs	Global Hydrological Models
GOES	Geostationary Operational Environmental Satellite system
GRDC	Global Runoff Data Centre
GVA	Gross value added
GWD	Groundwater Directive
HMWB	Heavily modified water body
IAM	Integrated Assessment Models
IED	Industrial Emissions Directive
INTERREG EU	instrument supporting cooperation across borders through project funding
IPBES	Intergovernmental Science Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
IPCC AR5	IPCC Fifth assessment report
JPI	Joint programming Initiative
JRC	Joint Research Centre
LIFE+	EU's funding instrument for the environment and climate action
LULUCF	Land Use, Land Use Change and Forestry
m.s.l.	Mean sea level
MAES	Mapping and Assessment of Ecosystems and their Services
MS	The EU Member States
NACE	Nomenclature Générale des Activités Économiques dans les Communautés Européennes (EU classification system)
NAP	National adaptation plan
NAS	National adaptation strategy
ND	Nitrates Directive
NGO	Non-governmental organization
NUTS	Nomenclature of Territorial Units for Statistics (Eurostat’s geocode standard)
NWRM	Natural water retention measure
OECD	Organisation for Economic Co-operation and Development
PESETA	Projection of Economic impacts of climate change in Sectors of the European Union based on bottom-up Analysis
PoM	Programme of Measures
RBD	River basin district
RBMP	River basin management plan
RCP	Representative Concentration Pathway
RDP	Rural Development Programme
RWR	Renewable Water Resources
SB	Sub-basin (ECRINS spatial reference scale)
SDG	Sustainable Development Goals
SEEA	UN System of Environmental Economic Accounting
SEEA-CF	UN System of Environmental Economic Accounting – Central Framework
SEEA-W	UN System of Environmental Economic Accounting – Water
SFDRR	Sendai Framework for Disaster Risk Reduction
SNA	UN System of National Accounts
SoE	State of Environment
SPA	Shared Climate Policy Assumptions
SPEI	Standardized Precipitation Evapotranspiration Index
SPI	Standardized Precipitation Index
SSP	Shared Socioeconomic Pathways
TWG	Technical working group
UN	United Nations
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UWWTD	Urban Wastewater Treatment Directive

UWWTP	Urban wastewater treatment plant
WB	Water body
WEFE Nexus	Water, Energy, Food, Ecology Nexus
WEI	Water Exploitation Index
WEI+	Water Exploitation Index Plus
WELF Nexus	Water, Energy, Land, Food Nexus
WF	Water footprint
WFD	Water Framework Directive
WG	Working Group
WISE	Water Information System for Europe
WISE 3	Water Information System of Europe – Water quantity
WS&D	Water Scarcity and Drought
WSI	Water scarcity index

Glossary

Summary overview schema

Duration or frequency of water stress	Causes of water stress					
	volumetric water availability is lower than long-term average		water demand exceeds the exploitable available water			
	natural	anthropogenic	anthropogenic			
	due to meteorological conditions	due to changing climate conditions	volumetric water demand for environmental flows not fully met	volumetric water demand of socio-economic sectors not fully met	water quality requirements of socio-economic sectors not fully met	accessibility is a limiting factor for socio-economic use
Temporary or incidentally	Drought		Water shortage			
Mid-term or frequent	Drought / Aridity		Water scarcity			
Long-term or permanent	Aridity / Desertification		Desertification			

Terms used in this report for different types of water stress situations, as determined by their primary causes and their duration/frequency.

Drought

A drought refers to a temporary water shortage which starts with reduced levels of precipitation compared to normal (meteorological drought). A drought may then propagate to reduced levels of soil moisture on agricultural land (agricultural drought), reduced levels of natural water flows to surface and groundwater (hydrological drought), and reduced capacity of water resources systems to supply adequate water to water users to meet their normal demands, thus causing losses and damages to socio-economic activities (socio-economic drought). The propagation from one stage to the other is not immediate. There are different lag times before the next stage happens and the capacity to mitigate the propagation depends on the preparedness of each society and the sophistication of its water technology. The duration of droughts may also vary from shorter to prolonged periods of droughts.

Water scarcity

Water scarcity occurs when the water demand for human needs frequently (though not necessarily year-round) exceeds the supply capacity of the natural system in river basins. Water scarcity is the

	consequence of anthropogenic impacts on the availability of water resources. Combination of water scarcity and drought occurrence in river basins exacerbates the impacts of water scarcity not only on ecosystem conditions but also on the maintenance and development of socio-economic life.
Water shortage	Water shortage occurs when the water demand for human needs exceeds the supply capacity of the natural system in river basins. When this happens frequently the term water scarcity is used.
Water stress	Water stress refers to the ability, or lack thereof, to meet human and ecological demand for water. Compared to scarcity and shortage, water stress is a more inclusive and broader concept. It considers water scarcity, but also water quality, environmental flows, and the accessibility of water(Schulte, 2020).
Water consumption	The water that is captured by the plants and exploited in plant processes for generating biomass and the drinking water being absorbed by humans and animals.
Water supply	Delivery of water to final users including abstraction for own final use (EC 2015).
Water use	Water that is used by the end users for a specific purpose, such as for domestic use, irrigation or industrial processing. This is usually the basis for paying fees. Returned water (at the same place and in the same time period) and recycling is excluded. (EC 2015)

Key messages

What is the current problem?

- Water stress occurs on 20 % of the EU territory and affects 30 % of the EU population on average per year, impacting environment, society and economy.
- The milestone set in the 2011 EU resource efficiency roadmap — by 2020, water abstraction should stay below 20 % of available water in Europe — has not been reached in 19 % of EU's territory in 2017.
- Despite the publication of the EU's Communication on water scarcity and drought in 2007 and the Blueprint to Safeguard Europe's Water Resources in 2012, EU policy on water scarcity and drought remains scattered and implementation has been slow.

How will this problem develop over the coming decades?

- Water stress in Europe varies depending on location. Southern Europe faces persistent or aggravated water stress problems throughout the year. In other parts of Europe water stress is not permanent, but tends to increase in frequency, magnitude and impact.
- Water stress shows a tendency to concentrate in three types of areas: urban areas, irrigated agricultural areas, and coastal areas with intense tourism. The latter two are mainly found in, but not restricted to, southern Europe.
- A positive trend is that water use efficiency is increasing in Europe: water abstractions in the EU27+UK in 2017 have decreased by 24 % since 2000, while in the same period the gross value added has increased by 52 %.

Which actions are required?

- Renewed or continued efforts must be made by EU Member States to develop Drought Management Plans (DMPs), based on long-term strategies for pro-active water management, and making the transition from crisis management to risk management.
- The data collection and information flows must be further refined and tailored to the spatial and temporal scale at which water stress makes itself felt, capitalizing on the results of current innovation programmes and lessons learned in sectors where decoupling is already being accomplished, such as the manufacturing sector. Based on this, a renewed analysis of the future water stress at EU scale is called for.
- A key factor contributing to the effectiveness of the EU water directives in progressing towards their objectives are the (binding) cross-references to the Water Framework Directive's objectives in other EU policies. Sectoral policy interventions must not only work in synergy with water policies but also actively support them.
- Impacts of water stress are felt at local and regional scale, while the drivers act from regional to global scale. Connection of these levels of analysis requires operationalised nexus approaches and systemic thinking. A practical first step is to foster projects with ecosystem service approaches and nature-based solutions in drought management, because these approaches inherently accommodate such thinking.

Executive Summary

Water stress in Europe

Water stress occurs when there is not sufficient water available to meet the demands of the environment and of the water-dependent socio-economic functions, in terms of quantity or quality. Water stress is a general term combining drought, quantitative scarcity, water quality and water accessibility. Drought reflects the shortage of water due to short or long-term precipitation deficits, while water stress is a combined effect of drought and socio-economic pressures. Water stress occurs when the water demand is higher than the availability of water in the environment.

There is a vast amount of fresh water on the planet, but it is not evenly distributed in space and time. In many areas short term abundance of water causes floods during parts of the year, while in other parts droughts may occur at the same location. Lack of water in other areas may result in desertification. Climate change is exacerbating the frequency, magnitude and geographical expanse of such events. In some cases, floods and droughts are experienced in the same area, due to increasing variability of hydro-climate conditions as result of the climate change impacts.

Since decades, many areas on the planet have been suffering from the climate change impacts in different forms of the droughts and water scarcity. In some places water stress is experienced due to changing climate conditions, whereas in other areas simply society could not access to good quality of sufficient water because of socio-economic shortages.

Droughts and water scarcity were not perceived as a Europe-wide problem until the early 2000s. It was regarded as a problem only occurs in southern Europe due to regional climate conditions. However, the improving information and data shows that droughts and water scarcity are no longer rarely experienced extreme events in Europe. Frequency and the area affected by either droughts or water scarcity are increasing and continuously expanding towards to central and western Europe as well as to those areas important for industry, electricity production and cities hosting millions of inhabitants. Today, on average, every year around 20 % of European territory and 30 % of total population is affected by water scarcity conditions (EEA, 2018b).

Water stress has already become a limiting factor on human well-being in general, socio-economic life and ecosystems in Europe not only because of shortage in the volume of water available, but also due to deterioration of the water quality. Polluted water can’t be used for certain economic sectors e.g. for drinking.

Water stress causes several adverse effects on the environment such as decreasing groundwater levels, salt-water intrusion, lowering river discharges and loss of wetlands.

Water stress, overall, is a local or regional issue limited where it occurs. But drivers causing water stress are usually a combination of geographically wider factors such as climate change, tourism, food production and consumption chains, electricity production and population density. This cross-cutting nature of the water stress issue calls for coordinated actions among different policy areas.

This report aims to update our knowledge on water stress in the European context to inform policy makers and interested stakeholders in regard to the current state of the art; and to present arguments for shifting from crise management to risk management by giving more emphasis on demand-side measures. The effectiveness of the implementation the policy measures for increasing the resilience of European ecosystems needs to be improved and more efficiency of socio-economy in order to prevent ourselves and our ecosystems from the unpredictable consequences of droughts and water scarcity. As pointed out in the SOER 2020 (EEA, 2019j) the tipping point for this transition has already been reached.

Policy context

The EU Water Framework Directive (WFD) established a legal framework at the EU level targeting to prevent the further deterioration and achieve "good status" for all water bodies in Europe, taking into account the water needs of aquatic ecosystems, and promoting sustainable water use. The WFD supports integrated water management; and sets provisions to improve efficiency of water use and water services. Through specific provisions laid out in its Article 1, the WFD creates a flexible and suitable frame for action against water stress, underscoring the relation between water quantity, water quality and ecological status.

Since 2000, overall, water use efficiency has improved and resulted in decreasing total water abstraction in Europe. However, issue of water stress continues escalating. Climate change drives seasonal variations in water availability. At the same time, water demand is increasing for sectors such as agriculture in certain periods of the year e.g. increasing irrigation demand in spring and summer, when water availability is at its lowest level, particularly in southern Europe. This causes increasing competition for water among the economic sectors, often pushing users to shift from surface to groundwater resources and ultimately exerting pressure on water bodies and the ecosystems depending on them.

In order to properly respond to various aspects of water stress from the supply and demand side of water resources management, in 2007 the EU adopted a Communication on water scarcity and drought in an effort to bring clarity on policy priorities on how to tackle water stress. Implementation of the Communication was reviewed in several stages and in 2012 the Blueprint to Safeguard Europe's Water Resources was published. Along with the policy provisions put forward by these two strategic documents, the EU resource efficiency roadmap, the CAP and the 7th Environmental Action Program also provided a number of policy mechanisms aiming to protect and enhance European natural capital and water resources.

The implementation of those policies has resulted in some positive developments e.g. decreasing the total water abstraction at the European level. Nevertheless, policies addressing water stress remain scattered and overall progress has been slow. Building on a paradigm shift that originated in the 1980s, EU water scarcity and drought policy activated a transition from crisis management to proactive risk management approaches. Yet, this transition has been mostly a conceptual one, as in its implementation, the change of paradigm exposed a lack of institutional capacity across many Member States. So far, not in all river basins could water abstraction be reduced below 20 % of total water availability.

Today, some Member States develop and implement flood risk management plans and drought management plans complementary to the river basin management plans under the EU WFD and Floods Directive. Nevertheless, the effectiveness of the implementation of these plans remain questionable.

The WFD recognizes the crosscutting character of water as a vital resource for social, environmental and economic systems, which places water policy in the middle of developments in other policy areas. Similarly, the 2030 Agenda for Sustainable Development has pointed to the need for systemic change that permeates recent EU policy, highlighting the importance of collaboration and policy integration and coherence. Concretely in this regard, SDG 6.5 promotes integrated water management and SDG 6.4 highlights the need to increase water use efficiency across all sectors and decoupling economic growth and water use. In this context, several new policy initiatives in Europe are at the eve of being implemented. The European Green Deal sets ambitious targets and objectives -among others- to protect, conserve and enhance the EU's natural capital. The new Circular Economy Action Plan explicitly appeals to *water stress* and includes provisions for *improving resource efficiency* in the context of water resources management. Similarly, the EU Biodiversity Strategy 2030 acknowledges the importance of *natural capital to industry and agriculture* and sets quantitative targets for ecosystem restoration including 25 000 km of free-flowing rivers. The new Climate Change Law, Sustainable Finance, Farm to Fork Strategy, the new CAP Pillar II and the 8th Environmental Action Program -among many others- appeal to increasing resource efficiency, protecting the natural capital and improving the human well-being by means of transitioning the European economy to be more sustainable by 2030-2050.

In the context of water stress, all these policy provisions and initiatives require strong coordination and collaboration at the implementation phase across sectors and ecosystems. So far, a major gap to achieve more effective implementation was the lack of adequate institutional frameworks and capacity to promote coordinated, cross-sectoral action and measure progress in tackling water stress. The European Green Deal and the upcoming new EU Strategy on Adaptation to Climate Change represent fresh opportunities to integrate water stress and drought policy objectives into other areas, increase coherence and propel implementation.

Renewable freshwater resources under a changing climate

Climate change is a major factor influencing the availability of renewable freshwater resources. The last decades recorded a series of the hottest and driest years over the last centuries and the annual average temperature for Europe has already increased 1.6 to 1.7 °C above the pre-industrial level (EEA, 2018b). Temperature rise increases potential and actual evapotranspiration, causes more frequent extreme drought occurrences, intensifies heavy precipitation, attenuates snowpack build-up and triggers early snow melting. These effects have led to a decrease of the annual precipitation in parts of southern Europe (EEA, 2020c), which, combined with increasing actual evapotranspiration, leads to increasing water stress. In contrast, in north-eastern and northern Europe, precipitation and intensity of heavy precipitation in winter and summer increases (EEA, 2020c). Decreasing snowpack on the Alps and Carpathians and earlier snow melting in lower attitudes of the Alps are already observable, while recent summer droughts have struck areas reaching up to the Arctic circle.

Monitoring indicates considerable shifts are already occurring in the frequency and the temporal and spatial distribution of precipitation in many parts of Europe. The consequences of these shifts are observable in decreasing river discharges in the south and an increase in the north(EEA, 2016g).

Water demand for environment and economy

The population of European urban centres increases further, while the population in rural areas decreases. This leads to the development of more peri-urban land to meet the additional needs for residence and work space. Moreover, tourism in Europe has reached record-levels over the last decade and this has resulted in rapid land conversion for the development of touristic facilities and supporting transport infrastructure. Urban sprawl accelerates in coastal areas, which are also vulnerable to future sea level rise. The expansion of impervious areas and land sealing increases the risks of urban floods and drains away water that could otherwise recharge local aquifers.

Every year about 230 000 million m^3 of freshwater corresponding to 13 % of the available water is abstracted in Europe for socio-economic purposes. Agriculture (58 %), cooling water for electricity production (18 %), mining, quarrying, construction and manufacturing (11 %) and public water supply (10 %) are the major water users.

After use, treated or untreated water is returned to the environment. The difference between water abstraction and return is regarded as water consumption (water use). The average return ratio of water by cooling is around 80 %[1], while agriculture returns around 30 % of total water abstraction back to the environment.

In many European basins, water is either over-abstracted with insufficient water left for environmental needs or returned with high pollution. Only three EU Member States (Cyprus, Hungary and the Netherlands) implemented ecological flows in all RBDs in 2016, whereas France implemented the ecological flows in 2 RBDs (EC, 2019b). In 2015, 58 % of river water bodies did not achieve good ecological status, for which water abstraction (8 %) has been reported as one of the main pressures and groundwater levels have already lowered in some of the EU Member States (Kristensen et al., 2018). Groundwater is often seen as cheap buffer resources, which can be used to supply high quality drinking water, especially when local surface waters are not suitable for exploitation or at times of water stress. Insufficient legal enforcement and incomplete tariff systems in the agricultural sector are still responsible for unauthorised water abstractions, over-exploitation of groundwater, which leads to saline intrusion in coastal aquifers. Meanwhile, around 84 % of freshwater habitats in Europe was found in unfavorable conditions according to the EU habitats directive assessment in 2015 (EEA, 2020b).

The EU27+UK has made substantial progress and has decreased water abstraction by 24 % in 2017 compared to the level of 2000, while in the same period its Gross Value Added (GVA) has increased by 52 %. Although the volumetric pressure on renewable freshwater resources has started to decline, significant improvements are not yet visible in the quantitative status of water bodies, partly because recovery can be a slow environmental process, and also because climate change and socio-economic development can offset volumetric gains and aggravate local pressures. The milestone set in the EU resource efficiency roadmap — i.e. water abstraction should stay below 20 % of available water resources in Europe — has not been achieved yet in 19 RBDs according to the estimate in 2015. According to estimations, 20 % of territory and 33% of permanent population were affected by water stress conditions in the summer of 2015, with water abstraction exceeding 20% of available water resources (EEA, 2018b).

There is a significant water saving potential across all economic sectors, but large investments are needed to unlock it. Monitoring, metering and authorisation of water abstractions and understanding of environmental interactions in river basins has progressed overall. Environmental flow requirements (e-flows) are better defined than they were, even though still not to a satisfactory level. Enforcement has improved; yet, there is a long distance to cover until full implementation of WFD requirements regarding e-flows across all EU water bodies. Leakages in the conveyance systems are still higher than 25% of total water supply in many eastern and southern European countries(EC, 2013b). Furthermore, attention is needed to avoid rebound effects.

As local water resources are getting more stressed or depleted, urbanisation also causes higher demand, which is often met by the implementation of storage and water transfer projects. Such projects have significant impacts on hydromorphology and environmental concerns have led to stricter permitting procedures.

[1] However, it is responsible for thermal pollution and risks for hypoxia due to its heat load

Promising approaches and measures

The analysis of the future gap between water availability and water demand points to increasing impact of the water stress issue in southern Europe, and in some parts of the other regions of Europe. This finding is consistent with earlier studies (JRC, 2020b).

Increasing water demand of socio-economic activities under a changing climate forces Member States to explore additional measures for water supply and water demand. Innovative approaches to supply water using non-conventional resources (e.g. desalination, water reuse, rainwater harvesting) are already implemented in many Member States.

The EU is dedicated to innovation as a means to tackle future challenges giving particular focus on better monitoring of the earth and its climate; better data management; better socio-environmental modelling; improvements in hydrological and drought forecasting; better technologies for increasing technical water efficiency; better tools for controlling water demand; and better technologies for enabling and promoting alternative water sources.

For the analysis of water stress related issues, the water-energy-land-food nexus (WELF nexus) provides a holistic conceptual framework. Adopting this approach leads to the acknowledgement that the nature of water, energy, land and food systems is interdependent. This facilitates the identification of synergies and trade-offs between these resources, i.e. additional benefits from simultaneous management of both resources or necessary sacrifices to one resource to gain the benefits from the other resource (Psomas et al., 2018; Ringler et al., 2013).

The application of nature-based solutions needs to be explored further. While the number of specific options for water stress is limited, the associated approach and stakeholder involvement offer a way forward for integrative solutions to complex problems. Natural water retention measures and aquifer recharge are promising options, but to be effective they must be implemented at sufficient scale. This requires precise assessments (models) and co-ordination.

Needs for integrated policy responses

Mainstreaming water considerations into other environmental and sectoral policies and finding synergies across them are key to enabling sustainable water management and reducing society's exposure and vulnerability to water stress. The recent WFD fitness check has highlighted that one of the key factors contributing to the effectiveness of the EU water directives in progressing towards their objectives were the (binding) cross-references to the WFD's objectives in other EU policies.

The recent adoption of the Water Reuse Regulation is a good example of integrated thinking. The new CAP programming cycle for 2021-2030 provides fresh opportunity to integrate more ambitious environmental safeguards that acknowledge local water resource limitations and scarcity situations.

The new Farm-to-Fork Strategy illustrates how the Green Deal aims to support integrated and systemic thinking, and promote more sustainable food systems. Such systemic thinking to reduce Europe's vulnerability to water stress still has to permeate policies of other economic sectors such as energy and industry, although some safeguards already exist.

Several EU initiatives support the use of nature-based solutions to enhance Europe's vulnerability to water stress and risk of droughts. The EU Adaptation Strategy 2013 (EC, 2013a), to be updated soon, recognises the importance of integrated solutions to tackle water stress, by scaling up environmental mainstreaming in sectoral policies and climate-proofing investments, and by improving the protection and restoration of European ecosystems. However, recent assessments indicate that synergies between water stress policies and climate change adaptation strategies are not fully exploited at Member State and river basin levels (EC, 2019e).

1. Introduction

1.1. Setting the scene

Water is vital for the three pillars of Europe's sustainable growth: its society, its economy and its environment. All three depend on the adequate availability and supply of water of sufficient quality at the right time and in the right location.

As it is, in many parts of Europe, a mismatch has evolved between the demand for water and the volume of available water, resulting in water stress. This report addresses the existing and future water stress conditions and risks in Europe, their impacts on the environment, society and economy, and the perspectives for action that are open for exploration.

Box 1.1 Terms related to water stress

Water stress is the general term used in this report for the situation where the available water does not cover the local demand (including environmental demand). Water stress can be caused by a volumetric shortage, by insufficient water quality, by droughts or by insufficient accessibility. See the Glossary for further explanation.

In southern Europe and in densely populated areas across the EU water stress is a permanent, year-round problem. In other parts water stress occurs only temporarily or even incidentally. This is a result of the varying water availability and demand in time, with meteorological conditions (average seasonal and year-to-year variability, extreme events in the form of droughts) and with economic activities.

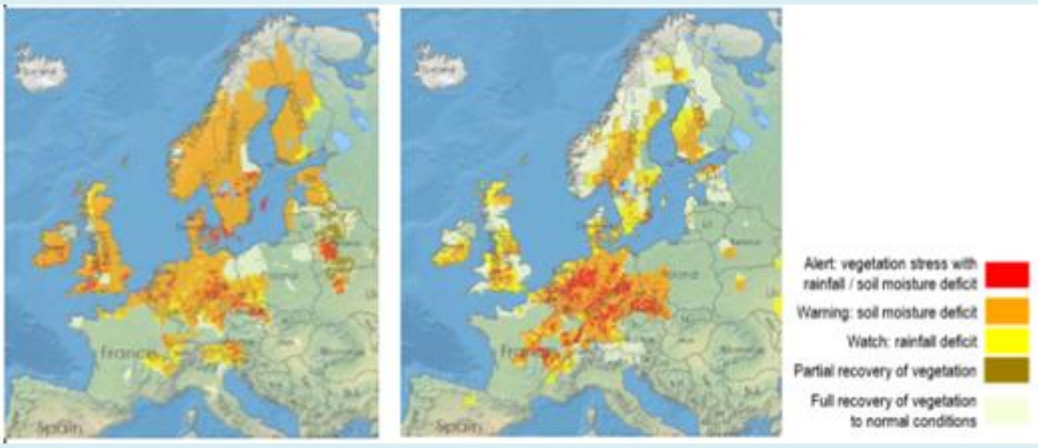
When water stress occurs structurally or frequently, the term 'water scarcity' is used. In water stressed regions the environment usually suffers first (from low river flows or low groundwater levels), but economic sectors may also experience shortages, at least during parts of the year.

The term used for conditions of irregular or incidental water stress is water shortage. Droughts and water shortages hit hitherto unexpected locations, as occurred in Western and Northern Europe in 2018 (Box 1.2). Some more recent drought events in areas which are normally not perceived as prone to droughts are the Arctic circle and Siberia in 2020 and 2019, the Elbe river basin in summer of 2015 and the Black Sea area in 2007.

Box 1.2 The drought of 2018 in Central and Northern Europe

During the spring and summer of 2018, central and northern Europe experienced severe drought conditions, a combination of exceptionally warm temperatures and low precipitation (Map 1.1). Indeed, many Member States in these areas recorded one of their three hottest and driest summers, ever. In contrast, southern Europe and particularly the Iberian Peninsula recorded a wetter than usual spring and summer (Eurostat, 2019b).

Map 1.1 The Combined Drought Indicator (CDI) for the last dekad of July 2018 (left) and the second dekad of September 2018 (right)



Source: (JRC, 2020a)

The 2018 drought has impacted farmers throughout Northern Europe. The 2018 yields of cereals, potatoes and sugar beets, crops in which northern European countries have a large share, showed a marked decline compared to 2017. Drought also heavily affected pasture (generally not irrigated) with detrimental effects on the livestock/dairy sector.

The drought also had severe impacts on other socioeconomic sectors (Toreti et al., 2019; Harris, 2018), for example, higher than usual death rates among elderly people, difficulties in power plant cooling, stability issues in the Dutch dike system due to lack of freshwater, extremely low river levels with negative impact on the transport sector industries dependent on water way transport and forest fires.

According to the estimation of the water exploitation index (WEI+)[2] about 13 % of the European territory suffers from all year round water stress conditions, and at least 120 million people are affected permanently by significant water stress in these areas. Assessments in this report underlines that the seasonal and structural water stress might be exacerbated in the future as well.

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[2] WEI+: the Water Exploitation Index Plus. The WEI+ is defined as the total water net consumption (abstractions minus returns) divided by the freshwater resources of a region, including upstream inflowing water. WEI+ values have a range between 0 and 1. Values below 0.1 denote “low water stress”, values between 0.1 and 0.2 denote “moderate water stress”, “water stress” when this ratio is larger than 0.2, and “severe water stress” if the ratio exceeds 0.4 (Feargemann, 2012).

Further information on the current state and future projections on water stress in Europe is provided in Chapter 5 of this report.

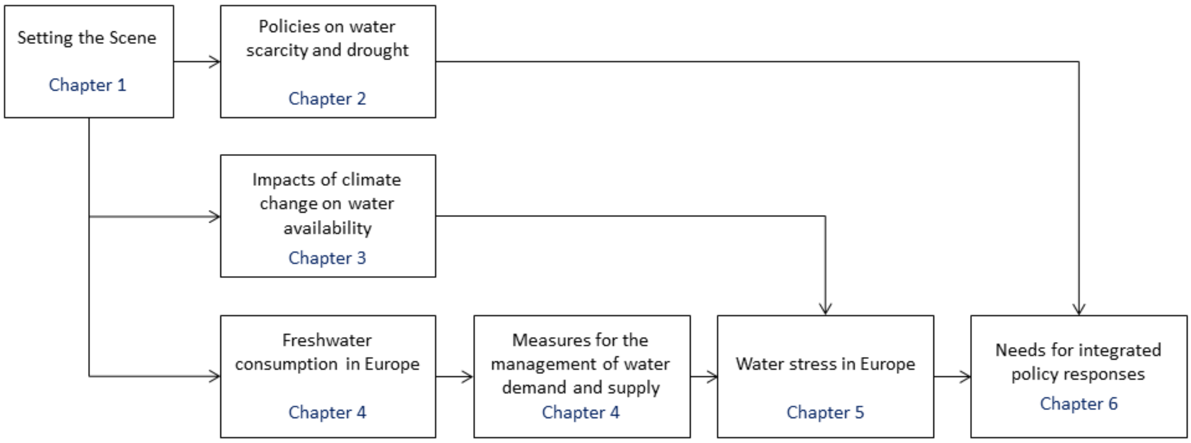
1.2. Scope and outline of the report

The overall aim of this report is, in accordance with Article 1 of the Water Framework Directive (WFD), to promote sustainable water use based on a long-term protection of available water resources. The report overall addresses to the trends in water availability, water abstractions and water use efficiency, including their impacts on the environment and on the main water-dependent economic sectors (agriculture, electricity production, manufacturing and domestic water supply). The report also explores the decoupling[3] of sectorial water abstraction from growth, future water availability and water demand, and evaluates the potential of current responses to water stress.

The DPSIR (Drivers-Pressures-State-Impact-Responses) framework has been followed as analytical framework in developing the report. Hence, the analytical framework followed in this report starts from climate change and socio-economic development as key drivers for water availability and water demand. An overview of water stress related EU policy responses is included in this report. Measures and policy responses can seize on any of the DPSIR steps. This is illustrated in a detailed schema in Section 4.10.

This report has been built on 6 different chapters in line with the DPSIR framework to address various aspects of the water stress issues, impacts of multi-drivers on European water resources and EU policy responses (Figure 1.1)

Figure 1.1 Structure of the report



Chapter 2 describes the European policy context, i.e. the policies implemented in the field of water scarcity and drought management, sectoral and environmental policies with a link to water use or

[3] Decoupling refers to the ability to sustain economic growth while reducing the amount of resources such as water or fossil fuels used, delinking environmental deterioration at the same time.

management, and cross-cutting integrative policies. It also highlights some links between the European policy landscape and recent global policy developments.

Chapter 3 presents climate change as the first of the two key drivers of water stress. The chapter addresses the meteorological parameters that have an impact on droughts and water availability and then illustrates how these are reflected in the stages of the hydrological cycle. The focus is given on precipitation and evapotranspiration patterns as determinants of water availability, and on the frequency and intensity of droughts. A drought starts with reduced levels of precipitation compared to normal. From there, a drought may propagate through the hydrological cycle and from there impact the environment and the economy. The time horizon varies around 2050-2100.

Chapter 4 starts off with the current state of water abstractions. It then highlights how water abstractions are guided by socio-economic developments, including land-use changes. The chapter gives an overview of how water is abstracted and used in the major water-dependent economic sectors: energy, agriculture, households, tourism and industry, and for the environment. The socio-economic development at large determines how the economic water-dependent sectors are developing, as a result of such underlying trends as population growth, technological innovations, and market relations from local to global levels. The key issue in this report is, how this will eventually affect the water demand of the sectors. The chapter concludes with an overview of existing policies and measures.

Chapter 5 provides a consolidated overview on the findings of Chapters 3 and 4 to sketch the future trend in water stress.

Chapter 6 Ways of dealing with the future water stress include innovative technologies, policy responses, nexus approaches and nature-based solutions. These options are introduced and their relevance for water stress management is explored. The chapter concludes with an outlook.

Chapter 7 presents the main conclusions of this report.

Primary stakeholders

Traditionally water stress concerns water users and water managers as they are the principal stakeholders. First at local to regional level, then at national level, and since the publication of the EU Communication on Water Scarcity & Drought in 2007 explicitly at EU level. In parallel, the diversity of the audience increases. Water stress and its expected adverse economic consequences increasingly draw the attention of the financing world and insurance companies (EEA, 2019c). The World Economic Forum has listed ‘extreme weather’ in its top-5 of risks with the highest likelihood since 2014, and in its top-5 of risks with the highest impact since 2017. The urgency and magnitude of the challenge is also stated in a recent World Bank report (World Bank, 2016) which, amongst others, indicates that water scarcity could cost some regions up to 6 % of their Gross Domestic Product (GDP). The adverse impacts of water abstractions on the environment have driven water stress and drought issues up the priority list of societal organisations such as Right2Water Citizen Initiative (Anonymous, 2020) and of nature protection NGOs such as the WWF and IUCN (Trémolet S. et al., 2019), while scarcity risk is addressed in the year plans of multinational companies such as Intel (Aquatech, 2019), Coca-Cola and Unilever. The Water Footprint Assessment has played an important role in raising awareness of the implicit role of water in global production and trade. Several networks of private enterprises (such as the WBCSD, the Carbon Initiative, Beverage Industry Environmental Roundtable (BIER)) have made steps to incorporate water as part of the scope of their corporate social responsibility (CSR) initiatives, as does the European Water Stewardship scheme. All this goes to demonstrate that water stress is no longer the sole concern of water managing authorities and direct water users. The 'newly involved' stakeholders can have a crucial role in the design and implementation of nature-based solutions, as illustrated in the NAIAD project (Section 6.4).

1.3. Relevance to the EEA activities

This report builds on a long chain of earlier EEA assessments and reports. A prominent predecessor is the 2009 report on Water resources across Europe — confronting water scarcity and drought (EEA, 2009). The current report is the updated version of 2009 report, hence, titled Water resources across Europe — confronting water scarcity and drought-II. Compared to 2009 report, the current report adds recent data, an update of determining trends and of the cross-links with adjacent sectors and disciplines, updates of policies and measures, and proposals for solutions.

Among many others, the following reports have been used as inputs in developing this report: *Effectiveness of urban wastewater treatment policies in selected countries: an EEA pilot study* (EEA, 2005), *Towards the efficient use of water resources in Europe* (EEA, 2012a), *Water resources in Europe in the context of vulnerability* (EEA, 2012b) , *Assessment of cost recovery through water pricing Economic instruments* (EEA, 2013a), *National adaptation policy processes in European countries – 2014* (EEA, 2014)*, Water-retention potential of Europe's forests: a European overview to support natural water retention measures* (EEA, 2015), *Public participation, contributing to better water management: experiences from eight case studies across Europe*(EEA et al., 2014), *Climate change adaptation and disaster risk reduction in Europe -Enhancing coherence of the knowledge base, policies and practices* (EEA, 2017a)*, Water management in Europe: price and non-price approaches to water conservation* (EEA, 2017g), *European waters- Assessment of status and pressures* (Kristensen et al., 2018), *Landscapes in transition-An account of 25 years of land cover change in Europe* (EEA, 2017e), *Industrial waste water treatment: pressures on Europe's environment* (EEA, 2019d)*, Climate change adaptation in the agriculture sector in Europe*(EEA, 2019a), *State of nature in the EU* (EEA, 2020f) and finally *The European environment: state and outlook 2020 : knowledge for transition to a sustainable Europe (EEA, 2019j)* presents a comprehensive analysis of the above elements and opens perspectives towards a systems approach.

Over the past years the EEA has put a large effort into the organisation and collection of data for the development of water accounts and indicators supporting the assessment of the state of European waters (EEA, 2019l). Furthermore two important reports have been published by European Topic Centre of Marine and Inland Waters on the establishment of water accounts (ETC/ICM, 2016; Zal et al., 2017). This report makes ample use of the results of that effort, most notably the Core Set of Indictors (CSI) on Water and Climate change [(4)].

Along with the above-mentioned reports, assessment from a number of the EEA water, climate, land and biodiversity related indicators have been intensively used in relevant chapters which have been referenced throughout the report. Databases of State of Environment, EEA dashboards on various

[4] All EEA indicators can be seen on: https://www.eea.europa.eu/data-and-maps/indicators/#c0=30&c12-operator=or&b_start=0

topics (EEA, 2018c, 2019i) and Eurostat database have also provided facility for quantified assessment on status and pressures around the European water resources.

2. Policies on water scarcity and drought

Key messages

- Globally, as well as in Europe, policy instruments, measures and strategies being devised to address water stress are transiting from crisis management to proactive risk management approaches.

- The WFD provides a flexible and suitable frame for action against water scarcity and drought, underscoring the relation between water quantity, water quality and ecological status.

- Despite the publication of the EU's Communication on water scarcity and drought in 2007 and the Blueprint to Safeguard Europe's Water Resources in 2012, EU policy on water scarcity and drought remains scattered and implementation has been slow.

- In the second RBMPs, sixteen Member States reported that water abstraction is a significant pressure for their surface water or groundwater at least in some parts of their national territory. However, only eight Member States reported DMPs as accompanying documents to all or part of their RBMPs whereas only three Member States developed ecological flows in all water bodies.

- The European Green Deal, the new Circular Economy Action Plan and the upcoming new EU Strategy on Adaptation to Climate Change represent fresh opportunities to integrate water stress and drought policy objectives into other areas, increase coherence and proper implementation.

2.1. Context: water scarcity and drought in EU water policy

Water stands amongst the oldest and most advanced policy areas in the EU *environmental acquis* (Josefsson, 2012; Giakoumis and Voulvoulis, 2018). Since 2000, the EU Water Framework Directive – WFD (2000/60/EC) is Europe's flagship legislation on water, under which the wide variety of EU regulatory instruments, strategies and policy mechanisms that have emerged and evolved over decades are coordinated. Under the WFD, the EU has set an overall aim to "ensure access to good quality water in sufficient quantity for all Europeans, and to ensure the good status of all water bodies across Europe" (EC, 2000). Article 1 of the WFD requires the Member States to "promote the sustainable use of water resources based on the long-term protection of available water resources" and "ensure a balance between abstraction and recharge of groundwater, with the aim of achieving good status of groundwater bodies". Through these requirements the WFD sets the basis for action against water stress and drought, and it underscores the relation between water quantity, water quality and ecological status. The Fitness Check of EU Water Legislation also concluded that the WFD provides a flexible and suitable frame for the planning and management of drought risk and the impacts of water scarcity events (EC, 2019f).

The management of water stress across Europe has traditionally focused on supply-side measures, while drought management has been characterized by crisis management measures. Driven by shifts in the study of vulnerability and risk that originated in the 1980s (Vargas and Paneque, 2017), and underpinned by global developments like the Yokohama Strategy for a Safer World (UN, 1994) and its successors, the last three decades have increasingly seen the adoption of strategies that shift the focus more on water demand management. In addition, there is increased emphasis on the need for a more proactive risk management approach against droughts, calling for a drought management approach articulated around the aspects of preparedness, crisis management and resilience building.

Box 2.1 Important terms

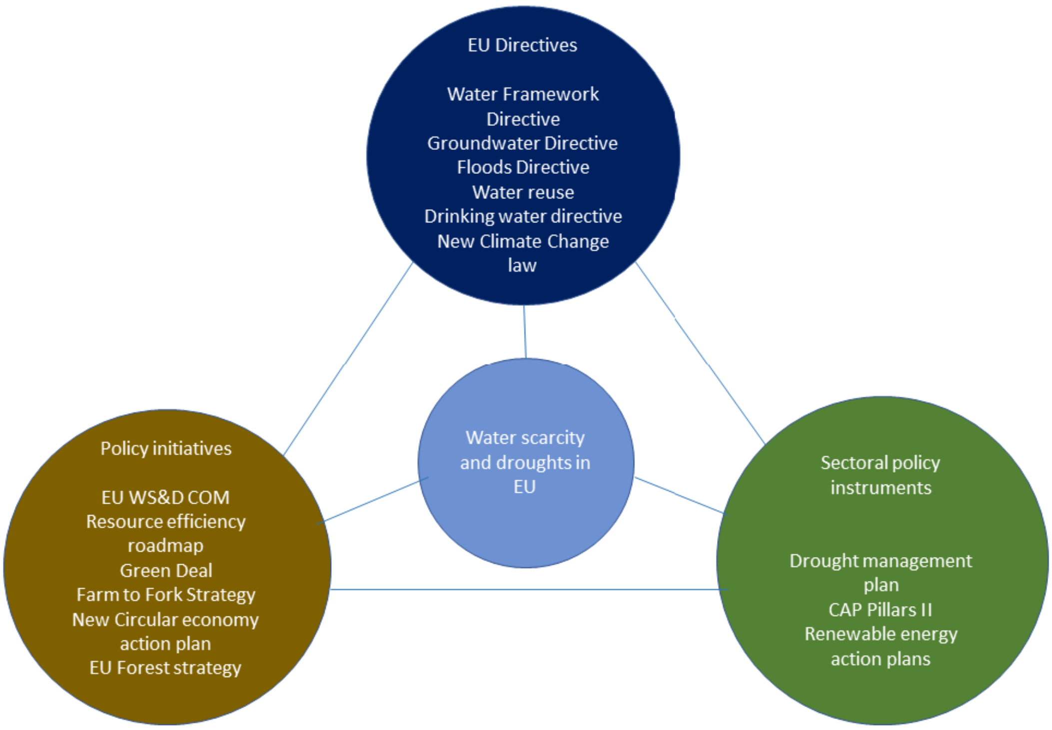
Preparedness: long-term water resources monitoring to evaluate the water-related risks and corresponding planning to manage effectively the anticipated water deficits, considering also the risks from probable drought events.

Crisis management: activation of pre-defined emergency plans and measures to deal with critical water deficits during the occurrence of drought events.

Resilience building: development of the necessary knowledge base, awareness, governance structure and technical infrastructure to support preparedness and crisis management against drought risks (e.g. raising awareness on water security concerns; providing capacity building and training; climate-proofing of socio-economic activities and areas; employing nature-based solutions for climate change adaptation; integrating ecosystem services in finance and insurance schemes dealing with water scarcity and droughts)

Overall, EU policy for water scarcity and drought has evolved around three supplementary pillars: EU directives (e.g. Water Framework Directive, Groundwater Directive, Floods Directive), policy initiatives (e.g. Communication on Water Scarcity and Drought, Circular Economy Action Plan, Resource Efficiency Roadmap) and sectoral policy instruments (e.g. Pillar II of the CAP and Regional Environmental Policy) as shown in Figure 2.1.

Figure 2.1 EU policy pillars in relation to water stress and droughts



The WFD itself establishes, at river basins scale, an integrated planning framework to enhance protection and improvement of the aquatic environment with the final goal of achieving the good environmental status of European waters. A key product of the WFD planning process is the River Basin Management Plan (RBMP), which is accompanied by a relevant Programme of Measures (PoM). The WFD recognizes the crosscutting character of water as a vital resource for social, environmental and economic systems, which places water policy in the middle of developments in other policy areas. To tackle water stress and droughts, the WFD puts more importance on acting on the drivers underpinning water demand (i.e. reducing demand from economic sectors consuming water) than increasing water supply. The WFD encourages abstraction control through permitting, water demand management, and efficient water use. However, supply-oriented measures, including reservoirs or diversions (inter-basin transfers), have also been planned in recent years by several Member States to meet their concerns on water security or shift their local water supply to alternative sources, because of the depletion and degradation local groundwater (Buchanan et al., 2019).

Nevertheless, despite their overall alignment with the above policy lines, several EU Member States (e.g. France, Greece) have reported their intention to further construct supply-oriented measures, such as reservoirs or diversions (inter-basin transfers), because they consider (whether or not correctly justified) that these measures could contribute to various goals, including water and energy security, adaptation to climate change, achievement of ecological flows in water-stressed aquatic ecosystems and protection of over-exploited groundwater bodies from further deterioration

In 2007, the European Commission published its Communication on Water Scarcity and Drought (EC, 2007), which outlines seven concrete policy options to address water scarcity and drought at European, national and regional levels:

- Putting the right price tag on water
- Allocating water and water-related funding more efficiently
- Improving drought risk management
- Considering additional water supply infrastructures
- Fostering water efficient technologies and practices
- Fostering the emergence of a water-saving culture in Europe
- Improve knowledge and data collection

The Communication calls for a “water efficient and water saving economy” that integrates “water issues into all sectoral policies”. There is an explicit recognition that economic development, in the form of e.g. new urban areas, industrial production capacities or irrigation perimeters, must take into account the availability of local water resources in order to avoid exacerbating water stress and the risk of damaging droughts. The implementation of the policy options promoted by the Communication was assessed in three yearly follow-up reports and a policy review (EC, 2008, 2010b, 2011b).

Two additional policy documents have since been published addressing water stress and droughts (Figure 2.2):

- The Blueprint to Safeguard Europe’s Water (EC, 2012) re-emphasized the need to take action against scarcity and droughts. It integrates a particular focus on the need to increase resource use efficiency and decouple growth from resource use, drawing on the Resource Efficiency Roadmap 2011 (EC, 2011a), and recently reemphasized in the new Circular Economy Action Plan (EC, 2020a) under the EU Green Deal (EC, 2019j).
- The EU Strategy on Adaptation to Climate Change (EC, 2013a), first published in 2013 and to be updated in 2021, served to establish reference points and define new aims on increasing climate resilience and disaster preparedness. In water management, this has closely linked

with efforts in improving drought risk management under the 2007 Communication and preparation of Drought Management Plans (DMPs) by Member States.

Figure 2.2 Timeline showing major policy developments related to water scarcity and drought since the adoption of the WFD.

Undertakings at the EU level have resulted in achievements in the form of research, policy options, and technical guidance to deal with water scarcity and drought (Hervás-Gámez and Delgado-Ramos, 2019). However, the EU policy approach towards water quantity has generally been less elaborate than it has been for water quality (Stein et al., 2016; Eslamian and Eslamian, 2017; Trémolet S. et al., 2019), and the pace of change in this specific policy area has been slow.

Developing comprehensive and incentive regulatory frameworks and pricing mechanisms is equally important as developing the necessary technical solutions to facilitate the uptake of new technologies (Buchanan et al., 2019). Recently, general considerations on water stress have been integrated in the EU Green Deal, as evidenced by the Biodiversity Strategy for 2030, the Farm to Fork Strategy, the 2030 Climate & Energy Framework, the new Circular Economy Action Plan and the 2050 Long-term Strategy. Elements of water security and insurance are also now embedded in the EU's Sustainable Finance Taxonomy. The challenge will continue to be the transposition of these principles and provisions at the operational level.

Implementation challenges

To this date, the management of water stress remains largely a national policy, but it operates within a multi-level governance scheme where different administrative levels play distinct roles. In keeping with the subsidiarity principle, the WFD and EU water scarcity and droughts policy provide a frame to integrate and build up on the Member States' knowledge of local conditions while avoiding that short-term regional or local interests put the future needs of the wider community at risk. This effectively means that the EU complements the regulation and management responsibilities of local and regional authorities (EU COR, 2011). Nonetheless, there could be cases where the responsible public administration fails to develop a long-term strategy looking beyond the 6-year management cycles of the WFD and building effectively on the RBMPs (Buchanan et al., 2019).

On the one hand, authorities and stakeholders in many Member States have scaled up collaboration in planning and management, leading to greater policy integration of water stress issues at local and regional level. This triggered action from some Member States, and the latest DMPs have been accepted in 2018. The compliance assessment of the second RBMPs (EC, 2019b) showed that sixteen Member States reported water abstraction as a significant pressure for their surface water or groundwater at least in some parts of their national territory[(5)]. However, only eight Member States reported DMPs as accompanying documents to all or part of their RBMPs[(6)]. Furthermore, the content of these plans and the depth of the analysis differ greatly among Member States, despite the existence of a relevant technical report on the development of DMPs[(7)]. Cyprus and Spain are two cases with very detailed and comprehensive DMPs accompanying their RBMPs. Some elements of these plans are regarded as novel and promising (Hervás-Gámez and Delgado-Ramos, 2019).

On the other hand, it should be noted that progress in implementation has been slow since the Blueprint to Safeguard European Waters back in 2012. The transition from crisis to risk management approaches has been mostly a conceptual one, as in its implementation, this change of paradigm has exposed a lack of institutional capacity across many Member States (Tsakiris, 2015). Further, to be truly effective, the risk management approach has to be adopted by all sectors which have a direct or indirect influence on water, e.g. via decisions on land use (EU COR, 2011). It will be important to renew the efforts on this, especially in areas with recurrent drought issues, as the impacts of temporary drought events can last much longer than the initial phenomenon and their socio-economic damages can be considerable. The EU Green Deal and the update of the EU Strategy on Adaptation to climate change are opportunities to do so.

Between the first and second WFD planning cycle, water pricing has been more widely applied by EU Member States, and new pricing schemes were introduced in various sectors (e.g. drinking water & sanitation, agriculture, industry). However, although incentive pricing is an explicit requirement of the WFD to ensure compliance with its principles and objectives, the current pricing mechanisms do not always provide adequate incentives for efficient water use and sustainable water management (Buchanan et al., 2019).

Furthermore, the key reason for delays in the implementation of measures tackling water stress is usually the lack of secure budgets. Measures can rely largely on the public budget, whereas the capacity of EU funds is not always fully exploited (Buchanan et al., 2019). The coordination of the European Common Agricultural Policy (CAP) and the Rural Development Plans (RDPs) is a good example here, as highlighted by EEIG Alliance Environnement (EC, 2020d).

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[5] Belgium, Cyprus, Greece, Denmark, Spain, Hungary, Italy, Malta, Portugal, Slovakia, UK, Bulgaria, Croatia, Czechia, Germany, France

[6] Cyprus, Greece, Spain, Italy, UK, Czechia, Slovakia, the Netherlands

[7] Expert Network (2008). Drought Management Plan Report - Including Agricultural, Drought Indicators and Climate Change Aspects. Technical Report 2008 – 023

Finally, the lack of robust governance on water stress at EU level has left ample space for discrepancies between Member States in interpretations, and drought policy has important limitations regarding compliance (Stein et al., 2016). For example, most Member States apply exemptions from registration or permitting for water abstractions considered to be "small"[(8)] in volume. Overall, the accumulation of all these small abstractions over a large area could result in a significant pressure (e.g. for local groundwater bodies), which is disregarded. Similarly, in some areas, there are issues with over-allocation of water rights which were issued before the adoption of the WFD. Although the WFD has provided a significant motivation for local authorities to review the pre-existing water rights, and revise them according to the identified over-exploitation problems, Member States usually have difficulties to intervene with permits that were granted a long time ago and the so-called "senior water rights". As a result, most Member States have become stricter with issuing newer water permits (EC, 2020d; Buchanan et al., 2019).

Combined, these barriers slow down progress in the achievement of the WFD's objectives and limit the ambitious implementation of EU WS&D policy. There is thus a continued need to address issues like policy integration, coherence and compliance (EC, 2020d, 2015d).

2.2. Sectoral policy responses and their links to water stress

Beyond the dedicated water policies which have been the main focus of this chapter so far, a wide range of sectoral and environmental strategies, instruments and measures are in places which directly or indirectly address the impacts of water stress and drought. These include policies in the fields of agriculture, energy, industry, transport, biodiversity, nature protection and climate change.

The EU Green Deal has largely managed to encapsulate global developments advocating systemic change, and its ongoing action plan intends to enable deep transitions in Europe. The strategy recognises the need to "restore the natural functions of ground and surface water" and tackle the "excessive consumption of natural resources". It sets out a number of industry reforms aligned to foster the transition towards circularity, and towards a greener and resource-efficient economy. At a macro-level, the Green Deal aims to increase sustainable finance and channel public and private investments into sustainable activities and projects. The use of crosscutting instruments such as the EU Sustainable Taxonomy is highlighted in the Green Deal, as they aim to establish financing standards to increase efficient use and protection of *–among others-* water resources across the European economy.

Agriculture is the sector with the largest demand for water, and also one of the worst hit in the recent drought events of 2018 and 2019. Relevant impacts for the sector include loss of crop yields and harvested production; increased costs for water supply and irrigation; and heightened potential for tensions, disputes and even conflict with competing users. The sector's flagship policy, the CAP, is undergoing a reform process that includes among its aims a readjustment of its focus to incorporate better water management into farm practices. Under the Rural Development Regulation, also known as Pillar II of the CAP, a set of measures including training and farm

[8] Perception and definition of "small" abstraction differs among Member States, e.g. France: 1,000 m3/year; Netherlands (indicative, varies per water board): 100 m3/h (registration is obligatory, but no permit required).

modernisation to promote water efficiency are concrete elements widening the scope of the agricultural practice to include environmental protection and improvement.

In the *energy sector*, common impacts include decrease of energy production in thermal plants due to low river discharges (and reduced access to cooling water); decrease of electricity production in hydropower plants due to low reservoir levels, and increased electricity prices. The EU Commission's reiterated commitment to achieve climate neutrality and fully decarbonised power generation by 2050, with 80% of the union's power generated from renewable sources, opens expectations for future changes in the sector's water demand. Links to water stress in the Renewable Energy Directive (EC, 2009) and the EU's Energy Union Strategy (EC, 2015a) are indirect and mainly stem from integrated climate and energy planning and monitoring of greenhouse gas emissions. The more recent EU Strategy for Energy System Integration 2020 (EC, 2020c) includes considerations on the water footprint of EU energy production and the potential for sustainable production of bioenergy from wastewater.

The industrial sector includes manufacturing operations as well as mining and quarrying, which are in many cases activities associated with high water demand levels. Impacts of imbalances in water availability include restrictions on production plans and even plant shutdowns in highly water-dependent operations. Policy responses in this sector have focussed primarily on resource efficiency and circularity approaches and include the Resource Efficiency Roadmap (EC, 2011a) and the Circular Economy Action Plan from 2015 (EC, 2015b)which was recently updated (EC, 2020a)under the EU Green Deal (EC, 2019j). The New Industrial Strategy for Europe (EC, 2020b)that surfaced in March 2020 does not include any clear references to water quantity issues.

Lastly, the transport sector can also be significantly impacted by water scarcity and drought events. The 2018 drought caused restrictions for inland navigation in Central Europe and disrupted supply chains along entire river basins.

These are just some examples of the main sectoral impacts and measures that give insight into the importance of concerted and coordinated action beyond sectoral silos.

Water stress in European climate change, nature and biodiversity policy

Worldwide, there is growing awareness of the need for policy responses that address the impacts of climate change on water (Quevauviller and Gemmer, 2015). In Europe, climate change and population growth are shifting conditions across a wider geographical spread (see Chapter 3). Member States like Sweden and Germany have suffered great economic losses stemming from droughts in 2018 and 2019, and increased variability in weather patterns is making the existing hotspots (e.g. Southern Europe) worse off. This is drawing renewed attention to water availability issues at the EU level, once more calling for updates on water scarcity and drought policy and action.

Regarding the consideration of climate change in the second RBMPs, significant progress was achieved compared to the first cycle. Most Member States used the CIS Guidance Document (EC, 2009) and climate change was integrated in a series of actions related to the preparation of the RBMPs. However, there are still large gaps to address before climate change can be considered fully integrated. In addition, eight Member States reported the planning of specific measures to address Climate Change Adaptation (CCA). Various Member States have also reported multi-purpose measures, which could be relevant in the context of climate change adaptation, although this is not explicitly stated (Buchanan et al., 2019; EC, 2019g).

The current EU Climate Change Adaptation Strategy aims to build capacity and increase resilience to extreme weather events, including droughts. In this regard, there have been explicit calls and efforts to explore and further develop adaptation solutions that incorporate natural elements in them, such as green infrastructure and nature-based solutions. Commonalities between EU adaptation policy, the EU Strategy on Green Infrastructure and the Biodiversity Strategy to 2030, represent another interface between policy areas where water plays a central role. Here, progress has been made on the study of natural water retention measures that enable the achievement of multiple objectives like increasing drought resilience and water security, reducing habitat fragmentation, decreasing the emission of greenhouse gases, and providing spaces for recreation. Nevertheless, the primary objectives behind the construction of natural water retention measures are currently flood risk management, nutrient buffering and wastewater treatment, hydromorphological restoration and biodiversity protection (Buchanan et al., 2019). Water quantity and climate change adaptation objectives seem to be less influential in motivating their application. The Mission area on Adaptation to climate change underpinning the EU's Horizon Europe research programme and the update of the EU Climate Adaptation Strategy are expected to drive more ambitious adaptation action through the funding of applied research and innovation and the demonstration of new solutions, including nature-based ones.

2.3. Policy developments at the global level

To tackle water scarcity and drought, the international community has recognized the need for an integrated approach between water, energy, food and ecosystems (EC, 2019i). The approval of the UN 2030 Agenda for Sustainable Development (UN, 2015b) invigorated the discussion on systemic change that permeates recent EU policy, highlighting the importance of collaboration and policy integration and coherence. The own nature of the SDGs is crosscutting and calls for joint implementation. As to their coverage of water stress issues, SDG 6.4 highlights the need to increase water use efficiency across all sectors and decoupling economic growth and water use and SDG 6.5 promotes integrated water management. Key sectors include agriculture, energy, industry and public water supply. This makes the WEFE (Water, Energy, Food, Ecosystem) Nexus approach suitable for the pursuit of the SDGs. WEFE Nexus assessments and projects are gaining traction around the world, and the underlying principles of the approach can also be identified in the most recent EU policy developments. The collective experience gathered by these projects could become instrumental in resolving known issues regarding the differentiation between concepts (e.g. water abstractions and water use) and the inclusion of environmental flows in the development and reporting of the indicator group on SDG 6.

From a climate resilience perspective, the previously mentioned paradigm shift on vulnerability and risk is largely reflected today in the UN Sendai Framework for Disaster Risk Reduction. Since its publication in 2015, the global framework has leveraged a transition away from crisis management towards risk planning that was already underway in European countries like Spain since the 1990s. It has also been effective in creating a frame for international coordination on the management of hydrometeorological risks such as droughts. The Sendai Framework will remain in force until 2030, and in the context of the current climate crisis that raises citizen awareness but also emboldens Member States interest on implementing measures to increase water supply. It will also be an important lever to maintain the emphasis on addressing unsustainable water management and exploitation practices.

3. Impacts of climate change on water availability

Key messages

- Climate change is expected to aggravate the existing pressures on the freshwater resources in Europe, the most so in southern Europe which already faces severe water stress, but also in parts of western and central Europe.

- Northern and north-eastern Europe and mountainous areas all across Europe will be affected by reduced snow cover and early snow melting.

- More frequent and intense droughts are already striking extended areas across Europe. Climate change will increase weather extremes, such as droughts and floods, and will trigger more frequent seasonal floods and low flows within the same year.

3.1. Freshwater availability in Europe

The renewable freshwater resources in the European environment per European citizen[(9)] amount to 4 560 m^3 per year (averaged for the period 1990-2017). However, this freshwater availability is highly variable and unevenly distributed in both space and time (Figure 3.1). For example, in 2017, the renewable freshwater resources per inhabitant ranged between 120 m^3 per year in Malta to 70 000 m^3 per year in Norway. At smaller spatial scales, e.g. when comparing a highly urbanized area with its surrounding rural region, even more variation occurs.

The spatial and temporal variation of freshwater resources is affected by numerous factors, such as global and regional climate circulation, hydrometeorology and local weather patterns, topography, land cover and use, and hydrogeology. Thus, low water availability can be a local issue, which is not compensated by high water availability in another part of the same country or region. Similarly, low water availability can be a temporary issue, which is not compensated by high water availability in another month or season of the year (e.g. a dry summer with a wet winter). National and regional aggregates of freshwater availability should therefore be dealt with caution, as they may obscure the local or seasonal realities, which are encountered by European citizens.

Freshwater availability alone is not an indication of high or low water stress, as the concept of water stress compares the water consumption by all socio-economic activities with the renewable freshwater resources over a specified area and period. Thus, the spatial distribution of population

[9] Calculated as the ratio of the total volume of renewable freshwater resources and the total population in EEA 38+UK

and socio-economic activities, and the time of their water demand must be factored in as well to identify a lack of capacity to meet the local and temporal needs for water.

Figure 3.1 Development of water availability per capita (m^3/capita – 2000-2017)

Country	2000	2010	2017
Austria	11,298	9,477	8,444
Switzerland	7,728	6,113	4,902
Romania	4,500	8,159	4,956
France	3,933	3,286	2,430
Spain	4,146	2,308	2,042
Italy	2,120	3,060	1,320
Germany	2,438	2,323	1,629

Source: (EEA, 2020j, 2019l; Eurostat, 2020f)

Between 1990 and 2017, the available water per inhabitant decreased in southern, western and northern Europe. An increase was observed in eastern Europe. These changes were largely driven by trends in population rather than climate change. For example: in western Europe, the annual renewable freshwater resources increased by 4 % while the regional population increased by 11 %. In eastern Europe there was an increase in renewable freshwater resources, but there was also a reduction (-6 %) in the regional population (EEA, 2018b).

Freshwater availability is expected to decrease further in some parts of the continent, such as the Iberian Peninsula, due to decreasing precipitation and increasing temperature and evapotranspiration (EEA, 2019g, 2017e, 2016h). The situation will be aggravated by random drought events, which are becoming more frequent and intense in the context of climate change(EEA, 2019g). In other parts of the continent, such as northern Europe, freshwater availability is expected to increase. This is due to projected increases in precipitation, including heavy precipitation that creates problems with excess water (e.g. floods). However, even these areas are projected to face higher temperatures and evapotranspiration, less snow, and more frequent and intense droughts than at present (Section 3.2).

3.2. *Key meteorological impacts of climate change*

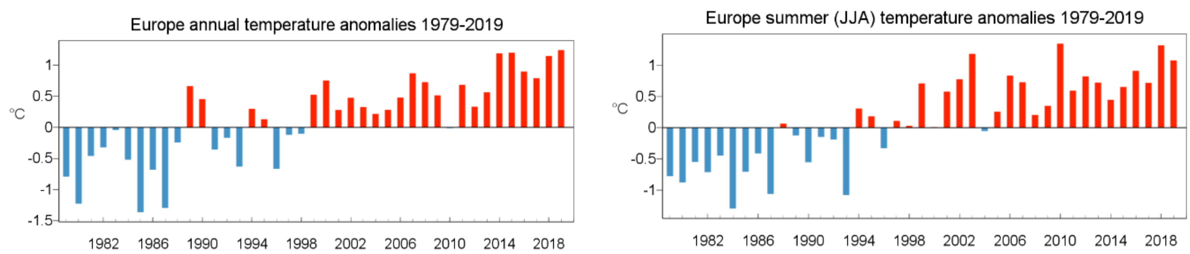
3.2.1. **Temperature**

Past trends in temperature

The mean average annual global near-surface temperature is increasing since the mid-19th century. Compared to pre-industrial levels (1850-1900), the global temperature has increased almost 1 °C. This increase has accelerated since the 1970s; it is estimated that the temperature increases 0.1 °C every 5 to 6 years. To prevent serious environmental, economic and societal impacts of climate change, all signatories to the United Nations Framework Convention on Climate Change (UN, 1992) committed in the 2015 Paris Agreement to limiting global temperature increase to well below 2 °C above pre-industrial levels by 2050 and to pursuing efforts to limit the increase to 1.5 °C (UN, 2015a). The observed warming up so far already amounts to half of the maximum 2 °C increase that would be compatible with the Paris Agreement(EEA, 2020c).

In Europe, the decade 2009-2018 was the warmest ever recorded, with the mean annual land surface air temperature being 1.6 to 1.7 °C higher than the pre-industrial levels. Since 2000, Europe has been struck by a sequence of extreme heatwaves (2003, 2006, 2007, 2010, 2014, 2015, 2017 and 2018) (EEA, 2020c), and it has recorded 11 of the 12 warmest years on record (Figure 3.2). The warmest year ever recorded in Europe was 2019, followed by 2014, 2015 and 2018 (ECMWF, 2019a). Almost the whole European territory is getting warmer; exceptions only cover a few small areas. The largest annual temperature increases are observed in central and eastern Europe. Warming is observed across all seasons, with changes being more pronounced in autumn (ECMWF, 2019a). The number of significantly warm days has doubled between 1960 and 2018 (EEA, 2020c). Water temperatures have also increased in European rivers and lakes. In major European rivers such as the Danube, Rhine and Meuse, water temperatures have increased by 1 to 3 °C over the last century.

Figure 3.2 Historic trends in annual and summer land surface air temperature anomalies across Europe between 1979 and 2019 (compared to the annual average for the 1981-2010 baseline period)

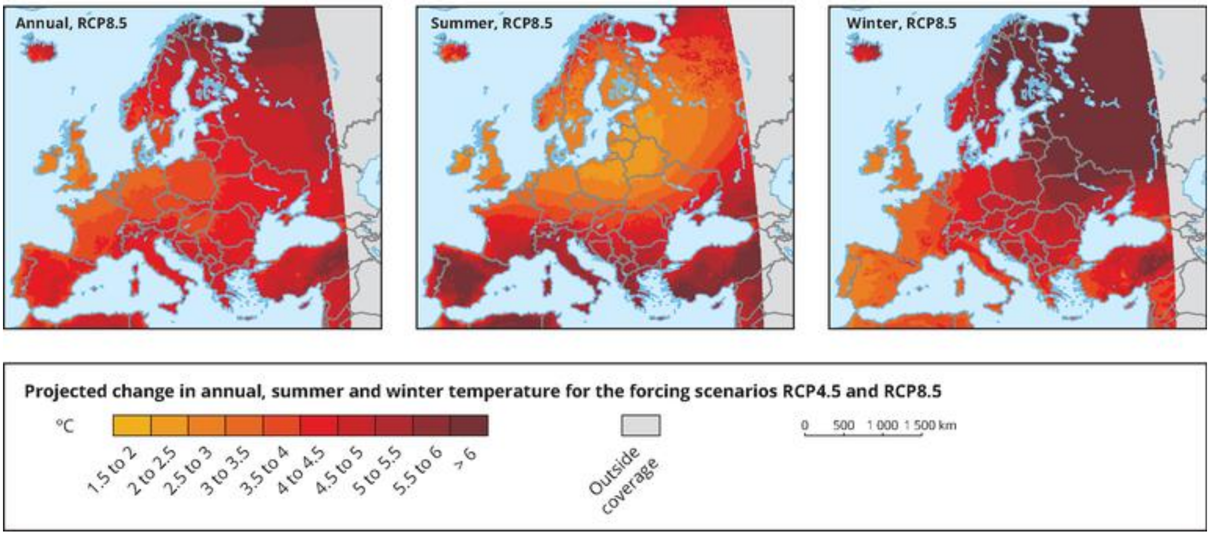


Source: (ECMWF, 2019a)

Future projections for temperature

Climate change projections comparing the historic period 1971–2000 with the future period 2071-2100 (under high-emission RCP scenario 8.5), suggest that the climate could become warmer by 2.5 °C to 5.5 °C, which is above the agreed UNFCCC threshold of 2 °C for the whole planet (Map 3.1). Extreme heatwaves are expected to occur much more frequently in the second half of the 21st century (e.g. once every two years) (Russo et al., 2015). In summers, the strongest warming is projected to occur in the Iberian peninsula and other parts of southern Europe. In winter, warming will affect the most north-eastern Europe and Scandinavia (EEA, 2020c).

Map 3.1 Future projections for annual, summer and winter land surface air temperature across Europe up to 2071-2100 (versus 1971–2000 average)



Source: (EEA, 2020c)

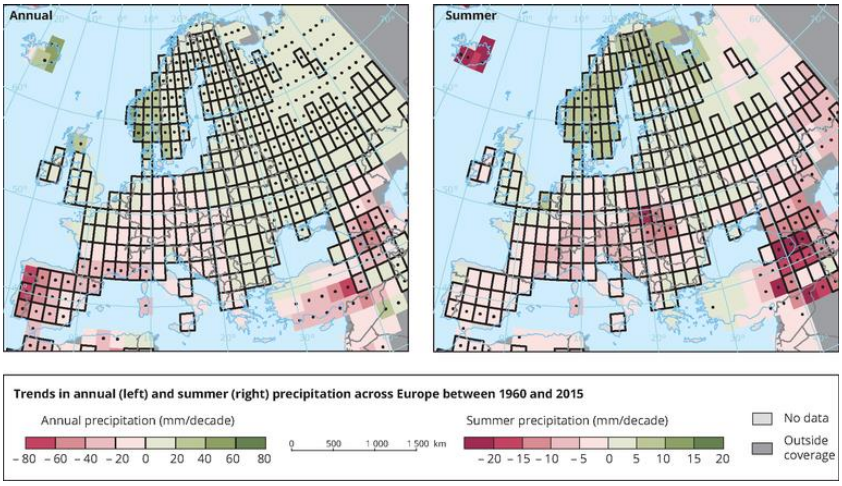
Projections show that the water in the oceans, rivers and lakes will also continue to warm in the future (EEA, 2020c, 2016i).

3.2.2. **Precipitation**

For the period 1960–2015 (EEA, 2017e), in parts of northern Europe, annual precipitation has increased by up to 7 mm and summer precipitation by up to 1.8 mm. By contrast, in southern Europe, annual precipitation has decreased by up to 9 mm and summer precipitation by up to 2 mm. In mid-latitudes of Europe, the precipitation shows no significant changes on an annual scale, but significant decreases can be observed in the summer season in parts of central and eastern Europe. This applies especially to the Danube river basin district shared by Slovakia, Hungary, Poland and Romania (Map 3.2).

The precipitation patterns are changing significantly within the year. Between 1960 and 2018, heavy precipitation in winter and summer has generally become more frequent and intense across Europe, especially in northern and north-eastern areas. A decrease is observed in heavy precipitation in the Iberian peninsula and southern France in winter and summer, and in the eastern coast of the Adriatic in summers (EEA, 2016e).

Map 3.2 Historic trends in annual and summer precipitation across Europe between 1960-2015



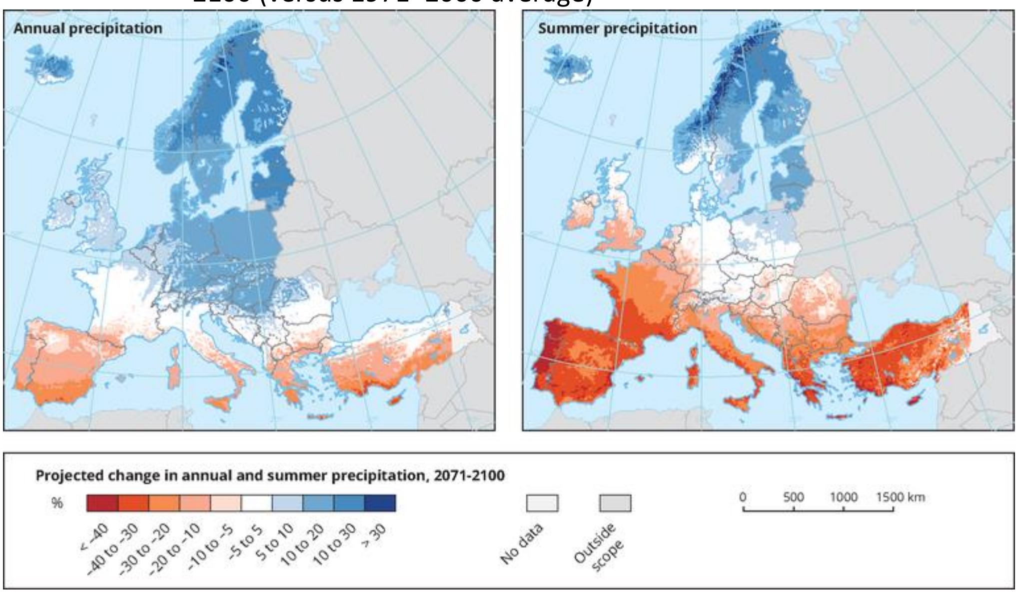
Source: Source: (EEA, 2017e)

Note: Boxes outlined in black indicate areas with at least three stations, so they are more likely to be representative; Areas with significant long-term trends are indicated by black dots.

Future projections for precipitation

Climate change projections (under high-emission RCP scenario 8.5), comparing the historic period 1971–2000 with the future period 2071-2100, suggest that (EEA, 2017e; Feyen et al., 2020) mean annual precipitation will decrease by 10-30 % in many parts of southern Europe and by more than 30 % in the south-eastern and south-western Mediterranean. Furthermore, a stronger decrease is expected in the summer season, as summer precipitation is expected to decrease by 20-40 % in an extended area that covers southern and western Europe, the Balkans and the Black Sea. In contrast, an annual increase by 10-30 % is expected in many parts of central, eastern and northern Europe. Especially in the Baltic and Scandinavian countries, significant increases of up to 30 % are also expected in the summer season (Map 3.3).

Map 3.3 Future projections for annual and summer precipitation across Europe up to 2071-2100 (versus 1971–2000 average)



Source: (EEA, 2017e)

Heavy precipitation is expected to become more frequent and intense in the future almost everywhere in Europe in winter, with significant increases of up to 35 % in Scandinavia, north-eastern and eastern Europe, due to more frequent extreme extratropical cyclones. Heavy precipitation in summer will remain similar or slightly increase in most parts of Europe. Exception are many coastal areas of southern European countries, as well as the Pyrenees and part of the Alps, where significant decreases are expected. The projected decrease in cyclone frequency in the Mediterranean contributes partly to the phenomena described above (EEA, 2016e).

Glaciers and snow

Snow accumulates over the colder period of the year and melts slowly in spring. Melted snow and glaciers flow as surface or groundwater discharges into streams and rivers with a lag time of many months after the initial time of snowfall. The snow cover thus affects significantly the timing of hydrological processes in a river basin. In general, snow cover is more common in areas of central and northern Europe and in mountain areas across the continent.

In western, northern and eastern Europe climate change has resulted in a shortening of the snow season of up to 25 days. In south-eastern Europe however, the snow season has expanded by up to 15 days, because the snow season starts earlier nowadays. Furthermore, the extent of the snow cover has decreased significantly in the northern hemisphere in the past 90 years, with the greatest part of this decline occurring since the 1980s. Overall, it is estimated that the extent of the snow cover in Europe (EEA 38+UK) has decreased by 13 % for the average March and April and by 76 % for the average June between 1980 and 2015. The equivalent mass of snow in melted water has also decreased in Europe (EEA 38+UK) over the same period by around 30 %, which is above the average observed reduction in the northern hemisphere, around 7 % (EEA, 2016h).

In recent decades, early snow melt is also observed in the Alps, which are considered the "water tower" of Europe (Box 3.1). Large European rivers, such as the Danube, the Rhine and the Po spring from the Alps. Thus, their flow regimes are affected by the changing patterns of snow fall and melting of glaciers and accumulated snow.

Future projections in snow cover

Future climate projections (under high-emission RCP scenario 8.5) indicate that the duration of the snow season in the northern hemisphere could further decline up to 40 days, the March/April snow cover could be reduced up to 25 %, and the respective snow mass could decrease up to 30 % (EEA, 2016h).

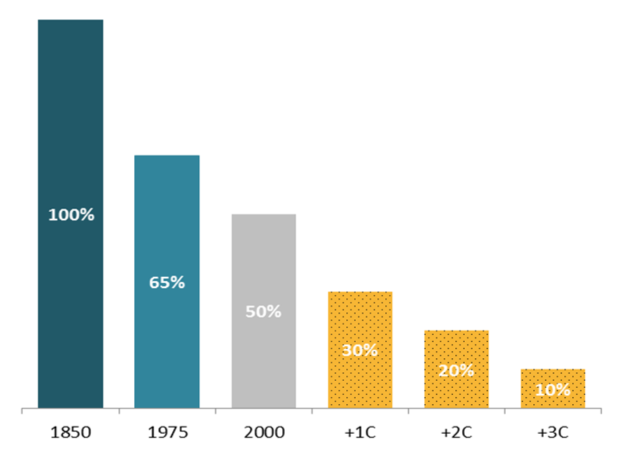
Box 3.1 Glaciers and snow cover are shrinking in the Alps since the 19th century

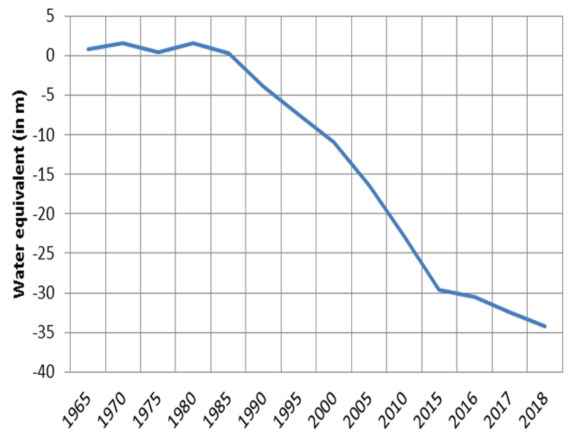
Sources: (Petita et al., 2017; Elmi et al., 2018; FOEN, 2020a, 2020b, 2020d, 2020c)

The Alpine region, which covers approximately 190 700 km^2, extends over eight European countries (Austria, France, Germany, Italy, Liechtenstein, Monaco, Slovenia and Switzerland) and it is inhabited by more than 14 million people. The average temperature in the area has risen by almost 2 ^oC since the 19th century, which is twice as fast as the average rate of temperature rise in the northern hemisphere. Furthermore, future climate change projections show that the average temperature will increase further by 1-2^o C in most parts of the region by 2050, which may result in significant impacts.

The extent of the glacier surface in the Alps now is less than 50 % of what it was in the mid-19th century, and it is projected to decrease further to 30 % or even 10 %, if the temperature increases by another 1 ^oC and 3 ^oC respectively (Figure 3.3, left). Furthermore, the Swiss scientists and authorities have observed that the cumulative mass of eight Alpine glaciers shows a decreasing trend which has been accelerated in recent decades (Figure 3.3, right). This is related to the increase of the temperature, which causes larger and earlier melting within the year. And it is also related to the change of the precipitation patterns, which results in an increase of the share of the precipitation falling as rain rather than snow. In the last 50 years, the snowpack in Switzerland has shown decreasing trends across all elevation zones from below 1000 m to over 2500 m.

Figure 3.3 Remaining glacier surface in the Alps (left); annual cumulative glacier mass balance in Switzerland (right)





Source: :(Petita et al., 2017) Source: (FOEN, 2020b)

The flow patterns of the rivers are impacted in various ways. For example, higher rainfall in winters causes higher winter discharges, increasing the risk of floods. Furthermore, the lower extent and mass of glaciers and snow decreases the storage of equivalent water, which could melt and recharge rivers, especially during the spring months. Higher temperatures are also causing higher evapotranspiration. Thus, summer discharges tend to become lower on average. As drought events are also occurring more frequently, especially in southern and south-eastern Alps, it is expected that climate change will cause further decrease in the observed low river discharges annually. River flow observations in the Swiss part of the Rhône (Porte-du-Scex) since the start of the 20th century show an amplification of seasonal patterns with increased discharges in winter and decreased discharges in summer.

The Alpine landscape constitutes a very diverse ecosystem, where 30 000 animal species and 13 000 plant species can be found. As the climate becomes warmer, those species that flourish in colder conditions need to migrate. Therefore, shrinking glaciers and snow cover limit the extent of the suitable habitats for traditional alpine species. It is projected that 30-50 % of the alpine plant species will lose over 80 % of their suitable habitats, resulting in chain effects upon the animal species also.

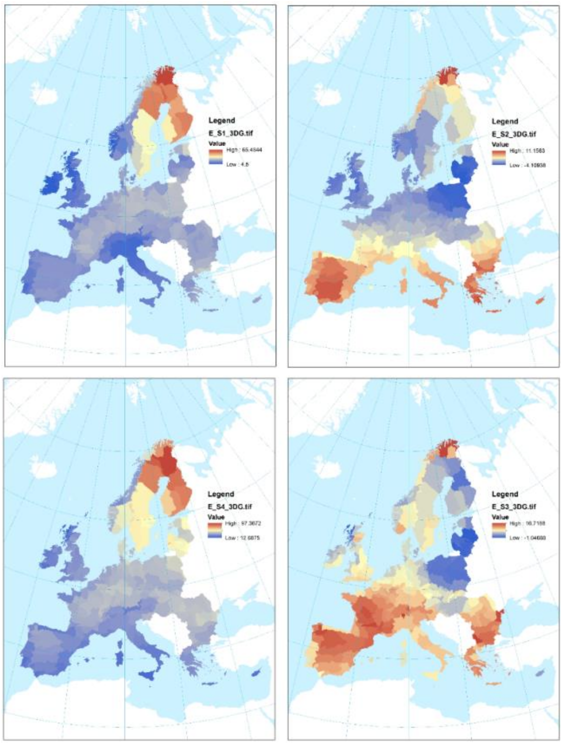
3.2.3. **Evapotranspiration**

Evapotranspiration is closely related to the type of the land cover and the applied climate conditions (e.g. temperature, wind, humidity, solar radiation) over a specified area. The analysis of the underlying E-OBS data used for the European water accounts (EEA, 2019l; Zal et al., 2017; EEA, 2018b) shows that evapotranspiration is increasing across all regions of Europe for the period 1990-2017. Proportionately, the most significant increases were observed in northern, eastern and western Europe (between 9 and 27 %), whereas the increase was lower (4 %) in already water-stressed southern Europe. These trends show that transpiration from vegetation and evaporation from soil and water surfaces in Europe has increased significantly in the past decades. The increase of evapotranspiration is mainly attributed to the increase of the transpiration from vegetation, which can be further linked with the expansion of agricultural land since the 1980s and the observed increase in the land temperature across Europe (Zhang et al., 2016).

Future projections for evapotranspiration

Driven by the projected increase in temperature, evapotranspiration in Europe will increase further in the future. However, the potential increase could be partly offset by reduced transpiration from vegetation due to higher atmospheric concentrations of CO_2 (EEA, 2016b). Most of the projected increase of evapotranspiration will occur during spring and summer, especially in southern Europe and southwestern France. In addition, it could also occur in areas of central Europe (e.g. Switzerland, Germany, the Netherlands) during summers. Increased evapotranspiration could also be observed in northern Scandinavia (Feyen et al., 2020).

Map 3.5 Evapotranspiration projections: Seasonal change (seasons S1, S2, S3, S4; clockwise) for a 3°C temperature scenario

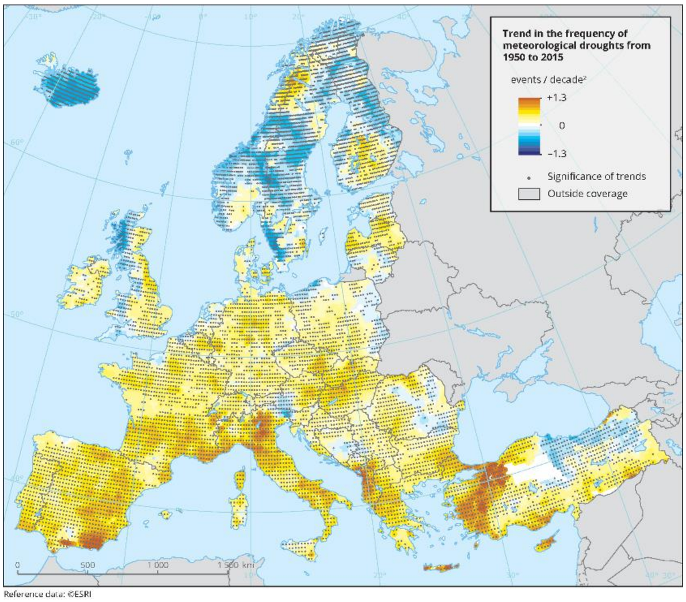


Source: underlying data obtained from (Feyen et al., 2020)

3.2.4. **Droughts**

In southern Europe and in most parts of central Europe droughts have become more frequent, with up to 1.3 additional droughts per decade, for the period 1950-2015 (Map 3.6). Furthermore, droughts have intensified roughly over the same areas, as the minimum discharges during the driest month of the year have decreased by between 5 and 20 %. In contrast, droughts have become less frequent and less intense in areas of Scandinavia and north-eastern Europe (EEA, 2019g).

Map 3.6 Historic trends in the frequency of meteorological droughts in Europe (1950-2015)

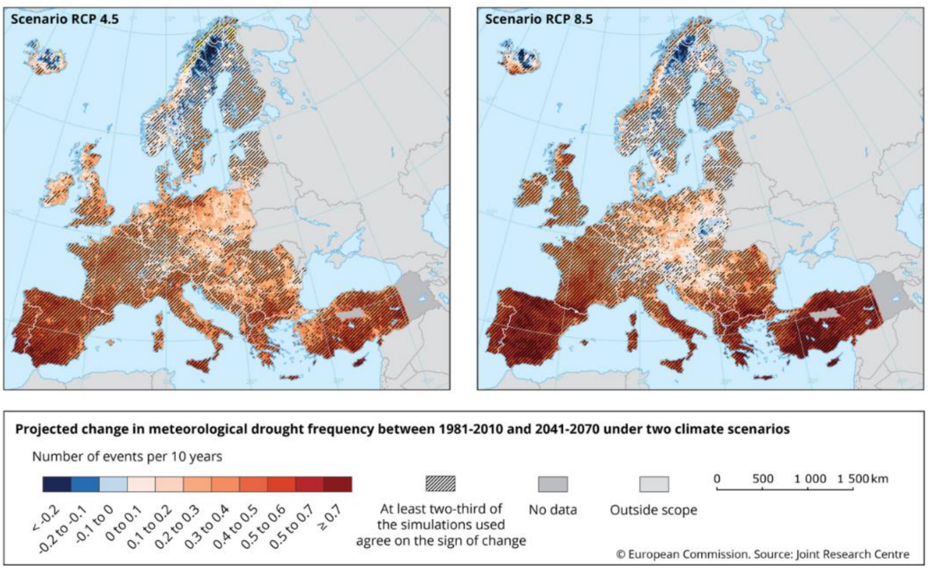


Source: (EEA, 2019g)

Future projections for droughts

Climate change projections (under high-emission RCP scenario 8.5), comparing the historic period 1981–2010 with the future period 2041-2070, suggest that the frequency of meteorological droughts will increase in most parts of Europe, with the exception of several areas in central-eastern and north-eastern Europe (Map 3.7). Southern Europe is projected to be the hotspot of more frequent and intense droughts in the future. On a seasonal basis, intense droughts will be more likely than today in summer, and then in spring and autumn, whereas intense droughts will become less likely in winter (EEA, 2019g).

Map 3.7 Future projections for the frequency of meteorological droughts across Europe up to 2041-2070 (versus 1981–2010 average)



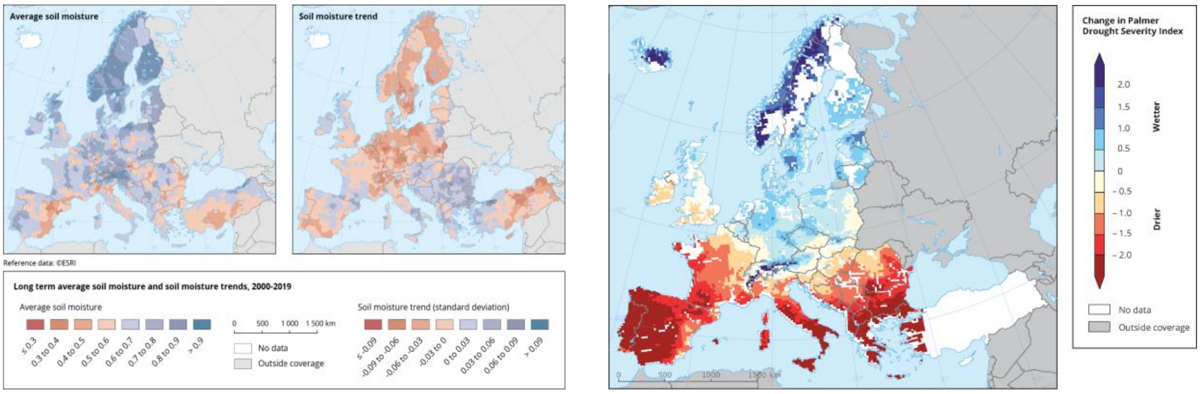
Source:(EEA, 2019g)

3.3. Impacts of climate change on the hydrological cycle

3.3.1. **Soil moisture**

The average annual soil moisture content shows a downward trend between 1979 and 2019, with this trend being more pronounced after 1990 and the last decade being the worst of the last 40 years (Map 3.8).

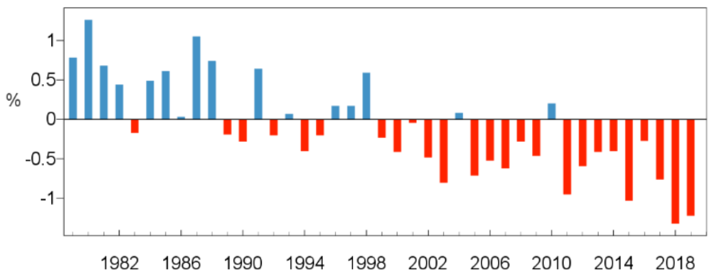
Map 3.8 Soil moisture trend (2000-2019) and projected changes in soil moisture in the period 2021-2050 compared to 1981-2010



Source: (EEA, 2017f)

In 2019, the average soil moisture in most parts of Europe was below the average of 1981-2010, with significantly low soil moisture being observed in central Europe during summer and in southeastern Europe during autumn (Figure 3.4) (ECMWF, 2019b).

Figure 3.4 Annual soil moisture anomalies in Europe between 1979 and 2019



Source: (ECMWF, 2019b)

Future projections for soil moisture content

Future projections of the soil moisture content, comparing the period 2021-2050 with the period 1981-2010, indicate a decrease of the soil moisture content in certain areas of southern Europe (e.g. the Iberian peninsula), especially during summer, and increase in central-eastern and north-eastern Europe (EEA, 2017f, 2019b).

3.3.2. **Groundwater**

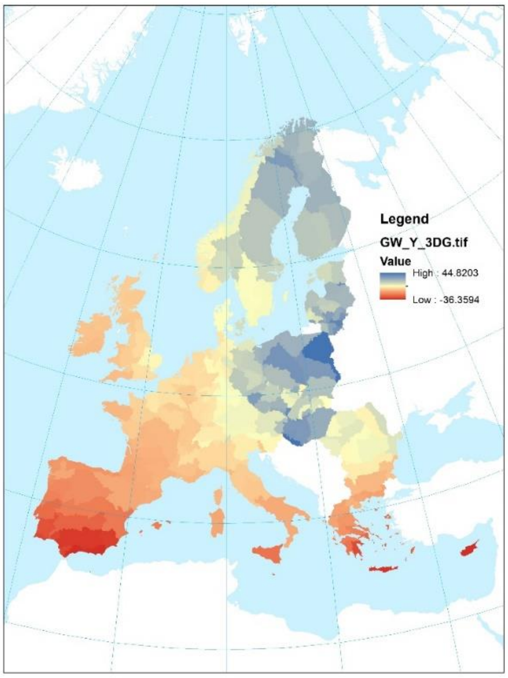
In principle, deep groundwater is less affected by seasonal variations in precipitation and temperature and more protected from pollution, compared to the surface waters. The chemical composition of the soil and its granularity may slow down the percolation of water and the leaching of pollutants. Because of this lag time, as well as because of compaction after draw-down, the recharge of depleted aquifers or the treatment of contaminated groundwater can be slow. Therefore, maintaining groundwater in good status is critically important.

Groundwater is often seen as cheap buffer resource, which can be used to supply high quality water for economic purposes. Water authorities then may turn to groundwater when the local surface waters are not suitable for use or at times of water stress due to drought events. This puts additional pressures to groundwater. The reporting under the WFD shows that 8 % of the groundwater bodies across Europe are in poor condition (EEA, 2018c).

Future projections for groundwater levels

In those areas where climate change is projected to cause lower precipitation and increased temperatures and evapotranspiration (see previous sections), it is expected that groundwater recharge will generally decrease. Decreases in groundwater recharge, are expected in southern and western Europe, whereas increases are expected in parts of eastern and north-eastern Europe (Map 3.9)(Feyen et al., 2020).

Map 3.9 Percental change in projected annual groundwater recharge for a 3 ^{o}C temperature scenario.



Source: underlying data obtained from (Feyen et al., 2020).

Furthermore, climate change is expected to cause a rise in the average sea level. This will affect coastal aquifers, and especially those which are being exploited intensively, when saltwater from the sea intrudes into the coastal aquifers and causes salinisation. This can make the groundwater unsuitable for use. In the above climate context, coastal aquifers are expected to become more vulnerable to saline intrusions.

Box 3-2 Climate change will lower groundwater levels in the Loire and southwestern France

Sources: (Maréchal and Rouillard, 2020; Delgoulet, 2015)

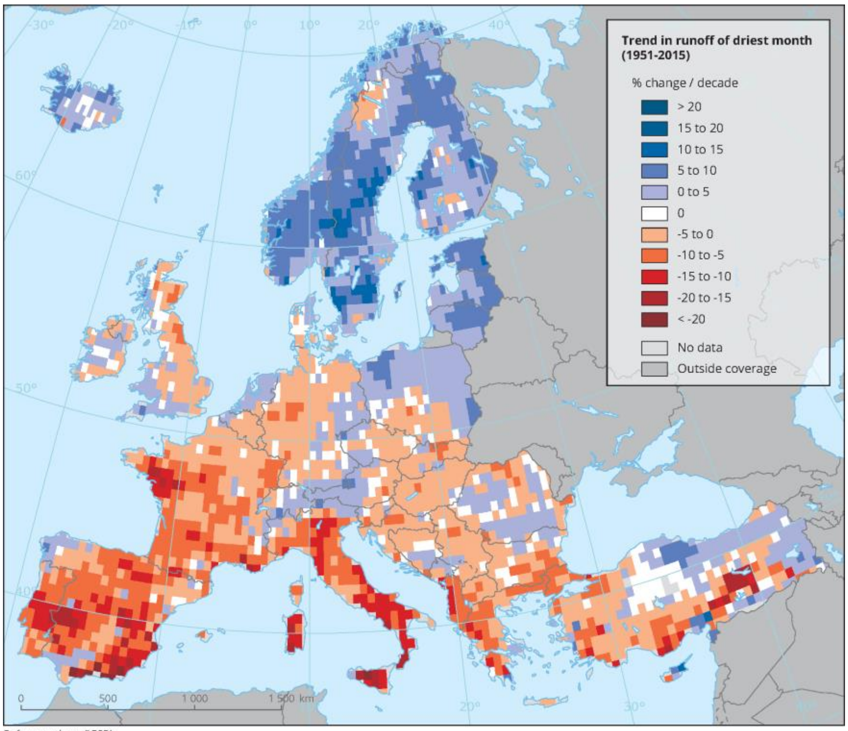
The Explore 2070 project has developed and assessed strategies to adapt to climate change impacts on hydrological systems and coastal environments in mainland and overseas France up to 2070, based on different climatic, demographic and socio-economic scenarios. Rises in temperature (and consequently evapotranspiration) combined with decreasing rainfall, will lead to a decrease of effective precipitation in the future. The application of seven climate models using the median Green House Gas (GHG) emission scenario (A1B, fourth GIEC report) enabled an estimate of the change in natural recharge rates. With predicted recharge variations of +10 to −30% in the optimistic scenarios, and −20 to −55% in the pessimistic scenarios, a decline of similar proportions in groundwater levels would be expected, and therefore groundwater resources are likely to decline significantly overall by 2070. Two areas which are likely to be more severely affected are the Loire basin with a 25–30% recharge decline across half of the basin area, and the south-west of France with a 30–50% decline in recharge. All of the scenarios also show a decline in average river flow by 2065, which varies from a 10 to 40% reduction in the northern half of the country, and a 30–50% reduction in the southern half, with local extremes of up to 70%. Despite this relative decline in river flow, some models show that very high surface water levels are nevertheless possible during the winter in some catchments (e.g. the Somme and Rhine Rivers), confirming the likelihood of lengthy periods of flooding.

Furthermore, water balance studies have shown that many catchments and aquifers present high structural water deficits, impacting environmental flows, leading to the imposition of abstraction caps on water users, in particular agricultural irrigation. In addition, over the last twelve years, more than 50% of the French departments concerned by restriction orders of use - watering, filling swimming pools, cleaning vehicles, etc. - in 2003, 2005, 2006 and 2011. The recurrence of these episodes of water stress has made it necessary to reinforce the security of the supply of drinking water services.

3.3.3. River discharges

In southern, western and parts of eastern Europe, the summer discharges in the years 1951-2015 show a decreasing trend. The trend is most pronounced in areas of Spain, Portugal, Italy, Greece, Turkey and France (Map 3.10) (EEA, 2016g).

Map 3.10 Historic trends in runoff during the driest month of the year in Europe (1951-2015).



Reference data: ©ESRI

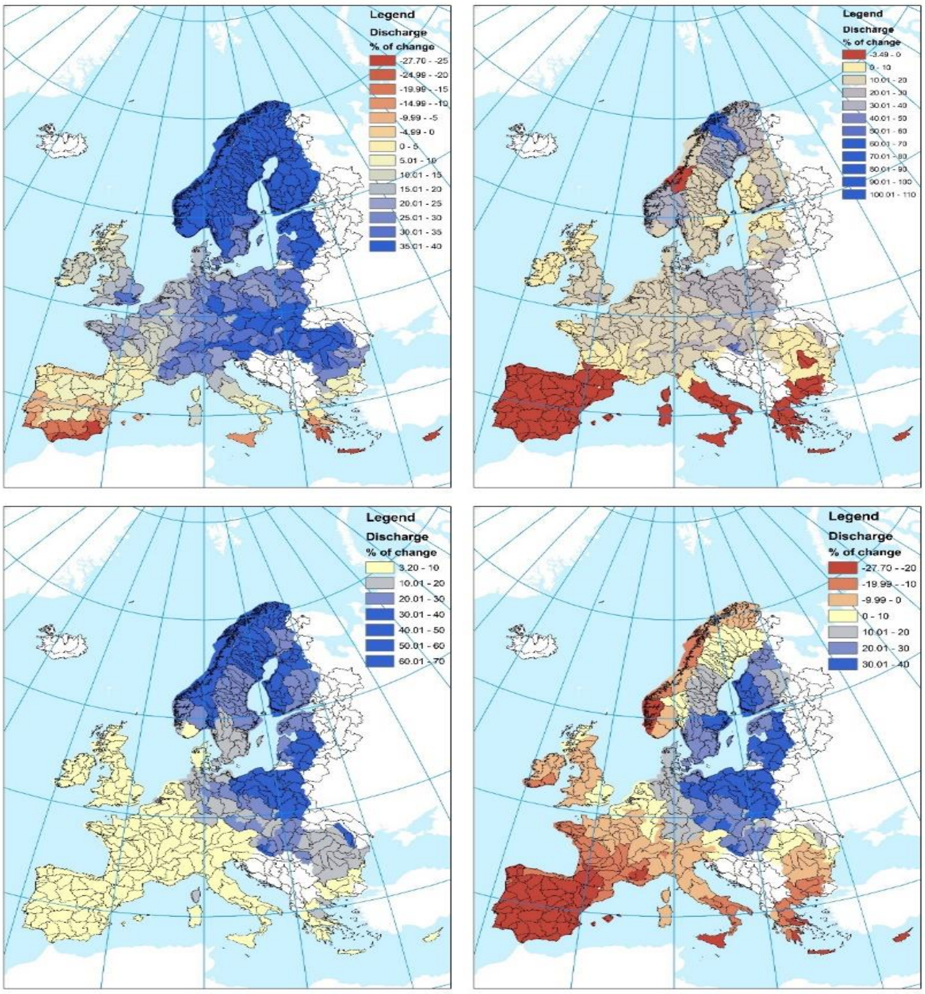
Source: (EEA, 2020h)

After a decade of very warm and dry years, 2019 was also a particularly dry year. As a result, the river discharges across Europe fell below average for almost two thirds of the year (i.e. during spring, and throughout July-October). The most extreme low river discharges were observed in central Europe. However, in November and December a rapid turnaround to high river discharges appeared in western Europe, causing a high number of flood events (ECMWF, 2019b).

Future projections for river discharges

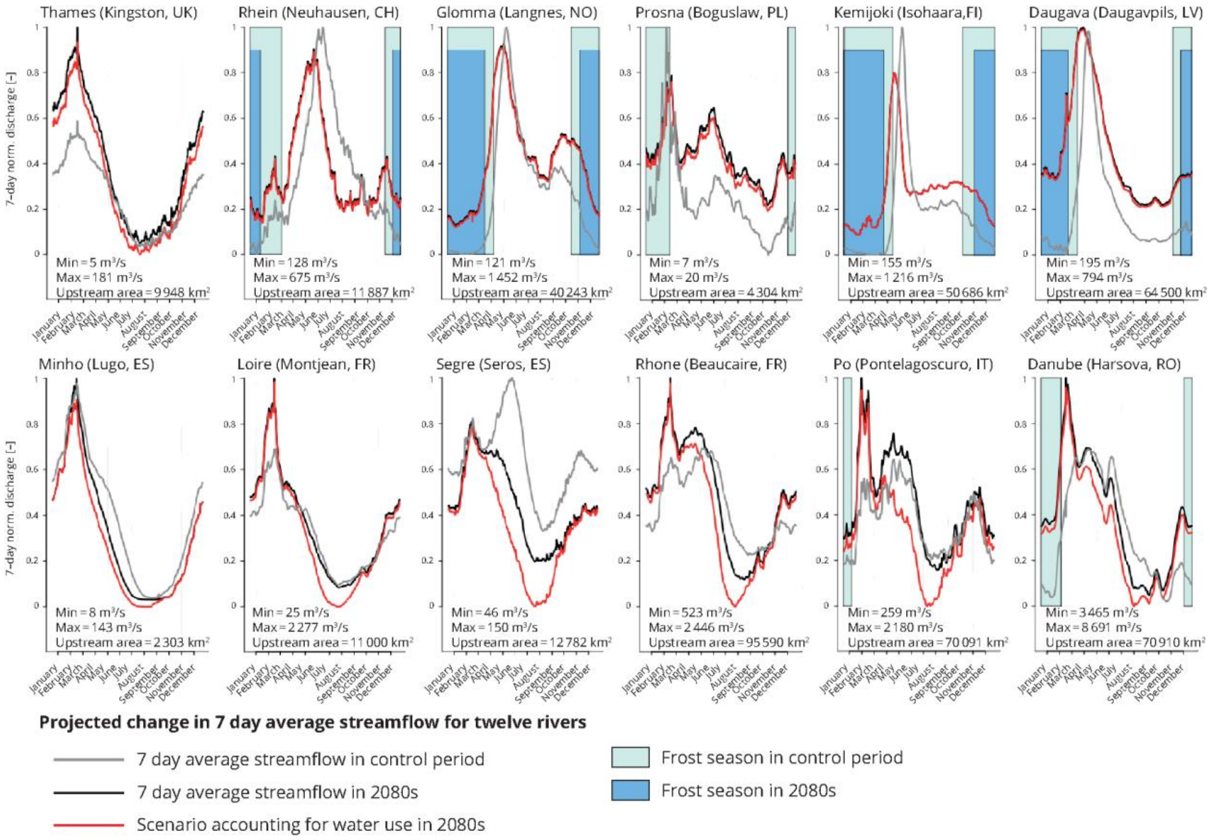
Climate change is shifting the seasonal patterns of river discharges across Europe and enhancing the occurrence of seasonal extremes (Figure 3.5). Future summer discharges are projected to further decrease in southern Europe and parts of western and northern Europe whereas increase in parts of eastern and north-eastern Europe during all seasons (Map 3.11) (Feyen et al., 2020). In addition, spring and summer peak discharges will generally occur earlier in the season, as a result of proportionately more rainfall instead of snowfall during winter and earlier melting of the snow cover and glaciers (EEA, 2016g).

Map 3.11 River discharge projections: Seasonal change (seasons S1, S2, S3, S4; clockwise) for a 3 °C temperature scenario



Source: underlying data obtained from (Feyen et al., 2020)

Figure 3.5 Projected change in seasonal streamflow for twelve rivers



Source: (EEA, 2016g)

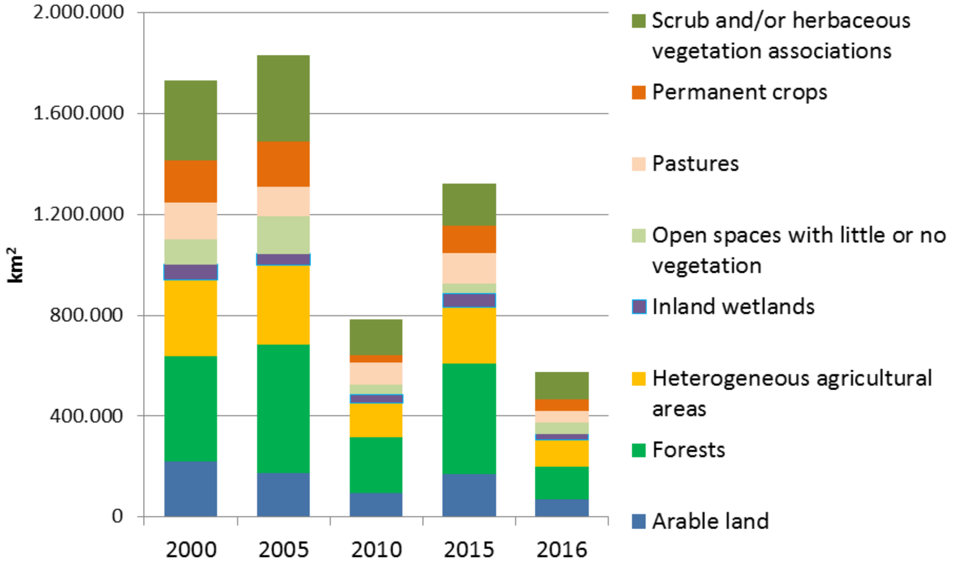
3.4. *Impacts of climate change on habitats and species*

The latest State of Nature report in Europe (EEA, 2020g, 2020f) shows that 5.4 % of the habitats and 4.6 % of species are currently affected by climate change as a pressure. Furthermore, from all cases related to climate change, almost half are associated with droughts and decreases in precipitation. The highest pressures from decreases in precipitation are observed in habitats, such as bogs, mires and fens. Coastal habitats, and especially those in the Atlantic and the Boreal region, are mostly challenged by sea level rise and wave exposure. In addition, the most affected species are the amphibians, which are very sensitive to shifts of both temperature and precipitation. Other species that are also affected include molluscs, specific mammals, as well as birds associated with reedbeds and reedy ponds.

As climate change is increasing temperature and changing the precipitation patterns, it is expected that the risks for biodiversity will increase. The loss of current habitats, the creation of favourable conditions for alien species to the European ecosystems and the amplification of the issues with invasive species are predicted to cause additional pressures for biodiversity in the future.

It is estimated that the average area in Europe affected by severe droughts is around 121 000 km^2 for all years between 2000 and 2016 (Figure 3.6). However, this area was actually highly variable, depending on the annual climatic conditions; e.g. ranging between 50 000 and 350 000 km^2 each year over the same period. The most affected land use types included forests, scrubs and/or herbaceous vegetation associations, heterogeneous agricultural areas, arable land and permanent crops. Moreover, the most affected geographical areas were the Iberian peninsula and southwestern France, measured both in terms of extent of areas under water deficit and in terms of vegetation growth decline. A large part of central Europe and the Balkans (e.g. Bulgaria, Hungary, Romania and Slovenia) were also affected by water deficits that caused decline in the vegetation growth (EEA, 2020i).

Figure 3.6 Area of vegetation productivity decrease due to water deficit, 2000-2016



Source: (EEA, 2020i)

4. Freshwater consumption in Europe under socio-economic change

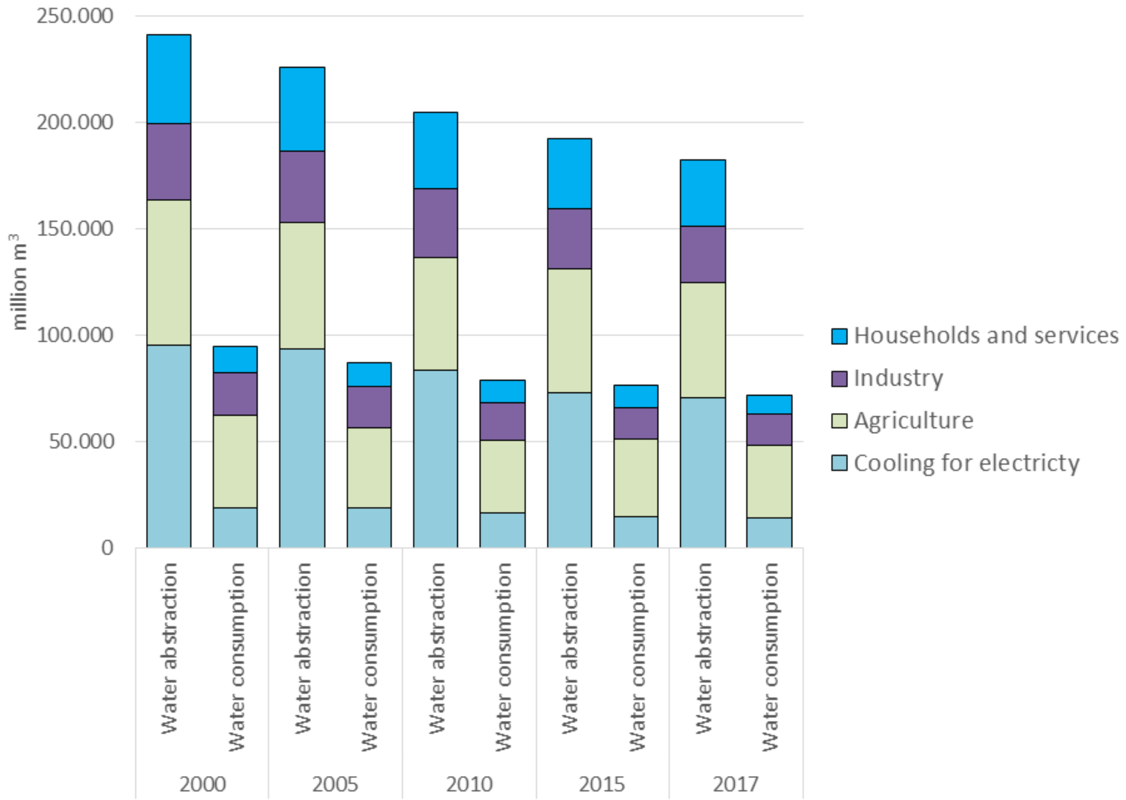
Key messages

- The environment is not sufficiently protected from water abstraction, as the definition and implementation of e-flows, and the subsequent revision of water permits, are lagging behind.
- 62 % of rivers, 51 % of lakes, 61 % of transitional waters and 51 % of coastal waters were not in good ecological status in 2015 (EEA, 2018c).
- 75 % of freshwater habitats in Europe were not in favourable conditions in 2020 under the Habitats Directive (EEA, 2020g).
- Two thirds of European wetlands were lost before the 1990s and their area has subsequently decreased, but the loss seems to have levelled off between 2006 and 2012 (EEA, 2020b).
- Agriculture remains the most prominent driver of water abstraction in Europe, because of high water consumption in irrigated agriculture in the south, but the sector shows signs of decoupling from growth in southern, western and northern Europe.
- The installation of renewable energy sources has contributed to significant reductions in water abstraction in the energy sector, because of replacement of combustion plants. Western Europe shows significant trends of decoupling water consumption in the energy sector from sectorial growth.
- The water consumption in the industrial sector is decreasing, while the value of industrial production continues to grow in western, northern and eastern Europe, suggesting a trend for decoupling.
- The public water supply sector achieved significant water savings overall in Europe. However, the volume of public water supply increased in southern countries and tourism has posed significant local pressures, especially in the Mediterranean.
- Shifting sectorial water management towards a more sustainable paradigm entails a series of challenges, because of the trade-offs between making a sector less water intensive and keeping up its production levels.
- Sustainable water management needs to rely more on water demand management, supply from alternative water resources, circular and nature-based solutions.

4.1. *Freshwater consumption in Europe*

Approximately 266 000 million m^3 of water were abstracted in Europe (EEA38+UK) in 2017 to serve the needs of the different sectors of the European economy. This is nearly 9 % of the annual renewable freshwater resources in Europe. After its abstraction, water is transported, treated, distributed, used in production processes, partly evaporated and transpired, and partly integrated in products. Intermediate losses, unused water and wastewater finally find their way back into the environment as returns. In 2017, around 40 % of the total abstraction was consumed and 60 % of the total abstraction was returned before or after use to the environment. Water returned to the environment may have its physical or chemical properties altered (e.g. higher temperature, pollution). The percentage of abstracted water that is returned differs greatly among sectors. In the agricultural sector it is 30 to 40 %, the returns of cooling water from the industrial and energy sector can be up to 80 %, while hydropower returns almost 100 % (EEA, 2018b) (Figure 4.1).

Figure 4.1 Development of water abstraction and water consumption in EU27+UK (2000 – 2017).

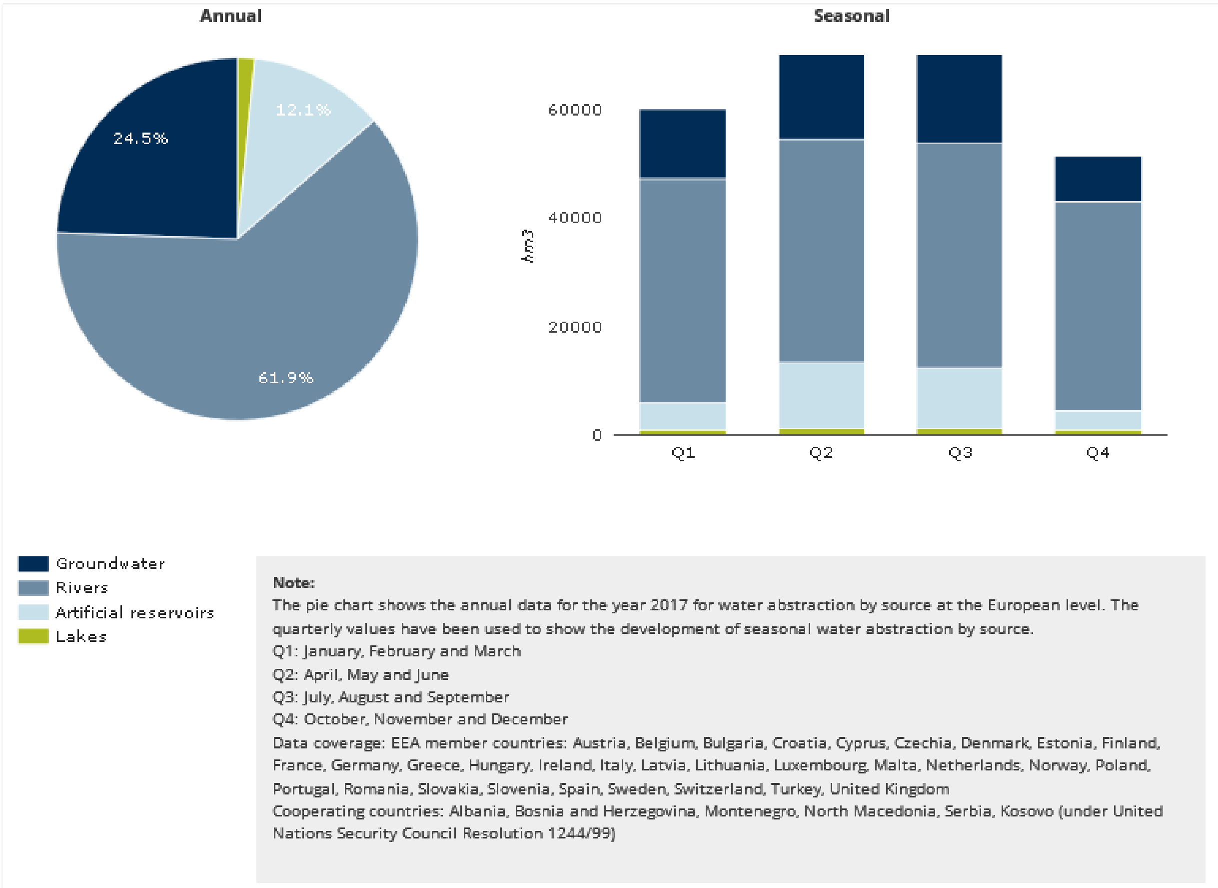


Source: (EEA, 2020j, 2019l; Eurostat, 2020f)

4.1.1. **Freshwater abstraction by source of water**

On average, rivers meet 62 % and groundwater 25 % of total water abstraction in Europe (Figure 4.2). Groundwater is mainly used for drinking water supply and agriculture. Around 12 % of the total volume of abstracted water is taken from artificial reservoirs and 1 % from natural lakes. The pressure on surface and groundwater resources is higher in spring and summer, due to the abstractions by agriculture and public water supply. In autumn and winter, the highest pressure, especially on rivers, is from abstractions for cooling water for the energy and manufacturing sectors (EEA, 2018b).

Figure 4.2 Water abstraction by source of water in Europe (2017)



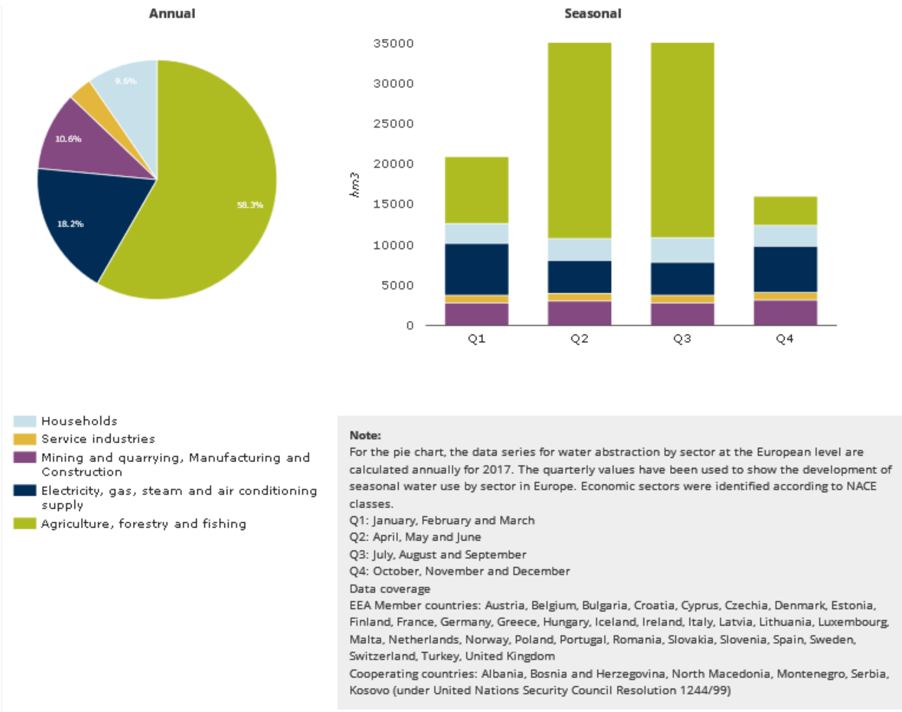
Source: (EEA, 2018b)

4.1.2. **Freshwater consumption by socio-economic sector**

In 2017, the sectorial break-down of water consumption was: agriculture (58 %), cooling water for electricity production (18 %), mining, quarrying, construction and manufacturing industries (11 %), households (10 %) and services (3 %) (EEA, 2018b).

There are significant regional differences in the break-down of water consumption. In western and eastern Europe, electricity production is the major water using sector, using water for cooling. In southern Europe it is agriculture, and in northern Europe manufacturing. Coal mining has been an important economic sector and water user locally in certain European areas (e.g. southern Poland, north-western Greece). Furthermore, total water consumption almost doubles during spring and summer compared to autumn and winter, because of the high demand of agriculture during the summer half year (Figure 4.3) (EEA, 2018b) .

Figure 4.3 Water consumption by sector in Europe (2017)



Source: (EEA, 2018b)

4.2. Socio-economic trends affecting water consumption in Europe

4.2.1. **Economic growth**

Economic development drives the water demand from industry and services and associated electricity production, although not in a linear manner. The potential Gross Domestic Product (GDP) is projected to increase by 1.3 % per year in the period 2016-2070 in EU27+UK (EC, 2018c). This growth will not be reflected linearly in water demand because of increasing water use efficiency and decoupling (Figures 4.11, 4.13 and 4.16) and a shift towards renewable energy sources. Furthermore, there is an EU-wide trend of an increasing share of the GDP covered by the services sector (EC, 2015c), a sector which is less water-demanding than others.

4.2.2. **Population change**

Between 1990 and 2017, the European population (EEA38+UK) increased by 11 %. The highest increase was in southern Europe (+17 %), followed by northern (+13 %) and western Europe (+11 %). In eastern Europe the population decreased by -6 %, due to migration to other countries (Eurostat, 2020c). Roughly 200 million people have migrated from one place of Europe (EEA38+UK) to another between 2000 and 2019 (Eurostat, 2020d). Immigration to Europe (EEA38+UK) from foreign countries intensified in the last decade. The 2018 Ageing report (EC, 2018c) projects the annual net migration inflows to the EU to decrease from about 1.5 million people in 2016 to 821 000 people by 2070 or 0.2 % of the total population.

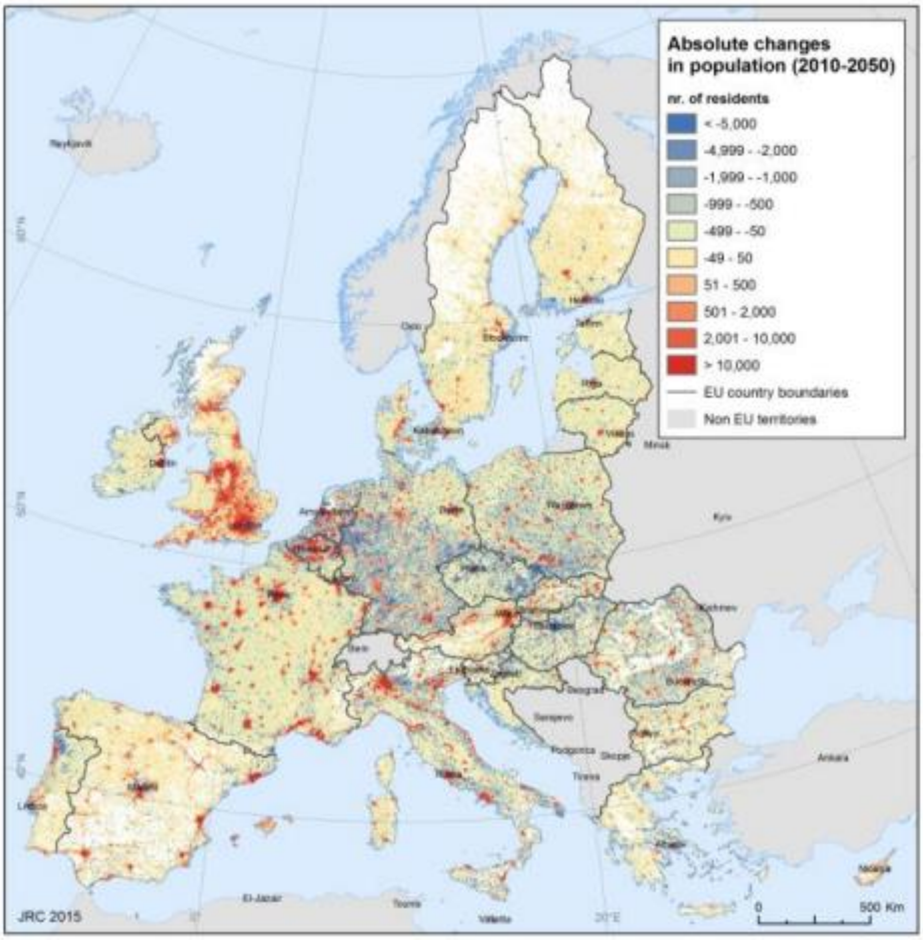
Over the last 70 years, the urban population in Europe has increased from around 55 % to around 70 % of the total population. Urban areas are attracting people of younger ages, who come to cities to study and work, whereas aged people tend to move into the periphery of urban centres and in peri-urban areas (EEA, 2017d). Currently, the most populated urban areas in Europe at NUTS3 level are Istanbul, Madrid, Rome, Berlin, Lisbon, Nord-Pas-de-Calais and Stockholm (Eurostat, 2020d).

Future outlook

Assuming that fertility rates, life expectancy and migration rates remain constant, then the population in Europe (EU27 + UK) is projected to increase in a slow rate until around 2030 and then decrease gradually by 30 % by 2100. The population in Europe is also aging, as the fraction of people over 65 years old is projected to increase significantly over the same period (EEA, 2016f).

The urban population is projected to reach 80 % of the total population around 2050 (EEA, 2017d). The major urban centres of western and central Europe are projected to show the highest increases in their population (Map 4.1).

Map 4.1 Projected population change between 2010 and 2050



Source: (JRC, 2015)

Box 4.1 Population growth as a prominent driver of urban sprawl and higher water consumption in Stockholm

Sources: (Eurostat, 2020d; EEA, 2109, 2018b)

The metropolitan region of Stockholm shows a 30 % increase between 2000 and 2019 (+1.4 % per year on average) with over 500 000 inhabitants added during the last 20 years. In the same period, 400 km^2 of artificial surfaces was added. Along with this population growth and urbanisation Stockholm also shows a significant share of water consumption compared to renewable freshwater resources: it usually exceeds 10% in summers (WEI+ indicator results).

Box 4.2 Population concentration and growth as prominent drivers of higher water demand offsetting increases in water supply in Istanbul

Sources: (van Leeuwen and Sjerps, 2016; Altinbilek, 2006)
Istanbul is the largest urban agglomeration in EEA 38 and it is classified as a megacity (i.e. a city with a population over 10 million people). Istanbul gathers a population of more than 15 000 000 million inhabitants. It shows a total population increase of 36 % in the last decade (1.7 % annual average growth).

Although not a "naturally dry" area, water scarcity is a local issue due to population concentration and increase over time. Despite the enormous efforts to increase water supply, the projected future urbanisation and population growth, together with climate change, will increase water demand further.

Figure 4.4 Water supply and demand in Istanbul, 1990-2040

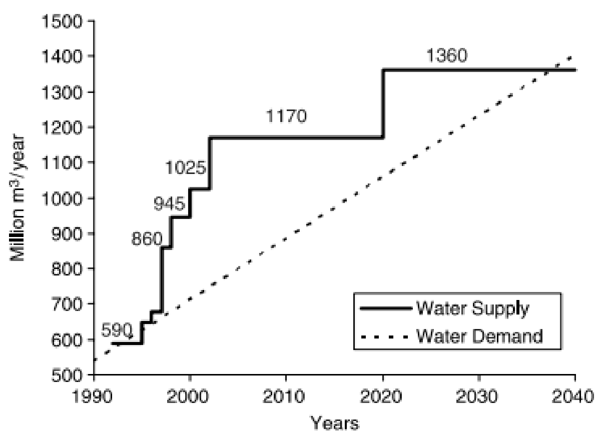


Figure 2. Water supply and demand

Source: (Altinbilek, 2006)

4.2.3. Freshwater consumption patterns

In 2017, the water consumption by all economic sectors in Europe averaged per European citizen[10] was estimated at 370 litres/day/person, but there are large regional differences. For example, in southern Europe, the average water consumption is much higher at 707 litres/day/person (EEA, 2018b).

People use water to meet basic needs, such as drinking, cleaning, washing and personal hygiene, as well as to support specific consumption patterns, such as dietary/lifestyle patterns and recreation

[10] Calculated as the ratio of the total water consumption (i.e. abstraction – returns) from all socio-economic sectors and the total population in EEA 38+UK

purposes. In addition, water use by humans is both direct (e.g. using tapped or bottled water) and indirect (e.g. water embedded in foods and beverages or participating in production processes for commodities). Therefore, the total number and the spatial distribution of population is an important factor, as it affects the demand for public water supply, as well as the demand for food and other products, and water needed for their production and supply.

However, due to human mobility (e.g. tourism, work migration), water use in one place does not necessarily occur by people living permanently in the same place. Similarly, due to trade, water use for the production of commodities, does not necessarily occur where the commodities are consumed. In a globalised environment the linkages between local water, food and material demand, local water use and local water stress can be very complex. Therefore, the water stress problems observed in Europe do not necessarily reflect the level of water consumption in the water-stressed areas or within Europe in general. Similarly, the water stress problems in areas of other continents can also be related to the consumption patterns occurring in Europe.

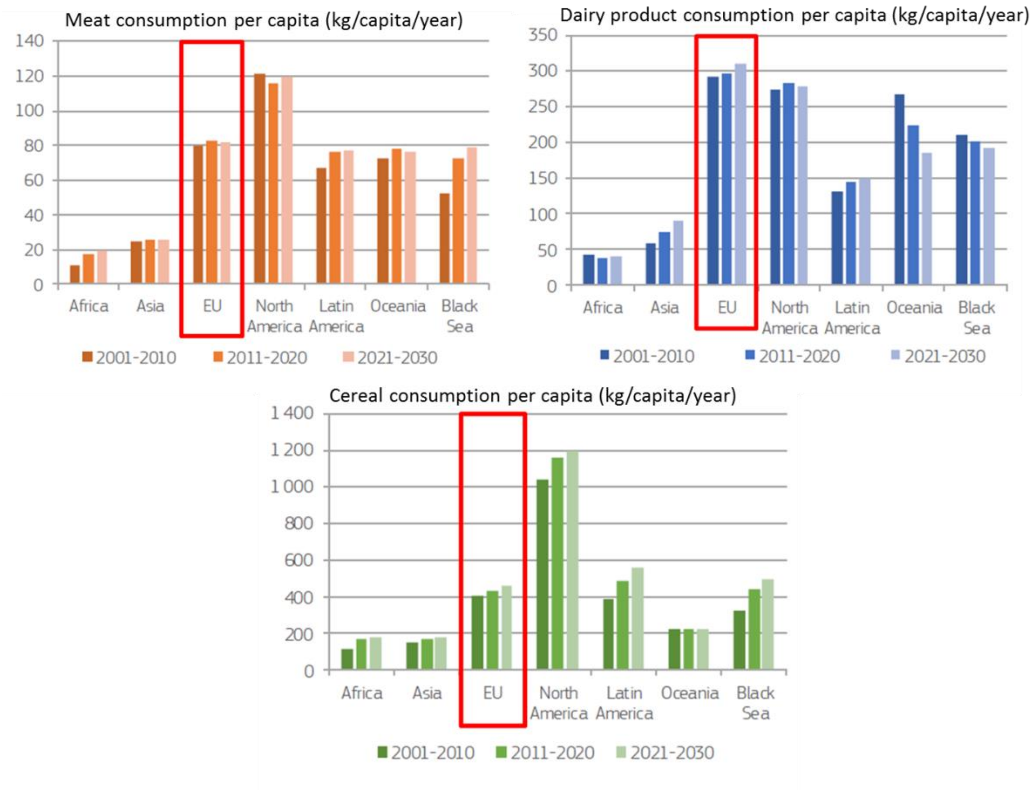
Changes in food consumption patterns in Europe

The average water footprint of food consumption (dietary patterns) in the EU is estimated at 5,730 litres/capita/day (Vanham et al., 2013). However, the average water footprint per capita in the Mediterranean (3,280-5,790 litres/capita/day) (Vanham et al., 2016) is much higher than in Scandinavia (2,940-3,550 litres/capita/day) (Vanham et al., 2017), which is partly explained by differences in bio-climatic conditions and composition of food consumption. For example, Mediterranean people have moved away from past dietary patterns, increasing their consumption of meat, dairy and processed food in the past decades. However, these products require proportionately more water than most crops for their production (Mekonnen and Hoekstra, 2012, 2011).

Overall, the average consumption of cereals, meat and dairy products per person is increasing in the EU (Figure 4.5), while Europe is one of the top consumers of these products in the world (EC, 2019e). However, not all food produced actually reaches the plate of consumers. Food waste through the whole food chain is a major concern, as it is also linked with considerable waste of water, soil and energy resources, which are being used to produce the wasted food. Currently, the average food waste in the EU amounts to 173 kg/capita/year, with 30 % occurring during production and processing and 70 % occurring in food retail, food services, or households (Stenmarck et al., 2016).

A recent outlook study until 2030 suggests that the consumption of cereals and dairy products will increase, whereas meat consumption will likely stabilise or reduce, partly because of a projected shift towards a more plant-based diet for the average European citizen (EC, 2019e).

Figure 4.5 Changes in consumption of food commodities per person in Europe, compared to the rest of the world.



Source: (EC, 2019e)

Note: Figures do not include butter. Black Sea includes Russia, Ukraine and Kazakhstan. Latin America includes South America and Mexico.

4.2.4. **Land use change**

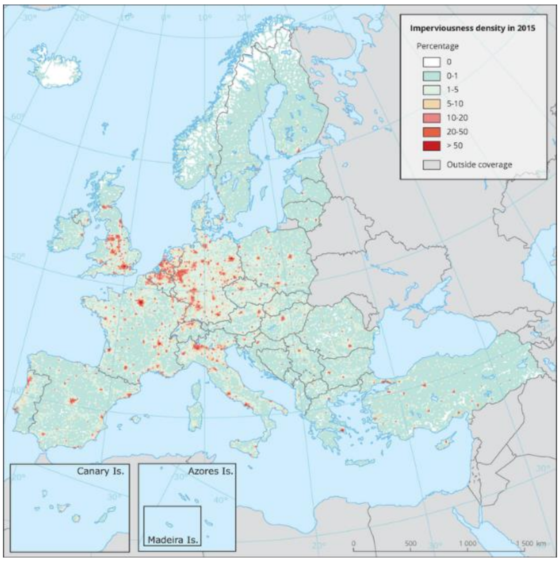
Area of urban land and soil sealing

Extended soil sealing causes serious environmental impacts. These include lower infiltration and groundwater recharge, drinking water quality problems in underlying groundwater bodies due to accumulation of urban pollutants, faster rainfall-runoff processes leading to more frequent and intense flooding. As a result of soil sealing, the soil can no longer perform many of its ecological functions in and above ground. Urban sprawl and expansion of transport infrastructure also causes fragmentation of landscapes and disturbance of ecosystems (EEA, 2019e, 2020d, 2019f).

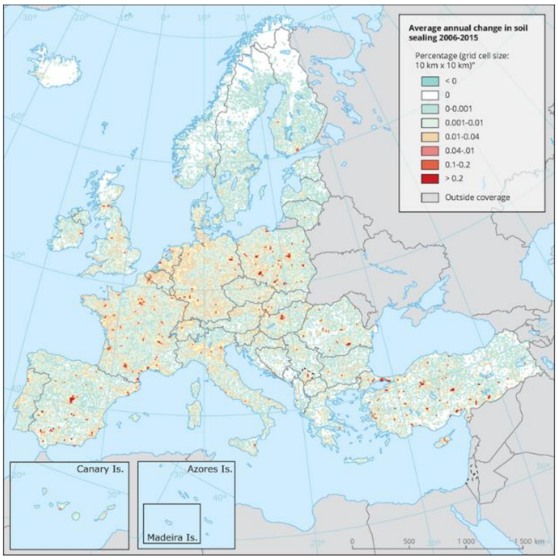
The significance of urban areas for the European economy is increasing. Urban areas have produced 50 % more GDP than the other areas in the EU between 2000 and 2013, while employment grew by 7 % and decreased slightly in other areas (EEA, 2017d). The increase of the European urban population has led to the development of more urban and peri-urban land, and the concentration of the demand for public water supply. In 2017, the artificial land cover, which includes residential, industrial and commercial land and transport infrastructure connecting areas, exceeded 4 % of the total land cover (EEA, 2109). The Netherlands, Belgium, France, Germany, the UK and Italy (particularly the Po river basin) are significant hotspots of urbanised/artificial land, while recent trends of urbanisation (2006-2015) show high rates of land conversion in France, Spain, eastern Europe and Turkey. Between 2000 and 2018, 78 % of the artificial land conversion in the EU27+UK affected arable lands and permanent crops, pastures and mixed farmlands, and grasslands.

In addition, urban sprawl has accelerated in coastal areas. However, the development of land and infrastructure at the coastal areas is vulnerable to climate change, e.g. the projected rise of the average sea level will increase the risks for coastal inundation and flooding from storm surges. Around 40 % of the European citizens currently live in coastal areas and a large share of the European tourism concentrates in the coastal areas and islands of Europe. In the past decades, there has been rapid land conversion for residential, touristic and recreational facilities and supporting transport infrastructure (e.g. highways, ports and harbours) (Map 4.2) (EEA, 2013b).

Map 4.2 Density of impervious cover across Europe in 2015 (left) and average annual change in soil sealing between 2006-2015 (right)



Source: (EEA, 2020e)



Source: (EEA, 2020a)

<u>Area of agricultural land under irrigation</u>

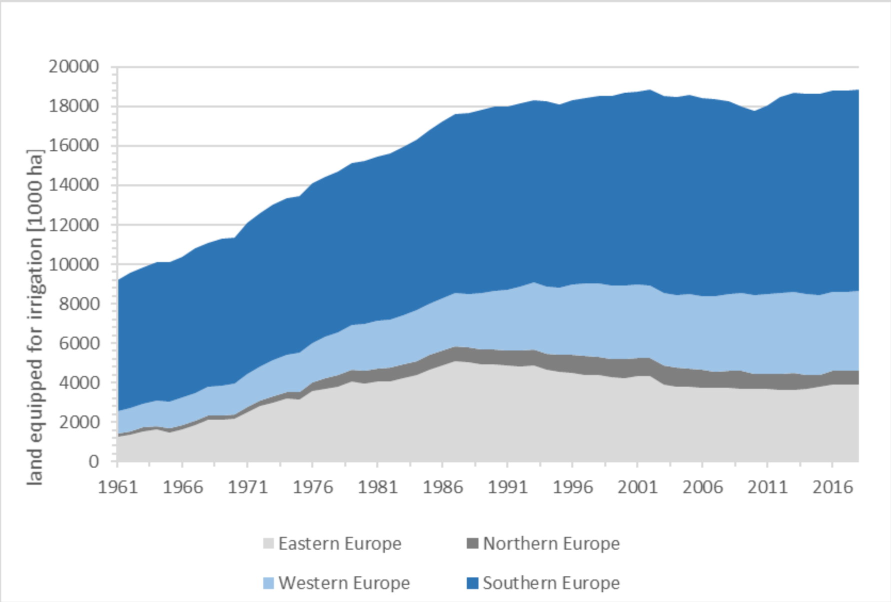
Agricultural land has expanded and intensified between 1990 and 2006; partly this occurred at the expense of high nature value farmland, pastures and marginal land. The period after 2006 has seen a reversal of the overall trend and the total agricultural land started to decline in Europe (EEA, 2017d). This decline can be related to the ongoing decline of the rural population, the 2006 CAP reform that (largely) decoupled production from payments, and the provision of relevant economic incentives by CAP to set aside or abandon existing agricultural land or cultivate it less intensively. Due to mechanisation and automisation, cultivation and management of large agricultural areas needs less manpower and labour effort per person nowadays. The decrease of total agricultural land has therefore not been substantial. Furthermore, significant conversions to agricultural land have been observed in some EU Member States (e.g. Germany, Czechia, Hungary, Baltic countries and Ireland). This could be potentially related to changing climate conditions that favour agricultural activities in northern latitudes of Europe, as well as to increased EU support through CAP for the newer Member States (EEA, 2017d).

In addition, farmers have used past economic incentives provided by the EU to expand the cultivation of crops with high water demands (e.g. cotton) also in water stressed areas, such as southern Europe. Around 60 % of all irrigated areas and 85 % of total irrigation abstraction in Europe takes place in southern Europe. This legacy is still putting high pressure on regional water resources, despite recent trends that show improvement in water intensity of crop production by 11 %

between 2005-2016 (EEA, 2019k). Figure 4.6 shows the increase in irrigable area in the four European regions since 1961.

There is a high likelihood of expansion of agricultural activities in central and northern Europe. In addition, the increased occurrences of droughts will increase irrigated areas in the future and intensify the pressure on local water resources, even in areas which are nowadays perceived as less threatened.

Figure 4.6 Irrigable area in the EU27+UK since 1961



Source: EEA, forthcoming report on Water and agriculture

Area of forested land and wetlands

In several Member States, including Finland, the Baltic countries, Poland, Hungary, Ireland and Portugal, there has been a significant conversion to forested land and woodland, resulting in the overall increase of forests in EU27+UK (EEA, 2017d). Furthermore, the area of water bodies and wetlands shows a small increasing trend between 2006-2012, which could reflect the implementation of policies related to nature protection, water retention, re-naturalisation and environmental restoration (EEA, 2017d).

Future outlook

The FP7 Volante project[11] "Visions of Land Use Transitions in Europe" concluded to a series of projections for land use change in Europe (Table 4.1). The key outcomes are that different drivers are expected to cause more urbanization, land uptake, land degradation, soil pollution, and loss of ecosystems. Furthermore, some parts of agricultural land will be abandoned, while other parts of agricultural land will be recultivated, including new areas of previous marginalised land, where

[11] https://cordis.europa.eu/project/id/265104

energy crops could be grown. Projections suggest that the total land occupied by crops will remain similar until 2040. Cultivation of crops is expected to become more intensive and sophisticated (e.g. precision farming) in the areas where farming prevails (EEA, 2017d).

Table 4.1 Relationship of global megatrends and the land system in Europe

Theme		**Global megatrend**	**Impact on land**	**Volante factsheet**
Social development	GMT1	Diverging global population trends	Land abandonment, recultivation	P3 Agricultural abandonment, recultivation and intensification V6 Agricultural abandonment
	GMT2	Towards a more urban world	Land take, urban sprawl, more transport infrastructure	P5 Drivers of change A12 Zoning for compact cities
	GMT3	Diseases and pandemics	(Redistribution of animal farming)	
Technology	GMT4	Accelerating technological change	Precision farming and irrigation	A7 Agricultural productivity increase A8 Bio-based economy and bioenergy
Economy	GMT5	Continued economic growth?	Land pressure, land grabbing, land degradation, soil pollution	A13 Climate change impacts with respect to flood protection
	GMT6	Increasingly multipolar world	Various	A15 Increased trade barriers for higher EU self-sufficiency
	GMT7	Intensified global competition for resources	Land grabbing, bioenergy cropping on marginal lands	P1 Displacement effects P5 Drivers of change
Environment	GMT8	Growing pressures on ecosystems	Loss of land-related ecosystem services and landscapes	A24 Ecosystem services
	GMT9	Increasingly severe effects of climate change	Erosion, flooding, desertification	A13 Climate change impacts with respect to flood protection A14 Climate change mitigation and agricultural emission taxes
	GMT10	Increasing environmental pollution	Soil pollution, land degradation	A6 Nitrogen and water quality
Governance	GMT11	Diversifying approaches to governance	Irrational land use transitions	P5 Drivers of change

Source: (EEA, 2017d)

4.3. Water consumption by agriculture

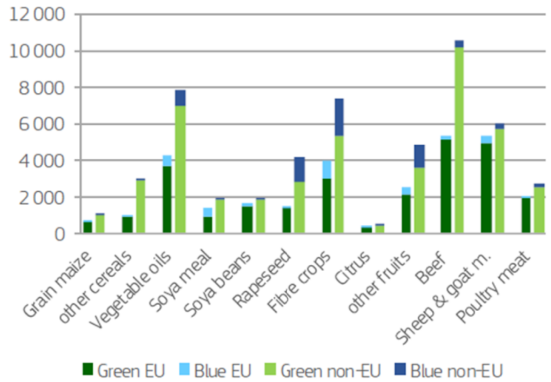
Agriculture contributes around 2 % of the GVA of the European economy and provides directly 4 % of total employment, without counting indirect jobs created in upstream and downstream activities. EU is the global leader of agri-food exports, which reached 138 billion € in 2018 (EC, 2019a). Imports of agricultural products are also important for the EU.

Water is an essential resource for agriculture. In areas with more temperate climates, agriculture is mostly rainfed, but irrigation is also applied to regulate seasonal water deficits and ensure satisfactory quality and yields of products. In drier climates, though, rainfed conditions can only provide part of the crop water requirements. Thus, additional water needs to be provided to enable the production of crops. Water is also needed for raising animals, covering their direct needs for consumption or the needs for growing their food and cleaning facilities. Aquaculture and forestry are also dependent on water availability, although they are not directly dependent on water abstractions.

Water abstraction in Europe for agriculture is very unevenly distributed: almost 90 % occurs in southern Europe, and only 10 % in the other parts of the continent. The area of arable land in Europe is around 113 million ha and its nearly 19 million ha is equipped for irrigation (irrigable area). Depending on the climatic conditions, the actually irrigated area is approximately 8 to 9 % of the total arable land. The shares of irrigated land are much higher in southern Europe, ranging from 28 % in Malta to 13 % in Spain and Portugal. Agriculture covers 40 to 60 % of the total water consumption in Europe, especially on irrigated land. Water consumption by agriculture shows the highest fluctuation throughout the year, since the demand for irrigation water rises sharply during spring and summer, especially in southern Europe. In southern Member States, agricultural water abstraction reaches approximately 80 % of total water abstraction (based on Eurostat data on agriculture (EEA, 2018b, 2019k).

The water footprint of different crop and meat products differs largely (Figure 4.7). The highest water footprint is observed for vegetable oils, fibre crops and fruits among crop products and for beef and sheep/goat meat among meat products. Crop and meat products which are produced in Europe are estimated to have a lower water footprint than the similar products imported in Europe from foreign countries, due to different climatic conditions, water management practices and environmental policy frameworks.

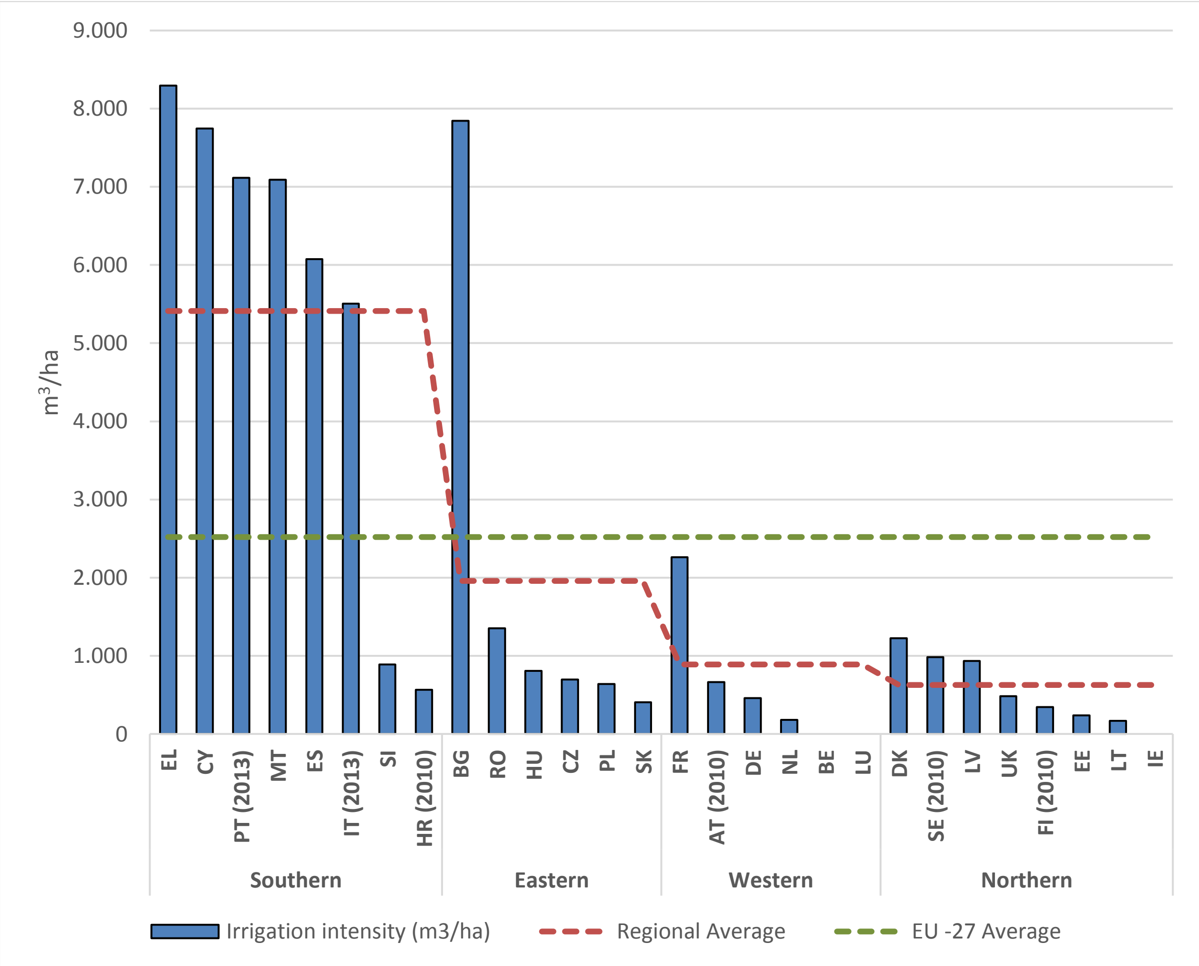
Figure 4.7 Water footprints of crop and meat commodities in the EU and in non-EU countries exporting to the EU (litre per kg of product).



Source: (EC, 2019e)

In general, the crop patterns in southern Europe include many crops with high water requirements (e.g. cotton, alfalfa, maize, fruit trees, vegetables) (Eurostat, 2019a; EEA, 2019k), which are cultivated there for various reasons, including favourable climatic and soil conditions, longstanding tradition and know-how (e.g. special equipment and trained professionals), current level of revenues (especially from fairly commercial/tradeable crops) and significant levels of self-consumption by households. Because of the low water availability and semi-arid conditions in many parts of southern Europe, the water demand of these crops is largely covered by irrigation. The irrigation abstraction per hectare exceeds 5,000 m^3 in most southern countries, as well as in Bulgaria. Values higher than 1000 m^3 are also observed in countries like Romania, Denmark and France (Figure 4.8).

Figure 4.8 Irrigation abstraction per hectare in Europe



Source: (EEA, 2019k, 2019l)
Note: Based on the data from 2016

The economic incentives for agricultural production , which were established by the EU and Member States for decades (e.g. farmers' CAP subsidies, low recovery of costs for agricultural water, VAT exemptions for agricultural water, special tax and social security regimes, etc.), have been a major driver leading to the expansion and intensification for irrigation in Europe. The switch to irrigated crops and more intense irrigation were perceived by farmers as ways to produce more harvest and gain more revenues, since irrigated yields are proportionately higher than rainfed yields. In addition, during the 1990s and 2000s the World Trade Organisation adopted serious reforms, which liberalised global trade. Stimulated global trade within a globalised economy has provided new opportunities and new markets for European agricultural products. However, after the 2006 CAP reform, part of the incentives was taken away to promote decoupling of payments from agricultural production. In most EU Member States this caused a slow-down or reverse in the expansion of irrigated areas.

Since 2002 the irrigated area has shrunk by 6 %, although the total utilised agricultural area expanded by 4 % in Europe. Nevertheless, in already water-stressed southern Europe, both agricultural land and irrigated area increased (+12 %) over the same period (EEA, 2018b).

A study of the climate change impacts shows that crop water requirements and crop water deficits have increased in many areas of southern and eastern Europe between 1995 and 2015. Furthermore, the growing season of crops is becoming longer, especially in northern and eastern Europe (EEA, 2016c, 2016a).

In recent years (2010-2017), the total water consumption by agriculture in Europe (EEA 38+UK) has decreased. However, in southern Europe water consumption increased in many countries, including Italy and Turkey, which are large consumers of agricultural water.

The following table (Table 4.2) presents the trends of water consumption per country (grouped in regions) for the period 2010-2017.

Table 4.2 Development of water consumption by agriculture in Europe (EEA 38+UK, 2010-2017)

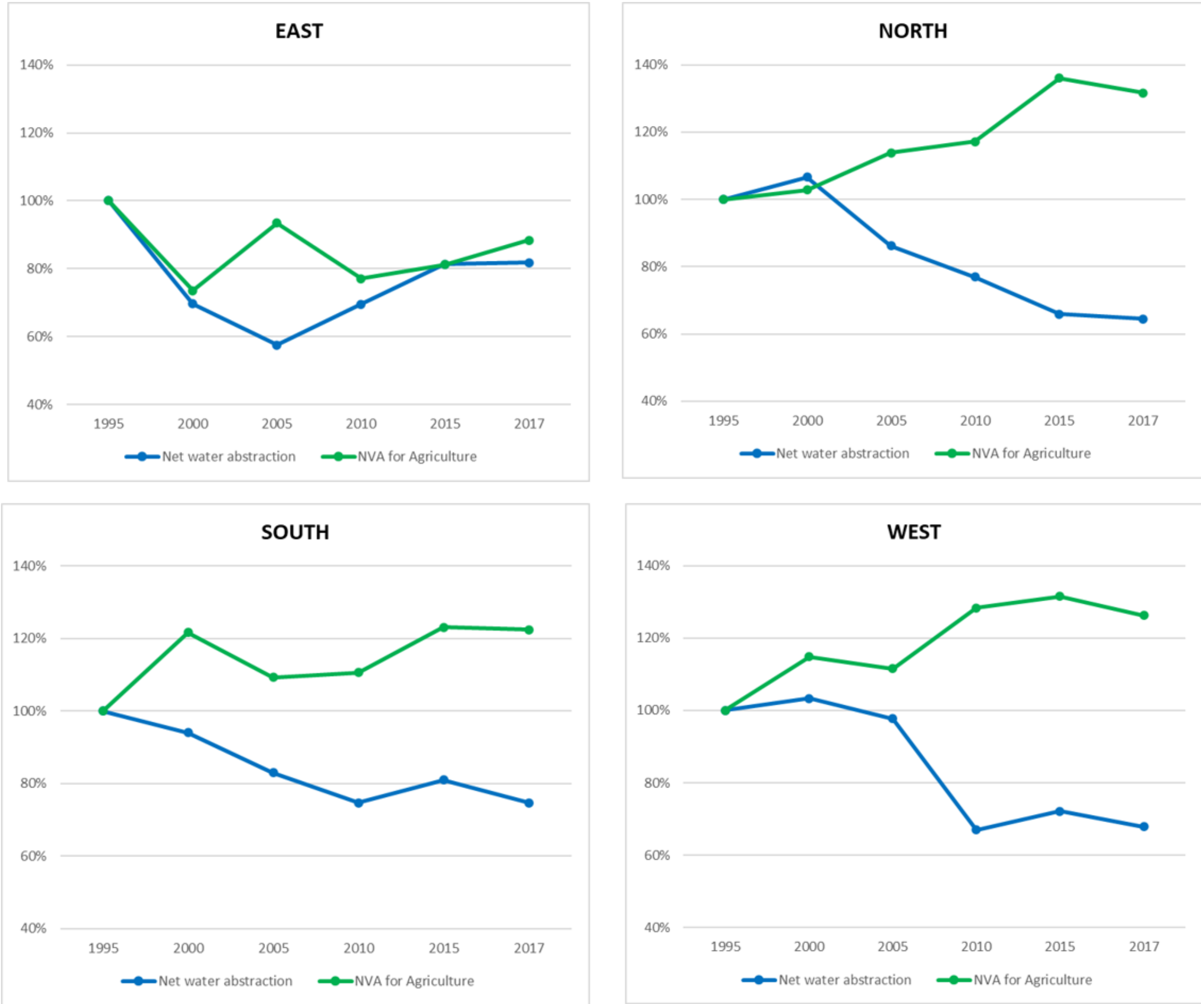
		Agriculture (NACE A)
CTY	UN-M49 GROUPS	2010-17
BG	Eastern Europe	Green
CZ	Eastern Europe	Green
HU	Eastern Europe	Red
PL	Eastern Europe	Green
RO	Eastern Europe	Red
SK	Eastern Europe	Green
DK	Northern Europe	Green
EE	Northern Europe	Green
FI	Northern Europe	Green
IE	Northern Europe	Red
IS	Northern Europe	Red
LT	Northern Europe	Green
LV	Northern Europe	Red
NO	Northern Europe	Green
SE	Northern Europe	Green
UK	Northern Europe	Green
AL	Southern Europe	Green
BA	Southern Europe	Red
CY	Southern Europe	Green
EL	Southern Europe	Red
ES	Southern Europe	Green
HR	Southern Europe	Red
IT	Southern Europe	Red
ME	Southern Europe	Red
MK	Southern Europe	Green
MT	Southern Europe	Red
PT	Southern Europe	Green
RS	Southern Europe	Red
SI	Southern Europe	Red
TR	Southern Europe	Red
XK	Southern Europe	Red
AT	Western Europe	Green
BE	Western Europe	Green
CH	Western Europe	Green
DE	Western Europe	Green
FR	Western Europe	Red
LI	Western Europe	Green
LU	Western Europe	Red
NL	Western Europe	Green

Data sources: (EEA, 2020j, 2019l; Eurostat, 2020f)

Note: Green bullet for decrease; Red bullet for increase

Moreover, the comparison of the total water consumption in the agricultural sector with its net value added (NVA) shows that trends for decoupling are already visible in northern, western and southern countries (Figure 4.9).

Figure 4.9 Comparison of regional trends between water consumption and economic growth for the agricultural sector.



Data sources: (EEA, 2020j, 2019l; Eurostat, 2020f, 2020a)
Note: Blue line – Water consumption volume in million m^3 (indexed 1995=100); Green line – Net Value Added in million Euros (indexed 1995=100)

__Future outlook__

A recent outlook study (EC, 2019e), based on agro-economic modelling and consultation with stakeholders, international institutions and experts, suggests that the agricultural land in EU is expected to decrease slightly by 2030 with the current agricultural and trade policies. This is in line with the findings of the recent FP7 Volante project, which also concluded that a limited reduction in the size of agricultural areas is the most probable scenario by 2030. Cereals, fodder and pasture are expected to decrease, whereas oil seeds, pulses and other crops are expected to increase. The study also indicates that the production of milk and beef could decrease in the EU.

Projections show that the warming climate could cause the growing season to become longer in most European regions. As a result, crops growing in warmer conditions could be cultivated in northern latitudes, and crop cultivation in certain areas of southern Europe (e.g. Spain), could shift into the winter season (EEA, 2016c, 2016a). Moreover warmer climate conditions earlier in spring and later in autumn may enable crop cultivation for longer periods of time and possibly with multiple harvests. As a result, climate change could increase the crop water deficits and the irrigation water requirements could increase more than 20% in southern Europe (Konzmann et al., 2013). An overall increase is projected across all Europe (EEA, 2016b). Regarding future crop yields, the projected patterns show high variability with location, crop type, climate and management conditions. Overall, a rise in productivity is expected in northern Europe and a decrease in southern Europe, although this is not uniform across all crop types (EEA, 2016j).

The potential water saving from individual technical measures for irrigated agriculture differs largely, and it relies upon site-specific conditions (e.g. soils, crop types) and applied technologies. An indication of potential water savings is provided in Table 4.2. It has been estimated that the potential water savings in irrigated agriculture could exceed 40 % of the total abstractions, applying combinations of the above measures (Dworak et al., 2007).

Table 4.2 Potential water saving of indicative technical measures in the agricultural sector

Measure	Potential water saving
Upgrade of conveyance infrastructure (e.g. closed pipes replacing open trenches)	10-25%
Change towards irrigation methods with higher application efficiency (e.g. drip micro-irrigation replacing furrow irrigation)	15-60%
Changes in irrigation practices (e.g. rescheduling irrigation; mulching)	30%
Crop restructuring (e.g. drought-resistant crops replacing water-demanding and drought-sensitive crops)	50%
Irrigation with reclaimed water	10%

Source: (Dworak et al., 2007)

Furthermore, as part of the Blue2 project, several scenarios were developed for potential water saving measures for irrigated areas in southern European countries (Benitez Sanz et al., 2018). The main outcomes were that up to 5 % of the annual renewable freshwater resources in each river basin could be saved, if all planned irrigation efficiency measures from the RBMPs are implemented. In comparison, 10 % of the annual renewable freshwater resources could be saved if all feasible technical measures are implemented, regardless of their total cost (e.g. upgrade of conveyance systems to reduce leakages, seepage and evapotranspiration losses; application of the most efficient irrigation technology per case). Although these gains are considerable, taking into account the significant water stress levels in many southern river basins (often exceeding 30 % of the annual renewable freshwater resources), they are not sufficient to reverse the water scarcity conditions only on their own. In addition, in order to capitalize the aforementioned potential water savings, which are feasible by improved irrigation systems and equipment, both investments and supporting actions are required (e.g. adjustment of end-users' management practices).

4.4. Water consumption by electricity production

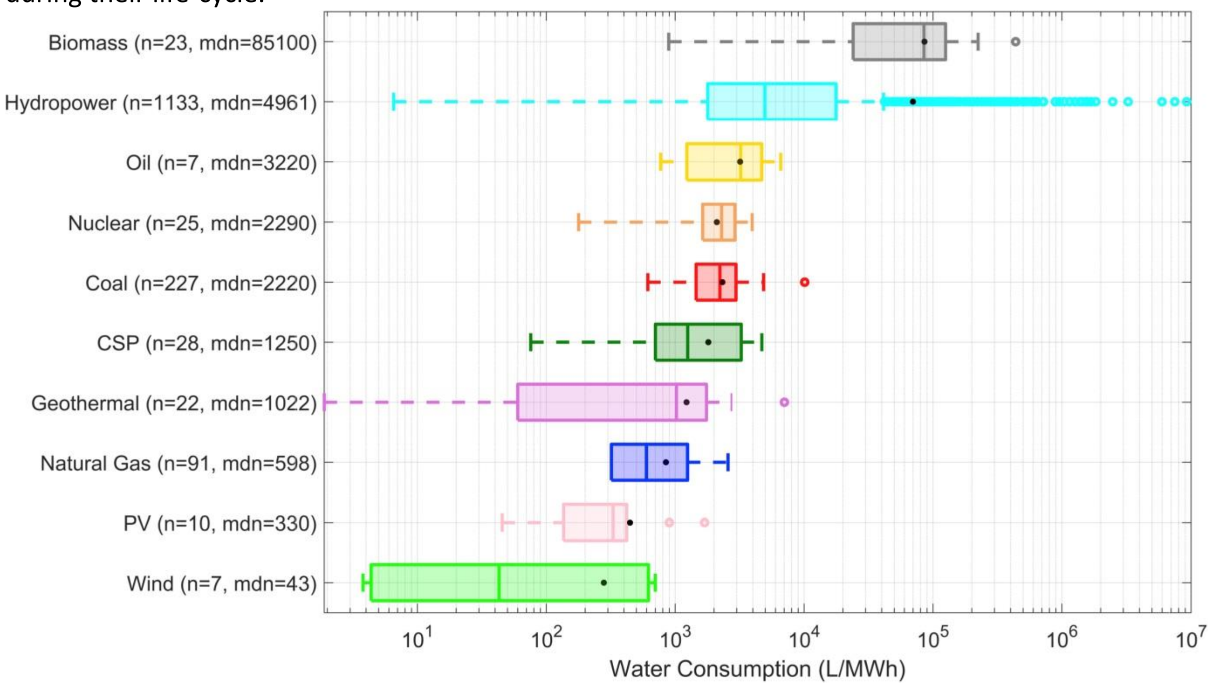
The energy sector comprises of a variety of subsectors and technologies. Focusing only on the production of electricity, the different technologies can be roughly categorised into combustion plants and nuclear stations, hydropower and renewable energy sources.

Combustion plants and nuclear stations need water to cool off the hot steam, which is created from burning fuel and used to rotate turbines. The discharge of cooling water to the environment causes thermal pollution to the receiving water bodies, resulting -*inter alia*- in risk for fish populations to suffer from hypoxia. Thermal power covers a significant share of the electricity consumption in Europe (60 %). Cooling water for electricity production is responsible for nearly 18 % of total water consumption in Europe in 2017. The use of cooling water is relatively high in western and eastern Europe. France and Germany have the highest consumption of cooling water; together they make up 45 % of Europe's total consumption (EEA, 2018b).

Hydropower plants using freshwater are usually combined with the construction of dams, reservoirs and diversions. Stored water is released and rotates the turbines which generate electricity. Almost all of the water released by hydropower plants is directly returned to the environment. The amount of water consumed by hydropower plants is considered negligible, but it actually depends on the site and the technology configuration, and there is no overall estimate for its range (IEA and OECD, 2010). Hydropower installations can have significant hydromorphological impacts, as they impede the natural water and nutrient cycle, and they create obstacles for the transport of freshwater biodiversity, sediments and substances. Generation of hydropower from large and small dams has increased substantially during the last century, but the growth has slowed down in recent decades, because the most productive locations are already occupied and because environmental permitting in Europe has become more comprehensive, following the adoption of the WFD (permitting procedure under Art. 4.7). However, hydropower installations have multiplied in areas such as the West Balkans. More than half of the electricity production in Albania, Austria, Croatia, Iceland, Luxemburg and Montenegro comes from hydropower (EEA, 2018b).

Renewable energy is largely generated by wind turbines and solar panels. These technologies show much lower needs for water consumption during their whole life-cycle than the conventional forms of energy (Figure 4.10). Furthermore, where favourable conditions are present, geothermal power is a potential source of heating in buildings. In general, exploitation of geothermal power is not considered a consumptive use. In addition, electricity production from biomass also considered a renewable form of energy. This fuel type is more water-dependent, though, because the raw material for this fuel type originates from crops and plant residues that have grown with rain and partly irrigation water.

Figure 4.10 Water consumption per unit of generated energy for different types of energy sources during their life-cycle.



Source: (Jin et al., 2019)

Note: CSP stands for Concentrated Solar Power; and PV for Photovoltaics. Hydropower is not a considered a consumptive use in this analysis, although it is shown as such in the above graph returns are generally considered similar to abstractions. Water consumption is visualized on a log scale. The annotation mdn gives the median value of water consumption for each fuel type. Circles represent the outliers, while the dots represent the average for each power type.

More than half of the final energy consumption in the EU occurred in the industrial sector (32%) and households (24%) in 2018 (Eurostat, 2020g). Therefore, both sectors not only consume large amounts of water directly, but also indirectly, through the energy that needs to be generated to cover their energy demand. As the energy consumption is falling across Europe (-10% between 2005 and 2016) and the less water-demanding renewable energy sources take up larger shares in the total energy mix (from 7% in 2005 to 14% in 2016), the energy production and the corresponding water consumption are generally decreasing (EEA, 2018b).

The following table presents the recent trends of water consumption for electricity production per country (grouped in regions) for the period 2010-2017 (Table 4.3). It shows that water consumption is decreasing in the majority of countries. This is related with upgrades of existing power plants, where aged equipment is replaced with new and more efficient installations, as well as with the decarbonisation of the energy system, as renewable sources of energy are increasing their shares in the energy mix (EC, 2015c).

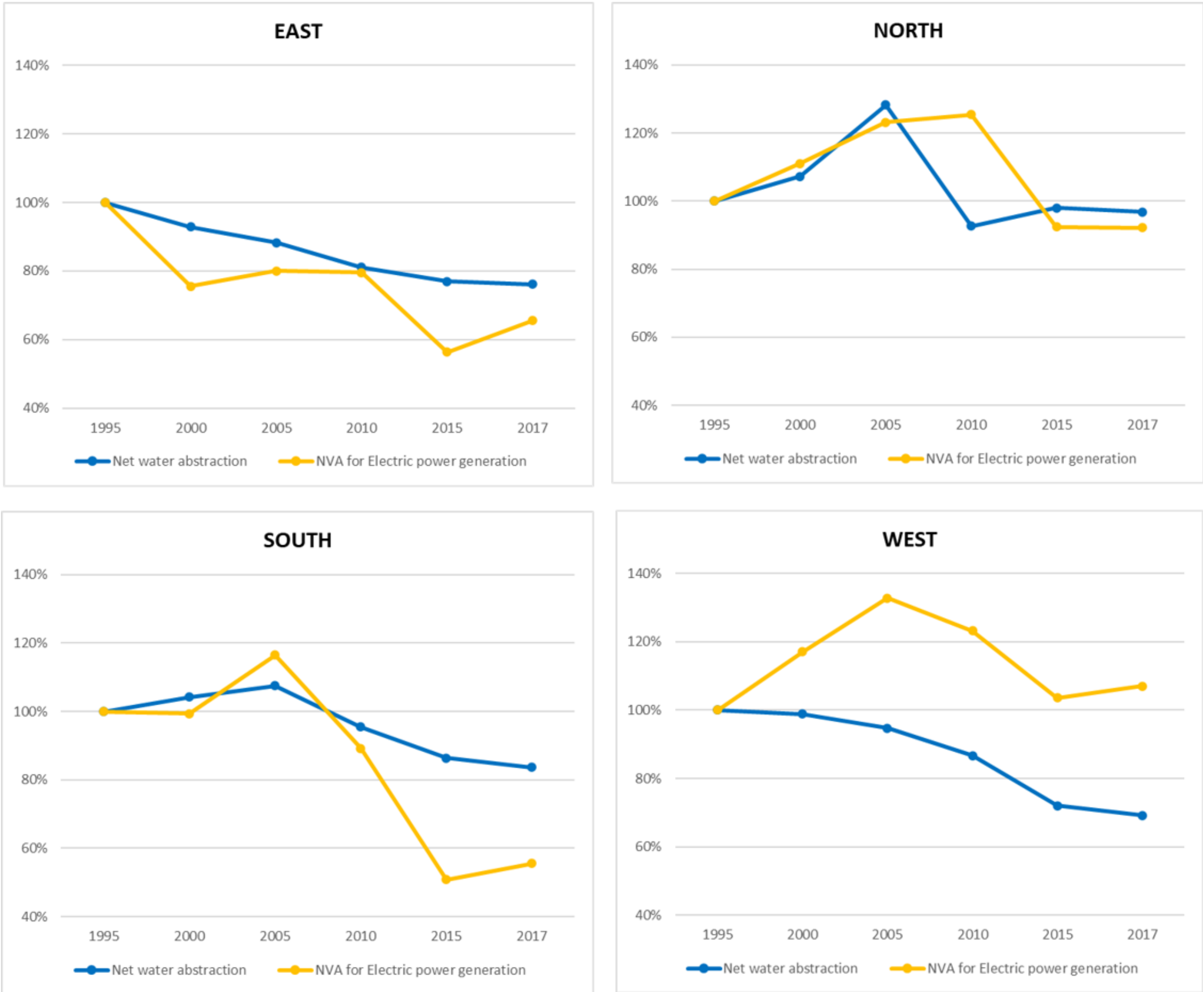
Table 4.3 Development of water consumption by electricity production in Europe (EEA 38+UK, 2010-2017)

		Energy (NACE D)
CTY	UN-M49 GROUPS	2010-17
BG	Eastern Europe	● (red)
CZ	Eastern Europe	● (green)
HU	Eastern Europe	● (green)
PL	Eastern Europe	● (green)
RO	Eastern Europe	● (green)
SK	Eastern Europe	● (red)
DK	Northern Europe	● (green)
EE	Northern Europe	● (red)
FI	Northern Europe	● (green)
IE	Northern Europe	● (red)
IS	Northern Europe	● (red)
LT	Northern Europe	● (green)
LV	Northern Europe	● (red)
NO	Northern Europe	● (red)
SE	Northern Europe	● (green)
UK	Northern Europe	● (red)
AL	Southern Europe	● (red)
BA	Southern Europe	● (red)
CY	Southern Europe	● (green)
EL	Southern Europe	● (red)
ES	Southern Europe	● (green)
HR	Southern Europe	● (green)
IT	Southern Europe	● (green)
ME	Southern Europe	● (red)
MK	Southern Europe	● (green)
MT	Southern Europe	● (green)
PT	Southern Europe	● (green)
RS	Southern Europe	● (red)
SI	Southern Europe	● (red)
TR	Southern Europe	● (green)
XK	Southern Europe	● (red)
AT	Western Europe	● (green)
BE	Western Europe	● (green)
CH	Western Europe	● (green)
DE	Western Europe	● (green)
FR	Western Europe	● (green)
LI	Western Europe	● (red)
LU	Western Europe	● (green)
NL	Western Europe	● (green)

Data sources: (EEA, 2020j, 2019l; Eurostat, 2020f)
Note: Green bullet for decrease; Red bullet for increase

The comparison of the total water consumption in the energy sector with the net value added (NVA) generated in the economy from that sector shows that trends for decoupling are already visible in western countries (Figure 4.11). Nevertheless, the positive sign is that water consumption for electricity generation is decreasing in all regions.

Figure 4.11 Comparison of regional trends between water consumption and economic growth for the energy sector.

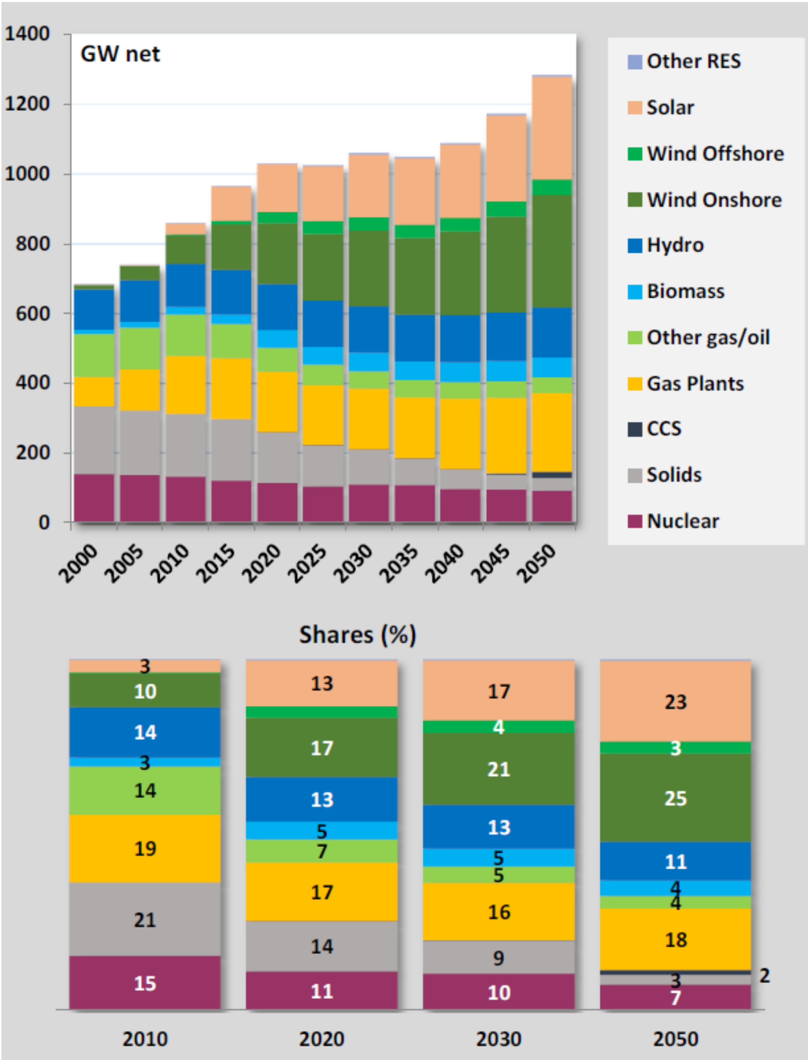


Data sources: (EEA, 2020j, 2019l; Eurostat, 2020f, 2020a)
Note: Blue line – Water consumption volume in million m3 (indexed 1995=100); Yellow line – Net Value Added in million Euros excluding renewables (indexed 1995=100)

Future outlook

A recent outlook study (EC, 2015c) established an EU reference scenario for energy, transport and greenhouse gas emissions up to 2050. The study reflects the long-term EU strategy for the decarbonisation of the EU economy, including the production and consumption of energy. The installed capacity of the energy system is expected to grow by almost 30 %, while this increase will be driven by the rapid expansion of renewable energy sources, and the replacement of coal and petroleum with natural gas. Investment are expected to focus by 70 % on new installations and by 30 % on upgrades and retro-fitting of existing installations (Figure 4.12). The replacement of obsolete with modern thermal power plants, and the construction of combined heat and power systems will result in higher efficiency in the use of input fuels. Furthermore, the retro-fitting of outdated installations of photovoltaics and wind turbines with new generation technology on the same site is considered an economic and feasible solution, with is expected to cause much lower environmental impacts.

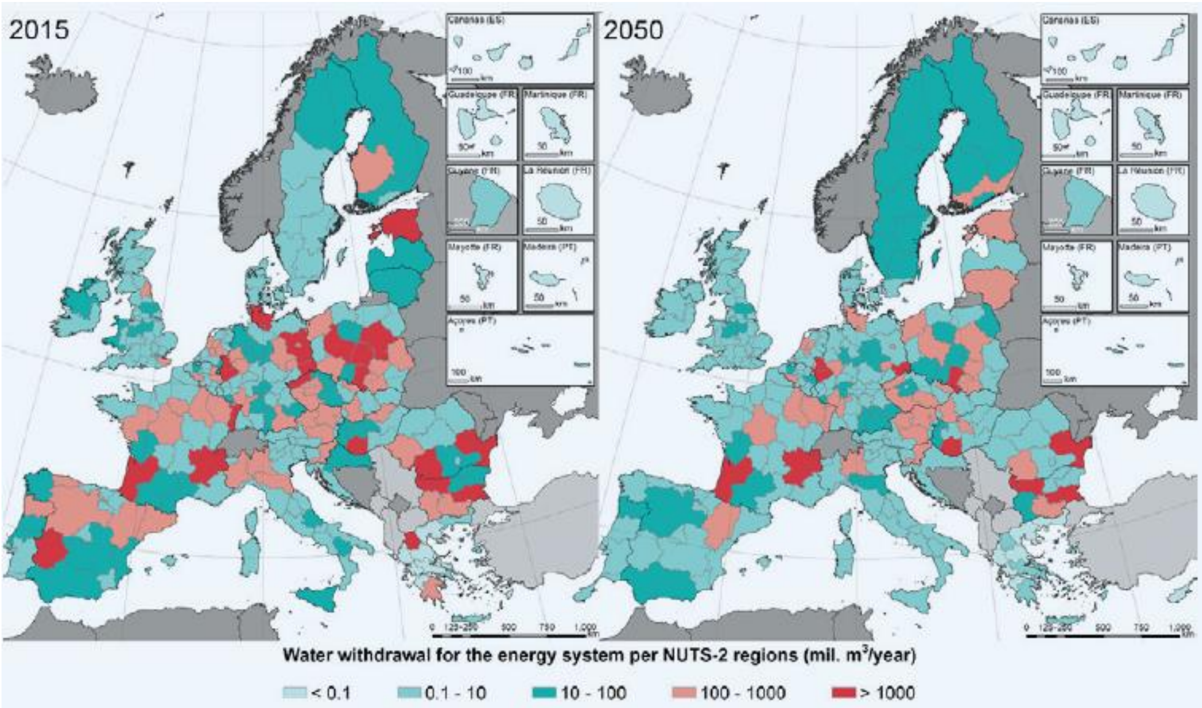
Figure 4.12 Outlook of installed capacity in EU per energy source



Source: (EC, 2015c)

Due to the projected decarbonisation of the EU energy system and the announced closures of nuclear and coal-fired power plants and coal mines throughout Europe, water abstraction and consumption in the energy sector are expected to decrease significantly by 2050 (Hidalgo González et al., 2019). The estimated amount of water abstracted by the energy sector (for primary electricity production, oil refining, and cooling of thermal power plants) could decrease up to 38 % by 2050 (Map 4.3). Water consumed by the whole energy sector is expected to decrease by 27 % (Hidalgo González et al., 2019).

Map 4.3 Change in water abstraction by the energy sector between 2015-2050



Source: (Hidalgo González et al., 2019)

Achieving a carbon neutral Europe by 2050 without increasing the pressure on freshwater resources, would require a shift to a low carbon energy system considering not only the expected gains in CO_2 emissions, but also the water needs of the replacing energy technologies. Some low-carbon technologies could use water more intensively than the system they replace, such as biofuels, hydrogen, and Carbon Capture Sequestration systems (Hidalgo González et al., 2019). For example, according to the European Commission Long Term Strategy, 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 1.6-2.3 TWh from hydrogen would consume around 30 % of the total water consumed in the energy sector today (Moya et al., 2020; Hidalgo González et al., 2019).

4.5. Water consumption by industry and mining

The manufacturing industry and mining are two different sectors, which both require water use mainly for processing activities before an end-product is delivered.

The manufacturing industry includes a variety of different sub-sectors, including food and beverages, textiles, chemicals, pulp and paper, iron and steel. The above sub-sectors need to use water for cooling purposes, processing activities, washing and cleaning of facilities and equipment, and water that is integrated into products. However, the returned cooling water can cause problems with thermal pollution and hypoxia. Furthermore, industrial discharges can be highly contaminated and then require appropriate treatment before discharge. In the case of washing and cleaning water consumption can be considered low to negligible, but discharged water may need treatment because of its nutrient and organic content (EEA, 2018b).

Mining and quarrying include a diversity of activities, such as mineral extraction (e.g. coal, ores, petroleum, gas) and preparatory actions for the supply of materials to the markets (e.g. crushing, grinding, cleaning, drying, sorting, concentrating ores, liquefaction of natural gas, agglomeration of solid fuels). Groundwater is pumped for the drainage of the mining and quarrying sites. Furthermore, water is abstracted and used during processing (e.g. rock crushing, dust depression). Water is returned to the environment as part of the de-watering process. These discharges contain pollutants, depending on the processing method. In 2017 the share of water abstraction for mining was the highest in western (40 %) and southern Europe (22 %) (EEA, 2018b).

It is observed that water consumption by the manufacturing industry and mining and quarrying is generally decreasing with the exception of many Balkan and eastern European countries (Table 4.4). This trend can be attributed to the modernisation of the production processes, technological improvements, more efficient methods, water recycling and reuse. Furthermore, water consumption by the industrial and mining sector has also declined, because of the de-industrialisation of specific regions in Europe, since the industrial production has been partly transferred abroad. At the same time, the overall production of the sector shows an increase (+9 %) between 2010 and 2017 (Eurostat, 2020e; EEA, 2018b).

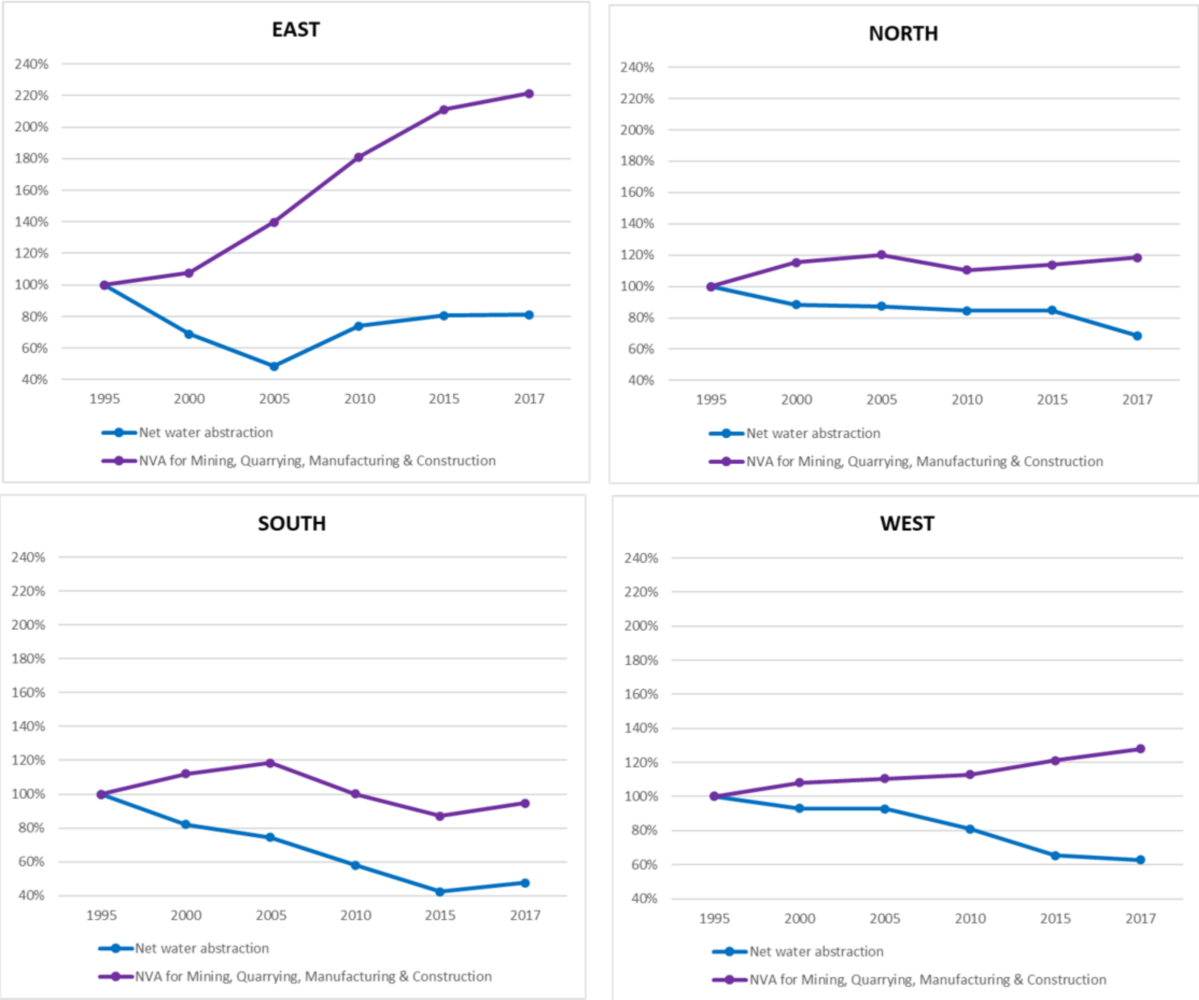
Table 4.4 Development of water consumption by industry and mining in Europe (EEA 38+UK, 2010-2017)

		Manufacturing, Construction, Mining & Quarrying (NACE BCF)
CTY	UN-M49 GROUPS	2010-17
BG	Eastern Europe	🔴
CZ	Eastern Europe	🟢
HU	Eastern Europe	🔴
PL	Eastern Europe	🔴
RO	Eastern Europe	🔴
SK	Eastern Europe	🟢
DK	Northern Europe	🟢
EE	Northern Europe	🟢
FI	Northern Europe	🔴
IE	Northern Europe	🔴
IS	Northern Europe	🟢
LT	Northern Europe	🔴
LV	Northern Europe	🟢
NO	Northern Europe	🟢
SE	Northern Europe	🟢
UK	Northern Europe	🟢
AL	Southern Europe	🔴
BA	Southern Europe	🔴
CY	Southern Europe	🟢
EL	Southern Europe	🔴
ES	Southern Europe	🟢
HR	Southern Europe	🔴
IT	Southern Europe	🟢
ME	Southern Europe	🔴
MK	Southern Europe	🟢
MT	Southern Europe	🔴
PT	Southern Europe	🟢
RS	Southern Europe	🔴
SI	Southern Europe	🟢
TR	Southern Europe	🔴
XK	Southern Europe	🔴
AT	Western Europe	🔴
BE	Western Europe	🟢
CH	Western Europe	🔴
DE	Western Europe	🟢
FR	Western Europe	🟢
LI	Western Europe	🔴
LU	Western Europe	🔴
NL	Western Europe	🟢

Data sources: (EEA, 2020j, 2019l; Eurostat, 2020f)
Note: Green bullet for decrease; Red bullet for increase

The comparison of the total water consumption in the industrial sector with the net value added (NVA) generated in the economy from that sector shows that trends for decoupling are already visible in eastern, northern, and western countries. In southern countries, decoupling trends are not visible (Figure 4.13).

Figure 4.13 Comparison of regional trends between water consumption and economic growth for the industrial sector.



Data sources: (EEA, 2020j, 2019l; Eurostat, 2020f, 2020a)
Note: Blue line – Water consumption volume in million m3 (indexed 1995=100); Red line – Net Value Added in million Euros (indexed 1995=100);

In (Bernhard et al. (JRC, 2020b), the average increase of water use efficiency in the industry sector between 2000 and 2015 is estimated at 2.2 % per year. This is roughly in agreement with Figure 4.16 (Dworak et al., 2007) provide an estimate of potential water savings in the industry between 15 and 90 %, with 43 % as central estimate.

Future outlook

The difficulty in getting more reliable estimated about water consumption and potential savings in this sector can be linked to the difficulty to obtain such information from enterprises, because of the diversity of the sub-sectors and technologies involved and because such data are considered as strategic information (Benitez Sanz et al., 2018; TNO et al., 2014).

The development of a partial inventory of three categories of cleaning equipment in industry (Benito et al., 2009) showed that the potential difference between the most and the least water-efficient techniques could range by a factor of 6. This may offer room for improvement, but the actual potential savings are extremely case specific.

4.6. Public water supply

Public water supply includes water services to meet the water demands for drinking, washing, cleaning, sanitation, cooking, home gardening, etc. in residential and commercial areas and in businesses. It also includes tourism and, sometimes, water for the industrial or the agricultural sector. The public water supply industry consists of utilities that abstract water from the environment, apply treatment to remove hazardous substances and pathogens, and supply the treated water to the end users. Furthermore, wastewater is collected and treated to remove organic substances, nutrients and pathogens, and discharged to the environment. In 2017, households accounted for over 60 % of the total public water supply. In 2017, around 50 % of public water supply took place in southern Europe, which is associated with the impact of tourism in this region (EEA, 2018b).

Public water supply is often faced with water quality issues in the water sources, such as salinisation in coastal areas, as well as problems with nitrates, sulphates, heavy metals, pesticides, pharmaceuticals, and other contaminants. The WFD requires that all Member States establish safeguard zones for drinking water protection and the Drinking Water Directive stipulates the quality standards for supplied water, to ensure mitigation of risks for human health.

In 2017, the average water consumption of households in Europe was estimated at 147 litres/day/person[12]. The daily minimum to meet basic human needs is estimated at 50 litres/day/person (Gleick, 1996) so the European average is comfortably above that threshold. Nevertheless, the average water supply to European households varies substantially on a national level, e.g. 115 litres/day/person in Belgium to 265 litres/day/person in Spain. Bernhard et al. (JRC, 2020b) have collected water use data of households for the period 2000 to 2013 at NUTS3 level. Aggregated to four categories of regions, based on climate and income, they find water uses varying between 112 to 159 litres/day/person; with the lowest values in cool/low income areas, and the highest in warm/high income areas.

Water leakages are a major concern, because they mean extra pressure on the water sources without actual benefit to the users, as well as wasted energy and resources for pumping and treating. Thus, they result in financial losses for the water providers and they may affect the affordability of the water services through higher billing. In major European cities, such as Athens, Paris, Istanbul or Madrid, drinking water may be tapped from very distant sources, which sometimes lie 100-200 km away (EEA, 2018a). The length, the operation and the maintenance of the pipes affects the level of leakages. It is estimated that the average leakage rate of the drinking water distribution networks across Europe is approximately 2 171 m^3/km/year (or an equivalent of 23 % of all water distributed by EurEau members) (EurEau, 2017). A review of cases studies across Europe (EC, 2013b) also indicated that the physical losses of the drinking water distribution networks could range between 10 % and 72 % of the abstracted volume.

Due to the combination of increased pricing, water-saving technologies and measures, and awareness campaigns, Europe has seen significant reductions in public water supply for households between 1990-2017 (-16%), despite the increase of the European population, which occurred in

[12] Calculated as the ratio of the total volume of household water consumption and the total population in EEA 38+UK

parallel. However, southern Europe did not follow the same trend, as there was an increase in public water supply for households by 10 % over the same period (EEA, 2018b).

Future outlook

(Dworak et al., 2007) estimated that domestic water use was feasible to reduce by 50% or more. Furthermore, Benito et al. (2009) estimate the potential water savings in households at 32% by using more water-efficient household appliances, and at 20% by using more water-efficient toilets and showers alone.

Increasing population and changes in household types (i.e. more single households, which show higher water needs on average) are expected to increase the demand for public water supply. In addition, the role of household income is ambiguous. On the one hand, increased income has led traditionally to the adoption of better living standards and has been considered as a factor increasing water use per individual. On the other hand, nowadays, higher household income can result in more rapid access to novel and more water and energy efficient household appliances, better maintenance and timely replacement. Thus, it could be a factor contributing to lower water consumption in households.

4.7. Water consumption by tourism and recreation

Tourism and recreation is a special sub-sector, which is supplied with water from public water supply, and it includes various types of water uses, such as water use for hotel and accommodation services, food and restaurant services, spas, saunas and swimming pools, golf courses, parks and urban green spaces, outdoor sports and leisure activities at natural landscapes. Water quality can be an important concern for this sub-sector because it requires the supplied water needs to meet different types of criteria, e.g. fit for human consumption and skin contact, suitable for bathing, as well as aesthetic criteria ("landscape beauty"). For example, eutrophication or revelation of embankments, because of low flows and draw-down, can have negative experience to visitors (EEA, 2018b).

As the tourism industry has risen in the past decades, millions of people within Europe and abroad are moving away from their permanent residence to visit popular destinations. It has been estimated that this mobility accounts for around 9 % of the annual water consumption of the accommodation and food service sector in Europe (EEA, 2018b). The most important tourist attractions in Europe are large cities, such as Paris, London, Brussels, Rome, and the coastal areas and islands of the Mediterranean, the Baltic, the North Sea or the North East Atlantic. Currently, Europe attracts 50 % of the global international tourist arrivals, with nearly 20 % of them arriving in the Mediterranean (World Tourism Organisation, 2017). Tourism in Europe reached record-levels over the last decade. It should be noted that tourism activities in the Mediterranean peak during the summer season, similarly to agricultural activities. This results in high levels of seasonal water stress. It is estimated that the annual number of tourists who visit the Mediterranean areas per year is 16 times higher than the permanent population of these areas, while water consumption of tourists is two to three times higher than local demands (Iglesias et al., 2007). In the last decade, the number of nights spent by tourists in Europe increased by 30 % in southern Europe, whereas there was no significant change in other parts of Europe (Eurostat, 2020b). Over the same period water abstraction for tourism almost doubled. The local and national economies of many southern countries (e.g. Cyprus, Greece, Malta, Spain, Turkey) are largely dependent on tourism.

Future outlook

Future development of tourism will rely on health considerations related to external shocks like Covid-19, and changes in the working and business environments. Technical water saving measures which can be implemented in the tourism sector are similar to those for households. However, estimating the potential water savings for tourism remains difficult, as little information is available and the future development of this sector is not clear. The water saving potential for tourism has been estimated around of 188 million m^3 per year (Dworak et al., 2007).

4.8. Environmental and socio-economic impacts from water consumption

4.8.1. Environmental impacts

Abstraction is considered a significant pressure, affecting up to 17 % of the total groundwater body area and 10 % of the total river length in EU27, Norway and the UK in 2016. However, the total groundwater body area and the total river length, which are affected by significant pressure from water abstraction, are much higher in water-stressed areas of southern Europe (e.g. Cyprus, Malta, eastern Greece, southern Italy and south-eastern Spain), reaching 26 % and 13 %, respectively (EEA, 2018c). In addition, water abstraction by any sector is reported as a significant pressure for surface and groundwater bodies in up to 77 % of all river basin districts of Europe. The results are provided per sector in Table 4.5.

Furthermore, 62 % of rivers, 51 % of lakes, 61 % of transitional waters and 51 % of coastal waters were not in good ecological status in 2015 (EEA, 2018c) and 84 % of freshwater habitats were not in favourable condition in 2015 (EEA, 2016d). Specifically for wetlands, it is estimated that more than 60% of them vanished before the 1990s. The lost area of wetlands has overall decreased since the 1990s, but this development seems to have stalled between 2006 and 2012 (EEA, 2020b).

Table 4.5 Extent of significant pressures from water abstraction by sector using water

Driver/Pressure	% of RBDs with affected SWBs or GWBs	Member States with significantly affected SWBs >10 % in number	Member States with significantly affected GWBs >10 % in number
Agriculture – Abstraction	42.8 %	Cyprus, Spain, France, the Netherlands, Bulgaria	Cyprus, Hungary, Spain, Greece, Malta, Italy, France, Belgium
Public water supply – Abstraction	57.2 %	Spain, Cyprus, France	Hungary, Luxembourg, Spain, Malta, France, Belgium
Industry – Abstraction	40.1 %	France	Hungary, Spain, Belgium
Energy cooling – Abstraction	11.2 %	-	Belgium

Source: (EEA, 2018c)

Although the volumetric pressure on renewable freshwater resources has started to decline (Section 5.1), significant improvements are not yet visible in the quantitative status of water bodies, partly because recovery can be a slow environmental process, and also because climate change and socio-economic development can offset volumetric gains and aggravate local pressures. High attention is needed, when implementing water efficiency measures, to avoid adverse impacts from rebound effects. There are signs that past efficiency gains in specific European river basins have already been offset, due to expansion of irrigated land and more intensive use by other sectors.

The main impacts of water abstraction on groundwater bodies are deterioration of the water balance and lowering of the groundwater tables, saline intrusion, enhanced pollution with chemicals and nutrients, and a poor condition of groundwater-associated surface waters and groundwater dependent terrestrial ecosystems. The main impacts of water abstraction on surface water bodies are the alteration of habitats due to hydrological or morphological changes, as well as the enhanced pollution with chemicals, nutrients and organics (EEA, 2018c).

In principle, the deterioration of the quantitative status of groundwater bodies can be linked with all the above environmental impacts. Even though the link to the different types of pollution (e.g. chemicals, nutrients, organics) may seem less obvious, it is explained by the following fact: Reduced water quantity in groundwater may result in lower dilution of pollutants, which increases their observed concentrations and, subsequently, increases the risk of exceedance of environmental quality standards (EQSs).

Furthermore, because of the hydraulic connectivity between groundwater and surface waters, where this occurs, groundwater pollution problems may propagate to surface water pollution (e.g. eutrophication; toxic substances/solutions). In addition, the drawdown of the groundwater tables can cause lower inflows to associated streams and lakes, and in extreme cases complete dry-out. Lower flows or stagnation of associated surface waters increases the occurrences of water quality problems. Both quantity and quality issues, as well as their combination, result in ecological problems in surface waters. The ecological functions of individual species of flora and fauna, as well as ecological processes in aquatic and terrestrial ecosystems (e.g. wetlands, estuaries, riparian zones), can be altered or disrupted, leading to the decline of species populations and the degradation of biodiversity.

Box 4-3: Ecological impacts of over-abstraction on wetland and riverine ecosystems in Spain

Sources: (Arroita et al., 2015; Benejam et al., 2010; De Stefano et al., 2015; EC, 2019c; Green et al., 2016; Muñoz-Reinoso, 2001; OECD, 2019, 2015; WWF, 2006, 2016; UNESCO, 2020)

Unauthorised water abstraction from groundwater is considered a significant problem in Spain. It is estimated that wells and boreholes without a permit by the competent river basin authority exceed 500 000 and, potentially, they account for 40 to 50 % of total groundwater abstractions. Furthermore, Spanish authorities have detected cases of licensed users, who are abstracting more than their allocated quota. Unauthorised water abstraction in Spain has been mainly driven by uncontrolled expansion of irrigated agriculture, urban developments and tourism facilities (e.g. golf courses). The problem has existed for decades, leaving a legacy of over-exploited aquifers across the country. The problem is also related to the existence of “senior water rights” (i.e. old water rights granted decades ago), which have not been revised to account for updated studies on water balances and water needs. Over-abstraction has impacted various riverine and wetland ecosystems.

The Doñana National Park is an important coastal wetland, designated as UNESCO World Heritage site, which lies at the delta of the Guadalquivir River and covers 54,252 ha of lagoons, salt marshes, fixed and mobile dunes, scrub woodland and maquis. Over the past decades, there have been land conversions for irrigated agriculture and touristic facilities in the periphery of the park.The expansion of irrigation has been particularly driven by the expansion of rice and strawberry fields. Both cultivations require a high amount of irrigation, and their production is largely exported to foreign countries. Over-abstraction for irrigation has resulted in the decline of the groundwater tables in several parts of the region, the depletion of temporary ponds, the decrease of local stream flows the reduction of groundwater recharge. In coastal areas, the groundwater-sea water equilibrium has been distorted, resulting in saline intrusion. The Doñana area is also suffering from nutrients and chemicals released from agricultural activities and heavy metals originating from upstream industrial activities. The over-exploitation of aquifers and the decrease of stream flows limits their capacity to dilute and flush out pollutants; thus, pollution problems like eutrophication are favoured. Overall, the natural ecosystem faces negative impacts, which may be observed in the alteration of vegetation (e.g. increase of xeric shrubs, pine trees and juniper woodland), the distortion of invertebrate communities (e.g. dragon flies), the decline of fish, molluscs and birds species (e.g. wintering and nesting ducks, and coots), and the spread of invasive over native species. The river basin authorities have launched several proceedings for identified breaches and closed a limited number of illegal wells in the past. However, in 2019, the European Commission decided to refer Spain to the European Court of Justice for insufficient action and alleged breaches of the WFD and the Birds and Habitats Directives.

Research studies on Spanish rivers have also shown that the natural flow regime has been significantly altered in various river basins. Over-abstraction has turned normally perennial rivers into intermittent flowing streams., and fish assemblages were seriously impacted on sites with high pressure from water abstraction. Reduction in carbon storage and breakdown, as well as in the population of shredder insects, were also observed in mountain streams affected by over-abstraction.

The friction between environmental and economic water demands is illustrated by the case of the River Basin Management Plan of the Tagus River in Spain. The current plan, in force from 2015 to 2021, did not effectively take environmental water demand into account, favoring economic functions (especially irrigated agriculture). In 2016, a group of civil associations and representatives of local municipalities submitted a legal challenge to the plan. In its 2019 ruling, the Spanish Supreme Court annulled the plan's provisions on environmental flows and required the River Basin Authority to enact urgent interim measures to cover the period until the start of the next planning cycle in December 2021.

4.8.2. **Socio-economic impacts**

The deterioration of a groundwater body to a poor quantitative status or the absence of improvement from a poor quantitative status may propagate into wider socio-economic impacts. Therefore, the management of water abstractions is important not only from environmental, but also from a socio-economic perspective. For example, this may cause limitations to the water supply from this source. Furthermore, in the case of a drought, groundwater might not support water supply the way it used in the past with negative consequences for the relevant water uses (e.g. drinking water). Water shortages can cause damages to high-added-value sectors like tourism and water-dependent industries. Due to the hydraulic connections between groundwater and surface water bodies, low groundwater levels may result in low recharge into rivers and lakes; thus, affecting the surface water availability also. Low discharges in rivers may affect water-dependent electricity production from thermal and nuclear power plants or hydropower facilities. In addition, low water availability can cause loss of crop yields and harvested production in agriculture and increased costs for irrigation water supply. There are also cases where the drawdown of groundwater tables has caused damages to infrastructures, due to land subsidence.

4.9. Environmental flows

A flow regime which is based on environmental requirements is a prerequisite to reach good ecological status in rivers (EC, 2016). Establishing ecologically-based flow regimes is therefore an important measure in the RBMPs (EC, 2019b). In most Member States, the work on defining and implementing environmental flows was still ongoing in the second cycle (EC, 2019b). In the second RBMPs, environmental flows have been reported to be derived and implemented for all relevant water bodies only in three Member States. In the majority of Member States, environmental flows have been derived and implemented only for a subset of the total water bodies, either in all or in part of their RBDs (Table 4.6).

Table 4.6 Derivation and implementation of ecological flows in the second RBMPs

Derivation and implementation of ecological flows		**Member States**
Ecological flows **derived**	**in all** water bodies	*All RBDs*: ES, CY, EE, HU, NL In some RBDs: FR (4 RBDs), IT (2 RBDs)
	in some water bodies (work is still ongoing)	*All RBDs*: CZ, AT, DK, RO, SE, SI *In some RBDs*: UK (Scotland, England, Wales, Northern Ireland), BE (1 RBD), BG (1 RBD), DE (7 RBDs), FI (7 mainland RBDs), FR (10 RBDs), PL (8 RBDs), PT (9 RBDs)
Ecological flows **implemented**	**in all** water bodies	*All RBDs*: CY, HU, NL *Some RBDs*: FR (2 RBDs)
	in some water bodies (work is still ongoing)	*All RBDs*: CZ, ES, AT, EE, RO, SE, SI *Some RBDs*: UK (Scotland, England, Wales), BG (1 RBD), DE (7 RBDs), FR (2 RBDs), IT (2 RBDs), PL (8 RBDs), PT (8 RBDs)
Ecological flows derived **but not implemented** but there are plans to do so in 2ndcycle		*All RBDs*: DK *Some RBDs*: UK (Northern Ireland), BE (1 RBD), FI (7 mainland RBDs)
Ecological flows **not derived** but there are plans to do so in 2ndcycle		All RBDs: LV, LU, MT, SK, HR *Some RBDs*: BE (7 RBDs), BG (3 RBDs), IT (5 RBDs), PL (1 RBD), PT (1 RBD)
Ecological flows **not derived** and no plans to do so in 2nd cycle		DE (3 RBDs), FI (1 RBD), IT (1 RBD), PL (1 RBD)

Source: (EC, 2019b)

Note: For some of the RBDs, where there is no intention to derive ecological flows, this is due to the fact that no river water bodies are reported

Box 4.3 Indicators for defining sustainability in water use

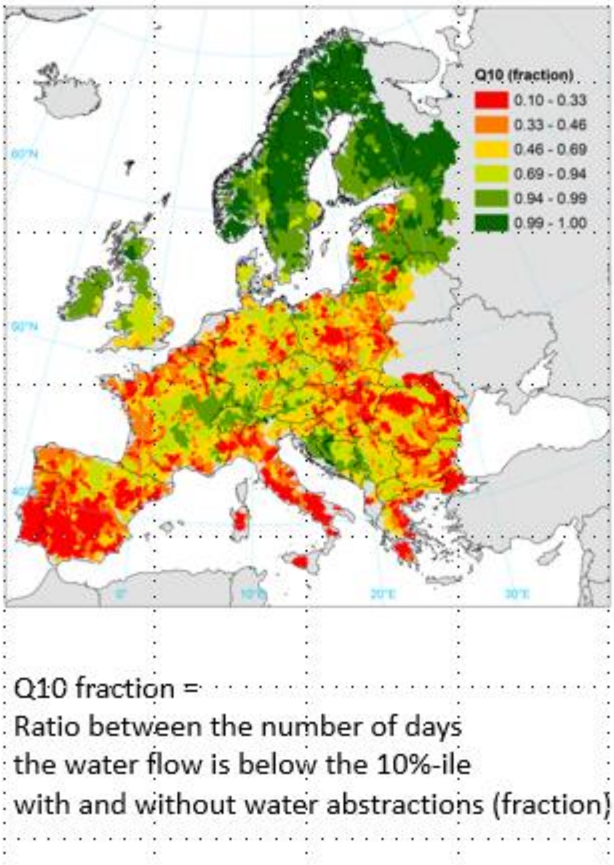
Setting a global threshold in identifying sustainable use of water resources is a scientifically challenging topic. For the time being, overall, three different indicators are widely implemented in defining whether actual water use is sustainable or not. These indicators are:

- *environmental flows indicating critical stages and discharges.* In principle, methods for defining e-flows can be classified in four major categories: hydrological methods; hydraulic rating; habitat simulation models; and holistic methodologies (Zeiringer et al., 2018). An inventory by Ramos et al. (Ramos et al., 2018) reveals that in most cases where environmental flows have been derived were mainly developed based on hydrological methods. This means a static or dynamic fraction of the mean annual flow is defined as environmental flow without making an explicit link with ecological variables. Also, most of the respondents do not differentiate the environmental flows between dry and normal years. Critical stages/discharges of rivers and artificial canals; environmental flows (e-flows), defined as minimum flow requirements using hydrological and hydro-ecological methods (EC, 2016)
- *Critical levels of water stress* e.g. Water exploitation index (Raskin and Gleick, 1997)*. The indicator takes 20 % of water abstraction from water availability in the environment as indication to water stress.*
- *Critical levels of droughts, applying* a set of available drought indicators (e.g. SPI)

In 2012, the Roadmap to a Resource Efficient Europe (EC, 2011a) set out as a key goal that the volume of water abstraction should decrease below the threshold of 20% of renewable freshwater resources. The threshold of 20 % is commonly proposed in literature (Raskin and Gleick, 1997) and commonly applied in relevant studies to distinguish sustainable from unsustainable levels of water abstraction, use or consumption[13]. Currently, the above objective is not attained in many river basins, especially in southern Europe, and relevant water stress issues are foreseen to amplify in the future. Furthermore, under the UN SDG 6.4.2, FAO has set a similar threshold of 25 % for defining unsustainable management.

JRC has used the LISFLOOD model and applied a hydrological method for the estimation of potential environmental flows in European rivers (Grizzetti et al., 2017). The study shows that, without any abstraction, large areas in southern, western and southern Europe could have 50 to 90 % less days of significantly low discharges in their rivers (see yellow, orange and red areas in Map 4.4).

Map 4.4 Ratio of the number of days with significantly low discharges without and with water abstractions



Source: (Grizzetti et al., 2017)
Note: “significantly low discharges” describes the discharges falling below the Q10 threshold, i.e. the value of the flow that is not exceeded only in 10 % of the time

13 Depending on indicator formulation every time

4.10. Measures for the management of water demand and supply

Boosting circular economy and improving resource efficiency to achieve decoupling between the use of resources and population or economic growth is a key policy objective of the European Green Deal for sustainable development. Although water is not explicitly mentioned in the Green Deal, the same policy guidelines are also relevant for the water domain. Economic growth and increase in population lead, in principle, to increases of water use, unless this is counteracted by increasing water use efficiency. For example, the invention and installation of more efficient appliances in households, agricultural holdings, industrial facilities and energy plants can decrease their water use. In 2007, it was estimated that there is a significant water saving potential (around 40 % on average) across all economic sectors in Europe until 2030 (Dworak et al., 2007), but higher investments were needed to unlock it.

Strategies to combat water stress are similar for most economic sectors, if considered at a sufficiently abstract level, and can be divided broadly into four categories (see Box 4.5). The water hierarchy (EC, 2007) promotes the consecutive measures to be investigated from top to bottom.

Box 4.4 Principal strategies for managing water stress

- Reduce water demand
    - Reduce losses in the supply system
    - Reduce losses during use
        - Raise awareness
        - Economic measures
    - Apply more water-efficient technologies
    - Select products for their low water demand
- Store water temporarily during water-abundant times
    - In surface reservoirs
    - In aquifers
- Accept shortage, focus on dealing with its consequences
- Increase water availability or water supply
    - Re-use wastewater
    - Desalinate brackish or salt water
    - Only if no other options are left: transfer water from water-rich to water-stressed locations
    - Transfer water from water-rich to water-stressed locations
    - In subsurface aquifers

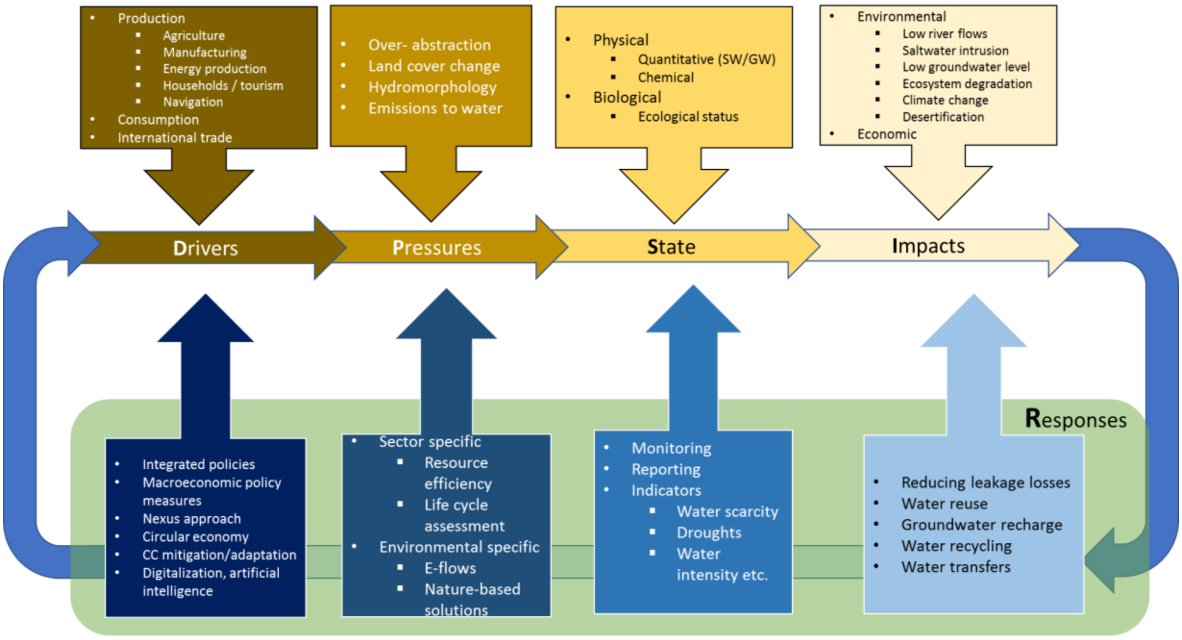
Measures are more sector-, time- and region-specific than strategies, but in all economic sectors they can be grouped in five types (see Box 4.6). Shifting sectorial water management towards a more sustainable paradigm entails a series of challenges, because of the trade-offs between making a sector less water intensive and keeping up its production levels. The broad challenge, similar for all types of water use, is to link water resources, resource efficiency and ecosystem conditions (thus, addressing the need for ecosystem-based management) in an integrated water resource management approach or a nexus approach. As a general rule, more sustainable water management will need to rely more on water demand management, supply from alternative water resources, circular and nature-based solutions.

Box 4.5 Types of measures for water scarcity management

- Structural measures
- Economic measures
- Legislative measures
- Adaptive measures: redistribution of risks and impacts
- Education and public awareness raising

Figure 4.14 provides a DPSIR overview schema of Drivers, Pressures and Impacts related to the state of water resources and main types of Responses for their management. Water abstraction is identified as a key pressure within this context.

Figure 4.14 DPSIR framework in assessing water cycle between environment and economy



Source: George Bariamis and Alexander Psomas

EU Member States are planning and implementing a wide variety of measures to tackle different aspects of water stress, as part of their national programmes related to the implementation of the WFD. Similar measures are also planned and implemented in non-EU countries which are cooperating with the EU and implementing legal frameworks similar to the WFD. The different measures could be categorised as follows (Buchanan et al., 2019):

- establishment of water balances and water accounts;
- establishment of environmental flows (e-flows);
- permitting, registration and control of water abstraction;
- establishment of pricing mechanisms promoting cost recovery and sustainable water management;
- diversification of water sources, including the use of non-conventional water resources;
- establishment of water saving and water use efficiency schemes;
- augmentation of water supply, including new storage and diversions, land use planning and natural water retention.

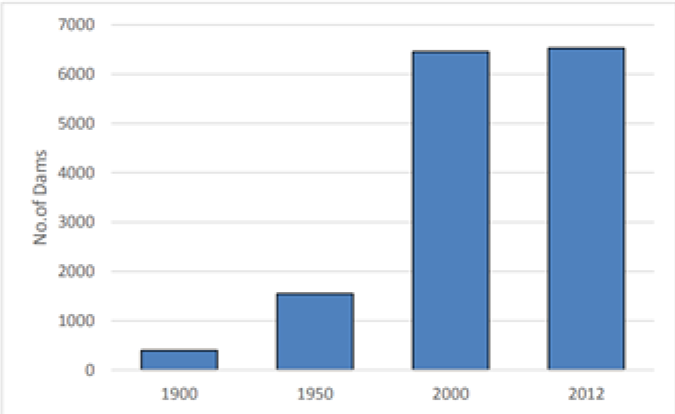
A review of outcomes from the Compliance assessment of the 2nd RBMPs, the Integrated assessment of the 2nd RBMPs and the Blue 2 project is provided in below.

Water storage and natural water retention measures

Since the early 1900s dams have been constructed in a rapid rate across European rivers (Figure 4.15), advocated by the need to supply drinking and agricultural water and produce hydropower. The break-down of the reservoir water storage in Europe is 38% for the Mediterranean region, 30% for the Atlantic region, 20% for the Continental region, and 12% in the rest regions (EEA, 2018b).

After 2000, the WFD provisions have provided a stricter framework for the justification and construction of dams. Nevertheless, despite their overall alignment with the above policy lines, several EU Member States (e.g. France, Greece) have reported their intention to further construct supply-oriented measures, such as reservoirs or diversions (inter-basin transfers), because they consider (whether or not correctly justified) that these measures could contribute to various goals, including water and energy security, adaptation to climate change, achievement of ecological flows in water-stressed aquatic ecosystems and protection of over-exploited groundwater bodies from further deterioration (Buchanan et al., 2019).

Figure 4.15 Cumulative number of dams constructed in Europe (1900-2012)



Source: (EEA, 2017b)

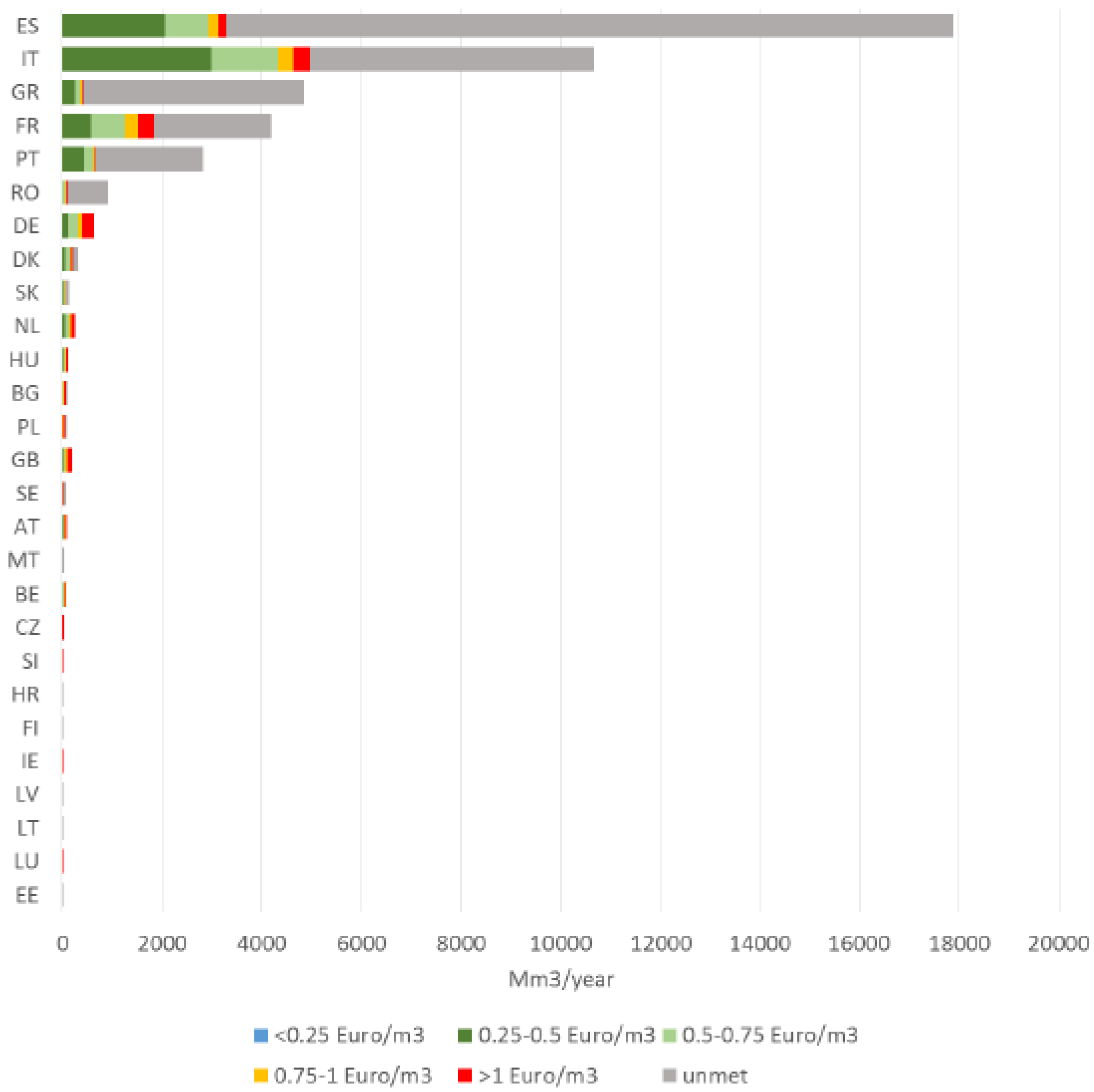
The RBMPs of the various EU Member States have not exploited fully the potential of water retention measures. The links between urban planning and water management have rarely been highlighted. National policies related to territorial planning and economic development plans could promote these approaches more in the future (Buchanan et al., 2019) (see section 6.2).

Non-conventional water supply measures

Water reuse

Water reuse represents a very low share of total water consumption in Europe, and it is mainly practiced in southern Europe (e.g. Cyprus, Malta, Spain) (Figure 4.16). Most reuse schemes target at generating alternative water supplies for irrigated agriculture or achieving managed aquifer recharge to mitigate saline intrusion in coastal areas (Buchanan et al., 2019). The European Commission aims at promoting water reuse further with its recently published regulations and guidelines(EC, 2020f, 2018a), which complement pre-existing regulatory legal frameworks in some Member States. It has been estimated that there is much higher potential for water reuse in Europe. In areas with significant intensity of agricultural activities, water reuse could help reduce water stress levels by an increment of 10%. The treatment and energy costs for water reuse are rather low compared with the total costs for developing the necessary infrastructure to carry reclaimed water from urban waste water treatment plants to irrigated areas. As these costs are highly variable, the economic attractiveness of reclaimed water for farmers may differ significantly. However, there are examples (e.g. Cyprus) where an incentive pricing policy is applied to promote water reuse further (JRC, 2017)

Figure 4.16 Water reuse potential per EU Member State (in Mm^3 per year) for different levels of production cost



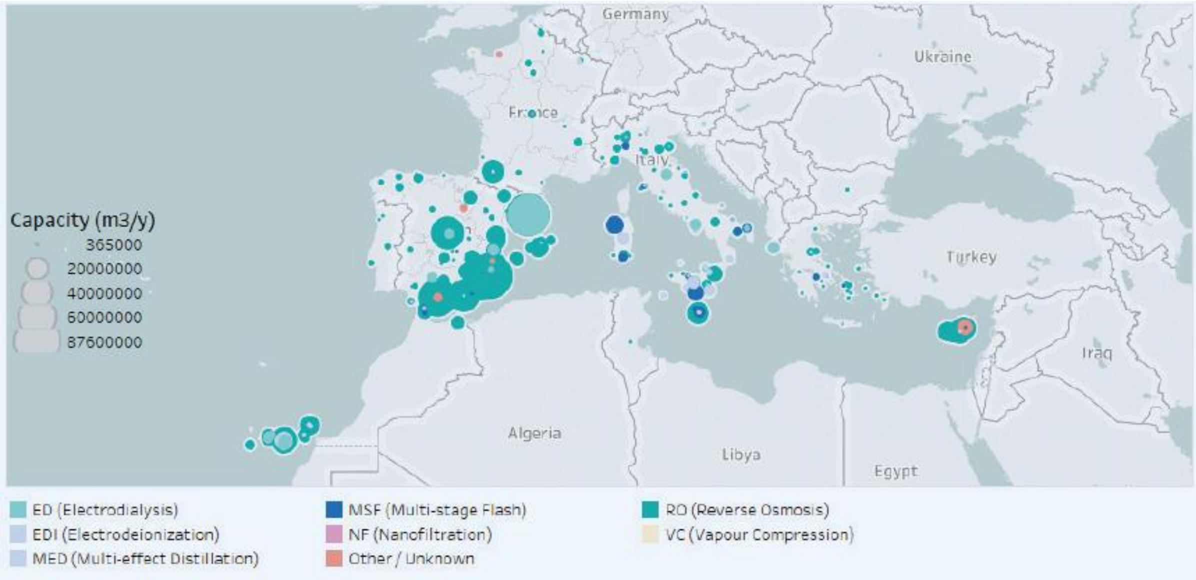
Source: (JRC, 2017)

Note: Amounts of reclaimed water that can be potentially deployed at different total costs for 27 Member States of the EU (Cyprus not included due to missing irrigation estimates). "Unmet" represents irrigation demand estimated for the Country, in excess of potential supply of reclaimed water.

Desalination

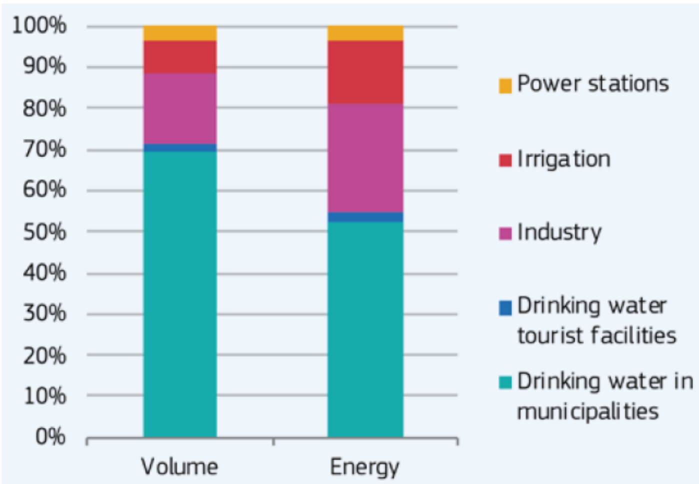
In addition, desalination has been mainly applied for drinking water purposes, but not exclusively for that. Currently, the highest share of the installed desalination capacity in Europe lies in the Mediterranean (Map 4.4). Under serious water stress conditions, desalination is becoming a more affordable and reliable option than other solutions for water supply (Hidalgo González et al., 2019) (Figure 4.17). The relevant costs have decreased significantly over the last decades' and for reverse osmosis of sea water in the Mediterranean they could be around 0.65 €/m^3 (World Bank, 2019). For brackish waters the costs could be lower. However, desalination is associated with significant environmental problems such as brine disposal, energy use and CO_2 emissions.

Map 4.4 Desalination capacity and technologies in the EU



Source: (Hidalgo González et al., 2019)

Figure 4.17 Volume and energy used during desalination of water supplied to various end-users



Source: (Hidalgo González et al., 2019)

Demand side measures

Water addressing water stress through tackling water efficiency have been in place for decades. Their implementation has been driven by climate and environmental policies followed in different Member States, and the needs for higher economic efficiency of water providers (e.g. increasing economic profits of water utilities). Southern Member States, where water stress is perceived as an acute and chronic issue, have planned and implemented such measures as part of their pre-WFD water strategies, as well as part of their RBMPs for the WFD. The WFD has placed even more emphasis on such water-demand measures. However, there are several Member States e.g. from the Baltic), where water stress in the context of climate change is not perceived as a significant feature in their RBMPs, and the planning of such measures is weaker (Buchanan et al., 2019).

5. Water stress in Europe

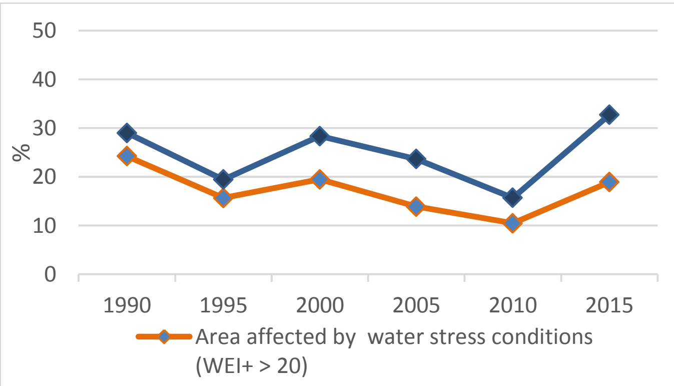
Key messages

- Water stress in Europe affects more than 13 % of the total area permanently and up to 32 % of the total area seasonally since 1990.
- In parts of the EU, increasing water use efficiency will help to keep pace with average climate change. In other regions, which in many cases are already water stressed now, water use is increasing and water availability is decreasing.
- In all of the EU, climate variability is expected to increase, while urbanisation leads to a concentration of water demand in urbanizing areas. The expected outcome is that in southern Europe water stress problems remain persistent, while in other, increasing areas of the EU, water stress will make itself felt irregularly but with increasing frequency and impact.

5.1. *Current water stress in Europe*

Using water exploitation index plus (WEI+)[(14)] as indicator of water stress, at least 13 % of the European territory suffers from all year round water stress conditions, and at least 120 million people are affected permanently by significant water stress in these areas (Figure 5.1). Furthermore, many areas in Europe are affected by seasonal water stress, which recurs usually during the driest season of the year (typically in summer). Since the 1990s, 32 % of the European territory was affected during at least one year by significant water stress, while 300 million people were affected by water stress in at least one year (based on (EEA, 2018b) results) (Map 5.1).

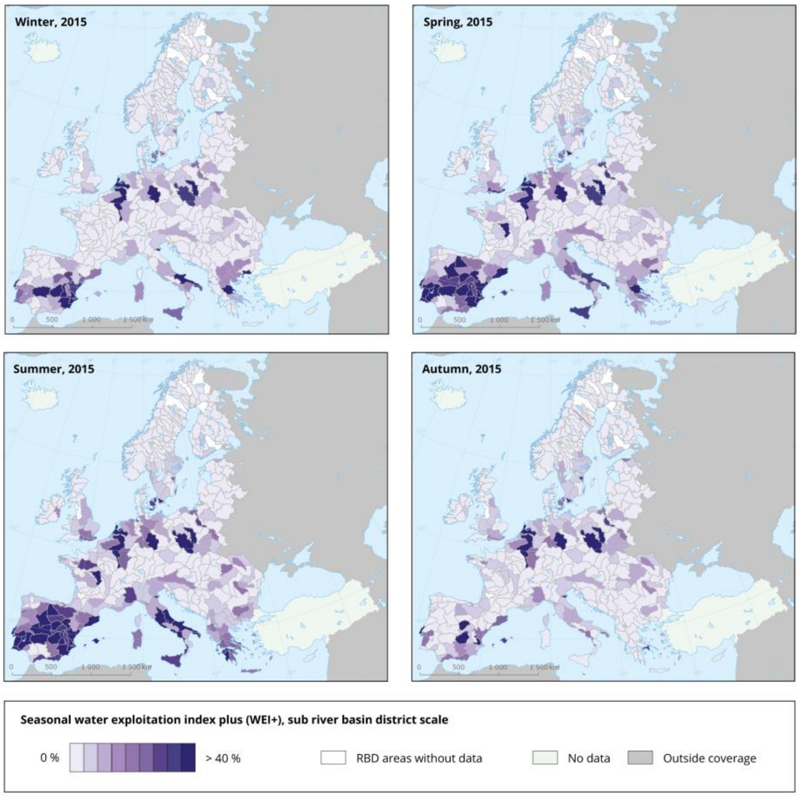
Figure 5.1 Population and area exposed to water stress conditions in Europe (summers 1990-2015)



[14] WEI+: the Water Exploitation Index Plus. The WEI+ is defined as the total water net consumption (abstractions minus returns) divided by the freshwater resources of a region, including upstream inflowing water. WEI+ values have a range between 0 and 1. Values below 0.1 denote "low water stress", values between 0.1 and 0.2 denote "moderate water stress", "water stress" when this ratio is larger than 0.2, and "severe water stress" if the ratio exceeds 0.4 (Feargemann, 2012).

Source: (EEA, 2018b)

Map 5.1 Seasonal water exploitation index in European sub-basins (2015)



Source: (EEA, 2019h)

Southern Europe is the most affected region (Map 5.1), with approximately 30 % of its population living in areas with permanent water stress and up to 70 % of its population living in areas with seasonal water stress during summers. On the one hand, this is a result of naturally occurring low water availability and aridity, which are embedded in the local climate. On the other hand, the water consumption by human activities, such as agriculture, electricity production and public water supply, is frequently significantly higher than the local renewable freshwater resources.

The pressures are particularly high between April and September, when water demand for agriculture, drinking water supply, and tourism or recreation, reaches a seasonal peak. Severe water stress problems are usually observed in areas with intense agricultural activities, which show high shares of irrigated land and high application of irrigation water, fertilisers or pesticides. In this context, agriculture causes water stress because of depletion of natural water sources (e.g. river dry-up, critical decrease of groundwater levels) or because of pollution of local freshwaters (e.g. high concentrations of pollutants, exceeding legally required water quality levels). Agriculture-driven pollution can make water resources non-suitable for other purposes (e.g. drinking water), unless significant costs are paid for their treatment. Severe water stress problems are also observed in coastal areas, because of high concentrations of human activities, including tourism. In such areas, local freshwater availability is usually low compared to the required water supply. In addition, the local water sources are vulnerable to saline intrusion. Therefore, pollution and poor water quality can also be a reason for local water stress issues in various parts of Europe.

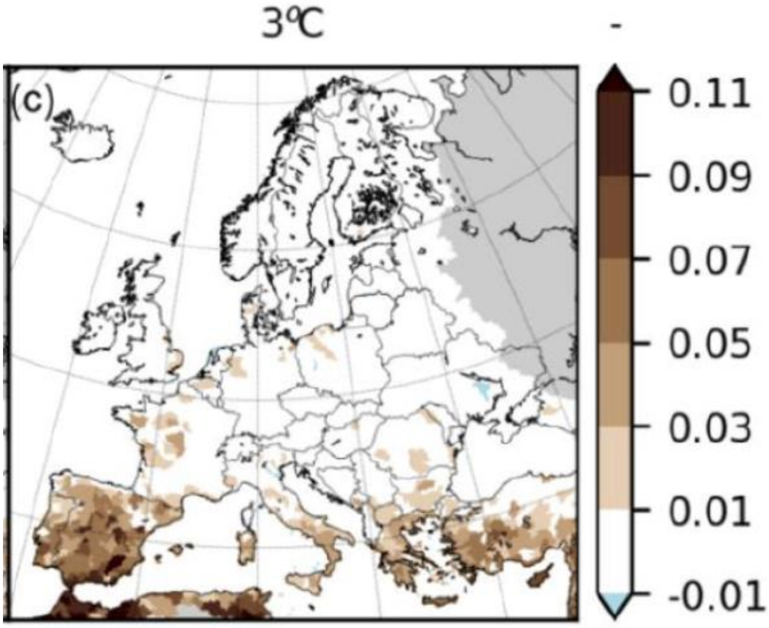
Furthermore, water stress issues increasingly occur in parts of western, eastern and northern Europe also. Compared to the average regional conditions, water stress levels are generally high in the wider area of Copenhagen (Denmark), London – Thames (UK) and Stockholm (Sweden), and the river basins of the Loire (France), Meuse (France-Netherlands-Belgium), Weser (Germany) and Oder (Germany-Poland), as well as in several sub-basins of Hungary, Romania and Bulgaria. This is usually a result of urbanisation, rising living standards and locally significant demand for public water supply and cooling water used in the industry and energy sectors.

Between 1990 and 2017 the abstracted volume of water in the EU27+UK declined by 9 % and in the EEA39 by 17 % (EEA, 2018b). Furthermore, between the first and second cycle of WFD implementation (2010 versus 2016), the area of groundwater bodies affected by over-abstraction decreased by around 7 % (WISE WFD data viewer). These overall trends are encouraging because they show a tendency to reduce the pressure from water abstraction in Europe. However, it should not be missed that water stress is a local and seasonal issue. Thus, overall reductions are not always informative on the actual severity of the problem at finer spatial and time scale. Similarly, water stress in rainfed agriculture and in rain-dependent nature areas is not or hardly mitigated by reduced water abstractions.

5.2. Future projections of water stress in Europe

Water stress in Europe is expected to further worsen in the future, as a result of climate change and socio-economic development. The JRC has modelled two different emission scenarios, resulting in three global temperature increases, with 3 ^{o}C as the highest, compared to pre-industrial levels (JRC, 2020b) (Map 5.2). For an increase in global temperature by 3 ^{o}C, the conditions of significant water stress will be extended and intensified in southern Europe, as well as in other parts of Europe, including areas in Bulgaria, Romania, France, Belgium, Germany and Poland. Moreover, the duration of seasonal water stress is projected to increase up to a month, with the highest increase expected in the Iberian peninsula and other parts of the Mediterranean. In these calculations it was assumed that the water use of the economic sectors increases with the ratio of GDP growth, so increasing water use efficiency was not included.

Map 5.2 Areas in Europe with additional water stress in the future under a temperature increase of 3 ^{o}C.



Source: (JRC, 2020b)

Combining the findings from the two previous chapters, the following estimate of the difference between water demand and water availability emerges, and how it will develop over the coming decades.

The impacts of climate change on water availability
As a result of climate change, average water availability in surface water and groundwater bodies is expected to increase in north-eastern Europe, decrease in southern and south-western Europe, while mixed patterns are expected in the central parts of Europe. Under the 3 °C temperature increase scenario (SCP 8.5), the mean summer discharge in Spain and other parts is estimated to become 20 to 40 % lower than it is now. In parts of the other Mediterranean countries the impact is less pronounced, but with reductions in the order of 10 to 20 % still very significant (JRC, 2020b). Aquifer recharge follows roughly the same pattern.

The potential of water saving measures
According to the available data (Figures 4.11, 4.13 and 4.16), over the 17-year period 2000 to 2017, water abstractions in EU27+UK have dropped by some 24 % while GVA increased by 52 %. No attenuation of the growth in water use efficiency is yet visible. The estimates of potential savings outlined in Chapter 4 are in the same order of magnitude. With an overall GDP growth rate of 1.3 % per year (EC, 2015c) and assuming that GDP growth is at the same level as NVA growth, the net decrease in water demand is estimated at 1.2 % per year. Words of caution are in place here:

- the collected data on water consumption are not covering all Member States and are partly based on proxies;
- general estimates at the level of the whole EU do not represent the actual local impact of water stress. An example: in Sections 4.3 and 4.6 it was pointed out that the increase of irrigated area and in per capita household water use is the strongest in southern Europe, which already is the most water stressed region in Europe.
- these estimates must be taken for what they are: rough indications of the direction that water stress is taking.

That said, there are clear signs that water is being used more efficiently in the European economy. This makes some room for better accommodation of environmental water demands (which have not yet been assessed at EU level) and for climate change impacts.

Comparison of the potential water savings with expected changes in water availability and water demand shows that in some parts of Europe, the current pace of water saving in the economy is sufficient to compensate for the decrease of water availability as a result of climate change. Environmental water demands have not been accounted for in this comparison. The water uses that directly depend on precipitation, such as rain-fed agriculture and terrestrial nature, do not benefit from these water savings. The impacts of increasing climate variability and spatial concentration of water demand for households and industry, too, are not mitigated by increased water use efficiency.

6. Needs for integrated policy responses

Key messages

- Only eight Member States reported Drought Management Plans (DMPs) as accompanying documents to all or part of their 2nd RBMPs.

- A key factor contributing to the effectiveness of water directives in progressing towards their objectives are the (binding) cross-references to the WFD's objectives in other EU policies. However, despite the 20 years of existence of the WFD, few integrated governance frameworks have effectively been implemented.

- Improvements in efficiency should be more transparently documented to promote cross-fertilization and transfer of technology and knowledge. A first instance of this would be to extract lessons from the decoupling trend observed in the manufacturing sector.

- Given the significance of abstraction pressures on European water resources, sectoral policy interventions must not only work in synergy with water policies but also actively support them.

- In those areas where the problems cannot be solved in a sustainable way at their own (local to regional) scale by current water-demand measures, systemic changes are called for (EEA, 2019j; IPBES, 2019).

- Major technological innovations that will contribute to improved drought risk management are expected in the field of earth observation, mobile data collection and data integration.

- Nature- based solutions can contribute to drought risk management by their integrative and stakeholder-driven approach and can thus provide a link towards nexus approaches and systemic change.

6.1. Synergy of policy initiatives at EU level for resilience to water stress

Mainstreaming water management considerations into other environmental and sectoral policies and finding synergies across them are key to enabling sustainable water management and reducing society's exposure and vulnerability to water stress. The recent WFD fitness check has highlighted that one of the factors contributing to the effectiveness of water directives in progressing towards their objectives were the (binding) cross-references to the WFD's objectives in other EU policies (EC, 2019f). However, despite the 20 years of existence of the WFD, few integrated governance frameworks have effectively been implemented (EC, 2019f). Until recently, sectoral policies at EU level have even contributed to increasing pressures on water resources, for instance when promoting agricultural development, industrial growth or development of hydropower without sufficient environmental safeguards (Rouillard et al., 2018; Carvalho et al., 2019; Kampa et al., 2020).

Under the 6th and 7th Environmental Action Plan 2014-2020, greater attention was given to align sectoral policy objectives with environmental targets. To tackle threats from water stress, the focus has been on promoting efficient use of water in economic activities. The Resource Efficiency Roadmap 2011, the recent Communication on a New Circular Economy 2020, and many of the initiatives funded under the European Innovation Partnership on Water as well as the Horizon 2020 research programme include technological innovations for increased water efficiency in production systems, as well as waste minimization and recycling strategies. This effectively opened a channel for a more active involvement of the industrial sector in EU environmental research and innovation activities and strengthened Corporate Social Responsibility and Extended Producer Responsibility schemes.

As shown in Chapter 4, manufacturing is the sector where decoupling is the most prominent, and this is reflected in all EU regions. To ensure the continuity of this trend and its replication in other economic activities, it is crucial to learn from these developments. Specifically, in the case of the industrial sector, sharing data on investments in water saving technologies would be fundamental both from the water and the resource efficiency policy perspectives. Improvements in efficiency stemming from implementations at the company-level should be more transparently documented to promote technology/knowledge transfer and cross-fertilization. This requires an adequate reporting architecture that centralizes the knowledge while protecting the strategic interests of private enterprises. Any progress made here could open pathways to increase transparency in other sectors like agriculture, mining and quarrying and establish a benchmark for concrete, integrated action towards systemic change.

One example of this integrated thinking, in a circular economy perspective, is the recent adoption of the Water Reuse Regulation which aims to increase the scale of urban wastewater reuse in agriculture. The EU Regulation sets out to harmonise minimum water quality requirements for safe reuse and groundwater recharge. Currently, very few countries reuse wastewater, except some notable exceptions such as Cyprus which reuses up to 90% of its wastewater (BIO by Deloitte, 2015). Most other references of this practice in the EU remain limited to small-scale experimental projects or local initiatives, which are focused on water reuse for irrigation and managed aquifer recharge. In principle, the total volumes of water that can be reused for irrigation are significant, and may help reduce water stress by up to around 10% in regions where irrigation is an important activity (JRC, 2017). Water reuse also lowers the need of fertilization, because reclaimed water can have a rich nutrient content. The treatment and energy costs for water reuse are rather low, when compared to the costs for infrastructure to bridge the distance from the urban wastewater treatment plants to the irrigated land. The variability of these costs affects the final costs and the attractiveness of reclaimed water to farmers (JRC, 2017). Where water is scarce, the benefit of reuse is to alleviate pressure from agricultural abstraction in surface water and groundwater bodies and from pollution from wastewater discharges. However, to effectively reduce abstraction pressure, reuse will need to act as a substitute for existing abstraction, and not as an additional source of supply for irrigation water (Drewes et al., 2017). The notion of “getting the economics right” discussed in the context of the Circular Economy Action Plan is fundamental and it is also a shared principle for water policy. Here the example of incentivizing water reuse through pricing policy in Cyprus is again worth a mention. The Mediterranean country is practicing water reuse both for tree cultivations and vegetables and it follows an incentivised water pricing policy to make reclaimed water more appealing to farmers.

As mentioned in Chapter 2, gaps remain in setting pricing strategies that effectively lead to an efficient use of water. The recent evaluation of the 2nd RBMPs reports that a number of Member States have upgraded their water pricing policies, notably by fulfilling the ex-ante conditionality for water under the Common Provisions Regulation for the European Structural and Investment Funds for the period 2014-2020. Furthermore, increased funding and investments are still necessary to meet the objectives of the WFD (EC, 2019b). Here, the wider exploitation of EU funds should finally be activated and used to leverage private investment employing the EU Taxonomy for Sustainable

Finance. This complementary source of the much-needed funding could be used to promote more ambitious planning and implement measures that help correct imbalances in cost bearing, effectively levelling the playing field for different water users (including the environment). However, any future investments must take stock of past experiences.

Furthermore, increased funding and investments are still necessary to meet the objectives of the WFD (EC, 2019b). Here, the wider exploitation of EU funds may leverage private investment employing the EU Taxonomy for Sustainable Finance. This complementary source of the much-needed finance could be used to promote more ambitious planning and implement measures that help correct imbalances in financing, effectively levelling the playing field for different water users (including the environment). However, any future investments must take stock of past experiences.

The integration of water into agricultural and rural development policies illustrates the difficulty to achieve fully synergistic policy interventions. Under the current Common Agricultural Policy (2014-2020), the European Agricultural Fund for Rural Development recognised efficient water use a key strategic objective for European agriculture, and Member States could actively support investments to tackle water stress issues on agriculture through their Rural Development Plans. Most RDPs planning measures on agriculture water use did so by supporting investments in irrigation water use efficiency in agriculture. However, few had set out ambitious water saving targets and encourage uptake of more drought-resistant crops. Instead, RDPs tended to support investments in irrigated areas, as a way to reduce the vulnerability of agriculture to water stress, while attaching few safeguards to prevent increasing abstraction pressure on scarce resources (see Box 6.1).

Box 6.1 Managing the rebound effect and Javons paradox in water stress situations

Increasing the efficiency of production is a main goal of European policies, with the overall goal to decouple economic growth from resource use. However, improvements in the efficiency of resource use do not always translate into net savings because producers and consumers adapt their behaviour (Paul et al., 2019). The rebound effect refers to the situation where efficiency gains do not result in associated reduction in resource use. In some cases, the same chain of events results in higher net resource consumption, known as the Jevons' paradox.

The rebound effect can occur when the efficiency improvements affect consumer's positive perception of the final product, leading to less restrain in its consumption or in the consumption of other products. It can also occur when efficiency improvements affect economic performance by reducing production costs. This may lead to increased production, reduction in product prices, or when cost saving is used to expand production elsewhere. Psycho-social and economic rebound effects lead to increased demand (Paul et al., 2019).

The rebound effect is well documented on the consumption of a number of resources, such as energy use. In water management, substantial evidence exists in irrigation water use, where the adoption of more water efficient devices is not necessarily accompanied with a reduction in water abstraction (Ward and Pulido-Velazquez, 2008; Dumont et al., 2013; Gómez and Pérez-Blanco, 2014; Berbel et al., 2018). Instead, the saved water is redirected to other beneficial economic uses, for instance higher value but more water consuming crops or an expansion of irrigated land.

The rebound effect can be particularly damaging for groundwater and connected surface water bodies. This is because inefficient irrigation practices have sometimes raised groundwater levels. Investments in irrigation efficiency may lead to a reduction in field water losses, reduced infiltration and percolation and reduced groundwater recharge.

Investments in water efficiency programs should therefore be accompanied by a careful consideration of water balances at farm, aquifer and basin level, including consideration of surface-groundwater exchanges (EC, 2015d). Clear limits to resource use should be established at hydrologically-relevant spatial scale. Policies promoting more efficient use of natural resources should also have a realistic assessment of the possible savings, and the producer and consumer impact of the policy.

Given the significance of agricultural abstraction pressures on European water bodies, it is essential that future agricultural policy interventions do not only work in synergy with water policies but also actively support them. The main funding scheme under the CAP, i.e. the European Agricultural Guarantee Fund, is an income support scheme, which has largely contributed to an intensification of agricultural practices in Europe, including of irrigation water use (EEA, 2020 – upcoming EEA W&A report). Recent reforms have reduced negative incentives from CAP payments, although there is still limited support to transition to more sustainable and resilient forms of farming, such as agro-ecology and organic farming (EEA, 2020 – upcoming EEA W&A report). The new CAP programming cycle for 2021-2030 provides fresh opportunity to integrate more ambitious environmental safeguards that acknowledge local water resource limitations and scarcity situations.

Once these safeguards are introduced, it will be important to overcome the known limitations in terms of institutional and technical capacities for monitoring and enforcement. The needs of WFD implementation have provided motivation to water authorities to push water suppliers to improve data collection, organisation and reporting. For example, water utilities and irrigation cooperatives have accelerated the installation of water meters or improved their maintenance and repair (Buchanan et al., 2019). However, opportunities remain. For instance, reported data and statistics frequently lack the necessary accuracy, because of the issue of over-abstraction (including incidents of unauthorised and unregistered abstraction). The challenge is more serious in the agricultural sector and, particularly, in southern Europe (Buchanan et al., 2019). Digitalisation has already become a common denominator for all sectors, but the exploration and validation of its potential applications is at different stages in each of them (e.g. energy being a frontrunner, water following slowly). This should be seen as an opportunity to use the experience of sectors that are well ahead to leapfrog towards meaningful and effective exploitation of digital solutions. For water policy implementation, digital applications could facilitate data collection and information sharing while reducing the administrative burden associated to reporting. Digital water is also seen as an enabler of circular economy models (e.g. turning wastewater treatment plants into “Blue Resource Centres”) and could carry potential to increase participation and mutual learning to identify new and innovative ways to overcome the societal challenges of our era.

The slow transition in agriculture towards sustainable water use is not only linked to the costs and complexities of modifying farm systems, but also in reforming whole production and consumption systems (EC, 2020h). Transformation of agricultural systems to tackle water scarcity issues and become more resilient to droughts requires a transition in supply chains and consumer demand in order to induce the right market signals on farmers (EEA, 2017c). The new Farm-to-Fork Strategy illustrates how the Green Deal aims to support such integrated and systemic thinking and promote more sustainable food systems. Emphasis is given not only on providing the right incentives to producers, but also by leveraging sustainable investments from food system actors (such as cooperatives and supermarkets), reducing waste along the food chain, and changing consumption patterns towards sustainable diets in order to reduce total demand on natural resources, including water (EEA, 2020 – upcoming EEA W&A report).

Such systemic thinking to reduce Europe’s vulnerability to water stress still has to permeate policies of other economic sectors, although some safeguards already exist. For instance, energy security and climate mitigation targets are major EU policy areas which drive substantial levels of investments notably towards renewable energy. However, some renewable sources of energy can increase scarcity issues and vulnerability to droughts, for instance the large-scale adoption of biofuels or hydropower impacting the hydrology and hydromorphological dynamics of surface water bodies (Vanham et al., 2019). The Directive 2009/28/EC on the promotion of the use of energy from renewable resources recognizes this when it calls for using sustainability criteria when cultivating crops for biofuels. In such cases, Member States will need to ensure that energy policies do not encourage the expansion of irrigation for the production of bioenergy where basins and aquifers are already overexploited. Currently, no Member States place such safeguard. With the renewed and expanded commitments on climate neutrality and 80 % of electricity production from renewable sources by 2050, this gains additional relevance. The classification system for "green" and "sustainable" economic activities of the Sustainable Finance Taxonomy should function as an additional layer of protection.

When developing their RBMPs under the WFD, authorities must pay particular attention to wetlands, which are often protected under the Birds and Habitats Directives. These two Directives have commonly been used to reinforce the case to reduce abstraction pressures in surface and groundwater leading to the degradation of wetlands and groundwater-dependent ecosystems.

Here, while the use of non-conventional water resources (regenerated wastewater and desalinated water) could provide viable alternatives, careful consideration of other environmental pressures associated with their production is required. This is specifically relevant for desalinated water. Currently, the highest share of the installed desalination capacity in Europe lies in the Mediterranean (Hidalgo González et al., 2019). Under serious water stress conditions, desalination is becoming a more affordable and reliable option than other solutions for water supply. The relevant costs have fallen as low as 0.30-0.60 €/m^3. However, desalination is associated with significant environmental problems such as brine disposal, energy use and CO_2 emissions.

Several EU initiatives support more or less indirectly the use of nature-based solutions to enhance Europe's vulnerability to water stress and risk of droughts. The multifunctional role of forests in regulating water flows in rural and urban catchments and in increasing resilience to climate change is recognized by the EU Forestry Strategy (to be updated in 2021). Wetlands and forests for instance form an important part of the EU Strategy on Green Infrastructure, which aims to build a coherent and resilient network of ecological corridors across Europe. The recent Biodiversity Strategy 2030 sets out to legally protect a minimum of 30% of the EU land area, and to promote widespread restoration. The Strategy emphasises in particular the importance of restoring environmental flows in rivers, notably through a review of abstraction permits. Further, the still elusive, yet expectable co-benefits of green infrastructure and nature-based solutions pursued in the mentioned policies represent a node for economic activities like tourism, recreation, sustainable agriculture and urban water services. This is especially relevant as an opportunity to address water abstraction, resulting in multiple pressures on freshwater ecosystems.

The EU Adaptation Strategy 2013, to be updated soon, recognises the importance of integrated solutions to tackle water stress, by scaling up environmental mainstreaming in sectoral policies and climate-proofing investments, and by improving the protection and restoration of European ecosystems. However, recent assessments indicate that synergies between water stress policies and climate change adaptation strategies are not fully exploited at Member State and river basin levels (Buchanan et al., 2019). Furthermore, Member States not yet facing water stress are not yet taking sufficient action to address future threat under climate change (Buchanan et al., 2019). As the onset of climate change continues, the intersect between adaptation, water and agriculture will gain relevance. On the basis of the expected changes in growing seasons and suitable crops across different European regions, economic integration and coordinated economic planning will be crucial to ensure the resilience of the EU economy. Knowledge and technology transfer would also be fundamental, and digitalisation could play a facilitating role. Here once more, the lessons learned from the energy sector in setting up the Just Transition Mechanism could prove useful in keeping up with the pace of environmental change.

6.2. Water resources management in international river basins

In international river basins, cooperation is usually sealed with formal international agreements, and frequently with the establishment of an international coordinating body. In such river basins, the EU Member States are required to prepare national RBMPs, covering their own territory but streamlined with the other RBMPs from the same river basin. Alternatively, they may develop shared international RBMPs (iRBMPs), where they should also involve non-EU countries that share the same river basin with them. This is practiced less frequently, though. In Europe, there are nine cases of international river basins with active international agreements, established international coordinating bodies and international RBMPs in place: Danube, Elbe, Ems, Meuse, Odra, Rhine, Sava, Scheldt, Teno/Tana. In other international river basins, a shared international RBMP or an international coordinating body can be missing. The cases where no international agreement has been signed are rare (EC, 2019g).

A review (EC, 2019g) of the above cases reveals that water stress is not highlighted as a significant issue requiring international cooperation in most of these cases. Thus, the issues of over-abstraction, water scarcity and droughts do not receive primary focus. The focus of international cooperation is placed commonly on water quality issues, hydromorphology or floods. Nevertheless, the following features have been identified related to the assessment and management of water stress under future climate change conditions:

- *Danube*: ICPDR Strategy on Adaptation to Climate Change developed in 2012 and updated in 2018, providing guidance on the definition of adaptation measures, such as restoring water retention areas and addressing water scarcity and droughts risks.
- *Elbe:* climate change outlooks considered for the economic analysis of water use in the long-term.
- *Ems*: assessment of future climate change impacts; climate proofing of measures considering their sensitivity to climate change impacts under different scenarios.
- *Meuse*: joint status assessment of transboundary groundwater bodies; ongoing work for a joint report on water scarcity that will support the development of an updated framework for managing low-flow events (for the current framework see Case 6.1); ongoing work programme to increase information exchange on national and international activities related to climate change assessment and adaptation.
- *Rhine*: ICPR Strategy for Adapting to Climate Change developed in 2015, considering climate change impacts, discharge regime of the river, prolonged periods of low-flows and frequency of flood events under different scenarios; definition of basic principles of selecting adaptation measures.
- *Scheldt*: initial exploratory Climate Memorandum signed, including droughts aspects, such as a discussion on possible restrictions to water abstraction.

Box 6.2 Dealing with low flows during droughts in the Meuse river basin

The Meuse International River Basin District (iRBD) covers parts of the territories of France, Luxemburg, Belgium (Wallonia, Flanders), Germany and The Netherlands. The iRBD covers an area of almost 35,000 km², with close to 9 million inhabitants. The length of the river is 905 km.

The Meuse is a typical example of a rain-fed river. High river discharges generally occur in winter and spring, lowest discharges usually in autumn. Flow variations can be sudden because of the geometry and geology of the basin which favour a quick reaction to intensive precipitation events. During extreme droughts the discharge can become so low that in certain stretches the river can be crossed on foot.

Urbanisation, industrialization, agriculture and navigation affect the status of the waters of the iRBD Meuse. The Meuse is the source of drinking water for almost 7 million people (a.o. in Brussels, Antwerp and

Rotterdam). Navigation is of particular interest in the area, both in Flanders and in the Netherlands. Over the past two centuries an intricate network of shipping canals was developed, which for its water supply depends entirely on the Meuse.

The estimated water exploitation index (WEI+) of the Meuse is ca 30 % on average. This makes the iRBD stand out as one of the more water stressed in western Europe (Map 5.2).

in 1995, after long negotiations, the issue of the distribution of the available water during low flows resulted in the Meuse discharge convention between Belgium (Flanders) and the Netherlands. The guiding principle of the Meuse discharge convention is to secure an equal use of water for economic purposes of both countries and to accept joint responsibility for the stretch of the Meuse where it marks the international border. In this stretch, low discharges can be harmful to the valuable ecology.

Simultaneously, in 1995, France, Wallonia, the Brussels Capital region, Flanders and the Netherlands reached agreement on a wider, multilateral convention on the protection of the Meuse. This convention was succeeded in 2002 by the International Meuse Commission (IMC) upon the signature of the Meuse Convention (Treaty of Ghent; now including Germany and Luxemburg). The purpose of the Convention is to achieve sustainable and integrated water management of the Meuse international river basin district.

The Maas discharge convention stipulates that both Flanders and the Netherlands take measures to limit their water use during water shortages. In the Netherlands this mainly involves pumping back water to the upstream stretches at the ship locks. Also the passing of ships at locks is performed in a 'water-economical' manner, using water saving devices. If this is not sufficient, the water allowance of other water user sectors are cut back, according to the prioritization described in the national priority sequence. Flanders limits its water use by the installation of pumps at the ship locks. A considerable part of the water intended for Flanders is used for these ship locks. When one of the parties at some point finds it difficult to meet the conditions of the treaty, it is jointly examined whether that party may temporarily use more water. The associated costs will be settled afterwards (Bastings et al., 2011)..

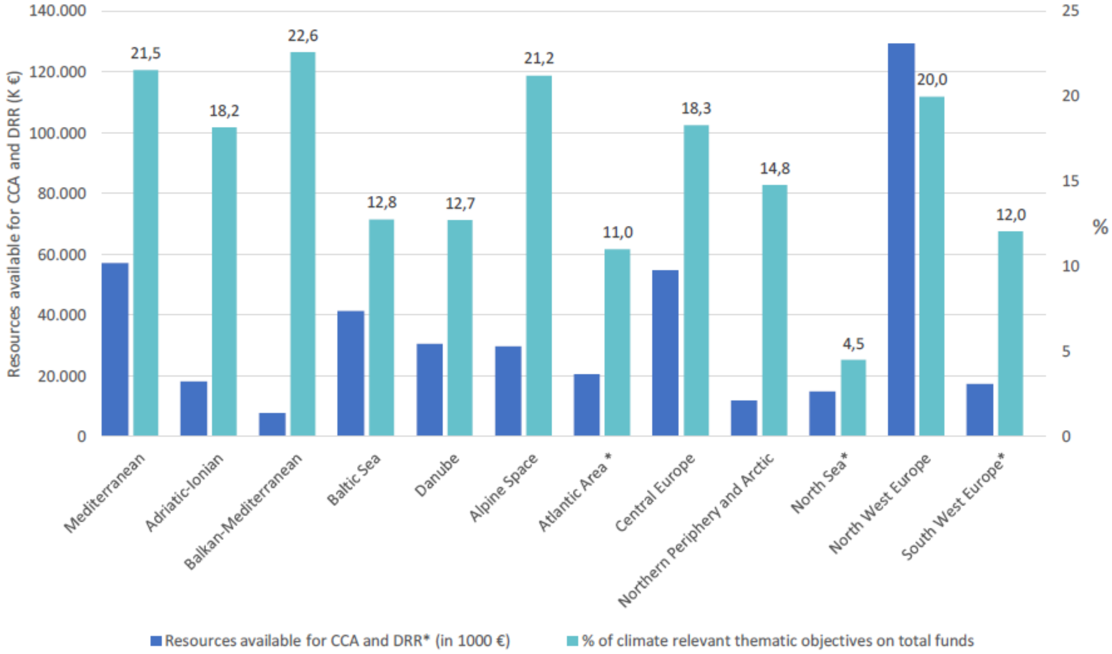
Lessons learned from the Maas discharge treaty (Bastings et al., 2011; Mostert, 1999). Mostert (undated)):

- Conventions are a matter of mutual trust. In the Meuse it took a long time to overcome historic disputes between Belgium and the Netherlands and build such trust;
- Linking different issues can result in a package deal that is attractive to all parties. In the case of the Meuse, breakthroughs were reached after linking water quantity in the Meuse with seaport accessibility in the Scheldt;
- To arrive at an attractive package deal, a cross-sectoral approach is often instrumental.

The 2018 drought again demonstrated the vulnerability of the Meuse basin for water shortages. Even though no major disasters or major water supply interruptions occurred, the economic and ecological damage was significant. The Dutch evaluation of the 2018 drought includes specific actions to reinforce the dialogue with Germany and France on the topics of drought and low flows (Ministerie van Infrastructuur en Waterstaat, 2019).

The consideration of climate change and the cooperation for climate change adaptation (CCA) at international level has also strengthened in Europe over the last decade (Ramieri et al., 2018). The EU Climate Adaptation Strategy launched in 2013 included references to cross-border issues. Furthermore, the evaluation conducted by the European Commission in 2018 showed that the strategy promoted several cross-border actions on climate risks between Member States[15]. Transnational strategies or action plans on CCA have been developed in many regions[16], including the Mediterranean, the Danube, the Alps and the Baltic. Existing international conventions (e.g. OSPAR, Barcelona Convention) have catalyzed the transnational dialogue and cooperation also on CCA issues. Moreover, web-based adaptation platforms, knowledge centers and networks have been activated, and transnational CCA-related projects are being implemented. However, CCA-related projects are more focused on knowledge creation and dissemination, awareness-raising, capacity-building, networking and cross-country exchange, and less focused on actual implementation of joint measures. Interreg programmes have provided significant support to transnational cooperation on CCA (Figure 6.1) (Ramieri et al., 2018).

Figure 6.1 Available funds for Interreg programmes related to Climate Change Adaptation (CCA) and Disaster Risk Management (DRR) in different regions of Europe.



Source: (Ramieri et al., 2018)

6.3. *Towards water-energy-land-food-ecosystems nexus management*

Societies around the world have always been aware that water, energy, land and food resources show interdependencies, while they also interact with natural ecosystems. Policy and research have addressed this idea already since late 1940s and 1960s (Wichelns, 2017). The Dublin International Conference on Water and the Environment and the Rio UN Summit on Environment and Development, which were held in 1992, contributed to the development of the principles that

[15] EC, 2018, Report from the Commission to the European Parliament and the Council on the implementation of the EU Strategy on adaptation to climate change (COM(2018) 738 final of 12 November 2018).

[16] North Sea, Northern Periphery and Arctic, Baltic Sea, Danube, Alpine Space and Mediterranean

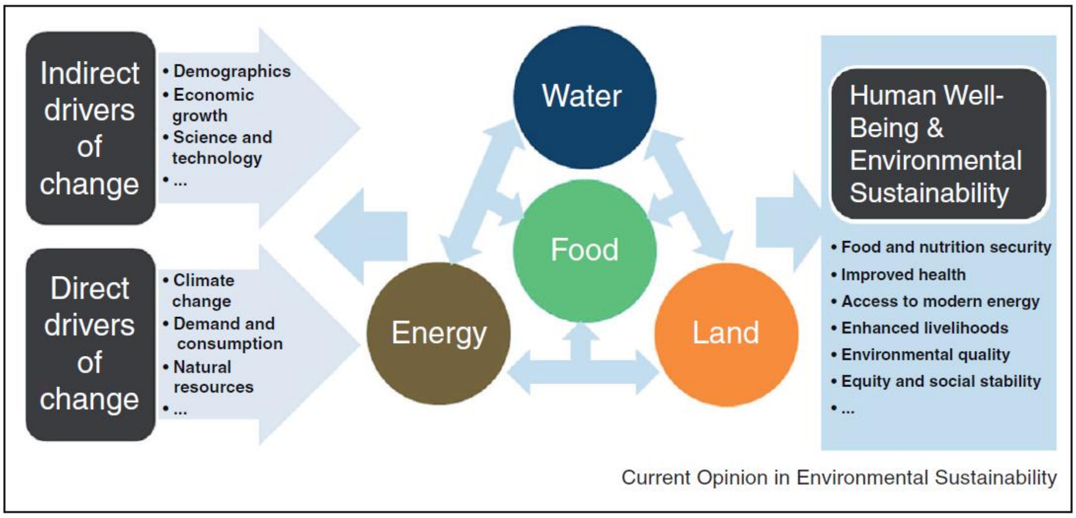
characterize the Integrated Water Resources Management (IWRM) paradigm. The Global Water Partnership initiative summarized IWRM with the following definition in 2000 (Global Water Partnership, 2000): *"A process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems."*

Therefore, the IWRM specifically addresses three pillars, i.e. environmental sustainability, economic efficiency and social justice, which are also used to describe our understanding of sustainable management. Furthermore, it makes specific reference to "water, land and related resources", as well as to the need to protect and conserve "vital ecosystems".

Nevertheless, research and policy have often developed in so-called "working silos" over the past decades, as a result of scientific specialization and administrational mandate. This has resulted in separated and often conflicting sectorial goals, strategies and policies, as well as fragmented actions overall (Leck et al., 2015). Furthermore, while research has also addressed the interactions between different resources, the relevant studies have mostly focused on the interactions between water and another resource (e.g. water-energy or water-food), thus missing a more holistic and systemic perspective (Endo et al., 2017).

The water-energy-land-food nexus is a holistic conceptual framework, which underlines the need for integrated and systemic thinking, as well as for cross-sectorial and multi-scale actions for the protection and management of resources systems (Figure 6.2). While it carries the legacy of the IWRM paradigm, it also considers the experiences gained from its implementation, and it modifies and expands it. Furthermore, adopting the WELF nexus approach in the analysis of environmental systems leads to the acknowledgement that the nature of water, energy, land and food systems is interdependent. This facilitates the identification of synergies and trade-offs between these resources, i.e. additional benefits from simultaneous management of both resources or necessary sacrifices to one resource to gain the benefits from the other resource (Psomas et al., 2018; Ringler et al., 2013).

Figure 6.2 Proposed set-up for understanding the Water-Energy-Land-Food nexus



Source: (Ringler et al., 2013)

Box 6.3 Water-energy-land-food nexus (WELF nexus)

The nexus concept was first introduced in 2011, when the World Economic Forum published a relevant report on the water-food-energy-climate nexus (Waughray, 2011) and the German Federal Government organised the Bonn 2011 international conference on "The Water, Energy and Food Security Nexus - Solutions for the Green Economy" (Martin-Nagle et al., 2012). The links to biodiversity, ecosystems and their services were also highlighted in subsequent research publications (Karabulut et al., 2016). Thus, the core of the WELF nexus is often expanded to include further considerations, such as interactions with climate and ecosystems, and to address not only resources themselves, but also the management objectives for the resources (e.g. water, energy and food security concerns). The WELF nexus has also been studied in the context of transboundary river basin management in the Mekong river (Keskinen et al., 2015) and the Upper Blue Nile (Allam and Eltahir, 2019).

The overall concept of the WELF nexus formed the underlying basis for the establishment of the Sustainable Development Goals (SDGs) by the United Nations in 2015. These global goals highlight the need for systemic approaches for meeting their targets, including those goals related to resource management (Weitz et al., 2014).

While the discussion on nexus has been widely theoretical or related to assessment studies, the operationalisation of nexus in real-life applications has been limited in Europe and worldwide (Bizikova et al., 2013; Leck et al., 2015). The recently formed Nexus Cluster is developing a list of relevant projects around the globe, including research projects funded by the EU (e.g. Sim4Nexus): https://www.nexuscluster.eu/Projects.aspx.

6.4. Application of Ecosystem Services and Nature Based Solutions

The added value of Ecosystem Service (ESS) approaches

Looking at water stress from an Ecosystem Services perspective brings a strong focus on combinations of economic benefits for water-using sectors with environmental and social values. This broadened scope is required to solve the problems that were caused by more traditional practices. As IPBES states (IPBES, 2019): '*Economic incentives have generally favoured expanding economic activity, and often environmental harm, over conservation or restoration. Incorporating the consideration of the multiple values of ecosystem functions and of nature's contributions to people into economic incentives has, in the economy, been shown to permit better ecological, economic and social outcomes.*'

Application of Ecosystem Services in water stress management

There are two ecosystem services that come to the fore in the context of water stress management: 1) provision of water and 2) temporary storage of water in aquifers, rivers and lakes during the wet season for use in dry spells. In addition, water bodies have an attenuating effect on temperature fluctuations during heat waves, especially in urban areas (a regulating service, connected to climate regulation as a prominent ecosystem service (JRC, 2020c).

Temporary water storage in aquifers and lakes helps to maintain, in parallel, the base flow in rivers during dry spells, thus providing the necessary conditions for water-dependent ecosystems. Non-sustainable water abstraction and land use changes causing quick discharge of water during rainfall events and a decrease in surface water storage and groundwater recharge, have led to a decrease of both ecosystem services (Section 3.3). This decrease is in some cases exacerbated by water quality problems, such as eutrophication and algae blooms in surface waters that become stagnant, saltwater intrusion in coastal areas, or reaching arsene-contaminated water in overexploited aquifers.

The benefits of restoring the ecosystem services to their natural level extend well beyond the interests of the economic sectors and stakeholders which have caused the deterioration. The case for an ecosystem approach can thus only be made if the affected stakeholders are known and involved in the assessment. Over the past years much research has aimed at mapping ecosystem services and quantifying their economic impacts for a wide range of water-dependent sectors. Examples that deal specifically with water stress, however, are scarce. The recent MAES assessment (JRC, 2020c) does not include ecosystem services specifically connected to water stress, but it illustrates how the degradation of ecosystems hampers their provisioning services (which also relate to water, both in quantity and quality). It thus provides a framework for future analysis of water stress.
A few examples from other sources include:

- The KIP INCA project on natural capital accounting, is preparing, by the time of writing this report, several outputs: Accounts on ecosystem extent and ecosystem condition, Accounts on ecosystem services, Valuation of natural capital & ESS. Water abstraction is one of the provisioning services that is analyzed in the project (EC, 2020e). A question to be answered is: what is the value of ecosystems in reducing or preventing water stress (in analogy to the value of ecosystems in flood control, which is estimated at €16 billion for the EU27+UK in 2012 (Petersen, 2019).

- The Blue2 project mapped the size and impacts of four environmental pressures and assessed a selection of related measures. One of the pressures considered is water abstraction. For the comparison and appreciation of different model outcomes for the measures considered, a step-wise approach is developed, based on estimations of the value of ESS by willingness-to-pay (WTP)-approaches. Some data are available in literature on the WTP for a step of improvement or deterioration of the ecological status. Apart from the uncertainties and discussions that stick to WTP-approaches, a methodological difficulty that remains to be solved is to connect a step up or down in ecological status to one of the available drought indicators (e.g. WEI+ or Q10).

- On a similar note, the DESSIN FP7 project has aimed at establishing the link between WFD status and ecosystem State (in the DPSIR frame). The focus on beneficiaries allows for a clearer identification of co-benefits and the incorporation of economic values, both relevant for the integrated management of the water resource (WW Water Centre, 2014).

The above examples provide a quick glance at the state-of-play with regards to the application of the ecosystem services concept to water stress problems. There are many initiatives evolving and good progress is being made. Knowledge gaps to be bridged include connecting ecological status to drought or stress indicators and valuation of the appreciation of environmental quality.

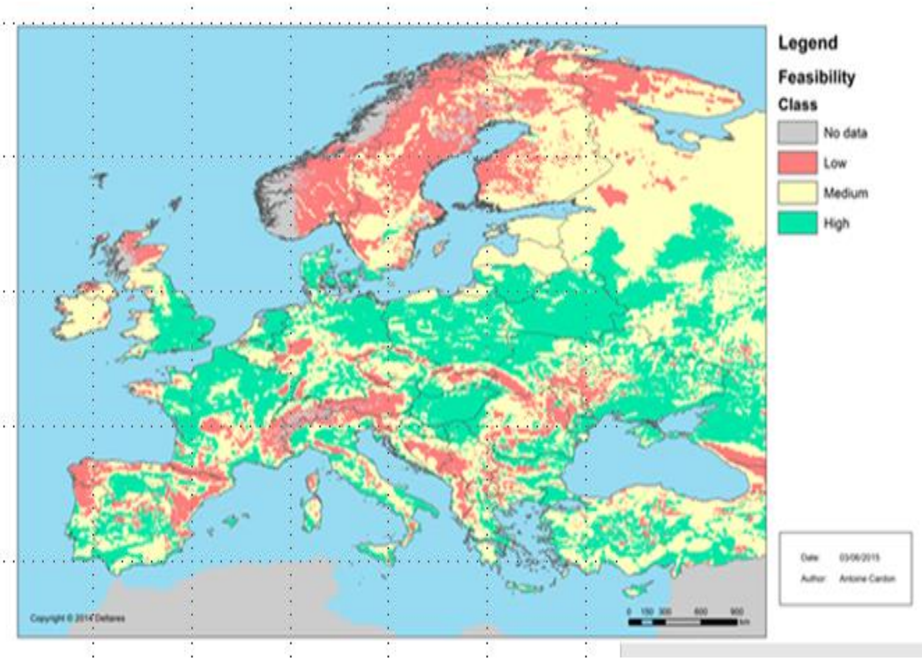
Design and application of nature-based solutions (NBS)

The 2012 Blueprint (EC, 2012) mentioned wetland restoration, floodplain restoration and groundwater recharge as promising nature-based multi-functional storage and regulation elements. Until now, there are only few well-documented cases of NBS which have been designed specifically to address the issues of water stress.

There is a wide range of small-scale on-farm measures which increase, as main or additional impact, the infiltration of rainfall into the soil and/or the storage of groundwater. Some examples: increasing surface water levels with weirs and dams, creation of natural water retention areas, measures to increase the carbon content of the soils (increasing the water retention capacity), measures to reduce runoff (e.g. contour ploughing), measures to reduce nutrients and pesticide loads (green strips, contour ploughing). The impacts of such measures are often local and limited in time, so for impact at catchment level a broad application is required. Co-benefits may be found in flood management, in nature areas, or in the value of an area for recreation. Calculation models to support the implementation of such measures need to be able to make clever combinations of the small scale of the implementation and the wider area that is impacted, assuming that the measures are widely applied. Two JRC reports (JRC, 2012a, 2012b), which were prepared in support of the 2012 Blueprint, offer examples of such an approach.

Managed Aquifer Recharge (MAR) is one of the options to improve aquifer conditions and raise groundwater levels. MAR is the intentional recharge of water to suitable aquifers for subsequent recovery or to achieve environmental benefits; the managed process assures adequate protection of human health and the environment. MAR can also reduce the occurrence and degree of flooding. Various methods are used to recharge aquifers, including bank infiltration, infiltration in boreholes and wells, in-channel interception and run-off harvesting. Some of these methods are more nature-based than others, e.g. infiltration via wells may be considered a less natural approach. MAR is already widely practiced across the world. The most common incentives are to increase the buffer capacity for seasonal droughts, manage saline intrusion and to create a strategic reserve for emergency situations. Benefits may extend to ecology and in specific cases to protection of wooden pilings or manage land subsidence. The suitability of the subsoil in Europe for aquifer recharge (not taking actual demand into account) was estimated using the PCRGLOB-WB model (Figure 6.5).

Map 6.1 Suitability of EU’s subsoil for aquifer recharge



Source: ?

NBS can be cost-effective for meeting the Sustainable Development Goals in cities (IPBES, 2019). An example: the H2020 Naturvation project[17] assesses what nature-based solutions can achieve in cities, examines how innovation is taking place, and works with communities and stakeholders to develop the knowledge and tools required to realize the potential of nature-based solutions for meeting urban sustainability goals.

The Horizon2020-funded NAIAD project[18], which aims at endorsing the upscaling of the implementation of NBS, emphasizes the insurance value of NBS as a means to set up convincing business cases. The insurance sector is a natural partner for this approach, both as insurance provider and as institutional investor. The project highlights the role of the funding, financing and procurement phases of NBS implementation projects. The proposed approach relies on collaborative modelling approaches, because only collaboratively built consensus can cover the diversity of affected and benefiting stakeholders and reach confidence in bringing all relevant benefits together in a complete business case (Altamirano et al., 2020). One of the project's case studies deals with water stress, albeit in qualitative terms only: the Medina del Campo aquifer in central Spain.

Current implementation challenges for NBS include the necessary upscaling of measures: challenges in financing, in quantifying the benefits, in securing the acceptance of the benefits. Furthermore there are knowledge gaps in understanding and securing social equity and in the impacts of climate.

6.5. The role of EU innovation policy in the reduction of water stress

The Lisbon Strategy, which was adopted by the European Council in 2000, laid down the foundations for a comprehensive and multi-dimensional approach for innovation policy in the EU for the period 2000-2010. Building on that legacy, the Europe 2020 strategy "for smart, sustainable and inclusive growth" was launched by the European Commission in 2010, covering the period 2010-2020 (EC, 2010a). Furthermore, the European Commission designed the so-called "Innovation Principle". This contributes to cross-checking that the agenda-setting, legislation and implementation of EU policies remains open to innovation potential, and a favourable regulatory framework is created to help innovation flourish (EC, 2019d). By the end of the Europe 2020 life-cycle, the European Commission ensured its commitment to remain a front-runner in promoting climate action and sustainable development worldwide, as set out in the reflection paper "Sustainable Europe 2030" (EC, 2019h) and manifested in the "European Green Deal" (EC, 2019j), which are also underpinned by the updated "EU Digital Strategy" (EC, 2020g).

Over the last programming period the European Commission has supported numerous research, development, innovation or demonstration projects on climate change adaptation, environmental

[17] https://naturvation.eu/home
[18] http://naiad2020.eu/

protection and resource efficiency through LIFE[19](EC, 2018b) and Horizon 2020 instruments [20,21], with Horizon 2020 also incorporating under the same umbrella past EU funding instruments. Moreover, innovation in Europe was also supported by Cohesion policy funds and loans made available by the European Investment Bank Group (European Parliament, 2020).

The European Commission has also supported the creation and operation of various initiatives and partnerships which foster innovation in Europe, including innovation in the area of water and environment: Innovation Partnerships (e.g. EIP-Water, EIP-Agriculture), Joint Programming Initiatives (e.g. JPI Water, JPI Climate, JPI FACCE, JPI Oceans), Joint Technology Initiatives, European Technology Platforms (e.g. WaterEurope; former WssTP). Furthermore, European research organisations on water have teamed up creating thematic fora (e.g. EurAqua).

In the field of water, the European research and innovation is currently focusing on a wide range of topics. The aspects which are most relevant to the topics of water quantity and water stress are:

- Better monitoring of the earth, its climate and of the water uses (e.g. satellite technology, remote sensing, unmanned aerial vehicles, citizen observations and information crowdsourcing, digitalisation of the water sector).
- Better data management and analysis (e.g. Internet of Things, Big Data science, machine learning, Geographical Information Systems, advanced Information and Communication Technologies, integrated data visualisation and decision support platforms).
- Better socio-environmental modelling and forecasting (e.g. near-real-time modelling and forecasting of natural phenomena including hydrological and drought forecasting, agent-based modelling of coupled socio-environmental systems, elicitation of social attitudes through serious gaming).
- Better technologies for increasing technical water efficiency (e.g. leakage detection and control in water networks, precision agriculture technologies, industrial symbiosis).
- Better tools for raising awareness and controlling water consumption (e.g. mobile applications promoting awareness and behavioural change against water consumption, schemes on water footprinting of processes and products).
- Better technologies for enabling and promoting water supply from alternative water sources (e.g. more energy-efficient desalination and water reuse with minimisation of environmental risks, real-time monitoring of water quality parameters for safe water reuse).
- Better technologies for Managed Aquifer Recharge for urban settings.

The Annex contains detailed information on a selection of recent EU projects related to water stress management.

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19 LIFE programme: https://ec.europa.eu/easme/en/life

20 Horizon 2020 programme: https://ec.europa.eu/programmes/horizon2020/

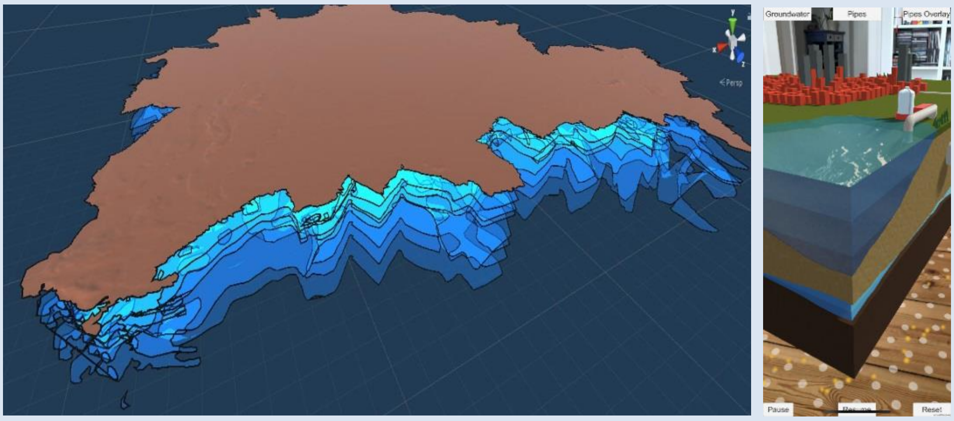
21 EC website on Research and innovation for the European Green Deal: https://ec.europa.eu/info/research-and-innovation/strategy/european-green-deal_en

Box 6.4 Berlin uses Augmented Reality to foster citizen engagement in urban groundwater management.

Since 2000, Germany has registered nine of its ten warmest years on record. This is considered an unusual accumulation of record years of high temperatures (Helmholtz-Klima-Initiative, 2020). In 2019, the neighbour states of Berlin and Brandenburg were ranked the two warmest German *Länder* (Berlin.de, 2020). Further, according to scenarios informing its climate adaptation programme, the city of Berlin expects to have Mediterranean climate by year 2100; similar to that of modern day Toulouse (Reusswig et al., 2016). In this context, prospects of decreased precipitation and variations in seasonality are bringing water resource challenges into the agenda of the German capital, and with this, a need for increased citizen awareness of the origin and management of their water resources.
Managed aquifer recharge, using the natural underground for treatment and storage, is the main process Berlin uses for drinking water production. The efficiency of the process in this city is high, but the average drinking water consumer is unaware of it.

Since 2019, the Digital Water City project (Digital Water City, 2020) is set to a) raise public awareness of Berlin's water resources; b) increase acceptance of policies promoting the sustainable use of urban water, and c) foster the public involvement in urban water management. To do so, the project is developing an Augmented Reality mobile application[22] providing its users with an immersive view into a "hidden part" of the water cycle. The app uses modelling of the city's geology and hydrology to enable visualisation of groundwater resources. By making groundwater visible (Figure 6.3), the project partners intend to build the citizens' trust in natural treatment techniques and promote the consumption of tap water over bottled alternatives. Incorporating the app into guided waterworks tours, public events and school initiatives, and installing QR codes at drinking water dispensers and well sites, the initiative aims to reach 20,000 citizens every year. The app is developed by a local SME in collaboration with the city's water utility.

Figure 6.3 Digital Water City AR mobile application, prototype visualisations



Source: (Digital Water City, 2020)

6.6. Outlook

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[22] For more information, please visit: https://www.digital-water.city/solution/augmented-reality-ar-mobile-application-for-groundwater-visualization/

The search for solutions for the increasing impacts of water stress can roughly take four directions, each with their preferred applications:

- Continued and intensified development of technologies for sectoral water demand measures and water savings, in domestic water use, agriculture, industry and electricity production. This can be considered a no-regret option. In the longer term it will become necessary in most parts of the EU, and in the short term it offers environmental gains.

- Intensified development of nexus approaches, capitalizing on synergies between economic sectors, and including nature-based solutions.

- Continued and intensified pursuit of additional means of water supply in areas with coastal tourism, high-value agricultural and horticultural areas near coasts, and urbanised areas. In this context, interbasin water transfers are considered a last resort because of their severe environmental impacts. Efforts must be aimed at keeping this measure restricted to the genuine necessities and where possible, combine them with nature-based solutions.

- Systemic change aimed at the root causes of overexploitation of natural resources, in a much broader transformation than in water management alone, following one of the conclusions of IPBES (IPBES, 2019): *Goals for conserving and sustainably using nature and achieving sustainability cannot be met by current trajectories, and goals for 2030 and beyond may only be achieved through transformative changes (fundamental, system-wide reorganizations across technological, economic and social factors, including paradigms, goals and values) across economic, social, political and technological factors.*

The most likely outcome seems to be a mixture of site- and case-specific combinations of the first three approaches, while the fourth option offers a fully alternative pathway – maybe first explored in areas where the current practices can no longer be continued. Whichever approach is chosen, it will be fully dependent on and must therefore be interconnected with economic and legal measures and measures to increase public awareness. What counts is the (public) awareness that continuation of current practices is no longer possible in the hotspot areas, and that there are areas that are likely to become additional hotspot areas in the coming decades.

A benefit of the gradual nature of the progress of water stress problems is that it leaves some time to develop new practices and exchange lessons-learned across the EU. Implementing water demand measures will buy some more time – provided lock-ins are avoided. Long-term planning may include such methods as adaptive planning and pathways to put short-term measures in a long-term perspective, to allow for a long-term view and to avoid as much as possible additional lock-ins.

7. Conclusions

Water stress can be caused by natural phenomena (drought events), by man-made phenomena (unsustainable water abstraction, deterioration of water quality, lack of access to water) or a combination (climate change). Climate change is manifesting itself with increasing impact. It is expected to cause a major increase of water stress occurrence, affecting an increasing area of the EU and an increasing percentage of its inhabitants annually. Water stress caused by over-abstraction is persistent, but this report presents clear evidence that the efforts made to reduce it show their effect.

Water stress caused by over abstraction is often a local and temporary phenomenon, associated with urban areas, irrigated agriculture or tourist hotspots in the summer months. Such areas tend to represent a high economic value and an associated high sensitivity to water stress. Impacts of over abstraction in such areas can be aggravated by droughts. The impacts are aggravated even more by the continuing trend of concentration of population and economic activities in urban areas.

In order to demonstrate past or future water stress impacts, the evidence needs to be available and presented at sufficient temporal and geographic detail. This level of detail is not always present in the data currently reported by the Member States to the EC and the EEA.

Evidence is growing that water is being used in the EU with increasing efficiency. The data of water consumption versus Net Value Added of the agriculture, energy and industry sectors clearly demonstrate this trend, even though not always consistently in the time span for which data are available (1995-2017) or between the four regions of Europe (East, North, West and South). Care must be taken that this gain does not result in reinforced economic growth (and associated water demands) but instead benefits the environment. One way of securing this is by incorporating environmental flows in River Basin Management Plans and Drought Management Plans. The analysis of sectoral water use and outlooks in this report signals that the environmental flows have not yet been defined well in most of the River Basin Management Plans.

The economic sectors that depend most on water availability are agriculture, electricity production, industry and drinking water supply. These sectors have potential for further water saving in the order of 20 to 40 %. Where demand management alone is not sufficient, alternative water supply methods such as wastewater reuse and desalination may offer perspectives at the local scale. This report has not addressed the costs and benefits of these measures.

Policy responses at EU level which address or touch on water stress form an intricate network. A central position is taken by the Water Framework Directive. Distinct progress is made in its implementation, while additional efforts are needed in monitoring, modelling and in licensing of abstractions. Intertwined are sectorial policies and the emerging integrative initiatives. Our analysis suggests that 'anchoring' water management objectives in sectoral policies is a prerequisite for successful water stress management. The European Green Deal and the upcoming new EU strategy on Adaptation to Climate Change carry great potential to leverage policy integration and increase Europe's climate preparedness and resilience.

Insufficient quality or coverage of data is a persistent and recurrent issue in water management in general, and also in water stress management. Emerging technological innovations offer promising perspectives for detailed (both in time and space) observations of such issues as snow cover, soil moisture, actual evapotranspiration and illegal abstractions. For data collection that depends on the cooperation of stakeholders (e.g. in the industry) collaboration must be intensified and the lessons learned expanded to other sectors.

In the parts of Europe where water stress problems press for urgent action, the challenge is to avoid continued lock-ins in technical solutions such as water transfers, and instead start off with an analysis that includes the root causes of the problem, using nexus approaches and systemic analysis. Measures readily associated with these approaches are ecosystem approaches and nature-based solutions.

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Annex : Recent EU innovation projects for water stress management

Box 6.4 Selection of recent EU projects dealing with water quantity challenges and/or digitalization in the water sector.

Research project	Vision & Key objectives
Globaqua Managing the effects of multiple stressors on aquatic ecosystems under water scarcity (FP 7, 2014-2019)	Globaqua explored the impacts from different combinations of pressures acting at the same time (e.g. organic and inorganic pollution, water abstraction, land use change) under water scarcity conditions, emphasising on the potentially unknown synergies that might take place and amplify the degradation of chemical and ecological status of freshwaters. Furthermore, the project studied and valuated the potential implications for associated ecosystem services following a participatory approach. The project also explored the potential to improve river basin management through the integration of ecosystems services in freshwater policies and management.
EartH2Observe Global Earth Observation for Integrated Water Resource Assessment (FP 7, 2014-2017)	EartH2Observe aimed at integrating available global earth observations via satellites and in-situ data from ground stations with global hydrological and land surface models to perform a re-analysis, and generate a comprehensive and consistent dataset for global water resources. The project reconstructed timeseries of sufficient length (several decades) for key components of the water cycle, such as precipitation, evapotranspiration, soil moisture, groundwater and others. Therefore, it improved the knowledge on the water budgets, especially in regions with gaps in their monitoring coverage. A key product of the project was the Water Cycle Integrator data portal, which provides all datasets online. The usefulness of the project outputs was demonstrated in selected case studies with the participation of local stakeholders.
DestinE Destination Earth (European Commission, 2021-2030)	The ambition of the Destination Earth Initiative is to create digital replicas of different subsystems of the Earth (e.g. weather and climate, global ocean circulation and biogeochemistry of the oceans, freshwater, food) and integrate them into a unique "digital twin" of the Earth. This digital twin will contain high-precision information on the status and operation of the physical world, including environmental and socio-economic activities, and it will be capable of simulating different scenarios for sustainable development. Therefore, it could improve policy and decision making in the EU. The core feature of the project will be a federated cloud-based modelling and simulation platform, which will provide access to advanced computing infrastructure, artificial intelligence applications and analytics, sophisticated software and datasets. It will be funded as part of the European Commission's programme for Digital Europe, while certain aspects will also be supported by Horizon Europe and the EU space programme. Although the initial end-users are the public authorities, the initiative will also provide opportunities for exploitation of the results by scientific and industrial users in the future.
Hydrousa Demonstration of water loops with innovative regenerative business models for the Mediterranean region (H2020, 2018-2022)	Hydrousa focuses on the development of a circular business model for the Mediterranean and other water-scarce regions across Europe and worldwide, by establishing decentralised regenerative solutions for water/wastewater treatment and management that close the local water loops, improve agricultural production and benefit local value chains. The project devises and demonstrates innovative solutions with low energy footprint for different types of water (i.e. rainwater, groundwater, wastewater, saline water and vapour). Proposed solutions adopt traditional handcraft and ancient technologies, and combine them with modern nature-based and nature-inspired approaches, as well as with information and communication technology systems and automations.

iWAYS Innovative water recovery solutions through recycling of heat, materials and water across multiple sectors (H2020, 2020-2024)	iWAYS focuses on the recovery of energy, material and water from industries with gaseous and wastewater emissions by applying non-disrupting approaches that combine exhaust condensation, water treatment and waste valorisation. The novel approaches will be tested in industries related to ceramics, chemicals and steel, which are considered water and energy intensive. The project targets to recover 30% of water and heat from humid chimney plumes and cut down freshwater consumption by 30% to 64%. In addition, it aims at recovering valuable acids or particulates from flue gases, which also protects the environment from harmful emissions.
Aqua3S Enhancing Standardisation strategies to integrate innovative technologies for Safety and Security in existing water networks (H2020, 2019-2022)	Aqua3S aims at combining standardisation of existing sensor technologies with state-of-the-art technologies to detect water safety and security risks for water networks, including the use of unmanned aerial vehicles, satellite images and citizen observations through social media crowdsourcing. The key project output will be an integrated platform, which serves as an early warning and decision support system. The platform will assist water utilities in mitigating risks, handling crisis events and alerting the public and the authorities on evolving issues with their water networks; thus, reducing the potential of water shortages and improving the response time in in the case of crisis events.
Digital Water.City Leading urban water management to its digital future (H2020, 2019-2022)	Digital Water.City investigates a range of digital solutions, which could be applied in urban and peri-urban environments to help the water authorities tackle modern water challenges and increase awareness and participation of the citizens in water protection and management. The project demonstrates case studies from five major cities in Europe (i.e. Berlin, Copenhagen, Milan, Paris and Sofia). Inter alias, it develops digital solutions for increasing the volume of safe water reuse, promoting precision farming, raising awareness for groundwater risks, and facilitating integrated monitoring and management of groundwater resources. A variety of methods and technologies is combined and tested, including artificial intelligence, machine learning, unmanned aerial vehicles, real-time sensors, modelling, augmented reality, mobile technology and cloud computing. The project also addresses the issues of interoperability, cybersecurity and governance regarding digital infrastructure.
Fiware4Water FIWARE for the Next Generation Internet Services for the WATER sector (H2020, 2019-2022)	Fiware4Water builds upon the FIWARE platform, which is an open-source smart solution incorporating modules that enable the connection of Internet of Things, Context Information Management, Big Data services and cloud services, and facilitates Smart City initiatives and the Next Generation of Internet initiative. The project aims at supporting the adoption of the FIWARE platform by end-users of the water sector (e.g. cities, water utilities, water authorities, citizens and consumers) and solution providers (e.g. private utilities, SMEs, developers), because of its capacities to enable interoperability, standardisation, cross-domain cooperation and data exchange. The project demonstrates four European case-studies with digital water solutions for optimised selection of water sources and routing of water, increased water saving and safety in the water networks, real-time monitoring and awareness of household consumption, and optimisation of wastewater treatment operation.
NAIADES A holistic water ecosystem for digitisation of urban water sector (2019-2022)	NAIADES focuses on real-time monitoring of water consumption in residential, commercial and public buildings and the exploitation of Big Data analytics in three dimensions (i.e. spatial, temporal and nodal). A mobile application has been developed to support awareness and behavioural change of consumers towards their personalised water consumption through a stepwise commitment to more sustainable water use goals. The project also measures the safety and reliability of water supply after examining equipment failures and maintenance schemes, in order to understand and improve water asset management strategies by water utilities. Furthermore, the project collects information on water quality and applies machine learning techniques to predict potential quality problems before they break out; thus increasing the confidence of water consumers regarding water quality of their tap water.