# WEFE nexus adaptation and mitigation strategies

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# Chapter 3
## WEFE nexus adaptation and mitigation strategies

# Executive summary

In addressing adaptation and/or mitigation strategies in the Mediterranean region, a focus on achieving multiple goals across the water, energy, ecosystems and food sectors is imperative. Identifying synergies between these aspects is crucial to avoid negative outcomes and trade-offs. An integrated approach to the Water-Energy-Food-Ecosystem (WEFE) nexus is necessary, one which takes into account its interconnected nature and the potential for rebound effects from addressing individual aspects separately. Because of the region's temporal and spatial variabilities, dealing with the WEFE nexus requires transdisciplinary approaches that incorporate social, political, and governance aspects. In cases of high expected impacts from climate change, transformative adaptation involving significant changes in human inputs and system reorganisation becomes necessary, as incremental adaptations may reach their limits in effectiveness. Watershed management serves as an effective unit for managing the nexus, especially given the Mediterranean region's vulnerability to water stress. The complexity of the region's socio-economic and political diversity necessitates transboundary strategies in adaptation and mitigation efforts, alongside global agreements as a complement to the Paris Agreement. Evaluating adaptation and mitigation strategies in a context-specific manner is essential to ensure effectiveness. While digital and technological solutions, early warning tools, and climate services are valuable, they must be integrated with nature-based solutions, and broad societal understanding and engagement are vital. Despite being solutions, improvements in irrigation techniques can lead to unintended consequences on the WEFE nexus, such as increased water use through the expansion of irrigated surface area and intensity. Embracing behavioural changes, such as reducing meat consumption and food waste, and encouraging restrained consumption and sufficiency, holds high potential for both adaptation and mitigation in the face of environmental challenges.

## 3.1 Adaptation and mitigation needs for the nexus

The Mediterranean region has a long history of adaptation to harsh environmental conditions, such as hot dry climates and poor soils. This has led to the development of heterogeneous and mixed landscapes and agricultural practices, such as complex irrigation infrastructures and agroforestry systems. However, population growth and climate change have presented significant challenges, leading to an increase of crop production and, in some cases, the emergence of monoculture landscapes with high water and energy demands. These changes have impacted ecosystem services (Caraveli, 2000; Daccache et al., 2014), especially considering the fact that the Mediterranean area is one of the 34 global biodiversity hotspots. This biodiversity has, however, been considerably impacted by human activities. Land use change, both throughout history, but particularly in recent decades, has resulted in considerable changes to species composition (García-Vega & Newbold, 2020). This is particularly concerning, as even ecosystem restoration in such arid environments does not result in recovered ecosystems and has significantly lower biodiversity levels and modified community composition (García-Vega & Newbold, 2020). Technological advancement has made it possible to increase agricultural productivity even more. However, in most cases, a narrow focus on adaptation pursued a single goal of producing diverse food items, many of them exported to countries outside the Mediterranean. This has led to a situation where the primary water user in the region is agriculture (around 80% of water withdrawals, with percentages varying depending on country) (EEA, 2001), leading to negative environmental consequences: water depletion, soil and aquifer degradation, and impacts on terrestrial and aquatic biodiversity (Carrão et al., 2016; Lagacherie et al., 2018; Zalidis et al., 2002). Likewise, measures such as the reuse of treated wastewater for irrigation have been related to some health risks (Kalavrouziotis et al., 2015; Lequette et al., 2020), whereas the increase of irrigation areas and the more widespread use of pesticides and fertilisers to ensure food production in the context of water scarcity, has resulted in surface and groundwater pollution, habitat reduction and biodiversity losses (Bilgili et al., 2018; Hadas et al., 1999; Terrado et al., 2016b). In addition, this has led to high vulnerability to climate change and potentially more severe impacts of droughts and heatwaves in the future, with an increased risk of wildfires (Jones et al., 2020).

Adaptation (i.e. actions that reduce the harm caused by climate change) and mitigation (i.e. actions that reduce the concentrations of greenhouse gases which cause climate change) are widely recognised as two pillars of climate action, and future climate and global change impacts will lead to increased societal demands for Mediterranean ecosystems

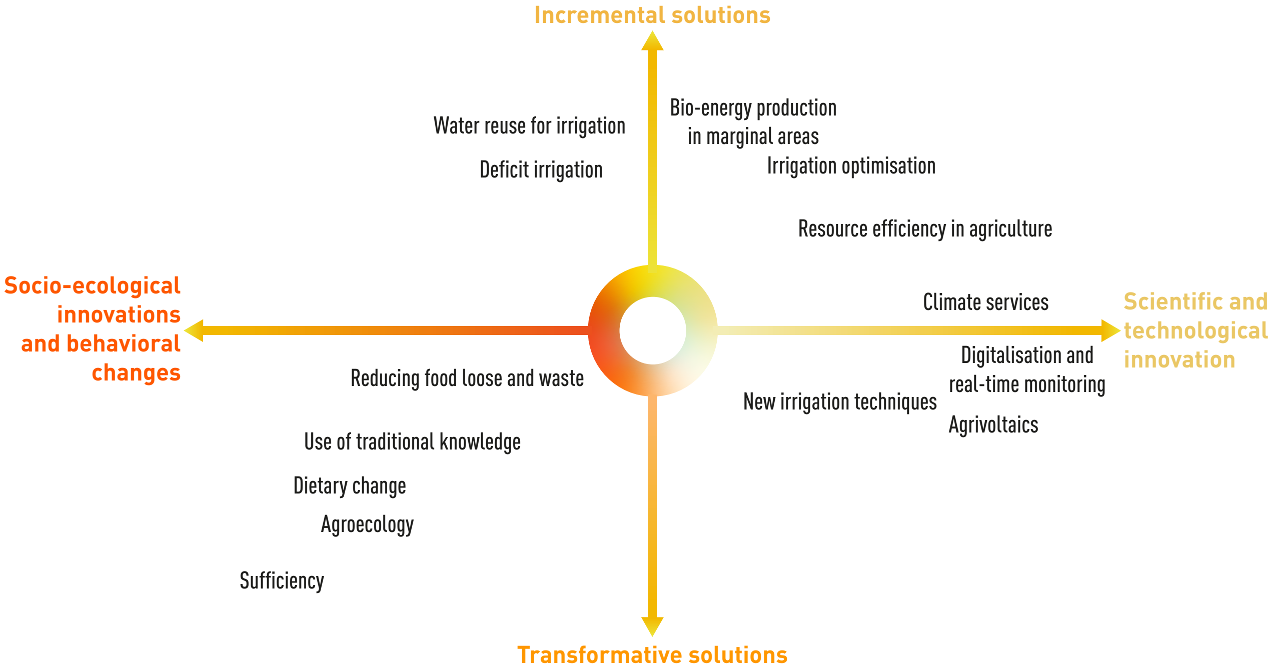


**Figure 3.1 | Different gradients of possible adaptation and mitigation solutions for WEFE components used around the Mediterranean region.** Adaptation and mitigation solutions range from incremental to transformative, and from socio-ecological innovations and behavioural change to scientific and technological innovation.

to support these actions. The last IPCC report (Begum et al., 2022) states that for adaptation, a solution is an option which is effective, feasible and conforms to principles of justice. From a WEFE perspective, adaptation and mitigation strategies in the Mediterranean need to focus on multiple goals to achieve synergies for water, energy, food and ecosystems. This is particularly relevant for the forestry sector, where promoting fast-growing high wood yield species has led to the spread of non-native tree species (eucalyptus, pine), resulting in negative impacts on biodiversity, water cycles and fire risk. For example, plantations of eucalyptus threaten Mediterranean plant communities, due to the species' rapid growth and encroachment on spatially limited habitats such as riverine vegetation (Badalamenti et al., 2018), and are already spread across considerable portions of protected areas in the Mediterranean, such as the Natura 2000 network on the Iberian Peninsula (Bussotti et al., 2015; Deus et al., 2018). All these examples demonstrate how adaptation and/or mitigation strategies to current and future global changes, particularly in the Mediterranean, need to focus on multiple goals where synergies for the water, energy, ecosystems and food systems can be achieved, or at least trade-offs in other aspects of the WEFE nexus can be avoided. This is particularly valid considering mitigation strategies, as several of them, which can be applied in other bio-climatic regions – e.g. large-scale tree planting – cannot be considered as equally valuable in the Mediterranean area, because of the possible impact on ecosystems and water resources.

Adaptation and mitigation solutions are usually distinguished on a gradient of two main types: incremental and transformative. The first include marginal changes over time within the existing system whereas the second include non-linear changes that fundamentally shift the function and operation of the system (Dilling et al., 2023; Pelling et al., 2014; Wilson et al., 2013). The last IPCC report emphasises the role of transformational adaptation, which changes the fundamental attributes of a socioeconomic system in anticipation of climate change and its impacts (Begum et al., 2022). Transformative adaptation requires increasing human inputs and system re-organisation, but it can be the most appropriate response to climate change and other environmental and human drivers, when the severity of the expected impacts is particularly high, the time available for implementation short due to severe impacts, or when current incremental adaptation options are reaching their limits in terms of implementation and functionality (Fedele et al., 2019). From another perspective, adaptation and mitigation solutions in the WEFE sectors can range from those more related to ecological and consumption-reducing behaviours to those more related to scientific and technological innovation (*Figure 3.1*).

## 3.2 The WEFE nexus as an approach to optimise adaptation and mitigation across the Mediterranean region

The WEFE nexus approach is proposed for designing better adaptation and mitigation strategies for different drivers affecting the Mediterranean region, including climate change leading to desertification, pollution, population growth, lifestyle changes and urbanisation (see *Chapter 2*). There are different national, regional, and global plans and actions with the objective of mitigating and adapting to the consequences of climate change. Specific strategies have the potential to generate mutually beneficial "win-win" situations in multiple sectors (Mbow et al., 2017). For example, implementing sustainable agricultural practices through soil management can reduce greenhouse gas emissions (benefiting climate) and conserve water (benefiting water). Also, supporting the adoption of renewable energy sources not only provides energy benefits but also mitigates environmental harm (beneficial to ecosystems). However, in some instances and contrary to expectations, sectoral strategies for adaptation and mitigation of climate change may potentially exacerbate adverse externalities and trade-offs within the nexus, as opposed to mitigating them (Mahlknecht et al., 2020). For example, agricultural intensification, hydropower, first-generation biofuels, and the transition to non-conventional water resources do not consistently align with the concept of nexus approach (Giordano & Quagliarotti, 2020). Simultaneously, the production of water, energy and food using business-as-usual strategies (see *Chapter 2*) may increase greenhouse gas emissions, thereby contributing to climate change.

Nexus solutions include a variety of interventions that benefit at least two of the four WEFE nexus sectors while ensuring non-negative or neutral outcomes for all sectors. Unlike other integrated approaches that are the dominant paradigm for integrated management within a particular sector and resource (such as Integrated Water Resource Management - IWRM and Integrated Natural Resource Management - INRM), nexus approaches lead to an integration that cuts across different sectors and resources (Roidt & Avellán, 2019). Likewise, the nexus framework benefits from the incorporation of green and circular economy principles, which involves the use of multi-functional production systems, cross-resources and cross-sector recycling, better able to ensure resource security and sustainable development by reducing waste (Carli & Quagliarotti, 2022; Segovia-Hernández et al., 2023) developing context-specific solutions that also value local knowledge in the implementation of actions. Such solutions can potentially help improve the management of water resources and ecosystems, improve use efficiency, maintain agricultural productivity and biodiversity conservation, and mobilise alternative sources of water and energy to increase their availability and access. By its nature, the WEFE nexus requires integrated technical, natural, social, political and governance aspects (see *Chapter 5*). Most WEFE discussions and applications have been developed so far at national and global level (see *Figure 3.5*), whereas there is a need for more research at local scales, and a diverse and flexible set of evidence-based solutions that can be integrated to maximise the overall resilience of the region. Transdisciplinary approaches are needed for addressing the interlinked temporal and spatial variabilities of the Mediterranean region (e.g. Lucca et al., 2023; Tàbara et al., 2018).

According to the classification adopted by the Climate-ADAPT platform and from the technical report of the European Topic Centre on Climate Change impacts, vulnerability and Adaptation (ETC/EAA, 2021), based on the IPCC (2014) report, adaptation solutions can be classified into three main classes: structural and physical options, social options and institutional options. Since those categories encompass a wide variety of solutions in sectors beyond the WEFE, options that have a direct relation to the sectors and have been implemented in the Mediterranean area have been selected from the categories. Mitigation and adaptation options are therefore organised as follows: technological options, ecosystem-based options (including nature-based solutions) and behavioural change options. Institutional options, including governance and policy, are discussed in *Chapter 5*. Finally, integrated assessments are needed to develop governance strategies for sustainability transitions that include social innovations (e.g. conscious consumption of resources such as water, food or energy) and technical innovations (e.g. renewable energy alternatives, organic agriculture or aquifer recharge) (Halbe et al., 2015). Examples of impacts of policy measures on nexus components include agricultural subsidies that aim to promote the productivity of woody crops, such as olive trees in southern Spain which have led to increased groundwater abstractions for olive irrigation and increased pressure on local groundwater resources (Salmoral et al., 2011). In the case of Egypt, Wichelns (2023) found that when planning which crops to invest in, farmers favoured crops that give a high return on land value rather than on water value, irrespective of there being a better national option to importing virtual water.

### 3.2.1 Technological options

Technological solutions in the Mediterranean are often related to technical developments for improving water and energy use efficiency as well as increasing the use of machinery to improve labour productivity in food production, although fuel consumption and engine emissions may have negative environmental impacts and could reduce their potential contributions to adaptation and mitigation from a WEFE nexus perspective (Lovarelli & Bacenetti, 2017). Often, different technologies are implemented together, such as protected crop cultivation in greenhouses combined with efficient irrigation and indoor climate control (Imache et al., 2009). It is worth noting that there is a technological gap, regarding modern technologies, between the Northern and Southern Mediterranean, which is expected to grow in several sectors, as well as a gap regarding the vulnerability to climate change, pressure on natural resources and nutritional challenges (Antonelli et al., 2022; Pérez-Castro et al., 2021). Under this category we also find traditional technologies and infrastructure. Below, there is a non-exhaustive list of technological solutions relating to WEFE components that have been applied in the Mediterranean. Given the relevance of water and ecosystems management in the region, irrigation technologies are presented in separate *Section 3.2.1.1*.

#### Use of renewable energy, alternative energy resources, and improving resource use efficiency in agriculture and other sectors

Renewable energy can play an essential role in meeting the need for electricity in the whole food production chain and transport. Examples include the use of solar energy in desalination plants, the use of renewable energy for wastewater reuse to irrigate crops and decorative plants, electrification of rural areas, improvement of local industrial production (e.g. solar-powered water pump), and provision of electricity to drinking water treatment plants (Malagó et al., 2021). Suitable (but limited to specific areas) geothermal energy can be an important energy resource for electricity generation and is also used directly in heating, food and agriculture, aquaculture and some industrial processes. For instance, it has been used for improving crop production in the Suez Gulf in Egypt (Fahmy et al., 2016). In Tunisia, about 1143 million $m^3$ are exploited from geothermal resources (temperatures between 30°C and 80°C), 76% of which is used for agricultural purposes, 19% for drinking water and 5% for industry and tourism (Ministry of Agriculture and Water Resources General Direction of Water Resources, 2005). Tunisia is one of the leading countries using geothermal water resources for heating plastic greenhouses. In the Kebili region, 98% of geothermal resources are utilised for agricultural purposes (71% for oases and 27% for greenhouses), the remaining part (2%) is used for bathing (hammams), tourism and pools (Ben Mohamed, 2010). Other specific applications for resource use efficiency include improved crop waste management (for example citrus, olives, grapes) through biorefineries. In the driest countries, the potential of renewable energy sources can be expressed mostly at farm/smallholder level, where the energy produced can cut the cost of irrigation and reduce GHG emissions associated with irrigation or biofuels produced on farms to be used by the machinery.

#### Agrivoltaics (AVs)

Agrivoltaics is a food-energy producing system that involves the simultaneous use of land areas for both solar photovoltaic (PV) power generation and agriculture. Agrivoltaics deployment could lead to significant benefits across the food-energy-water nexus, as it could simultaneously power carbon-neutral farms, allow for more resilient and sustainable agriculture, and support the clean energy transition (Herrero, 2020). However, the development of PV infrastructures necessary to meet carbon targets requires land (see *Chapter 2*) which could conflict with food production. Building PV panels over crop fields can reduce competition between solar and agriculture in land use (Valle et al., 2017), especially in regions characterised by land scarcity, such as small islands, and/or densely populated regions (Amaducci et al., 2018; Dinesh & Pearce, 2016; Herrero, 2020). Furthermore, in dry land environments, this combined use can help mitigate the impacts of climate change increasing land use efficiency and enhancing water management (Al Mamun et al., 2022; Amaducci et al., 2018; Barron-Gafford et al., 2019). PV panels, with their shielding, reduce heat stress and evapotranspiration and can optimise the distribution of solar radiation over crops (Dupraz et al., 2011; Herrero, 2020). This can lead to improved crop productivity and reduced water consumption and soil degradation (Barron-Gafford et al., 2019; Dupraz et al., 2011; Elamri et al., 2018). Moreover, they can protect crops against hazardous events, such as hail and frost which can endanger crop yields (Dupraz et al., 2011; Herrero, 2020). At the same time, PV panels make farms energy self-sustaining and, in these conditions, they even increase their electrical yield (Dinesh & Pearce, 2016), owing to the underlying microclimate and the possibility of modifying their tilt (Valle et al., 2017), both aspects that optimise the working conditions of PV panels. Despite the positive perspectives of installing agrivoltaics systems, there are still issues that need to be investigated, as the benefits may not occur for every type of crop, soil or in every period of the year, and not all the effects of modifying light and water availability, temperature, wind and humidity – the main factors that influence crop productivity – are well known (Trommsdorff et al., 2021).

### Digitalisation and precision agriculture

Digital solutions include remote monitoring, digital sensors, artificial intelligence, robotics and internet of things applied to agriculture and resource management for improving efficiency, productivity, product quality and sustainability, through better informed and real-time decision making. Using remote sensing in precision agriculture for irrigation water management can include crop water status monitoring, calculating evapotranspiration, infrared thermography, crop water status, and crop attributes (Samreen et al., 2023). Techniques such as drip irrigation, micro-irrigation, and precision irrigation deliver water directly to the root zone, minimising evaporation and runoff. These methods ensure that water is targeted efficiently, reducing water waste and improving irrigation efficiency (Chai et al., 2016). The agricultural sector has undergone a significant transformation through the adoption of Internet of Things (IoT) technology. This technology gives farmers immediate access to real-time data concerning environmental conditions and machine status. This information can help farmers to enhance decision-making across various facets of their work, encompassing both crop cultivation and livestock supervision. Through the integration of real-time data from IoT with geo-spatial information, farmers can engage in precision farming, leading to increased yields, minimised waste, and the implementation of more sustainable practices. Moreover, IoT technology helps farmers to remotely oversee their crops and livestock, resulting in reduced labour costs and ensuring the well-being and safety of their animals. The main barriers related to the use and application of these new technologies are related to the cost of their adoption and the need for know-how on their use (Fabiani et al., 2020). For this reason, the acceptance of digital assets by local authorities and institutions necessitates a co-production process involving stakeholders and end-users within the social and humanities domains. Reasons for concern regarding these types of technologies refer to (1) data ownership, accessibility, sharing and control, (2) power (re)distribution, and (3) impacts on human life and society (van der Burg et al., 2019).

### Early warning systems and climate services

Understanding past, present and future climate, environmental and socio-economic conditions is key to improving the resilience of the WEFE nexus in the Mediterranean region. In this sense, early warning systems, climate services and risk management approaches have shown broad applicability across various sectors in the Mediterranean (Sánchez-García et al., 2022). These approaches, which often rely on Earth Observations and/or modelling systems technologies, can support the improvement of business operations and policy decisions, which need to incorporate a nexus approach. Examples include decision support tools, online platforms, or other products co-developed with users that provide information and services to support their decision-making and co-producing local and regional integrated assessments that fulfil stakeholders' needs. The combination of the nexus approach with climate services and early-warning systems is essential to increase the societal understanding of trade-offs and co-benefits of actual and proposed policies and scenarios (Cremades et al., 2016, 2019). Demand for and supply of this information is growing rapidly, although access is not the same in all Mediterranean countries. In the Eastern and Southern Mediterranean, climate services have complemented the nexus approach, using a set of regional long-term climate model simulations for cross-sectoral impacts of hydro-climatic and socio-economic futures on water resources, habitat for species and food and energy production (Cramer et al., 2018; de Roo et al., 2021; Koutroulis et al., 2016; Terrado, et al., 2016b). Climate services have been used to anticipate climate change impacts on nexus components in Crete (Koutroulis et al., 2016). Using a set of representative regional climate model simulations from the EURO-CORDEX initiative, the study assesses future water availability under a cross-sectoral climate change impact framework. A decrease of local water resources ranging from 20–37% was projected under 2°C of global warming, mainly due to increasing irrigation demand. The study identified the business-as-usual scenario as the least cost-effective, whereas the high sustainability scenario was the most cost-effective option. Climate services across different time scales have been specifically used in agriculture to predict the risk of crop failure, pest damage, and water deficit, as well as natural hazards like heatwaves, droughts and storms, which can simultaneously influence various elements of the WEFE nexus. Examples of climate services focusing on three staples of the Mediterranean food system, i.e. grape, olive and durum wheat, are available for the Iberian Peninsula and Italy (Dell'Aquila et al., 2023; Terrado et al., 2023). While supporting optimal agro-management decisions and activities from sowing to harvesting, such tools take into consideration various elements of the WEFE nexus. Apart from attaining more stable crop yields, decisions therefore also need to address sustainable crop growth, which involves reducing pollution impacts of food production on soils, water and ecosystems as well as optimising the use of irrigation water. Likewise, climate services and early warning systems have also been used for improving water management from an integrated perspective in bassins across the Mediterranean. For instance, seasonal forecasting tools have been applied to assess water allocation for artificial snow and ice-making in Alpine ski resorts, taking into account different stakeholder demands (Hanzer et al., 2020; Sánchez-García et al., 2022). Climate forecasts have also been applied, together with the use of flexible operating policies, to guide reservoir management in the water-stressed Messara valley in Crete (Crippa et al., 2023). Using climate forecasts for reservoir operation was useful for balancing competing demands within the region. To be effective, these tools need to be developed following a transdisciplinary approach, coupling scientific knowledge from various disciplines (i.e. breaking silos) with practitioners' knowledge.

### Increase bio-energy crop production in marginal areas

Competition with food production is a common trade-off when producing bio-energy crops, and growing them in Mediterranean marginal areas that are otherwise not used (such as contaminated areas or abandoned ones) would not lead to negative trade-offs with food production (IRENA, 2017). The use of abandoned land for bioenergy production can bring added value, generate new revenue sources for landowners, and stimulate the growth of short bio-based value chains resulting in job creation opportunities (Khawaja et al., 2021). Special care needs to be taken when selecting such marginal areas, first, in defining what is marginal (Csikós & Tóth, 2023), second, to select those most agronomically suitable, and third, to avoid potential impacts on ecosystems and water resources, such as habitat disruption, soil degradation, introduction of alien species and alteration of water balance. Solutions identified as suitable in one region, might be disruptive in other, neighbouring regions, as shown by Núñez et al. (2013) in Spain, where such crops could make sense in the Northeast, but could lead to water conflicts in the south-eastern part of the country. In addition, while studies indicate potential synergies between bioenergy crop production in marginal areas and ecosystem restoration, there is little evidence on how bio-energy crop production could impact different species or landscape connectivity, as it could lead to homogenisation of heterogeneous marginal lands (Pulighe et al., 2019). Furthermore, crops need to be resilient to droughts and have lower water demands. Moreover, a rebound effect can be caused by the use of monoculture on big surfaces, decreasing biodiversity and associated ecosystem services.

## Box 3.1

### Opportunities using solar energy (innovation) for groundwater pumping in the Kebili Region (Tunisia): new challenges for water resources

In the distant past, traditional oases in the Kebili region (southern Tunisia) were established on artesian springs. Increased adoption of solar-based groundwater pumping is chiefly observed among farmers who are off-grid, in private agricultural extensions that now represent a much larger area than traditional oases. Research revealed that this increase in solar panels plays a growing role in the depletion of groundwater resources (Mekki et al., 2022). In North Africa, discussions are yet to start about how to frame the development of solar panels within a broader perspective, which would make it possible to limit risks (especially groundwater depletion) and tap opportunities (such as "green" production of energy). The challenge is to develop integrated approaches and evaluation tools, in order to characterise and evaluate the public policies and individual adaptation strategies which induce feedback on agricultural production, energy and water use. This would require connections between actors in the agriculture and water sector on the one hand, and energy on the other hand. Addressing groundwater depletion in North Africa has been found to need: (1) better legal and regulatory frameworks (Hartung & Pluschke, 2018) and better implementation of these frameworks; (2) better knowledge of irrigation systems, practices and dynamics of aquifers; and (3) the building of coalitions of actors (Faysse et al., 2018; Kuper et al., 2017). The growing use of solar panels for irrigation would require broadening actions along these three axes, but this time considering the whole agriculture-water-energy nexus. This is urgently needed, as the uptake of solar panels, both for water extraction, as well as for further distribution and irrigation, is likely to expand to all "groundwater economies" in North Africa in coming years (Mekki et al., 2022).

### *3.2.1.1 Water conservation and irrigation related solutions*

Water management for irrigation and related water sources are central to the WEFE nexus in the Mediterranean given the key role of water for food production in the region, where water scarcity is set to be exacerbated with climate change. Given the particularities of the Mediterranean climate, water conservation and irrigation in the Mediterranean has a long history of technological innovations and adaptation measures are common in the region. Before the Roman era, water-harvesting techniques were applied extensively in North Africa (Oweis et al., 2004). Over the centuries, these techniques have improved agricultural production by directing and concentrating rainwater to plants through runoff and have also been used for domestic purposes in dry areas. The following section describes several water management and irrigation options used in the Mediterranean.

#### Unconventional water resources, improved water use efficiency and reducing leakage

Unconventional water resources, such as desalinated water in conjunction with solar power generation, are expected to play a key role in narrowing the water demand-supply gap (Jones et al., 2019). From a study conducted in Cyprus, the use of concentrated solar power co-generation plants makes it possible to harvest energy and transform it to heat and storage. In this process, the heat released by the turbine and other thermal subsystems can be used to obtain drinking water through desalination (Papanicolas et al., 2016). Moreover, an example of desalination combined with the generation of electricity could be the EcoPeace WEN Pilot Project designed to create a regional desalinated water – solar energy community between Israel, Jordan and Palestine that would result in healthy and sustainable regional interdependencies. Israel and Palestine would produce desalinated water and sell it to Jordan, while Jordan sells Israel and Palestine renewable energy, thereby enabling each partner to harness its comparative advantage in the production of renewable energy and water (Bromberg et al., 2020). Approaches to increase water efficiency, particularly in and close to urban areas, will also be important, but they require a multi-faceted approach that considers factors like population growth, water demand management, infrastructure investment and alternative water sources. Reducing water leakage losses and wasteful use is expected to help stabilise water demand in Mediterranean countries (Burak & Margat, 2016). Many water scarce countries lose considerable amounts of water in the public supply network. This is the case of Italy (leakage losses of 38%), Spain (29%), Cyprus (24%) and Greece (21%). Reducing urban leakage makes it possible to save water that can be used for food, energy production or to maintain environmental flows.

### New irrigation techniques

Depending on the region, 33.8 to 46.3% of all water used for irrigation is lost due to inefficient conveying systems or irrigation techniques (Malek & Verburg, 2018). In addition, the vast majority of irrigation in the Mediterranean is still performed using the least efficient technique of surface irrigation (FAO, 2022), which is also the least costly system (Sauer et al., 2010). While uptake for the most efficient technique of drip irrigation is limited both by the need for large investments and the inability to irrigate many staple crops such as cereals, the adoption of sprinkler systems is still low, ranging from 8% in the Eastern Mediterranean, to 30% in the European Union Mediterranean Member States (FAO, 2022). Overall, the Mediterranean region could save 35% of water resources by using improved irrigation techniques (Fader et al., 2016). Modernisation of irrigation systems using water– and energy–saving technologies (e.g. sprinkler system, drip irrigation) can help in saving water resources and increase food productivity. These improvements are especially relevant in the Southern and Eastern Mediterranean, so as to compensate to some degree for increased water demand due to climate change and population growth. However, the use of new irrigation techniques in Libya led to soil salinisation, lowering of the water table, and increasing the amount of energy used (Al–Samarrai & Sadeg, 2020). The energy supply for irrigation generally evolves from pump units consuming diesel to modern pumping stations supplied by the electricity grid or solar energy. Focusing on only ensuring additional water resources and improving efficiency, without actions to improve water extraction and use, or reducing use, could lead to rebound effects due to more cost-efficient irrigation (Jensen, 2007) and thus impact the other WEFE components. In many case studies, an increase of irrigated surface areas, a change towards more water-intensive export crops, or an intensification of agricultural practices have been observed following the acquisition of water-saving irrigation techniques (Venot et al., 2017), for example in Morocco, in the area of Ain Chegag, Bitit, Guerdane, Issen and Lamzoudia (Hoff et al., 2019), resulting in maladaptation. This is particularly important because, under some global change scenarios, south-eastern Mediterranean countries are expected to be unable to cover irrigation demand by the end of the century (Fader et al., 2016, 2020). Given the high investment required to incorporate these systems, they can also result in small–scale farmers abandoning agriculture in favour of large-scale farmers and increasing inequality between these two social groups (Albizua et al., 2019).

### Deficit irrigation

Deficit irrigation involves intentionally applying less water to crops than their full water requirements, and in particular concentrates the application of limited seasonal water supplies on moisture-sensitive crop growth stages to maximise the productivity of applied water (Schaible & Aillery, 2012). This approach aims to optimise water use efficiency and address water scarcity challenges while still maintaining acceptable crop yields or even improving yields, for some crops in some contexts, presenting a low-cost solution to reducing water use (Geerts & Raes, 2009). « There are several deficit irrigation solutions. (1) Implementing water-efficient irrigation techniques such as drip irrigation, micro-irrigation, and precision irrigation deliver water directly to the root zone, minimising evaporation and runoff. These methods ensure that water is targeted efficiently, reducing water waste and improving irrigation efficiency (Chai et al., 2016). (2) Deficit irrigation involves carefully managing crop water stress levels to balance water availability with crop needs. By monitoring soil moisture levels and crop water requirements, irrigation can be applied strategically to maintain a certain level of water stress without severely impacting crop productivity. This approach requires a thorough understanding of crop water requirements and the stage-specific sensitivity of different crops to water stress. These methods include partial root-zone drying (Iqbal et al., 2020). (3) Choosing crop varieties that are more tolerant to water stress and have a higher water use efficiency is crucial for deficit irrigation, using traditional ancient varieties or new ones, which are adapted to limited water availability, have deeper root systems, and exhibit higher drought tolerance. These traits enable crops to withstand water stress conditions and maintain acceptable yields with reduced irrigation. (4) Accurate irrigation scheduling is essential for deficit irrigation. Monitoring soil moisture, weather conditions, and crop growth stages can help determine the optimal timing and amount of water to apply.

### Water reuse for irrigation

There is high potential for water reuse in irrigation, which is already taking place across many parts of the Eastern and Southern Mediterranean (Elbana et al., 2017; Tal, 2016). In recent decades, the spread of treatment plants has allowed treated water reuse to become a relevant source of water for agricultural production, as irrigated areas continue to expand. However, a systemic evaluation of real performance of many treatment plants or disinfection technologies has not been undertaken and relevant information such as maintenance, costs, and safety are not available. The reallocation that water reuse entails is often innocuous, when wastewater is highly diluted in a river before being reused downstream. But it can be more contentious when wastewater is either already reused directly (typically informally), or when it plays a major support role during periods of low river flow (Ait-Mouheb et al., 2020). Water reuse quality is influenced by factors like source control, sewage system type, treatment, operation, storage, and distribution. Control measures ensure treatment reliability and good operation, while appropriate management of industrial wastewater discharge reduces toxic risks. Microbiological parameters are crucial. Water reuse's impact on agricultural soils must be carefully planned to avoid negative impacts on ecosystems and other WEFE aspects (Levy et al., 2011). This is mostly due to the potentially hazardous properties of water: nutrients (mainly nitrogen and phosphorus), dissolved salts (sodium, boron, etc.) and other constituents such as heavy metals that may accumulate in the soil over time (Levy et al., 2011). Salts may accumulate in the root zone because of the absence of leaching. Over time, the absence of leaching may have harmful impacts on soil biological and chemical activity and hence on crop yields. The problem of soil salinity and sodicity can be solved by increasing soil mineral retention capacity through the application of soil conditioners – natural (manure, compost) or artificial (for example polyacrylamide compounds (Green & Stott, 2001)). In addition to the accretion of salts and nitrates, irrigation with recycled water can, under certain conditions, transfer pathogenic bacteria and viruses to groundwater, i.e. in karst systems, potentially impacting ecosystems. Nonetheless for agriculture, it can also be advantageous. In a controlled experimental system under semi-arid conditions in Sicily, recycled water increased tomato yield by 20% compared with crops using conventional water (Cirelli et al., 2012). In field sites located in Murcia, south-eastern Spain, for lemon trees, the benefits of using recycled water for irrigation are increased soil nutrients, increased crop yield and reduced doses of fertiliser (Pedrero et al., 2010). Nutrient loading from every 1000 $m^3$ of recycled water range from 4 to 24 kg of phosphorus, 16 to 62 kg of nitrogen, 2 to 69 kg of potassium, 18 to 208 kg of calcium, 9 to 110 kg of magnesium and 27 to 182 kg of sodium (Qadir et al., 2007). However, depending on the level of wastewater treatments, some drawbacks are also evident, and include soil salinisation, contamination of sensitive vegetable crops by pathogens, and loss of soil infiltration capacity (Pedrero et al., 2010).

### Ancient irrigation systems in the Mediterranean

The recurrent droughts that characterise the mediterranean climate have resulted in the development of a multiplicity of efficient ancient systems for collecting and conserving water for irrigation. As an example, the main water-harvesting techniques encountered in Tunisia can be subdivided into three major groups (Oweis et al., 2004): (1) runoff water harvesting that makes use of runoff as it is collected, thus eliminating the need for storage. These systems include the related micro-catchment techniques called *meskat* and *jessour;* (2) floodwater harvesting and spreading or spate irrigation using diversion dykes *(mgoud)*; and (3) runoff water collection and storage in reservoirs of variable capacities, which provides drinking water for people and animals, as well as water for irrigation. The *khettara* system, a centuries-old traditional canal system in Morocco, was used for groundwater drainage in oasis areas. It captures water from the groundwater table and plays a crucial role in agriculture (El Khoumsi et al., 2017). Indeed, many of these systems are developed together with specific agricultural practices. This is the case of the *navazo* system, used throughout south-western Spain, the *masseria* in Portugal and the *mawasi* in the Middle East. It is an ingenious system in which interconnected cultivated areas are established between dunes. Crops are planted in areas where the water table is close to the surface, meaning water is supplied by capillary action and tidal forces (Sánchez & Cuellar, 2016). The energy efficiency of this system and the way it is integrated into the natural environment make it an interesting example of an inherited agro-ecosystem and a sustainable agriculture model. Despite their importance and WEFE nexus potential, many of these systems are under threat due to loss of functionality, agricultural intensification and urban development pressures (Martínez-Fernández et al., 2013). Development programmes aim to preserve this ecological and socio-cultural heritage that has proven its resilience in the context of climate change. Traditional water management systems are essentially socio-technical systems that can only operate within their proper social context. Changes in practices are therefore not enough but need to be accompanied by deeper changes and new development paradigms. They contribute to soil conservation, traditional landscapes and cultural heritage to build living and resilient ecosystems, and to adapt to climatic changes (Barontini et al., 2017). They also contribute to societal awareness and the recognition of the great diversity of cultural and social values water has to human civilisation, especially in the MENA region (Berndtsson et al., 2016), in order to both preserve natural resources and ensure social equity in access to water.

## Box 3.2

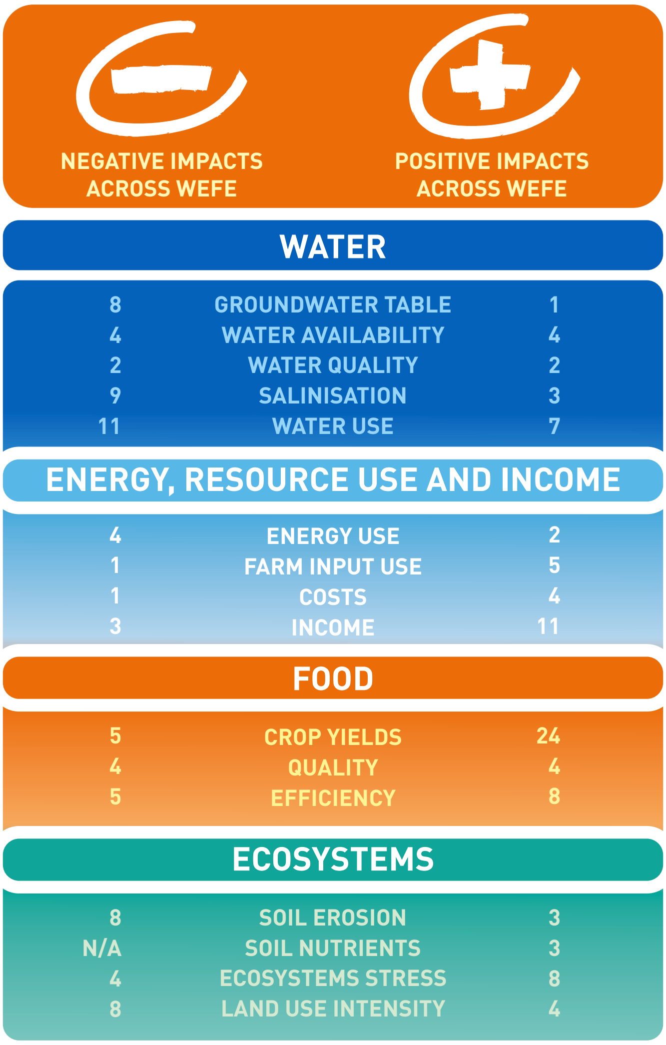
### The reuse of wastewater: some examples from the Mediterranean region

In Jordan, 87% of safely treated wastewater is now reused directly or with little dilution as water for irrigation. Israel, where treated wastewater accounted for 40% of all water used for irrigation in 2011, and to a lesser degree Tunisia, where about 25% of treated water is now reused, have become recognised leaders in this rapidly expanding field (Kellis et al., 2013). Israel, in particular, uses more than 300 million m$^3$ yr$^{-1}$ of tertiary-treated effluents or secondary chlorinated effluents in agricultural irrigation, mainly for industrial crops, cotton and fodder, citrus trees, and cooked food and unrestricted irrigation crops (Karnib, 2016). To put this volume into perspective, it represents about 40% of the total amount of treated water used in the whole European Union. However, despite recent improvements, wastewater treatment is still far from being universal in the MENA region. For example, it is estimated that only 8% of the wastewater generated in Lebanon is treated. About 11% of the population benefits from safely managed wastewater systems in the northern and southern governorates, compared to only 7% and 3% in Greater Beirut and Bekaa, respectively (Karnib, 2016). This calls into question the possibility of planned water reuse under national regulations. As a consequence, a wide array of reuse methods exist that range from unplanned, small-scale use of raw wastewater for vegetable production in peri-urban areas of Algeria, Egypt or Morocco to the sophisticated use of ultra-purified water for sensitive crops such as vegetables in Italy. Across the Mediterranean there are examples of all types of reuse levels, from no treatment at all to tertiary treatment. The recently established Bahr El Baqar wastewater treatment plant in Egypt treats the raw drainage water from the Bahr El Baqar Drain (capacity of 2 billion m$^3$ yr$^{-1}$), contributing to the cultivation of about 92,000 hectares. The plant will produce 5.6 million m$^3$ day$^{-1}$ of irrigation water and sludge using solar drying facilities with an annual capacity of 165,000 tonnes at 75% dryness level (Abdel Monem et al., 2022).

### *3.2.1.2 A WEFE analysis of irrigation options*

While the WEFE nexus has been widely proposed to address sustainability challenges in the Mediterranean region (e.g. Saladini et al., 2018), it remains unused when it comes to adaptation in the region. While the rare existing approaches are limited to case studies on a field level (e.g. Fabiani et al., 2020), cross Mediterranean analyses of adaptation in irrigated systems reveal that the WEFE approach has high potential for ensuring sustainable and just outcomes of adaptation in the region (*Figure 3.2*). At the same time, neglecting the WEFE nexus can lead to negative outcomes for other aspects of the nexus, in particular ecosystems.

Across the region, farmers have been adapting their farm practices by improving irrigation efficiency, reducing water use per unit of crop produced, or to deal with water shortages. While the resulting impacts on improved irrigation efficiency and water footprint of produced crops are widely known, potential co-benefits and trade-offs for other aspects of the WEFE nexus (other than water) are less obvious. At farm level, focusing only on the water aspect of the WEFE nexus for adaptation to irrigation systems can lead to undesirable negative trade-offs on other aspects of the nexus, but also on water itself (*Figure 3.2*). Improving irrigation efficiency can increase energy use, impact crop quality, increase salinisation and ecosystem stress, and negatively



| NEGATIVE IMPACTS ACROSS WEFE | | POSITIVE IMPACTS ACROSS WEFE |
|---|---|---|
| | **WATER** | |
| 8 | GROUNDWATER TABLE | 1 |
| 4 | WATER AVAILABILITY | 4 |
| 2 | WATER QUALITY | 2 |
| 9 | SALINISATION | 3 |
| 11 | WATER USE | 7 |
| | **ENERGY, RESOURCE USE AND INCOME** | |
| 4 | ENERGY USE | 2 |
| 1 | FARM INPUT USE | 5 |
| 1 | COSTS | 4 |
| 3 | INCOME | 11 |
| | **FOOD** | |
| 5 | CROP YIELDS | 24 |
| 4 | QUALITY | 4 |
| 5 | EFFICIENCY | 8 |
| | **ECOSYSTEMS** | |
| 8 | SOIL EROSION | 3 |
| N/A | SOIL NUTRIENTS | 3 |
| 4 | ECOSYSTEMS STRESS | 8 |
| 8 | LAND USE INTENSITY | 4 |

**Figure 3.2 | A summary of observed impacts across the WEFE nexus from a recent review of implemented adaptation in Mediterranean irrigation.** The left–hand column shows how improving irrigation by only addressing the water aspect of the WEFE nexus can lead to negative outcomes across WEFE components, and the right–hand column shows the observed positive impacts. The values are a percentage of 142 reviewed studies on farm level adaptation across the whole region.

Source: Harmanny & Malek (2019).

impact the groundwater table. Conversely, achieving co-benefits for other parts of the WEFE nexus is possible and considering them while planning adaptation measures can lead to better outcomes. As an example of these mixed effects of improving irrigation efficiency on different aspects of the WEFE nexus, the modernisation of Spanish irrigation has reduced water use per hectare, but total water use has remained stable (and increased in certain regions). Increased efficiency was offset by the expansion of irrigated area, and energy use greatly increased, as well as GHG emissions due to energy use, infrastructure construction and maintenance, and methane emissions from water bodies (Aguilera et al., 2019). This clearly shows that only focusing on one aspect when adapting to climate change, such as improving water use efficiency, can potentially degrade other issues of the WEFE nexus, such as increased energy consumption and negative impacts on ecosystems due to water use.

### 3.2.2 Ecosystem-based approaches

The IPCC (2014) included within ecosystems-based approaches a diversity of options such as ecological restoration, including wetland and floodplain

| Typology | Examples of NbS | Contributions to WEFE nexus | Reference |
|---|---|---|---|
| **WATER** | Constructed wetlands | Water purification, flood protection, wildlife support, and recreation | Liquete et al. (2016)<br>Matter & Gado (2024)<br>Saquib et al. (2022) |
| | Utilisation of permeable surfaces | Improve tree health and enhanced delivery of ecosystem services | Fini et al. (2017)<br>Jessup et al. (2021) |
| | Green roofs and trees | Assess information on the performance of green infrastructure to moderate urban surface runoff and increase biodiversity | Cristiano et al. (2021)<br>Zölch et al. (2017) |
| | Straw mulch | Decrease runoff, erosion, and soil loss rates due to the expansion of drip irrigation | Bogunović et al. (2023)<br>Keesstra et al. (2019)<br>Rodrigo-Comino et al. (2019) |
| | Reconstruction of the homonymous artificial reservoir | Improve crop yield production and agricultural income, secure water supply, and groundwater resources | Panagopoulos and Dimitriou (2020) |
| | Rain gardens | Stormwater management and generate impact on water runoff and catchment in cities | Koppelaar et al. (2021) |
| **ENERGY SECURITY** | Biomimetic architecture | Achieve sustainable and energy-efficient design for reducing urban heat islands and increase the comfort of living | Bar-Cohen (2011)<br>Mirzaei (2015) |
| | Waste-to-energy | Waste management, energy union, and climate change | Jouhara and Malinauskaite (2019) |
| **FOOD SECURITY** | Urban and peri-urban agriculture | Ten key challenges: climate change, food security, biodiversity and ecosystem services, agricultural intensification, resource efficiency, urban renewal and regeneration, land management, public health, social cohesion, and economic growth | Artmann and Sartison (2018)<br>Filippini et al. (2018)<br>Soulard et al. (2017)<br>Viljoen and Bohn (2014) |
| | Perennial grains | Locate areas for sustainable land management strategies | Peter et al. (2017) |
| | Organic farming | Minimise environmental impact and enable producers to earn a decent living | Eyhorn et al. (2019)<br>Muller et al. (2017)<br>Muneret et al. (2018) |

**Table 3.1 | Schematic diagrams of water, food, and energy-related NbS intervention typologies.**
Source: Yuan et al (2022).

conservation and restoration; increasing biological diversity; afforestation and reforestation; bushfire reduction and prescribed fire; controlling overfishing; fisheries co-management; assisted migration or managed translocation; ecological corridors; ex situ conservation and seed banks; community-based natural resource management; adaptive land-use management; and green infrastructure. Several of these options currently come under the most recent concept of nature-based solutions, or in the case of food, agroecological approaches, which can play a prominent role in Mediterranean ecosystems.

### *3.2.2.1 Nature-based solutions*

Nature-based solutions (NbS) are solutions inspired and supported by nature which are cost-effective, simultaneously provide environmental, social and economic benefits, and help build resilience (European Commission, 2024). Moreover, according to the IUCN, NbS are "actions to protect, sustainably manage, and restore natural and modified ecosystems, that address societal challenges effectively and adaptively, simultaneously benefitting people and nature" (IUCN, 2016). NbS are highly important in terms of water, food, energy and ecosystems (Yuan et al., 2022) (*Table 3.1*). In general, the possible strategies defined under the umbrella of NbS imply the implementation of blue and/or green infrastructure. The bulk of examples found in the literature fall in the latter category and include green roofs, green walls, woodland-like structures, urban grasslands and meadows, urban scrubland and heathland, horticultural gardens, vegetated filter strips, swales, constructed wetlands, restored wetlands, restored ponds and bioretention basins.

One promising NbS in urban contexts are green roofs, as they can help to fight against climate change effects, and particularly heat stress of the Mediterranean population (Cristiano et al., 2021). Experimental results in Mediterranean cities show the potential of green roofs to reduce energy demand and storm water runoff, although runoff reduction is lower during high precipitation periods (Fioretti et al., 2010; Maiolo et al., 2020). In addition, green roofs contribute to the restoration of Mediterranean vegetation in the urban environment, increase biodiversity, improve air and water quality, and add aesthetic value to the city (Benvenuti, 2014; Cristiano et al., 2021). *Table 3.1* contains a list of contributions to different components of the nexus provided by different NbS, which are classified according to their main contribution either to water, energy or food security. Although the table presents positive contributions, some trade-offs may also occur for some NbS. An example would be organic farming, which may result in lower yields for monocultures in some contexts but minimises environmental impacts while enabling producers to earn a decent living. As found in some studies comparing organic and conventional agriculture in the Mediterranean area, the main objective of sustainability should be the balance between input management, food production, and services provided by agroecosystems, rather than solely the attainment of high yields (Ioannidou et al., 2022; Litskas et al., 2019).

### *3.2.2.2 Agroecological approach*

Mediterranean farming has coevolved with harsh environmental conditions creating an abundant heritage of traditional knowledge for managing agroecosystems. An agroecological approach to agriculture is founded on the integrated application of scientific and traditional knowledge to design agricultural and food systems that work with nature in order to protect the environment and develop resilient, safe, accessible and just agrifood systems. Agroecology is founded on systems thinking so it considers the whole food system, highlighting the role of reconnecting food production and consumption associated with the recovery of the locally adapted, largely plant-based Mediterranean diet (Aguilera et al., 2020; see *Section 3.2.2*). Agroecology therefore provides a nexus entry-point for agricultural management, since a WEFE response through food needs to explore synergies between responses on both the production and consumption sides. Changes in agricultural management practices that follow an agroecological approach at farm level, like intercropping, conservation tillage and organic fertilisation can benefit both soil quality and soil fertility and generate some positive interactions with other WEFE components (Ioannidou et al., 2022; Morugán-Coronado et al., 2020), including biodiversity conservation, efficient water use, water conservation and reducing energy dependency (e.g. through elimination of chemical fertilisers). Conservation tillage practices, including no-tillage and reduced tillage, significantly promote carbon sequestration in Mediterranean agroecology. Combining organic

# Box 3.3

## Effect of applying technical and ecosystem-based adaptation solutions to the provision of ecosystem services in the Llobregat river basin

In the context of the Water Framework Directive, EU regional river basin authorities are required to propose a list of management actions or measures to be included in the River Basin Management Plans (RBMPs) with the aim of attaining a good ecological status of water bodies. The effect of a number of selected management actions proposed in the RBMP for the Llobregat river basin (Spain), on the provision of ecosystem services in the basin was assessed (Terrado et al., 2016a). The Llobregat basin is typical of semi-arid conditions and constitutes an example of a highly populated, highly impacted and severely exploited area in the Mediterranean region. It is the main water source for Barcelona and its metropolitan area, with a population of more than 3 million people. Although the main aim of the application of management measures is to attain a good ecological status (related to the ecosystem's health), these measures also need to consider other sectors and uses co-existing in the basin, such as water provision for agriculture, drinking, industrial use or energy production. In other words, the measures need to be established considering a nexus perspective.

The regional basin authority proposed 18 measures, including environmental river flows, river connectivity improvement, urban wastewater treatment, and saline pollution reduction. These four measures were selected since they are illustrative of the most commonly applied management actions in European basins (EEA, 2011). The measures had positive and negative impacts on ecosystem services and WEFE nexus components. For instance, the improvement of wastewater treatment also improved surface water quality. This is important since the river receives the discharge from several urban and industrial wastewater treatment plants, especially downstream, where there is a higher concentration of population. Also, the implementation of environmental flows in the upper basin improved ecosystem status, since they ensured suitable water levels for ecosystems, but caused losses in hydropower production and water availability for industry, drinking, and irrigation (*Figure 3.3*). Actually, the basin has several small hydropower plants that take water from the river, routing it through derivation channels to the plants and returning it to the river after several metres. Therefore, environmental flows can compromise the amount of water that can be derived for hydropower production, especially in periods when water levels are low. The identified trade-offs reveal that management actions designed to improve ecosystem status can also have detrimental effects on other components of the WEFE nexus that need to change, if not structured and implemented on a nexus basis.

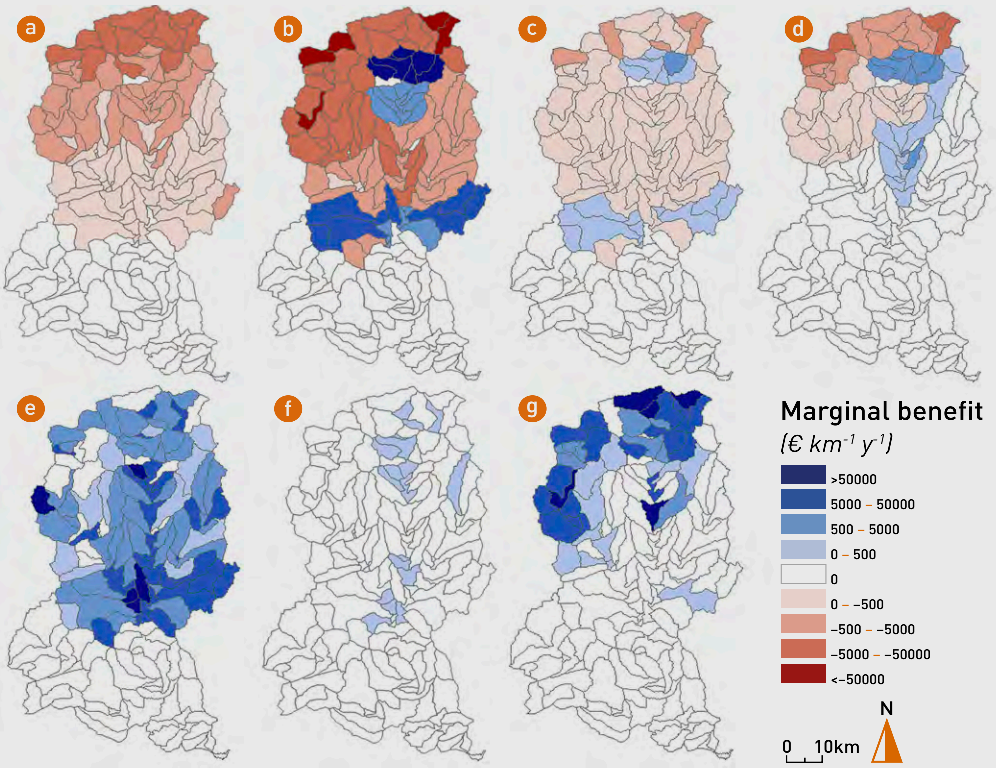
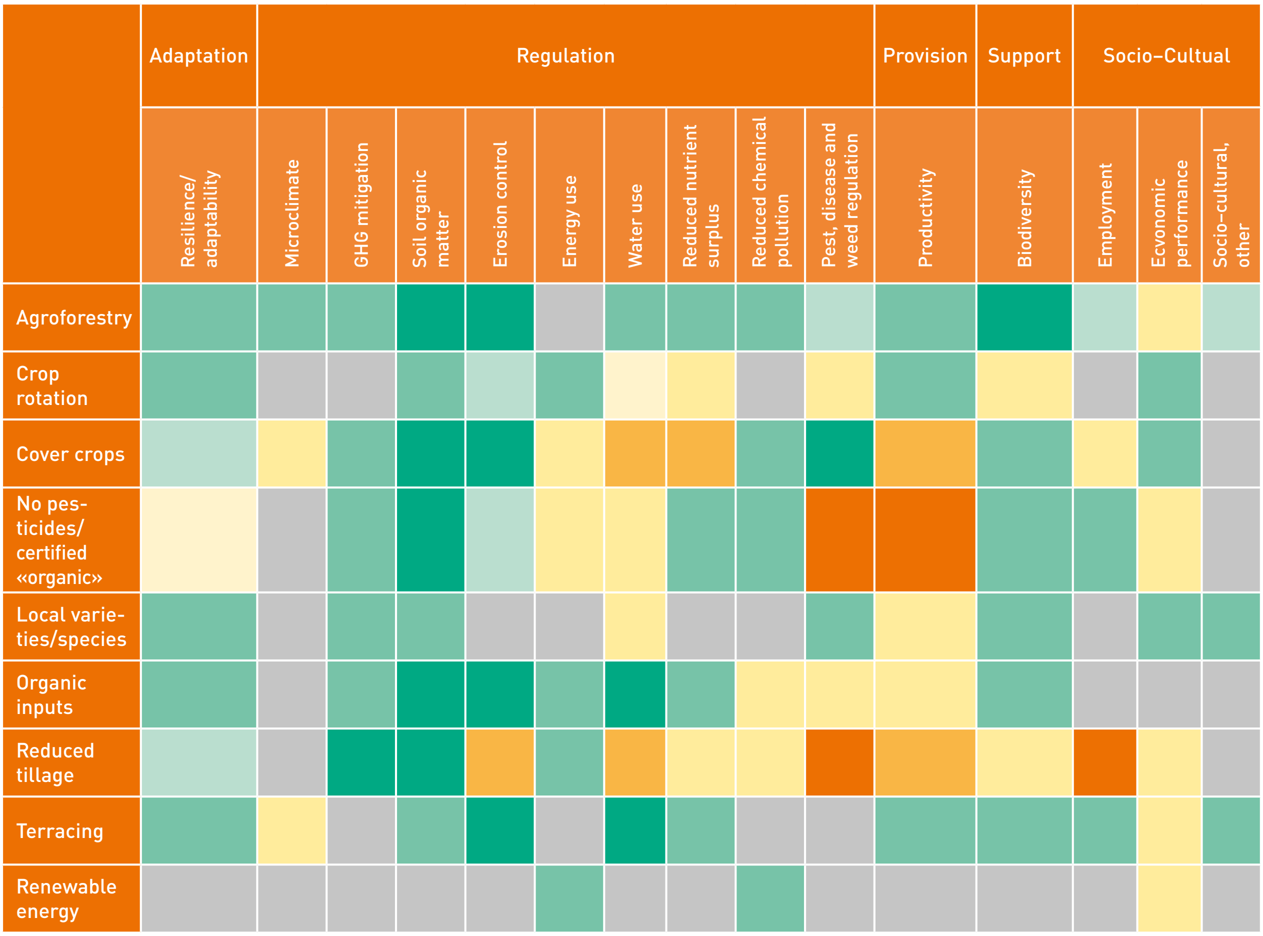


**Figure 3.3 | Effects of the establishment of environmental river flows in the upper Llobregat basin on the potential benefits for hydropower production (a), water for drinking (b), water for irrigation (c), water for industry (d), environmental/social benefits (e), existence/conservation of species diversity (f) and enjoyment of recreational areas (g).** Results are expressed as marginal values in € per kilometre of river per year. More details in Terrado et al. (2016a).



| | Adaptation | Regulation | | | | | | | | | Provision | Support | Socio-Cultual | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Resilience/ adaptability | Microclimate | GHG mitigation | Soil organic matter | Erosion control | Energy use | Water use | Reduced nutrient surplus | Reduced chemical pollution | Pest, disease and weed regulation | Productivity | Biodiversity | Employment | Ecvonomic performance | Socio-cultural, other |
| Agroforestry | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 | ⬜ | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 | 🟨 | 🟩 |
| Crop rotation | 🟩 | ⬜ | ⬜ | 🟩 | 🟩 | 🟩 | 🟨 | 🟨 | ⬜ | 🟨 | 🟩 | 🟨 | ⬜ | 🟩 | ⬜ |
| Cover crops | 🟩 | 🟨 | 🟩 | 🟩 | 🟩 | 🟨 | 🟧 | 🟧 | 🟩 | 🟩 | 🟧 | 🟩 | 🟨 | 🟩 | ⬜ |
| No pesticides/ certified «organic» | 🟨 | ⬜ | 🟩 | 🟩 | 🟩 | 🟨 | 🟨 | 🟩 | 🟩 | 🟥 | 🟥 | 🟩 | 🟩 | 🟨 | ⬜ |
| Local varieties/species | 🟩 | ⬜ | 🟩 | 🟩 | ⬜ | ⬜ | 🟨 | ⬜ | ⬜ | 🟩 | 🟨 | 🟩 | ⬜ | 🟩 | 🟩 |
| Organic inputs | 🟩 | ⬜ | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 | 🟨 | 🟨 | 🟨 | 🟩 | ⬜ | ⬜ | ⬜ |
| Reduced tillage | 🟩 | ⬜ | 🟩 | 🟩 | 🟧 | 🟩 | 🟧 | 🟨 | 🟨 | 🟥 | 🟧 | 🟨 | 🟥 | 🟨 | ⬜ |
| Terracing | 🟩 | 🟨 | ⬜ | 🟩 | 🟩 | ⬜ | 🟩 | 🟩 | ⬜ | ⬜ | 🟩 | 🟩 | 🟩 | 🟨 | 🟩 |
| Renewable energy | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ | 🟩 | ⬜ | ⬜ | 🟩 | ⬜ | ⬜ | ⬜ | ⬜ | 🟨 | ⬜ |

**Table 3.2 | The performance across the WEFE nexus of selected agroecological practices in crop production under Mediterranean conditions.** Green cells represent generally positive responses (>75% positive), red generally negative ones (>75% negative), yellow mixed or neutral ones, and grey lack of data. Darker colours represent data from meta-analysis of Mediterranean climate studies, medium colours represent evidence from non-systematised field studies in Mediterranean areas, and light colours represent evidence from non-Mediterranean climate areas. Refer to Aguilera et al. (2020) for details of the analysis.

amendments with cover crops or conservation tillage shows good performance in carbon sequestration. At landscape level, agroecology considers the positioning, quality and connectivity of fields and semi-natural habitats. The spatial and temporal organisation of semi-natural elements and the crop mosaic interact (Jeanneret et al., 2021). Such mosaic land systems can therefore also address restoration needs, and adaptation to new climate realities, such as more frequent heat and water stress (Aguilera et al., 2020). Agroecology adaptation to climate change in the Mediterranean involves biodiversity and crop diversity management, increasing soil organic matter (that also reduces soil erosion), reducing fossil fuel dependence, managing extensive herds, using local breeds, and implementing pasture and forage management. These practices enhance adaptation to climate change and ecosystem services related to food production and consumption (*Table 3.2*). Agroecological practices' focus on soil conservation contributes to water conservation, facilitates the sponge effect and thereby reduces water needs for farming.

Agroforestry is an agroecological practice that has a positive effect on crop adaptability, productivity, reduced water use, biodiversity, and other environmental indicators, although there is no available evidence regarding energy use. The experimental assessment shows how the use of agroforestry or mixed forestry/agricultural production can improve the carbon balance, increasing overall carbon storage (Jha, 2018). Organic fertilisers reduce energy and water use and promote biodiversity but have mixed effects on productivity measured in kg ha$^{-1}$. In general, the short-term negative impacts on crop production measured in kg ha$^{-1}$ (as opposed to number of people fed per hectare) are a common problem for agroecological practices, although yields may benefit in the long term from the positive effects of soil organic matter increase, which are significant in the low organic matter soils found in the Mediterranean (Oldfield et al., 2019).

### *3.2.2.3 Forest management: reforestation, afforestation and extensive livestock farming*

A considerable proportion of Nationally Determined Contributions (NDCs) of Mediterranean countries to mitigate climate change relates to the land use sector, in particular forestry. Countries have pledged to reforest, afforest or restore massive amounts of land to capture and store carbon, while at the same time achieving other nexus co-benefits, such as desertification or soil degradation prevention. In fact, afforestation and carbon accumulation in forests have been ongoing in most of the Mediterranean basin since the mid or late 20th century, due to the combination of land abandonment and fire suppression policies (Martínez-Valderrama et al., 2021; Şahan et al., 2022). Nevertheless, evidence suggests that particularly in the Mediterranean, these large-scale mitigation solutions (with otherwise high potential for adaptation) have to be planned carefully. Numerous case studies across the region demonstrate increased fire risk and decreased biodiversity due to fire suppression policies and the promotion of fast-growing forest plantations (with notable examples of Eucalyptus and Pine plantations in the Iberian Peninsula) leading to continuously forested areas (Ojeda, 2020). Indeed, while fire suppression policies have been effective in decreasing short-term fire (Boccard, 2022), they may have also increased the long-term risk of mega-fires with more devastating consequences, as has been observed in Mediterranean areas of France (Curt & Frejaville, 2018), Portugal (Oliveira et al., 2017) and Greece (Sarris et al., 2014) or impacts on water resources. These trends in forest management combine with climate change to increase fire-related risks. Climate change is already affecting fire severity, as has been observed in Portugal (Turco et al., 2019) and is expected to further increase wildfires in Mediterranean Europe (Dupuy et al., 2020). In addition, the combination of fire with climate-change related events such as extreme rainfall could enhance other impacts such as soil erosion (Morán-Ordóñez et al., 2020), further underlining the need to reduce fire risks. Moreover, most of the focus is on short-term forestry goals, such as quick carbon storage or high timber yields in short rotations. Long-term consequences on the wider WEFE nexus, such as water availability or species composition and biodiversity are mostly not evaluated, meaning that these actions could, in fact, fail to contribute to adaptation over the longer term (Vilà-Cabrera et al., 2018). Another review has identified extensive livestock farming in partially open landscapes as the best way to reduce fire risk while also increasing biodiversity and improving landscape organisation and flows between its components (García-Ruiz et al., 2020), and later studies are exploring different management techniques involving the use of extensive livestock farming (Ameray et al., 2022; Nuss-Girona et al., 2022; Schlickman & Milligan, 2022) and prescribed fires (Davim et al., 2022; Fonseca et al., 2022) for wildfire management in Mediterranean areas. In fact, reductions in the amount of combustible material, fuel load, and biomass, as well as a decline in the frequency of fires exceeding one hectare, were noted. Furthermore, the clearance of shrubland and extensive livestock grazing yielded additional environmental advantages such as mosaic landscapes and enhanced ecosystem services (Lasanta et al., 2018), whereas land abandonment with the related rewilding and consequent accumulation of biomass in unmanaged forests are among the most significant causes of higher fire density and severity, economic damage, and land degradation (Colantoni et al., 2020). In this sense, agroforestry has been identified as one relevant option for reducing wildfires in Mediterranean regions (Damianidis et al., 2021). Moreover, extensive livestock farming at correct density, can improve biodiversity conservation (Broom et al., 2013) and agroecological transition (Aguilera & Rivera Ferre, 2022). Overall, a new consensus is building up advocating for a deep transformation of forest policies away from fire suppression and mono-specific productivity-oriented measures and towards more interdisciplinary and participatory approaches involving "fire coexistence" and multifunctional management of forests (Moreira et al., 2020; Otero & Nielsen, 2017; Stoof & Kettridge, 2022; Wunder et al., 2021), thus simultaneously addressing all the components of the WEFE nexus. For example, in a modelling study, Mieziïte et al. (2022) estimated that strategies aimed at minimising forest vulnerability to drought were the most effective in preventing crown fires while also performing well in timber provision and water supply. Likewise, agroforestry systems within an integrated land management approach have been proposed as "productive fuel breaks", to reduce fire risks while recovering rural activity and restoring traditional landscapes (Wolpert et al., 2022).

### 3.2.3 Social options: behavioural changes

Science and technology are part of the solution but require a broad understanding and societal engagement to achieve transformation. The IPCC (2014) organises social options into (1) educational, including sharing local and traditional knowledge, participatory action research and social learning or knowledge-sharing and learning platforms; (2) informational, including climate services, integrating indigenous climate observations, community-based adaptation plans (or participatory scenario development); and (3) behavioural change (agroecology adoption would be included in this group). Behavioural change can facilitate deliberative transformation processes (Begum et al., 2022). Here we focus on behavioural change that affects the WEFE components.

In the food sector, policies and behaviour that operate across the food system, including those that reduce food loss and waste and overconsumption and that influence dietary choices, enable more sustainable land-use management, enhanced food security, zero waste, clean water and other benefits. The Mediterranean diet (*Figure 3.4*) has recently received increased attention due to its potential to reduce human pressure on the environment (Dernini et al., 2017). It is widely acclaimed for its health and sustainability benefits and is suited to the agroecological conditions of Mediterranean climate areas, as both the diet and the agroecosystems have evolved jointly over millennia (Aboussaleh et al., 2017). The beneficial role of the Mediterranean diet in sustainable development, based on a greater consumption of vegetables, fruit and fish, involves striking a balance between food production, and protection of ecosystems, biodiversity and agricultural practices (Burlingame & Dernini, 2011). Returning to locally-based production systems with reduced resource use, together with a reduction in super-intensive livestock production, could increase food security in the Mediterranean region (Dernini et al., 2017). Recovering certain agricultural practices from traditional Mediterranean landscapes (such as multi cropping, terraces, etc.) would be more labour-intensive. Doing so might only be possible through public policies to subsidise this kind of production.

However, adherence to this diet by the population of Mediterranean countries has progressively decreased (Obeid et al., 2022; Vilarnau et al., 2019). Meat overconsumption has been associated with current dietary patterns in the Mediterranean, and is an important factor for GHG emissions, associated with changes in land use, industrial processes, transport and energy (see *Chapter 2*) (Castaldi et al., 2022). Recovering the Mediterranean diet, particularly in European countries, has been shown to be linked to benefits across the WEFE nexus (Germani et al., 2014), including reduced water footprint (Blas et al., 2019; Vanham et al., 2021), reduced energy use and overall biocapacity use (Bôto et al., 2022; Galli et al., 2017), a more healthy diet (Guasch-Ferré & Willett, 2021; Sofi et al., 2014; Tilman & Clark, 2014), improved ecosystems through reduced eutrophication potential, land use and GHG emissions (Belgacem et al., 2021; Berry, 2019; Bôto et al., 2022; Dernini et al., 2017) while promoting biodiversity use, conservation and sustainable natural resources management (Aboussaleh et al., 2020; Capone et al., 2012). According to Sanz-Cobena et al. (2017), a 40% reduction in meat and dairy consumption could reduce GHG emissions by 20–30% in the Mediterranean. In Spain, following Spanish dietary recommendations could reduce GHG emissions by 17% (42% when considering diets' nutritional qualities) (Batlle-Bayer et al., 2019), while increasing adherence to the Mediterranean diet would reduce GHG emissions (72%), land use (58%) and energy consumption (52%), and to a lesser extent water consumption (33%) (Sáez-Almendros et al., 2013). Cutting down consumption waste could further decrease diet-associated GHG emissions by 10% (Batlle-Bayer et al., 2019). Also, in Spain, a comparison between the

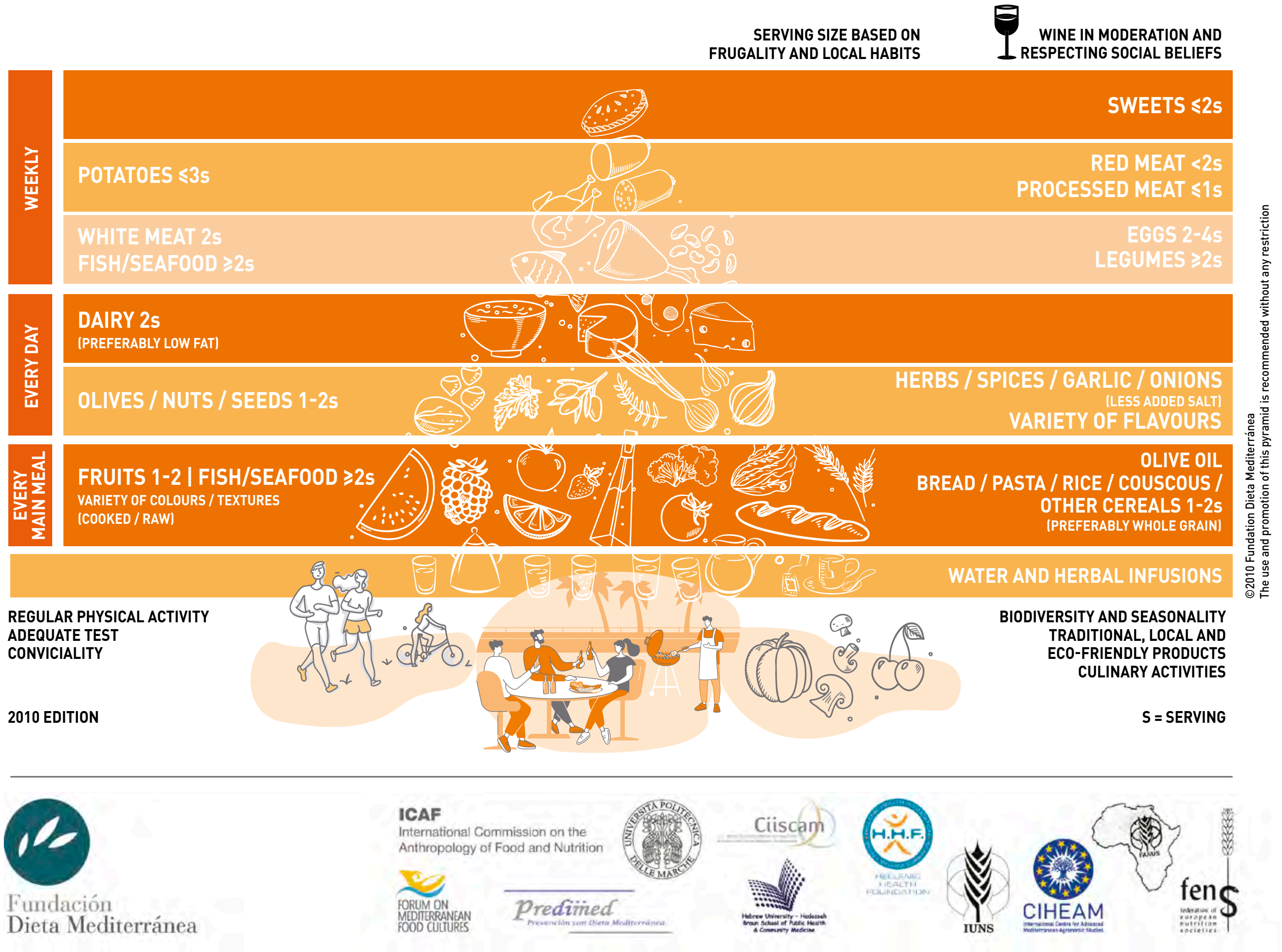
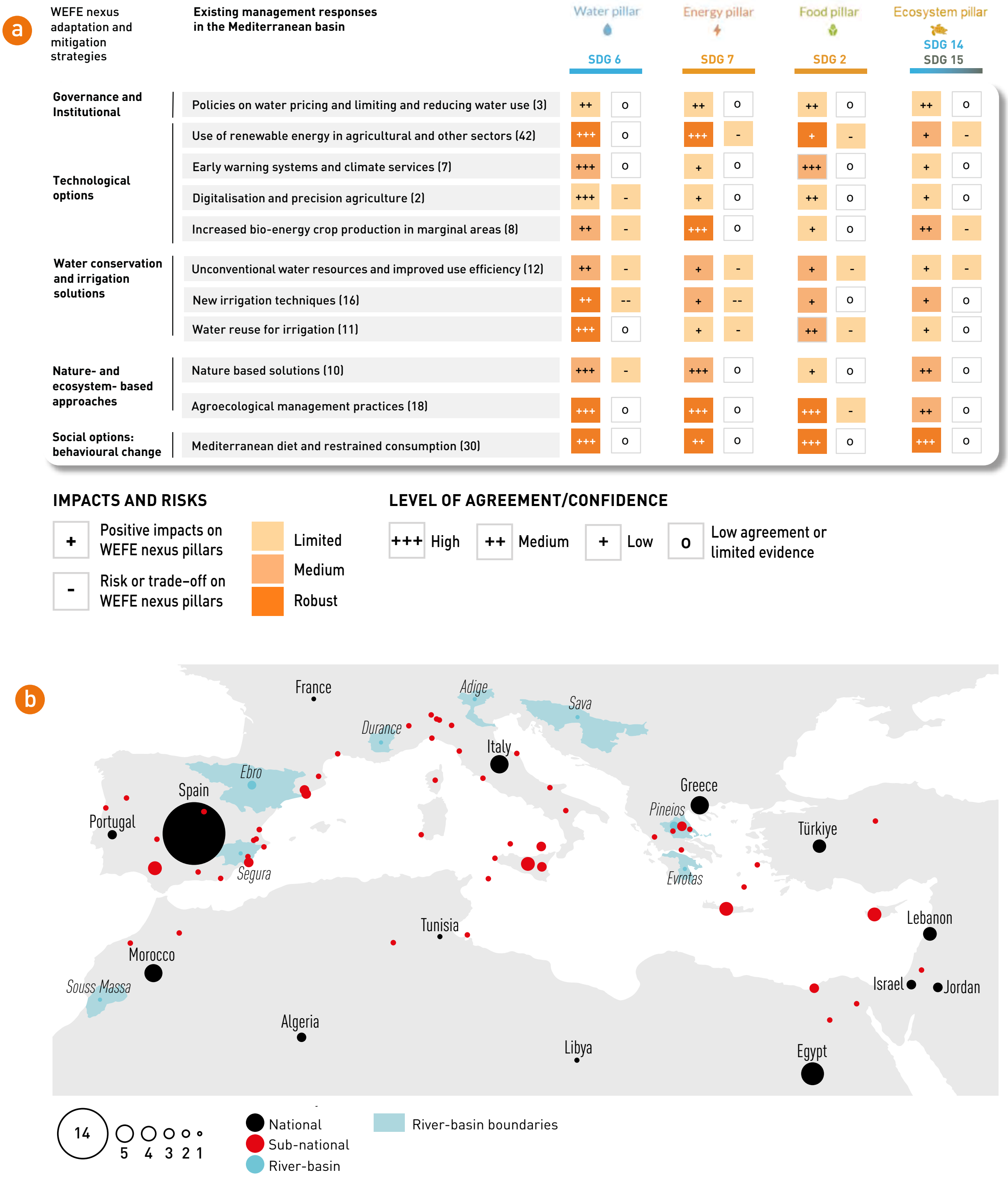


**Figure 3.4 | The Mediterranean diet pyramid.**
Source: Bach–Faig et al. (2011).

EAT-Lancet diet and Spanish current dietary patterns shows that the EAT-Lancet diet requires less water resources (3056 l day$^{-1}$ per person) and a lower level of GHG emissions (2.13 kg $CO_2$ eq day$^{-1}$ per person) than the Spanish diet (3732 l day$^{-1}$ per person and 3.62 kg $CO_2$ eq day$^{-1}$ per person, respectively) (Cambeses-Franco et al., 2022). In the MENA region, changes towards healthy diets, in four food groups (red meat, vegetables/beans, nuts/seeds, and fruit), can result in a median reduction in total water footprint of approximately 20% and a reduction in GHG of approximately 45%, but a median increase in blue water footprint of approximately 27% and an increase in energy use of approximately 56% (Bahn et al., 2019). Analysis conducted in different regions of Türkiye revealed that adherence to the Mediterranean diet resulted in lower GHG emissions (Bayram & Ozturkcan, 2023). The ability of production systems to sustain the Mediterranean diet also requires local animal breeds and plant species enhancing agrobiodiversity and the capacity of farmers to adapt to climate change (Bach-Faig et al., 2011). To account for these benefits, a new Mediterranean diet pyramid has been developed that includes both the health and environmental dimension (Bach-Faig et al., 2011; Serra-Majem et al., 2020) (*Figure 3.4*) as well as new indicators to measure the multifunctionality of the Mediterranean diet (Prosperi, 2015).

Despite existing differences between northern, southern and eastern Mediterranean countries in terms of contribution to environmental degradation, statistics show a rapid growth in resource consumption trends in MENA countries (e.g. electricity consumption may triple by 2025) and in pollution. Pollution risks are expected to increase in these countries, which calls for smart developments integrating green and circular



| WEFE nexus adaptation and mitigation strategies | Existing management responses in the Mediterranean basin | Water pillar SDG 6 | | Energy pillar SDG 7 | | Food pillar SDG 2 | | Ecosystem pillar SDG 14 SDG 15 | |
|---|---|---|---|---|---|---|---|---|---|
| Governance and Institutional | Policies on water pricing and limiting and reducing water use (3) | ++ | o | ++ | o | ++ | o | ++ | o |
| Technological options | Use of renewable energy in agricultural and other sectors (42) | +++ | o | +++ | - | + | - | + | - |
| | Early warning systems and climate services (7) | +++ | o | + | o | +++ | o | + | o |
| | Digitalisation and precision agriculture (2) | +++ | - | + | o | ++ | o | + | o |
| | Increased bio-energy crop production in marginal areas (8) | ++ | - | +++ | o | + | o | ++ | - |
| Water conservation and irrigation solutions | Unconventional water resources and improved use efficiency (12) | ++ | - | + | - | + | - | + | - |
| | New irrigation techniques (16) | ++ | -- | + | -- | + | o | + | o |
| | Water reuse for irrigation (11) | +++ | o | + | - | ++ | - | + | o |
| Nature- and ecosystem- based approaches | Nature based solutions (10) | +++ | - | +++ | o | + | o | ++ | o |
| | Agroecological management practices (18) | +++ | o | +++ | o | +++ | - | ++ | o |
| Social options: behavioural change | Mediterranean diet and restrained consumption (30) | +++ | o | ++ | o | +++ | o | +++ | o |

**Figure 3.5 | (a) Assessment of the main impacts and trade–offs of the WEFE nexus adaptation and mitigation solutions implemented in the Mediterranean countries.** The link is made to the SDGs through the nexus pillars. The numbers in brackets are the number of articles used for assessing each solution. The amount of evidence is quantified by the number of reviewed articles (given by numbers in brackets and categorised by limited in red, medium in orange and robust in green), while the degree of agreement measures the consensus between the articles (o for low agreement or limited evidence, + for low level of agreement/evidence, ++ for medium and +++ for high). This table does not review all possible solutions, but those implemented in the Mediterranean, reported in the scientific literature and assessed in the report. **(b) Spatial distribution of examined case studies.**

economy approaches, given the projected strong industrial growth linked to population growth and lifestyle changes (de Villamore-Martín, 2016). A paradigm shift in the way in which goods and services are consumed and produced around the Mediterranean is also proposed to decouple development from environmental degradation and resource depletion. A nexus approach may help foster an efficient use of energy and water in the food production process while reducing food waste and negative externalities (Kibler et al., 2018; Laso et al., 2018). The current food production system is to a large extent part of the growth-based economic system and is overall very productive but extremely inefficient in terms of energy use, also leading to ecosystem degradation. The Spanish agrifood system uses 6 units of energy to produce one unit of energy available in the form of food (Infante Amate & González De Molina, 2013). Transforming agrifood systems for sustainability means moving beyond the growth paradigm. It requires reconceptualising human food metabolisms according to values, food practices and lifestyles that strive for sufficiency, regeneration, distribution, commons and care (McGreevy et al., 2022), focused on needs and rights (Koch et al., 2017). A move towards agroecology and corresponding new consumption patterns (i.e. local, seasonal food, less meat consumption) can reduce resource use in the agrifood system and contribute to degrowth (Infante Amate & González De Molina, 2013) and the principles above, providing multiple benefits across the WEFE. Aguilera and Rivera Ferre (2022) estimated a net carbon sequestration of 24 Mt $CO_2$ eq $yr^{-1}$ for an agroecological transition in Spain that combines the Mediterranean diet and reduction of food loss and waste with changes in agricultural practices. Compared to the present situation, this transition would free 8.2 Mh in third countries, reduce water contamination from nitrates by 87% and the consumption of fossil fuels for the supply of domestic food consumption by 84%, bringing it entirely within the limits of the country's natural resources. Reducing food loss and waste, which have increased with the industrialisation of agriculture, and promoting circularity within food systems, can also have a series of positive interactions with other WEFE components (Edwards & Nelson, 2020). Food loss and waste impacts include waste of the resources that are used to produce and process the food (e.g. land and water, see Blas et al., 2016, 2018), GHG emissions, land degradation, and ground and surface water pollution caused by the intensive use of nitrogenous fertilisers in agriculture, together with the impacts of agriculture expanding into wild areas and mono-cropping biodiversity loss (Lacirignola et al., 2014; Mbow et al., 2019). In this shift, small-scale farms are considered the main sustainability actor, providing higher yields and biodiversity in their farms (Ricciardi et al., 2021).

An assessment of the main impacts and trade-offs of WEFE nexus adaptation and mitigation solutions is summarised in *Figure 3.5*.

## 3.3 Challenges of WEFE interventions for mitigation and adaptation

### 3.3.1 Financial challenges and multiple societal and environmental goals

Assigning monetary values to solutions that span different aspects of the WEFE nexus remains difficult (Gambella et al., 2021). Financing such approaches can be further hindered by the fact that WEFE programmes have many important socially-oriented components that are typically of limited commercial value and potential (Adamovic et al., 2019). Nevertheless, by addressing different societal and environmental goals at the same time, WEFE approaches are the optimal for achieving several sustainability agendas (see *Chapter 5*).

First, they could help achieve many of the targets set by the United Nations Sustainability Development Goals (SDGs; see *Chapter 4*). In particular, the WEFE nexus directly targets SDG 2 "Zero hunger", SDG 6 "Clean water and sanitation", SDG 7 "Affordable and clean energy", SDG 11 "Sustainable cities and communities", SDG 12 "Responsible consumption and production", SDG 13 "Climate action", SDG 14 "Life below water", and SDG 15 "Life on land" (UN, 2015). Secondly, the WEFE nexus could offer a suitable platform for fulfilling existing agricultural policies, such as the European Union Common Agricultural Policy (CAP). The CAP has several clear sustainability goals that will lead to a more sustainable agricultural system for the EU, and where a nexus approach is necessary: climate change action, environmental care, and preserving landscapes and biodiversity (European Commission, 2019).

Overall, large amounts of funding could be required, which will require the adoption of fiscal and funding policies (Gambella et al., 2021), as well as changes to subsidies (FAO, 2022) to support behavioural changes. This is why the awareness-raising and education of policymakers, and the general public is a prerequisite (as mentioned in the previous section). WEFE approaches can become viable through Public-Privates Partnership (Adamovic et al., 2019). While public funding might be necessary initially, it should at some point be blended with private contributions.

### 3.3.2 Scientific challenges

The WEFE nexus is a relatively new concept and one of the major issues is the lack of available data and indicators to enable a science-based assessment of its impacts. One of the main advantages of WEFE approaches is the many benefits they can offer different sectors (Carvalho et al., 2022). At the same time, this advantage makes it very difficult to assess these benefits. This inherent complexity and the multi-disciplinary nature of nexus mean the models and methods to assess them and provide results of the full spectrum of their benefits need to cover many different scientific fields. In addition, the data are not necessarily collected or available over the long-term, meaning that in many cases, original data is necessary to showcase the benefits of WEFE approaches compared to other solutions. One approach to address this could be open data platforms with successful examples and the benefits of their implementation. Ideally a bottom-up approach that takes into account the different sub-models would be used to quantify the nexus. A Nexus Project Toolkit based on experience from real-life examples of nexus projects can increase wider acceptance of the nexus approach (Adamovic et al., 2019). This would also facilitate the cross-sectoral coordination at the relevant levels of governance that is a necessity for this approach to be truly successful and effective. The ecosystem services community has a lot of experience in mainstreaming novel data and modelling approaches, and moreover, integrating them into relatively simple and straightforward frameworks, which the WEFE nexus could build upon (e.g. Natural Capital Project, 2023).

To accurately assess the impact of WEFE approaches, they need to be implemented at different scales (Carvalho et al., 2022). Currently many efforts have been implemented at a micro-scale in urban settings primarily focusing on neighbourhood scale and rarely at the city scale. Future research efforts need to focus on moving on towards the meso- and macro-scale.

### 3.3.3 Urban challenges

Natural resources in the Mediterranean are seriously limited, and this can lead to conflicts between different sectors. Increasing urbanisation is both a Mediterranean and global trend that will continue to increase with many negative environmental impacts (Almenar et al., 2021; Keivani, 2009). WEFE approaches can therefore be used to help develop sustainable and healthy urban environments. The key for their successful implementation will be to address the needs of the people of the urban area, requiring knowledge about the causal relationships between water and ecosystem services, energy and food needs and urban challenges. Other essential components, that in many cases are neglected in the design of WEFE approaches, are the social, cultural and economic parameters. In most cases, this will be the key factor for long-term adoption and maintenance. One of the major sectors that urban areas are competing with for resources is agriculture. In the Mediterranean, irrigated agriculture provides the major livelihood income for rural areas but is also the largest consumer of freshwater, the most limited resource in the region (Daccache et al., 2014). In the future, demands for domestic and industrial water use, as well as water for energy generation, is expected to increase, leading to potentially increasing conflicts between urban and agricultural water users (Flörke et al., 2018). This means that both reduction in water use by households, tourism, industry and agriculture, as well as efficiency improvements in the Mediterranean will be necessary, while ensuring sufficient water for ecological functioning. The WEFE nexus can be of use when navigating through different users, limiting and reducing potential conflicts.

### 3.3.4 Geographic challenges

The Mediterranean has numerous coastal and mountainous areas with a high diversity of use intensity, topographic characteristics and population density. Mediterranean coastal areas are heavily urbanised, which will likely increase in the future (Reimann et al., 2018). Mediterranean mountainous areas, however, are facing a demographic decrease and/or abandonment (Bruno et al., 2021). This divergence between urban and rural areas, but also between intensively managed landscapes and semi-natural vegetation in the hinterland means that different WEFE aspects could be important across the Mediterranean region. Whereas in the coastal areas, WEFE approaches can alleviate the problems caused by increasing population and tourism, in the mountainous regions WEFE approaches could help better manage abandoned areas that used to be productive, but will also provide an incentive to maintain the young generation or attract people that prefer to live in less stressful conditions closer to nature. Moreover, different countries in the region will have different levels of acceptability and adoption of WEFE approaches. Many northern Mediterranean countries (e.g. France, Italy, Spain) that have strong economic, governance and social adaptation readiness are more likely and more financially ready to support such initiatives (Sarkodie & Strezov, 2019). In contrast, the southern and eastern countries of the Mediterranean could require international support and commitment in the form of financial or scientific support to increase the adoption of the new approaches that will lead to the sustainability of the entire Mediterranean in the long term. This difference is primarily between the northern and southern-eastern Mediterranean countries and should be considered when developing WEFE approaches. Moreover, some studies underline that northern countries rely on a large net appropriation of resources from the Global South (Hickel et al., 2022), and this is also true for Mediterranean countries. This can be exacerbated by international crises, which are detrimental to international changes. In this sense, resilience to the impacts of changes and related expected crises would also greatly benefit from relocating water, energy and basic food production as much as possible within every country.

### 3.3.5 Knowledge integration challenges

Missing expert and traditional knowledge and data on the interconnections between water, energy, food and ecosystems is a disadvantage for supporting integrative and diverse discussions on the application of the WEFE nexus. In the Mediterranean region, systemic approaches to increase resilience include agroecology (transhumance, pasture and forage management, agroforestry and fire management through grazing) as well as water catchment techniques for proper management of ecosystems (e.g. Aguilera et al., 2020; Oteros-Rozas et al., 2013). For example, the majority of the ancient Mediterranean grape and olive growing sites follow the layout of the terracing and the water systems network that allows for water storage, energy saving and food production, also contributing to shaping the landscape (Laureano, 2007). These traditional practices offer valuable insights in creating holistic and sustainable approaches, which inherently consider the WEFE nexus, while enabling the recovery of traditional knowledge and the coproduction of new local knowledge for enhancing resilience. Although traditional knowledge may be replaced or its practice hindered as sophisticated technologies provide ways of saving time and effort, when these technological means become more expensive or inaccessible, the return to traditional practices emerges as an adaptation strategy to global change in the Mediterranean, again reinforcing traditional knowledge (Ponti et al., 2016). Integration of different types of knowledge thus remains a feasible objective to develop WEFE-based strategies and support North-South collaboration.

## Box 3.4

### Case study: transboundary basins, the Sava River Basin

The Sava Basin is in the Western Balkans, spanning Bosnia and Herzegovina, Croatia, Montenegro, Serbia, Slovenia, and Albania (*Figure 3.6*). Substantial proportions of residents of these countries live in the Basin. The Basin is of high importance to these populations since it provides freshwater, hydropower, and hosts considerable portions of the Western Balkan's economic activity. Stakeholders from the different sectors, ministries and various interest groups relevant to the nexus participated in a workshop organised by the United Nations Economic Commission for Europe (UNECE, 2016). A key output of the workshop was identifying the current conditions and related trade-offs regarding nexus linkages (*Figure 3.7*).

The solutions identified to address the intersectoral challenges in the Sava River Basin are (UNECE, 2016):

- **Institutional solutions:** Improving existing governance by clarifying roles and responsibilities in order to monitor

**Figure 3.6 | The Sava River Basin.**
Source: UNECE (2016).

the resources of the basin and support implementation of sustainable development principles.

- **Knowledge sharing / Data sharing solutions:** Develop a shared knowledge base. This should include monitoring, forecasting and guidelines on best practice for harmonising approaches (e.g. navigation, hydropower or ecotourism), as well as policy instruments aimed at resource efficiency (e.g. adoption of low-flow appliances in households, water and energy efficient technologies, and efficient irrigation practices).
- **Infrastructure solutions:** Flexible use of infrastructure (e.g. dams, irrigation and drainage systems), upgrading water infrastructure (e.g. wastewater treatment); investments in renewable energy sources (e.g. hydropower); and protection of natural infrastructure (e.g. floodplains and riparian areas and wetlands).

The international stakeholders identified numerous nexus benefits from the improved management of basin resources (UNECE, 2016). Identified economic benefits included: viability of economic activities, development of the agricultural sector, development of sustainable river tourism, reduced economic costs of water-related hazards, reduction of transport costs or increased volume of traffic, lower energy costs and reduction of water infrastructure costs. Social and environmental benefits included employment opportunities (e.g. agriculture and tourism), reduced human casualties of water-related hazards, health benefits from improved water quality, improved water services for users, and improved recreational opportunities. In addition, there are numerous potential indirect nexus benefits from enhanced trust between the countries of the Sava Basin, such as: increased trade through waterways, development of regional markets for goods, services and labour, and increased cross-border investments.

One prerequisite for successful nexus implementation is international coordination and cooperation at basin and regional level. This was achieved by utilising a pre-existing legal and institutional framework for cooperation at international and inter-sectoral scales. Specifically, the International Sava River Basin Commission (ISRBC) enabled the establishment of joint objectives that can be implemented by different countries at different stages of development. Different interest groups (recreation and tourism, industry, agriculture or navigation) are represented to discuss, coordinate and develop intersectoral plans and the establishment of integrated systems. To further enhance the ISRBC, an agreement on the implementation of the Framework Agreement on the Sava River Basin (FASRB) and its protocols, the EU Water and Flood Directives, as well as transboundary planning processes such as the Sava River Basin Management Plan and the Flood Risk Management Plan for the Sava River Basin were signed.

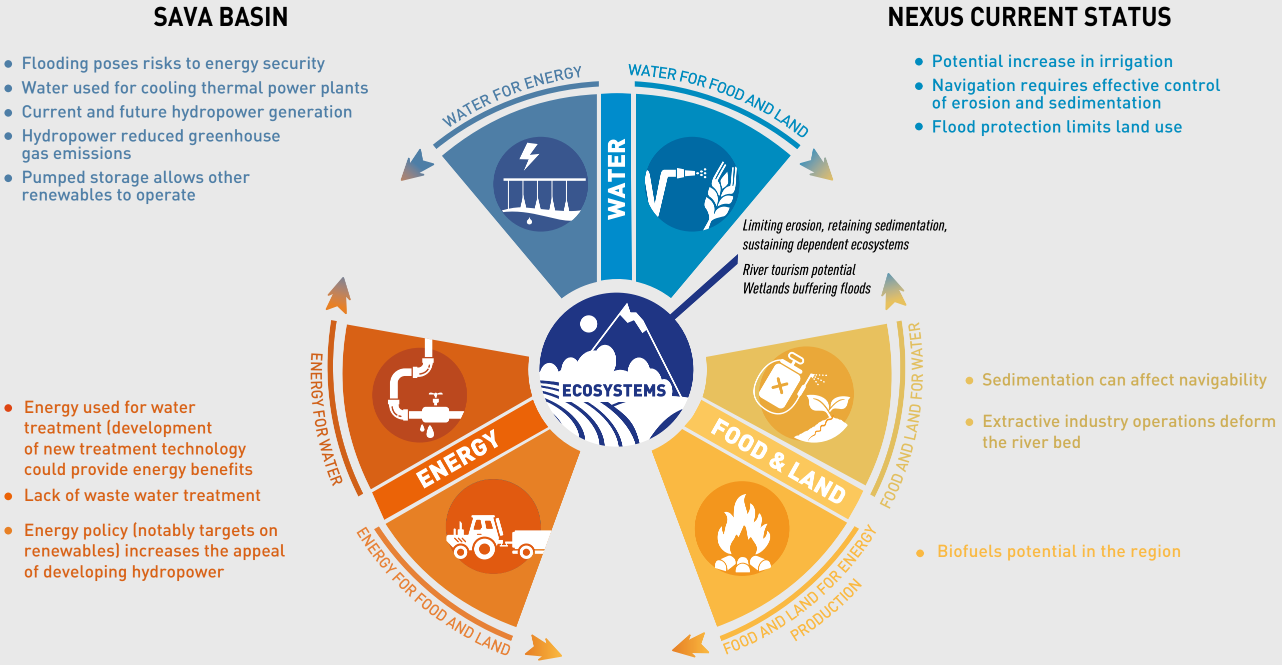


**Figure 3.7 | The current status of the WEFE nexus linkages in the Sava River Basin.**
Source: UNECE (2016).

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