MedEC
Mediterranean Experts on Climate and environmental Change

MedECC Special Report

Interlinking climate change with water - energy - food - ecosystems nexus in the Mediterranean Basin
Draft Summary for Policymakers

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MedECC

The Mediterranean Experts on Climate and environmental Change (MedECC)[1] is an open and independent network of scientists founded in 2015, that specifically focuses on climate and environmental changes within the Mediterranean region. The objective of MedECC is to provide decision-makers, stakeholders, and citizens with scientific assessments of scientific knowledge on climate and environmental changes including associated risks and social aspects.

To date (April 2024) more than 300 authors contributed to MedECC reports in an individual capacity and without financial compensation. MedECC scientists are located in 35 countries, including 19 countries registered as Contracting Parties to the Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (Barcelona Convention) and 23 countries that are members of the Union for the Mediterranean (UfM).

Since 2018, Plan Bleu has hosted the Secretariat of MedECC as part of a partnership with the UfM and helps ensure its functioning through various funding sources. The UfM supports MedECC through technical assistance contracts for the MedECC via the AIR Climat association (2018-2020, 2021-2023 and 2024-2026) thanks to the funding from the Swedish International Development Cooperation Agency (SIDA). The Mediterranean Action Plan of the United Nations Environment Program (UNEP/MAP) has also contributed to support MedECC since 2022.

The MedECC published the First Mediterranean Assessment Report (MAR1) in November 2020, which includes a Summary for Policymakers (SPM) that has been approved line by line during a plenary session attended by government representatives from Mediterranean countries in September 2020. The SPM has been endorsed by the Contracting Parties to the Barcelona Convention during COP22 and acknowledged during the 2nd UfM Ministerial Conference. MedECC was awarded the prestigious North-South Prize 2020 of the Council of Europe for their efforts for peace and democracy. The MAR1 report has significantly laid the groundwork for the first ever chapter on the Mediterranean Basin in an IPCC report, published as a cross-chapter paper in the IPCC 6th Assessment Report in 2022.

MedECC reports are produced for use by policymakers and a broader audience. They are developed on the basis of scientific criteria only. The reports are an expert-based assessment of the available relevant scientific and technical literature. The available knowledge concerning the risks studied by MedECC has significant gaps, often due to limited monitoring systems or scientific research capacity – these gaps have been communicated as clearly as possible. Despite best efforts, errors and omissions are nevertheless not unlikely.

This Special Report

The **Special Report "Interlinking climate change with water - energy - food - ecosystems nexus in the Mediterranean Basin"** responds to the MedECC Steering Committee's decision to produce three Special Reports as part of the 2021-2023 MedECC work program. These reports focus on specific issues identified after the publication of the First Mediterranean Assessment Report (MAR1) in November 2020, including considering suggestions from government representatives and stakeholders.

This Special Report identifies and assesses the impact of environmental and climate change on the Water-Energy-Food-Ecosystems (WEFE) nexus in the Mediterranean Basin, related risks, adaptation options and solutions along five chapters. In this report, the WEFE nexus is addressed as a key concept for a more resilient adaptation to the climate crisis in the Mediterranean region. It addresses the interlinked water, energy and food security — and their connection with the surrounding ecosystems. Thus, security issues, and therefore adaptation actions, are the key focus of this report, leaving the mitigation consequences of the nexus approach as potential synergies and trade-offs

[1] https://www.medecc.org/

derived from the interconnections among WEFE components. The focus is on the nexus between water, energy and food security and ecosystems' health, extending to the coasts of the Mediterranean Sea, and the report does not address the details of marine environment. Chapter 1 provides the context, background and key dimensions of this assessment, Chapter 2 assesses the drivers of change impacting on the WEFE nexus and the cascading effects associated to these impacts, Chapter 3 assesses the existing and prospective responses and management options to implement the WEFE nexus approach in the context of climate change. Chapter 4 addresses the link between the WEFE approach and the Sustainable Development Goals (SDG). Finally, Chapter 5 reviews governance, policies and research options for the WEFE nexus implementation in the Mediterranean Basin.

The Special Report has been prepared by a team of volunteer leading experts and scientists in the various related fields of research. The outline was developed during a Scoping Meeting where experts and scientists were consulted alongside governmental representatives and stakeholders. The framework and outline were reviewed and approved by the MedECC Steering Committee. The authors were selected and approved by the MedECC Steering Committee based on their expertise, country and gender balance (**60 authors from 15 countries**). The Zero Order Draft (ZOD) of the report underwent internal review in March and April 2023. The MedECC Secretariat received 479 comments from 15 reviewers. **The Special Report includes the SPM composed of headline statements and a high-level summary and narrative of the key messages from the longer report.** The First Order Draft (FOD) of the report and draft SPM underwent external peer-review and broad consultation with governments, decision-makers and stakeholders in July-September 2023. As a result of external review and the consultation, 820 and 247 comments for the longer report and SPM had been received respectively. The authors revised the draft SPM between October 2023 and March 2024, addressing all comments. The stakeholder consultation on the SPM was concluded through the online plenary consultation on **April 29, 2024**.

The MedECC Coordinators are very grateful for the expertise, rigour and dedication shown by the Report Coordinators, Coordinating Lead Authors and Lead Authors, working across scientific disciplines in each chapter of the report, with essential help by the many Contributing Authors. MedECC Authors and Coordinators want to thank all reviewers for their time and effort and the MedeCC Secretariat for their support.

Notes

● In the SPM, **references for material contained in the full Special Report** are given in **curly brackets {}**.

● **The SDG Index**: in the SPM, the Sustainable Development Goals (SDG) Index assessing each country's overall performance on the 17 SDG, giving equal weight to each goal is used. The score signifies a country's position between the worst possible outcome (score of 0) and the target (score of 100). The 2023 SDG Index edition includes 97 global indicators. Two-thirds of the data come from official statistics (typically United Nations custodian agencies) with one third from non-traditional statistics (such as derived from large-scale collection of passive data or remote sensing, produced by research centres, universities, and non-governmental organisations). Published since 2015, the SDG Index and dashboard has been peer-reviewed and the global edition has been statistically audited by the European Commission in 2019. More detailed information is available on the website www.sdgindex.org.

● Each assessment finding is grounded in an evaluation of underlying evidence and agreement. A level of confidence is expressed using five qualifiers: very low, low, medium, high and very high, and typeset in italics, for example, *medium confidence*. The following terms have been used to indicate the assessed likelihood of an outcome or result: virtually certain 99–100% probability; very likely 90–100%; likely 66–100%; about as likely as not 33–66%; unlikely 0–33%; very unlikely 0–10%; and exceptionally unlikely 0–1%. Additional terms (extremely likely 95–100%; more likely than not >50–100%; and extremely unlikely 0–5%) are also used when appropriate. Assessed likelihood is typeset in italics, for example, *very likely*.

● In the SPM, Special Report on Emissions Scenarios (SRES) defined in IPCC AR4 and Representative Concentration Pathways (RCP) defined in IPCC AR5 are cited. RCPs are greenhouse gas concentration trajectories (not emissions) used for the 5t^{h} coupled model intercomparison project (CMIP5) and labelled after a possible range of radiative forcing values in the year 2100, 2.6, 4.5, 6.0, and 8.5 W m^{-2}, respectively and corresponding to one stringent mitigation scenario (RCP2.6), two intermediate scenarios (RCP4.5 and RCP6.0) and one scenario with very high GHG emissions (RCP8.5). SRES scenarios are organised into four socio-economic families (A1, A2, B1 and B2), translated in terms of greenhouse gas and aerosol emissions. SRES scenario B1 is similar to RCP4.5, scenarios B2 and A1B1 are similar to RCP6.0 and scenario A2 is similar to RCP8.5. In the report, low-emission scenario refers to RCP2.6, intermediate emission scenarios refer to SRES scenario B1, B2, A1B1 or RCP4.5 and RCP6.0 and high-emission scenario refers to SRES scenario A2 or RCP8.5.

Acronyms

The SPM avoids using acronyms to the extent possible, except to refer to organisations or technical and scientific reports.

AARINENA – Association of Agricultural Research Institutions in the Near East & North Africa
AR6 – Sixth Assessment Report
CIHEAM – Centre International de Hautes Etudes Agronomiques Méditerranéennes
CMI – Center for Mediterranean Integration
CNRS – French National Centre for Scientific Research (Centre National de la Recherche Scientifique)
ENABEL – Belgian Development Agency (Agence de développement de l'État fédéral belge)
EU – European Union
FAO – Food and Agriculture Organisation
GHG – Greenhouse Gases
GIZ – German Corporation for International Cooperation (Deutsche Gesellschaft für Internationale Zusammenarbeit)
GWP-Med – Global Water Partnership-Mediterranean
IPCC – Intergovernmental Panel on Climate Change
IRD – French National Research Institute for Sustainable Development (Institut de Recherche pour le Développement)
IWRM – Integrated Water Resources Management
MAP – Mediterranean Action Plan
MAR1 – First Mediterranean Assessment Report
MedECC -–Mediterranean Experts on Climate and environmental Change
MENA – Middle East and North African countries
NbS – Nature-based Solutions
NGO – Non-Governmental Organisation
PRIMA – Partnership for Research and Innovation in the Mediterranean Area
RCP – Representative Concentration Pathway
SDG – Sustainable Development Goals
SIDA – Swedish International Development Cooperation Agency
SRES – Special Report on Emissions Scenarios
UfM – Union for the Mediterranean
UNDP – United Nations Development Programme
UNECE – United Nations Economic Commission for Europe
UNEP – United Nations Environment Programme
UNFCCC – United Nations Framework Convention on Climate Change
USAID – U.S. Agency for International Development
WEFE – Water - Food - Energy - Ecosystems

Executive Summary: Water-Food-Energy-Ecosystems (WEFE) nexus in the Mediterranean

The Mediterranean Basin, cradle of an ancient cultural heritage, culinary traditions, indigenous knowledge of agricultural practices and biodiversity, is often referred to as a "climate change hot spot", as the regional projections of global climate change are exacerbated with larger rates than globally and displays high susceptibility of specific critical resources (water, agriculture, etc.) and socio-economic elements (adaptive capacity, human population growth, etc.). Population and economic growth, agricultural intensification, urbanisation, high pollution levels of air, land, seawater, and freshwater, tourism and increasing resource demand and inequality, increase the vulnerability of local communities, the impacts on human health and the level of insecurity for the water, energy, food and ecosystems (WEFE). Resources overexploitation is contributing to their rapid depletion and consequent environmental degradation: it puts at risk the capacity of Mediterranean countries to reach the Sustainable Development Goals (SDGs) of the 2030 Agenda. The unsustainability in the WEFE elements is not only characterised by insecurity but also by the large disparities across countries (North-South divide mainly) and across territories (rural and urban areas), and by the multiple interlinkages (nexus), including synergies and trade-offs, between the four elements of the WEFE nexus.

Among the key challenges faced by Mediterranean countries are water scarcity issues and strong dependency on energy and food imports. Three main pathways for action are being currently implemented to promote synergies between the water, energy, food and ecosystem elements: (1) implementation of innovative technological solutions often relying on renewable energy and enhanced efficiency; (2) ecosystem-based, including nature-based Solutions (NbS) such as agroecology, urban engineering and wetlands and (3) social approaches to reduce or modify consumption patterns, such as promotion of sobriety or Mediterranean diet adoption, respectively.

However, despite the actions, the current situation is not satisfactory for these four elements in regard to nexus approach expectation, showing a concept-to-operation gap. Such gap is due to (1) the lack of accessible and reliable data on key indicators and variables; (2) the insufficient knowledge, understanding and awareness of nexus synergies and trade-offs; (3) insufficient incentives and investments; (3) higher costs of nexus approaches in the short term as compared to silo approaches and (4) the lack of adequate governance, which include the lack of inter-sectoral and multi-level coordination.

Despite existing platforms for exchanging and consolidating know-how and experiences in the Mediterranean, series of actions and interventions need to be enhanced to build institutional capacities which include (1) science-policy interface as one way of reinforcing coherence; (2) enhanced finance mechanisms; (3) intra-regional dialogue; (4) deliberative approaches and (5) pilot nexus approaches through modelling and assessment for more coordinated WEFE actions in the Mediterranean.

A. Interconnected water, energy, food and ecosystem security challenges

A.1. Background for the assessment

A.1.1. All recent assessments of anthropogenic climate change for the Mediterranean Basin, including the IPCC AR6 and MedECC assessment reports, indicate ongoing warming of the atmosphere (+1.5°C above the pre-industrial level) and the sea (0.29°C–0.44°C per decade since the early 1980s) exceeding global average rates, changes in rainfall distribution (10 to 30% drop on average) and continuous sea level rise (1.4±0.2 mm yr^{-1} during the 20th century). The combination of observed and projected increases in climate hazards, coupled with high regional vulnerability and exposure, make the Mediterranean area a 'climate change hotspot' (*high confidence*) {1.2}. High temperatures cause direct damage to humans and ecosystems. Among the main risk factors identified in the Mediterranean is drought (meteorological, hydrological, agricultural and socio-economic droughts), due to trends characterised by a widespread increase in evaporative demand resulting from temperature increase, and a decrease in precipitation, leading to an increase of the duration and intensity of meteorological and hydrological droughts {1.2}. The drier conditions and the increasing water scarcity are significant threats to agriculture and ecosystems, and to a lesser extent energy, through hydropower and thermoelectric plants (*medium confidence*) {2.2.2}. At sea, the consequences of climate change are the increasing acidification of seawater *likely* reducing marine productivity, affecting species distribution and triggering local extinction, as well as the rise in mean sea level, which has already increased by 6 cm over the past 20 years (*high confidence*). It could reach between 40 cm for the lowest greenhouse gas emission scenario and 100 cm for the highest emission scenario by 2100[2], increasing the risk of coastal flooding (*high confidence*) {1.2}.

A.1.2. Greenhouse gas emissions in the Mediterranean Basin represent 6% of global emissions, equally distributed between the Northern and Southern rims, corresponding to an equivalent proportion of the global population, with fossil energy accounting for 76% of the energy mix with large variation between countries. The power production sector represents 30% of the total, while the industry represents 14%, the building sector 16%, the transport sector 28% and the other sectors 12%, including industrial process emissions, indirect emissions (for nitrous oxide only), agriculture (agricultural soils, agricultural waste burning, enteric fermentation, manure management), and waste. Mediterranean countries have significant potential to mitigate climate change with high potential for renewable energy, particularly in the South and East. Adverse effects of climate change on thermo-electric production and hydropower and to a lesser extent solar and wind energy production should be accounted for to meet the energy demand, expected to decrease in the North of the basin and increase in the Middle East and North African (MENA) countries {1.2}.

A.1.3. The Mediterranean Basin has a long history of adaptation to harsh environmental conditions, such as dry and hot climate and often poor soils. This has resulted in landscapes and agricultural practices that have been developed over millennia of human presence in this

[2] Refer to "Notes" for the explanations on RCPs.

region {1.2; 3.1}. Those practices and associated knowledge have been substituted through industrialization and lifestyle changes that were not adapted to Mediterranean conditions with impacts on WEFE components {2.1.1.2}.

A.2. Current status of the WEFE nexus in relation to the Sustainable Development Goals (SDGs)

Insecurity for all elements of the nexus (water, energy, food and ecosystems) is the rule rather than the exception in many countries of the Mediterranean Basin, which has far-reaching implications in terms of sustainability. The region faces pressing challenges of water insecurity (e.g., water stress), energy insecurity (with large dependence on fossil fuels mostly imported), food insecurity (comprising the triple burden of nutrition) as well as ecosystem insecurity (e.g., fast rate of biodiversity loss, on land and in the ocean) (Figure SPM1). However, the unsustainability in all elements is not only characterised by insecurity but also by the existence of large disparities between countries, as well as by the multiple interlinkages between the four nexus elements.

A.2.1. Mediterranean countries are facing numerous and interrelated challenges in terms of access to and availability of water, energy, food and fertile land, as well as in how these elements depend on and potentially impact ecosystems. Mediterranean countries face several challenges in their implementation of the 2030 Agenda for Sustainable Development and are not on track to achieve many Sustainable Development Goals (SDGs). This is particularly relevant for those SDGs relating to WEFE components, such as food (SDG 2), water (SDG 6), energy (SDG 7), and ecosystems (SDGs 14 and 15). The Mediterranean region shows that it has a general SDG index score of 73.5 but there are huge differences between the sub-regions; the SDG index shows better performance in western Europe and lower values in eastern Europe and MENA countries. The SDG scores of Mediterranean countries in 2022 ranged from 81.1 in France (ranking 4th at the global level) to 59.3 in Syria (ranking 126th at the global level), no data available about Palestine {4.1}.

A.2.2. Water insecurity originates from water scarcity due to droughts, flood-induced risk on infrastructure, degradation of water quality as well as unequal access {1.2; 2.1.1.3}. Water plays a critical role in maintaining healthy ecosystems, reducing global disease, empowering women, enhancing the welfare and productivity of populations, adapting to climate change, and fostering peace, acting as a vital connection between the climate system, human society and the environment so reaching SDG 6 (clean water and sanitation) is essential to achieve all other SDG which is of particular importance in the Mediterranean Basin {1.1}. **From the perspective of SDG 6 large disparities between countries exist and most of the countries have significant challenges to address {4.1}.** Already, 180 million people suffer from water scarcity in the Mediterranean, but the quality of water also decreases with increase of water salinity due to groundwater overexploitation and the presence of pollutants (e.g., nutrients and heavy metals) {1.2; 2.2; 2.3.1}. The key challenge for all MENA countries is water availability – due to frequent drought leading to water scarcity as well as unsustainable use of the limited water resources and overconsumption {4.1}. Challenges related to overexploitation of water resources, unsustainable water use leading to water shortages, are due to a lack of sound water governance and in particular, right implementation of Integrated Water Resources Management (IWRM) {1.2}. Water shortage can lead to competition between sectors,

including agriculture, industry, drinking water supply and tourism {1.2}. It can also lead to conflicts when combined with socio-political, economic, and environmental factors {2.3.1.3}.

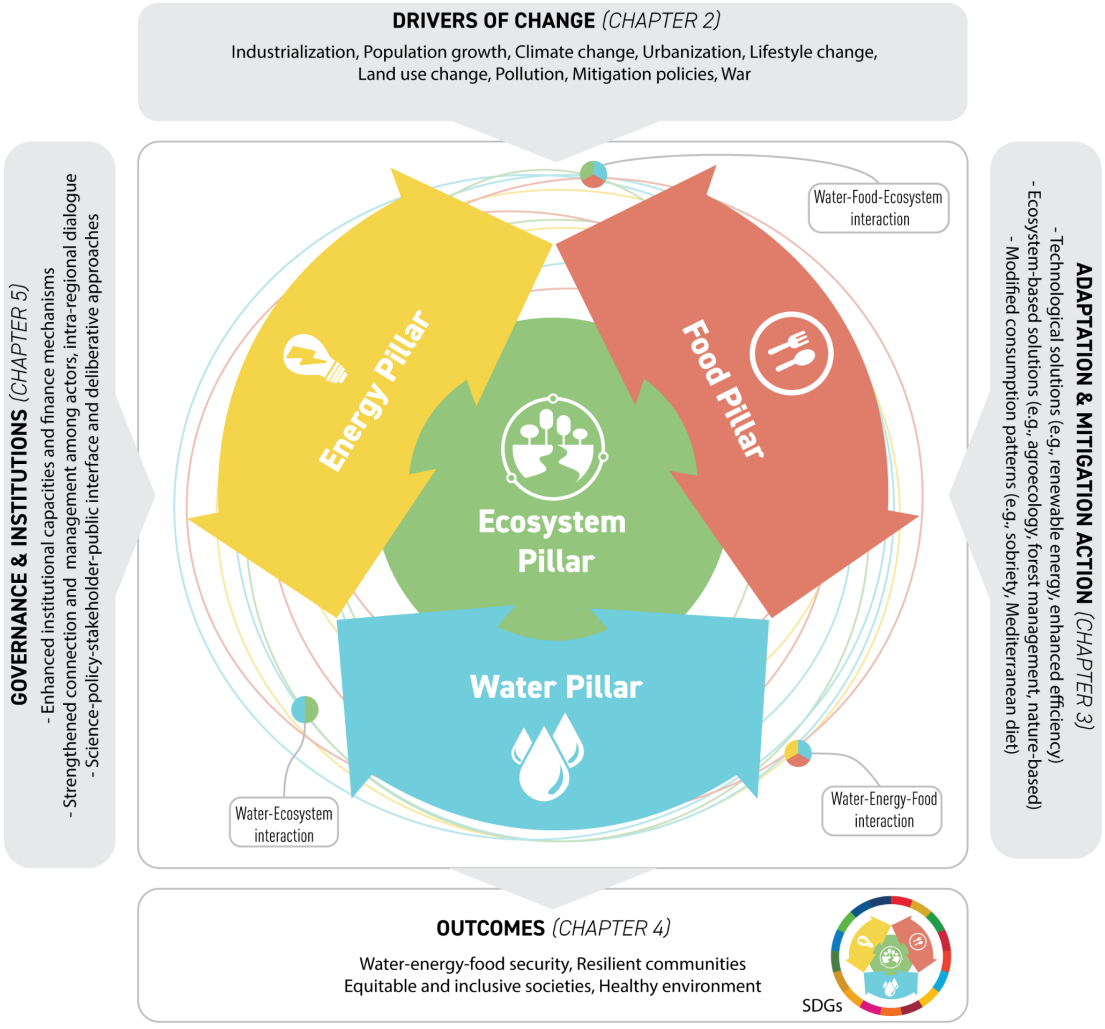
A.2.3. Food insecurity in the Mediterranean is significant and it is characterised by the triple burden of malnutrition: undernutrition, overnutrition and hidden hunger. The worst cases are found in North Africa, where all countries face major challenges. Indeed, SDG 2 (zero hunger) is the one presenting the most critical situation of all WEFE elements. Statistics on the prevalence of undernourishment are not available in the literature for countries such as Palestine and Syria. None of the Mediterranean countries achieved the targets by 2020 and for all of them either significant or major challenges remain with however disparities between countries {4.1}. The high dependency on food imports, particularly for MENA countries, makes the region highly vulnerable to external uncertainties and variability, outside the Mediterranean region. A dietary shift away from the traditional Mediterranean diet among the population, particularly children and adolescents, is mainly accompanied by increased malnutrition trends in the form of overweight and obesity, as well as degradation of ecosystems and greenhouse gas emissions (*high confidence*) {2.3.1.3; 3.2.6; 4.1}.

A.2.4. The region faces challenges in securing its energy supply and matching demand. From the perspective of SDG 7 (affordable and clean energy), two Mediterranean countries (Malta and Portugal) had already achieved the SDG by 2020 while many others seem on track to achieve it, as they only face moderate challenges. Access to electricity in urban areas is universal in most Mediterranean countries (i.e., 100% of the urban population has access to electricity). Access to electricity is lower in rural areas {4.1}. The challenge for nearly all Mediterranean countries, except Algeria, Egypt and Libya, is their strong energy dependence on imports. Energy insecurity in the region is also increased by the existence of political conflicts between countries {4.1}. The share of electricity produced from oil, gas and coal sources ranges from less than 10% in France to more than 90% in Algeria, Croatia, Cyprus, Egypt, Israel, Jordan, Lebanon, Libya, Malta, Syria and Tunisia. In general, Mediterranean countries are still highly dependent on fossil fuels to produce electricity {3.2; 4.1}. Renewable energy consumption only accounts for 11% of the total energy consumption in 2020, about nine percentage points lower than the European Union and three percentage points lower than the global level {1.2}. Reducing energy demand, including increased energy efficiency and energy sufficiency, is needed to reduce environmental degradation. Additionally, it is advantageous for the region to explore alternatives to guarantee energy security, particularly in light of the limited presence of established policies to reduce energy demand. The Mediterranean countries have significant potential to mitigate climate change through an accelerated energy transition, including renewable energies deployment {1.2} that requires effective land and sea use planning to avoid conflicts with other uses {2.2.4}.

A.2.5. Marine and terrestrial ecosystems are under acute pressure in the Mediterranean region. Biodiversity loss, deforestation, wildfires, land use changes, as well as pollution, are trends widely reported that are severely undermining Mediterranean ecosystems {1.2; 4.1}. Both marine and terrestrial ecosystems face significant challenges in the Mediterranean where most of the countries are not on track to achieve SDGs 14 (life below water) and 15 (life on land): forest degradation is expanding, some polluting sectors are undergoing rapid growth, such as coastal mass tourism or land and maritime transport {1.2; 4.1}. Regarding marine

ecosystems, unsustainable fishing, warmer temperatures, acidification and water pollution, including underwater noise, reduce marine productivity, affect species distribution and trigger local extinctions {1.2}. So as for SDG 14, 12 Mediterranean countries still face major challenges, while 7 others face significant challenges. The situation improves slightly with terrestrial ecosystems (SDG 15), but still, 10 Mediterranean countries face significant challenges, whereas three countries face major challenges to achieve this SDG {4.1}.

Figure SPM1 | Schematic of the WEFE concept and report outcome for the Mediterranean Basin. A variety of direct and indirect drivers of change impact the WEFE components. WEFE has a series of two, three and higher levels interactions that need to be addressed through appropriate governance and institutions capable of developing adaptation and mitigation actions that promote synergies to achieve water, food, energy security and ecosystems health in compliance with the SDGs.



A.3. Impact of the drivers of change on the WEFE nexus

WEFE challenges are amplified by current and future direct and indirect drivers of change external to WEFE, particularly climate change, pollution, land use changes, population growth, lifestyle changes, urbanisation, migration, industrialisation and conjunctural shocks like pandemics and conflicts.

A.3.1. Water security in the Mediterranean is affected by a combination of factors, including climate change, densely concentrated population growth, pollution, saltwater intrusion, land use practices and unsustainable resource management, among others {1.2; 2.2.1}. Future mean precipitation projections for the Mediterranean region foresee reductions by approximately 4% per 1°C global warming (*high confidence* for global warming levels above 2°C with a marginal projected increase in winter at the northern boundary of the northern Mediterranean Basin) {1.2; 2.2.1.1}. Under a 2°C warming scenario, the frequency and duration of meteorological droughts are projected to increase in the southern rim countries, and the frequency of agricultural droughts is projected to be 150 to 200% more likely (*high confidence*) {2.2.1.1}. Population growth, economic development and lifestyle changes have led to increased water demand, resulting in water shortages and depletion of water resources (*high confidence*). The increasing levels of urbanisation, industrialisation, and unsustainable agricultural practices have led to a heightened need for water, which has resulted in unsustainable rates of water consumption {3.1; 3.2}. Inefficient irrigation methods are responsible for the squandering of water resources and the aggravation of water scarcity in the area {3.2} (*high confidence)*. Moreover, unsustainable resource management has resulted in pollution of water resources and groundwater depletion {2.2.1.3}. In addition, inadequate land and resource management practices are also a contributing factor to water insecurity. The water-infiltration and water-holding capacity of soils can be adversely affected by activities such as deforestation, soil erosion, and improper land use practices, which can increase the likelihood of flash floods and reduce the water quality {2.2.1}.

A.3.2. Land and environmental degradation, pollution, land use changes, water scarcity, rural exodus and urbanisation, climate change, and dietary change lie behind the current levels of food insecurity in the Mediterranean {2.3.1}. Large disparities between regions, with a significant gap between the northern and the southern and eastern rims exist. Population growth and conflict in some countries increase food insecurity. Climate change presents a significant threat to agricultural productivity, especially in arid and semiarid regions. Decrease in crop yields, caused by reduced water availability and heat stress, is likely to affect staple crops such as olives, grapes, fruits, cereals, and vegetables. Levels of projected changes vary depending on countries, scenarios and crops, ranging from –80% for sunflower in Spain and to +26% for olive in the whole Mediterranean Basin (*medium confidence*). Agricultural land can be lost due to coastal water, soil salinisation and desertification {2.3.2}. The livestock sector is expected to suffer the negative effects of heat stress, limited feed resources, and deteriorating health and productivity. Climate change also impacts fisheries and aquaculture, resulting in the regional eradication of significant aquatic taxa {2.3.1.1} and modification of species distribution {1.2}. Furthermore, industrialisation and urbanisation have contributed to significant transformations of the Mediterranean agricultural sector. This transformation has been exacerbated by various factors, including a shift towards modern lifestyles, increased food demands or increased international trade. The region is subject to significant implications

resulting from changes in land use {2.3.1}. The food security concerns in the region are further aggravated by the compounding challenges arising from conflicts such as the Russo-Ukrainian War, and the region's significant reliance on food imports. The potential consequences of disturbances in the food and fertiliser industries, in conjunction with the impacts of climate change, can be significant in terms of both the availability and accessibility of food {2.3.1.3}.

A.3.3. **The main drivers of change of the energy production and demand are mainly non-climatic (population growth, lifestyle changes, industrialisation and mitigation policy planning)** {2.4.1}. Climate change through increased temperatures affects marginally solar energy production (less than 2% decrease for global warming levels up to 3°C) (*low confidence*) {1.2; 2.4.1.1}. Regarding wind energy, the projected wind speed decline affects wind energy production (up to 8% decrease for global warming levels up to 3°C) (*low confidence*) {1.2}. Hydropower and thermo-electric production, including nuclear, is expected to decline, due to decreased streamflow and increased water temperature, leading to up to 10 to 15% decrease in thermopower by 2050 in the highest emission scenario (*high confidence*) {1.2; 2.4.1.1}. Nuclear power plants situated along the coast are exposed to the potential impact of rising sea levels and flooding caused by extreme weather events. Quantification of global warming impacts on future energy demand is still highly uncertain but non-climatic drivers (e.g., population growth, urbanization and modernization) suggest a decrease by 10 to 23% by 2040 compared with 2015 in the north of the basin and an increase by 55 to 118% in 2040 compared with 2015 in the MENA countries {1.2; 2.4.1.2; 2.4.1.3; 2.4.1.4}.

A.3.4. **Climate change has major impacts on dryland ecosystems in the Mediterranean region, which include vegetation productivity, biodiversity, and stability and the northward expansion of semi-arid regions.** The coupled effect of warming and drought increasing aridity is related with the decrease of the provision of several terrestrial ecosystem services such as soil conservation, water storing capacity, timber, mushrooms and food production, tourism and recreation, biodiversity and C-storage. Furthermore, climate change increases the vulnerability of ecosystems towards diverse forms of disturbances, such as wildfires, pests, and diseases, among others {2.5.1.1}.

A.3.5. Conjunctural drivers of change, such as recent conflicts and pandemics have suddenly negatively impacted the WEFE nexus and its hierarchical constituents as well as the SDGs indicators {4.1}.

B. Cascading impact of drivers of change through the nexus components

The change in the WEFE elements due to climatic and non-climatic drivers can affect the relevance of adaptation and mitigation measures at various temporal and spatial scales. Indeed, the complex web of interactions among WEFE elements can first result in cascading effects through which changes in one element from drivers of change, result in changes in the other WEFE elements, in turn generating multiple loops and feedback paths. Sustaining healthy ecosystems needs to be at the heart of the interventions, since degraded ecosystems cannot provide the ecosystem services associated and hamper water, food and energy security.

B.1. Cascading from the water pillar (**Figure SPM2**)

B.1.1. The globally negative change in the water element causes almost directly a negative change of all food access and availability indicators as the water and food pillars are significantly correlated *(high confidence*) {2.2.2; 2.3.1.1}. Water scarcity reduces agricultural yields, and the agricultural sector, which is a significant water consumer in the region, is facing mounting challenges in obtaining adequate water resources for irrigation purposes {2.2.2; 2.3.1}. Actions seeking to increase water availability for irrigation using groundwater, can lead to sea water intrusion and salinisation, reducing water quality and availability and further degrading ecosystems. The energy required to pump this water may contribute to greenhouse gas emissions and reduce energy available for other purposes. Actions seeking to increase water availability for irrigation using treated wastewater, contribute to reduce pollution and can provide fertilisers that increase food availability, but compete with other energy uses {2.2.2}.

B.1.2. The projected declines in streamflow and increases in water temperature may lead to a strong decline in hydropower and thermoelectric power usable capacity in the Mediterranean (2.5–7.0% for hydropower in 2050s and 10–15% for thermoelectric power) (*high confidence*). The reduction of CO_2 emissions from the potential loss of thermoelectric production from nuclear (low-CO_2 emissions) or fossil fuel (large CO_2 emissions) depends on the technologies {2.2.2; 2.4.1.1}.

B.1.3. The changes in the hydrological cycle and water quality by the pressure of climatic and non-climatic drivers significantly impact the structure and operation of wetlands and riparian ecosystems, being recognised as biodiversity hotspots in the Mediterranean (*high confidence*). These changes cause a loss of habitat for the aquatic biota, the rich and dynamic riparian plant communities, waterbirds, and impact important migratory corridors and foraging hotspots. {2.2.2; 2.5.1.1}.

B.2. Cascading from the food pillar (**Figure SPM2**)

B.2.1. To address the impacts on food security of the drivers of changes, actions aiming at increasing agricultural yield through business-as-usual responses linked to agricultural intensification and industrialisation, can negatively impact ecosystems health through salinisation or changes in land use (*high confidence*) {2.3.2; 2.3.3}. Increased irrigation, as the main strategy for boosting crop productivity in the Mediterranean, can have a high cost in terms of water use and water pollution (e.g., nitrates leaching and salinisation of over-exploited aquifers) (*high confidence*) {2.3.2.; 2.3.3; 3.2.2}. The contamination of water bodies by industrial and agricultural activities results in a decline in water quality, making it unfit for human consumption and detrimental to the well-being of ecosystems. Additionally, the projected increase of irrigation crop requirements under climate change scenarios (*medium confidence*) can exacerbate existing competition for water resources among sectors {2.3.2}. Industrialisation of agriculture leads to ecological deterioration, characterised by deforestation, amplified emissions of greenhouse gases, escalated energy consumption, and augmented water and fertilisers usage. The implementation of intensification techniques frequently results in agricultural land abandonment and a shift towards the cultivation of annual crops and monocultures, thereby affecting ecological sustainability and posing potential threats to biodiversity and agrobiodiversity. The diminution of agrobiodiversity poses an additional peril to the robustness of agricultural systems and the customary Mediterranean cuisine (*high confidence*) {2.3.1}.

B.2.2. Increased consumption of animal-based products due to population growth and lifestyle changes is responsible for an increase in greenhouse gas emissions and the disruption of local and regional nitrogen cycles, causing relevant impacts on ecosystems health (*high confidence*). Addressing this challenge by increasing unsustainable production and not targeting consumption behaviour leads to the same cascading effects as further agricultural industrialisation, with impacts on the water and ecosystems elements {2.3.3}. The link with the energy element is the growing energy need for food production, with further detrimental impact if fossil-fuels are the source of energy production, and the increasing CO_2 emissions with decreasing adherence to the Mediterranean diet {2.3.2; 2.3.3}.

B.3. Cascading from the energy pillar (Figure SPM2)

B.3.1. Promotion of renewable energy to address the impacts of the drivers of change on the energy element can lead to land competition. The land requirements already necessary in the Mediterranean region to fulfil 100% of the primary energy use are lower than 10% for hydropower, solar photovoltaics and wind, while for biomass, the spatial requirements already exceed 100%. The spatial requirements for nuclear or natural gas never exceed 0.7%. With the energy demand in the MENA countries expected to double by 2040 compared with 2015, the fraction of land dedicated to energy production could reach more than 10% of the total land with risks in terms of land degradation and biodiversity loss, while it could also conflict with food production and negatively impact food availability *(medium confidence)* {2.4.2}. Spatial planning and reduction in demand could help avoid these potential trade-offs.

B.3.2. Increasing energy production implies more water use. In Europe, water withdrawals for energy production are on average similar to those for agricultural irrigation {2.4.2}. In the MENA region, the share dedicated to irrigation is much higher (80%) which is, however, to be put in regards of the water scarcity in these countries. Only a small fraction is consumed (6% for EU countries with large disparities between countries), the remaining part being returned to the hydrological system. However, the energy sector remains an important part of withdrawals, negatively affecting the water availability and competing for water with food {2.4.2}. Impacts on ecosystems due to excessive water withdrawal are also considerable. Thus, dependence of the Mediterranean region on power generation methods that require significant amounts of water, such as hydroelectric, thermal, and nuclear plants, exposes it to the risk of reduced water availability and difficulties in managing water resources due to the effects of climate change.

B.3.3. Energy is a crucial input (upstream) in food processing and fertiliser production. If no changes are introduced to agricultural practices, the potential reduction in fertilisers will influence agricultural production by introducing lower yields into current monocropping agricultural systems. Consequently, a smaller quantity of farm products would be available to the food processing industry, leading to a reduction in market supply and a potential increase in prices {5.1.4}. Any increase in energy prices can also result in an increase in food prices, limiting food access to the poorest people.

B.4. Cascading from the ecosystem pillar (Figure SPM2)

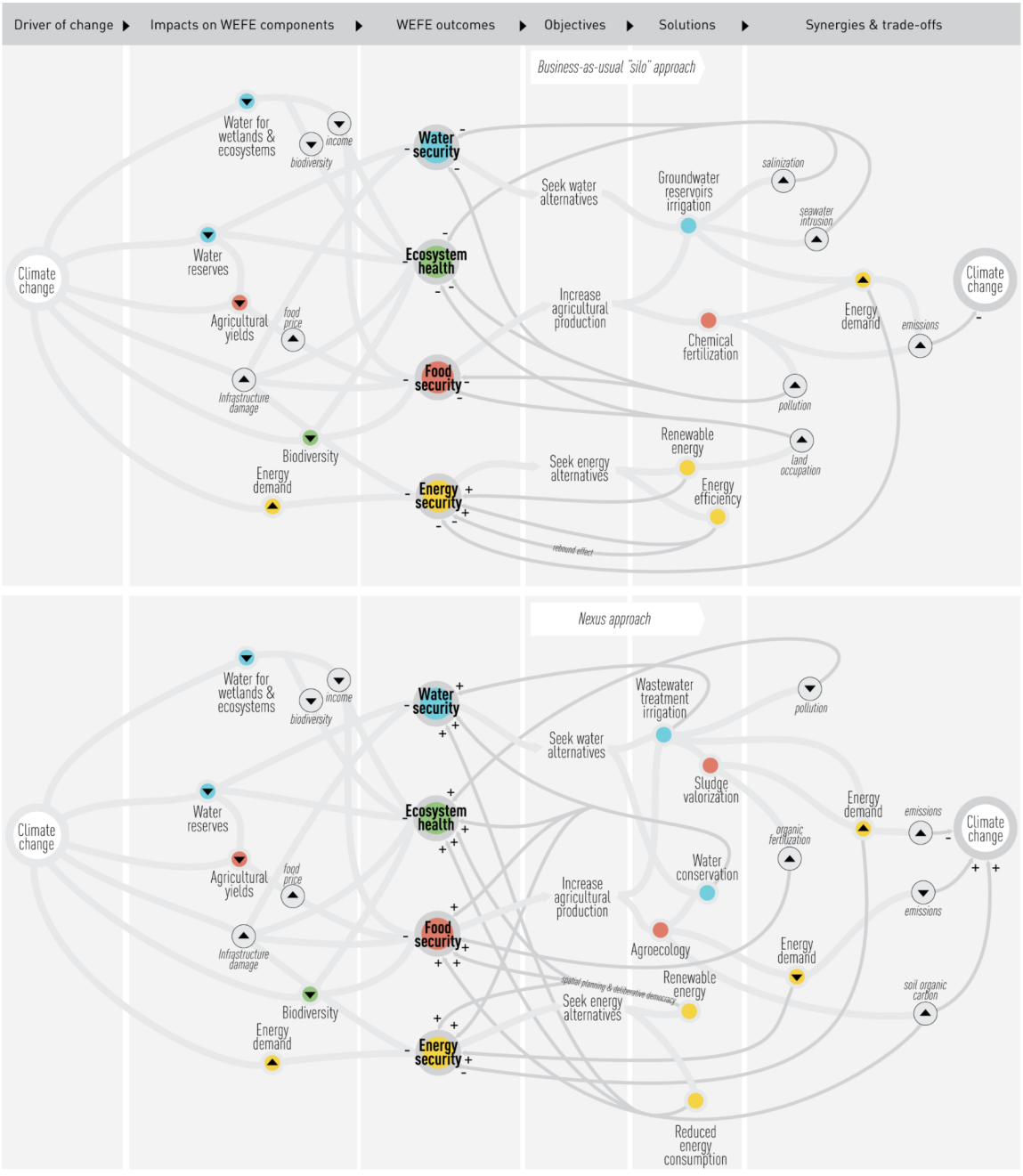
B.4.1. Impact of climate change on ecosystems health can reduce the productivity of ecosystems and diversity at all levels, from intraspecific to landscape level. The degradation or depletion of

ecosystems reduces the provisioning (water, food, biomass) and regulating ecosystem services (water quality, storm protection, carbon sequestration) provided by healthy ecosystems. In the case of water, climate and environmental changes combined with heightened concentrations of pollutants in aquatic environments could potentially result in a reduction in the quality of water, and a rise in sediment accumulation. Nevertheless, the effects are intricate and multifaceted, and not all ecosystems are affected equally. It is noteworthy that certain changes in climatic conditions may even lead to the enhancement of ecosystem services in specific instances {2.5.2}.

B.4.2. The reduction in biodiversity and degradation of ecosystems negatively affects the maintenance of soil structure and fertility, decomposition, remineralisation, and recycling processes, pollination, seed dispersal, and pest and disease control, which subsequently negatively impacts food availability {2.5.2}.

B.4.3. Changes in ecosystems, such as the removal of forests or alterations in water availability, may impact the accessibility and durability of energy resources, thereby carrying potential implications for the production and provision of renewable energy sources such as biomass and hydropower {2.5.2}.

Figure SPM2 |Impacts, interactions and cascading effects on the WEFE outcomes of drivers of change and solutions. Climate change impacts the WEFE components. To achieve water, food, energy security and ecosystem health, policy-makers need to find solutions. Solutions developed following a silo-approach may reinforce the trade-offs, negatively impacting WEFE outcomes and increasing climate change. A nexus approach, by integrating complexity, can significantly reduce those impacts and promote positive WEFE outcomes.



B.5. Adaptation and mitigation solutions

Adaptation measures focusing on a single societal goal and one WEFE element can result in negative trade-offs, leading to maladaptation. In agricultural systems, this happens partly because adaptation pursued a single goal - maximising food production in the short term, which in several cases meant intensive agriculture, detrimental for soils and biodiversity. In the forestry sector, adaptation focusing on single societal goals, such as the spread of non-native tree species, can lead to higher fire risk (medium confidence). Integrated adaptation solutions are needed to address security issues, noting that mitigation consequences of the nexus approach can result from potential synergies and trade-offs derived from the interconnections among WEFE components.

B.5.1. A nexus approach to adaptation and mitigation actions promote synergies between the WEFE elements and minimise potential trade-offs. This is clear in the Mediterranean region as the evolution of the climate and environment negatively affects WEFE elements both separately and through the cascading impacts of the drivers of change (*high confidence*). Silo approaches include poor and unsustainable irrigation practices leading to increased soil salinity and overall land degradation or overexploitation of rangelands leading to soil erosion and land degradation (*high confidence*). Nexus approaches can include new irrigation techniques or recovering traditional ones, reuse of treated wastewater or desalinated water using renewable energy, agrivoltaics without land competition, or agroecological practices, such as agroforestry, intercropping and cover crops, that can reduce freshwater consumption, increase water conservation and reduce energy footprint while attempting to maximise local food production and protect ecosystems {3.2.1; 3.2.2}.

B.5.2. Adaptation and mitigation solutions are usually distinguished on a gradient of two main types: incremental and transformative (**Figure SPM3**). They include a variety of options, such as ecosystems-based approaches (including Nature-based Solutions, NbS), technological and social innovation, including behavioural changes targeting consumption and lifestyle patterns, that can effectively address interrelated WEFE security issues and SDGs {3.2} (**Figure SPM4**). NbS includes a set of actions inspired and supported by nature that simultaneously provide environmental, social and economic benefits, and helps build resilience {3.2.2.1}. NbS strategies imply the implementation of blue and/or green infrastructure (e.g., green roofs and walls, urban grasslands and meadows, horticultural gardens, vegetated filter strips, swales, constructed and natural(ised) wetlands and ponds). Early warning systems, climate services and risk management approaches have also shown a broad applicability across various sectors in the Mediterranean and would benefit from incorporating an integrated nexus approach. Decision support tools, online platforms, or other products co-developed with users can provide information and services to support their decision-making {3.2.3.1}. Policies and actions that operate across the food system, promoting sustainable ecosystem and forest management that include changes in agricultural and livestock management to increase carbon storage in soils (e.g., agroecological approaches such as agroforestry or well-managed extensive livestock systems) and simultaneously targeting behavioural change, including reduce food loss and waste or influence dietary choices (e.g. reducing overall consumption of meat), enable more sustainable land-use management, enhance food security, reduce water use, water contamination, soil degradation, promote biodiversity conservation and can have a significant potential to adapt to climate change and reduce emissions, among other benefits (3.2.2; 3.2.3; *high confidence*).

B.5.3. Drivers of change are evolving at fast pace with strong implication on the WEFE elements {2.2.1, 2.3.1; 2.4.1; 2.5.1} potentially jeopardising the resilience of already implemented actions. The assessment of modelling-based nexus approach based on different climate, socio-economic and demographic change scenarios helps understand the resilience level of sustainable development options, and avoid maladaptation and unanticipated effects. Thus, It is advisable to consider changes in system variables when designing integrated policies.

B.5.4. Transformative adaptation relies more on social innovation and requires increasing human inputs and system re-organisation, but it can be the most appropriate response to climate change and other drivers of change, when the severity of the expected impacts is particularly high or when current incremental adaptation options are reaching their limits in terms of implementation and functionality {3.1}. Adaptation and mitigation solutions can range from those more related to ecological and consumption-reducing behaviours to those more related to scientific and technological innovation {3.2}. Science and technology are part of the solution but require a broad understanding and societal engagement to achieve transformation through behavioural change. The varying levels of engagement of, and trust in, different stakeholders including civil society in the Mediterranean region, hampers the development of a nexus approach that demands a high level of cooperation and mutual trust {3.3}. Implementation of new technologies requires to enhance participation and consider social concerns to avoid maladaptation.

B.5.5. Adoption and implementation of adaptation and mitigation measures can be bracken by some financial, scientific, geographic and institutional challenges. The implementation of solutions that consider the nexus can be more cost-effective and cost-efficient compared to other solutions, however it requires considerable funds in the initial stages. Financing such approaches can be further hindered since WEFE programs have many and important socially oriented components that are typically of limited commercial value and potential (3.4.1). Many northern countries of the Mediterranean are more likely and more financially ready to support such initiatives, whereas the southern and eastern countries of the Mediterranean could require international support and commitment in the forms of financial or scientific support to increase the adoption of the new approaches that will in the long-term lead to the sustainability of the entire Mediterranean (3.4.4). Indeed, technology implementation in southern countries still lacks adequate financing besides appropriate policies {3.4.4}.

Figure SPM3 | Different gradients of possible adaptation and mitigation solutions for WEFE components used in the Mediterranean region. Adaptation and mitigation solutions range from incremental to transformative, and from scientific and technological innovation to socio-ecological innovations and behavioural change.

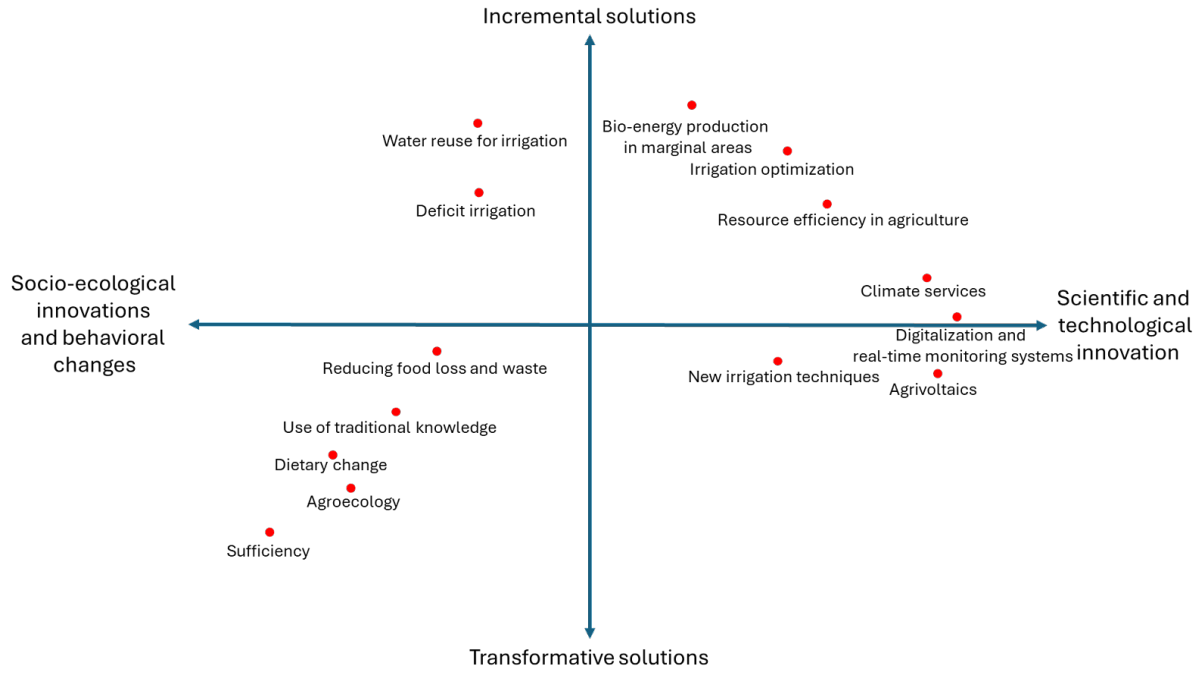


Figure SPM4 | (a) Assessment of the main impacts and trade-offs of the WEFE nexus adaptation and mitigation solutions implemented in the Mediterranean countries. The link is made to the SDGs through the nexus pillars. The numbers in brackets are the number of articles used for assessing each solution. The amount of evidence is quantified by the number of reviewed articles (given by numbers in brackets and categorised in 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 on the Mediterranean, reported in the scientific literature, and assessed in the report. **(b) Spatial distribution of examined case studies.**

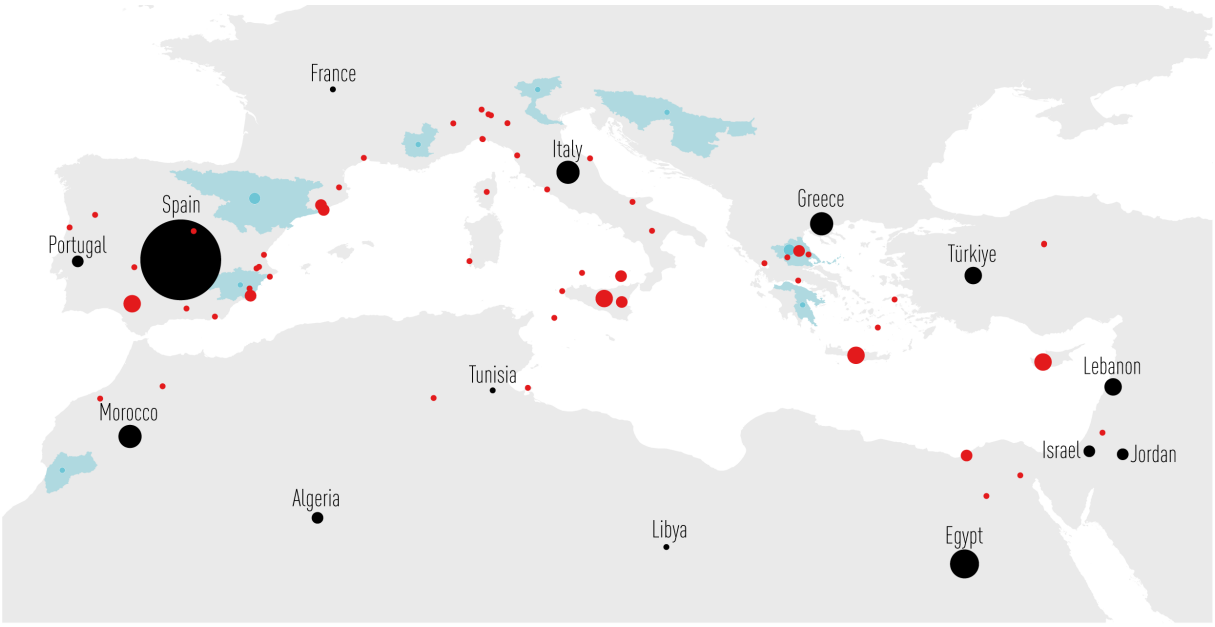
WEFE nexus adaptation and mitigation strategies	Existing management responses in the Mediterranean basin	Water pillar SDG 6		Energy pillar SDG 7		Food pillar SDG 2		Ecosystem pillar SDG 14 SDG 15	
Governance and Institutional	Policies on water pricing and limiting and reducing water use (3)	++	o	++	o	++	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
	Digitalization and precision agriculture (2)	+++	-	+	o	++	o	+	o
	Increase bio-energy crop production in marginal areas (8)	++	-	+++	o	+	o	++	-
Water conservation and irrigation related 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 sobriety (30)	+++	o	++	o	+++	o	+++	o

Impacts and risks
+ Positive impacts on WEFE nexus pillars
- Risk or trade-off on WEFE nexus pillars

Amount of evidence
Limited
Medium
Robust

Level of agreement/confidence
+++ High ++ Medium
+ Low o Low agreement or limited evidence

Relation with Sustainable Development Goals



National case studies
Sub-national case studies
River-basin case studies
River-basins

Number of case studies
14 5 4 3 2 1

C. From the nexus concept to its implementation for sustainable development

C.1. Data, indicators and assessments

C.1.1. **Existing approaches to tackle sustainability challenges in the WEFE sectors of the Mediterranean region have adopted fragmented planning and management frameworks that lack sufficient consideration of the intricate interconnections between these resource systems *(high confidence)* to address sustainability challenges in the Mediterranean {4.2}**. WEFE nexus approach offers an integrated planning, cross-sectoral cooperation, and decision-making framework to analyse the interactions between the WEFE sectors of the Mediterranean region and identify trade-offs and co-benefits that might be overlooked in single-sectoral approaches *(high confidence)* {4.42}. The WEFE nexus allows better distinguishing potential synergies or conflicts between sector policies because it provides a framework in which the role of ecosystem services is more explicit. The sustainable use of ecosystems and conservation of biodiversity are indispensable pillars to successfully achieve sectoral development goals in the Mediterranean region {4.2}.

C.1.2. **Lack of complete and disaggregated data on the components of the WEFE nexus together with other issues related to data quality and accuracy, and unwillingness of authorities to make certain types of required data available to researchers and other stakeholders represent a major barrier to a wider adoption and application of the WEFE nexus in the Mediterranean region** {3.4; 4.2; 4.4}. The complexity and multi-disciplinary nature of nexus means that 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 typically are not necessarily collected or available on the long-term, meaning that for many cases original data is necessary to showcase the benefits of WEFE approaches compared to other solutions {3.4.2}. Still, the currently available data have been key to the creation of indicators for nexus indexes specific to the Mediterranean region. Monitoring tools and spatial indicators, generally related to multiple SDGs, have been developed to describe national and local characteristics of the food-water-energy-ecosystems interdependencies in the Mediterranean region, highlighting their high heterogeneity both within countries and between countries, allowing ranking Mediterranean countries {4.3}.

C.2. Governance and stakeholder engagement

C.2.1. **Governance for WEFE nexus requires strengthened connection and better management through coordination, integration, coherence, deliberation and collaboration among actors and their respective strategies and actions, rather than through creation of new institutions {5.2}.** To effectively utilise WEFE nexus approach for sustainable development, key principles must be followed including understanding the interconnections among resources within a system, developing novel technologies for innovative solutions and roadmaps for their broad exploitation throughout the region, facilitating social innovation and deliberative approaches, and ensuring coordination across sectors and stakeholders {4.2}. Deliberative processes that work well for: i) values-driven dilemmas; ii) complex problems that require trade-offs; and iii) long-term issues that go beyond the short-term incentives of electoral cycles can contribute to WEFE nexus management {5.2.5}. WEFE governance is a polycentric system, with diverse and varying decision centres or actions within sectors, which requires to identify independent and

overlapping key state and non-state actors – governments (acting through different ministries and public institutions), private sector, NGOs, citizen groups, funders, multilateral and regional organisations (e.g. FAO, Plan Bleu, UfM, UNECE, etc.), national and international research institutions (AARINENA, CMI, CNRS, CIHEAM, European Commission's Joint Research Centre, GWP-Med, IRD, etc.), and national and International Development Agencies (e.g. GIZ, ENABEL, USAID, SIDA, etc.) {5.2.1} (**Figure SPM5**).

C.2.2. Policies aimed to achieve sustainable development ambitions require systemic approaches and flexible forms of governance (i.e., the removal of institutional, technical, regulatory and economic barriers), so as to facilitate interdependencies across sustainability challenges and favour holistic approaches {4.2}. A pioneer of the WEFE concept at policy level is the IWRM framework designed to improve water resources management {4.2.; 5.1.1.}. The involvement of stakeholders from the quadruple helix (public administrations, academia, private sector and civil society) in the development and implementation of nexus approaches is crucial to provide multiple perspectives, ensure political legitimacy and promote dialogue on the sustainability of the WEFE elements {4.2}. Deliberative democracy instruments, such as citizens' assemblies, can increase the legitimacy of political decisions and actions, enhance trust and provide with useful information on people's preferences and what trade-off they are ready to make {5.2.5}. Involving intra-Mediterranean transnational collaboration is needed to face the climate emergency and promote an equitable sharing of the risks and burdens associated with the sustainable development {5.3.3}.

C.3. The concept-to-operation gap

A concept-to-operation gap has been identified in the Mediterranean context, meaning that the current situation is not satisfactory for the WEFE in regard to nexus approach expectation.

C.3.1. **Political and social conditions within Mediterranean countries imply varying levels of WEFE nexus policy implementation.** The practical implementation of WEFE nexus policies has been limited and lacks coordination among the different levels of managing authorities, among sectoral departments, political actors, and stakeholders. EU countries have a common policy framework, which is not the case of MENA countries**.** Most policy initiatives on the WEFE nexus in Mediterranean countries have focused on assessments and analyses of the WEFE nexus, reaffirming the importance of the concept. However, the implementation of such an approach is still lacking, and several measures are still designed in "silos" {5.1.1; 4.3} (**Figure SPM5**). Disjointed legal frameworks, marked by diverse and frequently conflicting laws, particularly in relation to transboundary resources are obvious on both sides of the Mediterranean Basin. Therefore when deciding on policies to implement, it is beneficial to thoughtfully consider the potential cross-sectoral implications {5.1.1; 5.1.3}.

C.3.2. **The limited effective implementation of WEFE nexus approaches in the region is attributed to an insufficient understanding of nexus trade-offs amongst science-policy-stakeholder interactions, to insufficient incentives {4.4}, limited vision, knowledge, development and investment, as well as the lack of solid empirical evidence on the potential benefits of a WEFE nexus approach {4.2}**. Universities and research organisations who are knowledge generators and brokers could integrate nexus thinking and organise policy dialogue into their research agendas and curricula {5.2.3}. Another key challenge is related to the costs of nexus approaches which may be higher in the short term than those of silo approaches, due to the information, expertise, time, coordination and financial resources required {4.2}.

C.3.3. **A series of actions and interventions are needed to build institutional capacities; enhance finance mechanisms; support intra-regional dialogue between implementers of the nexus approach, policy makers, and the general public; and pilot nexus approaches through modelling and assessment {5.3}**. Public-Private Partnerships are found effective to fund the WEFE nexus and improve capacity building and awareness of involved partners {5.3.3}. Approaches that integrate both environmental sustainability and considerations of local, regional to global governance and economic factors are more likely to succeed in achieving real-world applicability {4.2}. WEFE nexus governance should promote transparency, participation, and accountability through dialogue and cooperation among Mediterranean countries, complemented by collaboration with international organisations and favour deliberative processes of citizens {5.1.1; 5.1.2; 5.1.5; 5.2.5} (**Figure SPM5**).

Figure SPM5 | Multi-level integrated/sectoral policies on WEFE nexus in the Mediterranean (see {5.3.1; 5.3.3} for AIMNET, ERANETMED, MENA RIH and PRIMA programmes description).