Contributions of the WEFE nexus to sustainability

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Chapter 4
Contributions of the WEFE nexus to sustainability

Executive summary

The Mediterranean region is grappling with significant challenges involving water insecurity (e.g. water stress), energy insecurity (e.g. electrification level), food insecurity (e.g. undernourishment and malnutrition), and ecosystem insecurity (e.g. biodiversity loss, deforestation and pollution). These challenges, amplified by climate change, have profound implications for sustainable development in the region, evidenced by the fact that most countries have yet to achieve, or are not progressing towards achieving the SDGs relating to food security (SDG 2 – zero hunger), water security (SDG 6 – clean water and sanitation), energy (SDG 7 – affordable and clean energy), and ecosystems, both marine ecosystems (SDG 14 – life below water) and terrestrial ecosystems (SDG 15 – life on land).

Traditionally, the approaches and efforts to address sustainability challenges in the Mediterranean WEFE sectors have been supply-oriented, sector-focused, and fragmented, often failing to adequately consider the intricate interconnections between different resource systems. However, scholars and policymakers in the Mediterranean are increasingly acknowledging the need for systematic and integrated governance approaches and innovative tools to account for interdependencies between sustainability challenges and approach them holistically to address sustainable development challenges in the Mediterranean region. This need has prompted the emergence of integrated approaches for analysing and managing the interactions between components of the WEFE nexus and their trade-offs and synergies. The WEFE nexus has therefore evolved to focus on achieving SDGs by improving water, energy and food security, as well as the functionality of ecosystems through increasing the efficiency of resource use, reducing trade-offs, strengthening synergies, and enhancing governance across different sectors. However, existing research efforts and policy initiatives on the WEFE nexus in Mediterranean countries have tended to be conceptual, reaffirming the importance of the concept, but there is still a lack of concrete examples of the actual implementation of such an approach. This limited effective implementation of WEFE nexus approaches in the region can be attributed to the fact that WEFE nexus approaches are data-driven and require widely accessible information and reliable data, which in many cases underpin the implementation of nexus approaches.

To transition from conceptualisation to implementation of the WEFE nexus approach, it is essential to develop appropriate methodologies and indicators for measuring, monitoring, and examining progress. The operationalisation of the WEFE nexus approach involves methodological challenges. First and foremost is that there is no single methodology best suited for all WEFE nexus challenges and at all scales, due to the diverse nature of the addressed problems, different resolutions and boundary conditions. Moreover, there is the need to better integrate both nature and societal domains. Holistic, predictive, transferable and scalable methodologies represent the general features most appropriate for operationalising the WEFE nexus approach. Finally, when operationalising the WEFE nexus approach, it is crucial to consider the existence of trade-offs (conflicting goals) and synergies (mutually beneficial outcomes) between sectoral sustainability policies across the SDGs. An awareness of the interconnection between goals is essential for making informed decisions. Without this awareness, trade-offs may arise, and progress towards one sustainability target could potentially hinder advancements towards other targets. Therefore, sustainability policies that effectively balance the preservation of ecological integrity and the promotion of economic growth and social equity often result in more instances of synergistic interactions between different SDGs. WEFE nexus interventions that holistically address both ecological and socioeconomic concerns tend to yield positive outcomes across multiple goals.

4.1 The looming resource challenge and the Sustainable Development Goals in the Mediterranean region

Land and water ecosystems, and the biodiversity they support, provide essential resources for the Mediterranean's livelihood and human settlements. However, as shown in *Chapter 2*, population growth, agricultural intensification, urbanisation, and industrial production, together with the impacts of climate change, are creating competition for these resources, leading to rapid degradation. More than seven years after the adoption of the 2030 Agenda and its 17 SDGs, Mediterranean countries still face major sustainability challenges including water security, poverty, hunger, malnutrition, widening socioeconomic inequality, energy insecurity, pollution, and environmental degradation. To tackle these challenges, it is essential that policymakers aim to enhance the resilience of WEFE systems.

For the WEFE water component, the scarcity of water resources stands as a crucial challenge for sustainable development in the Mediterranean region, exerting considerable pressure on available water resources (*Table 4.1*). In addition, the region is grappling with the dual challenges of water-resource mismanagement, and an uneven distribution, exemplified by the fact that 90% of the 1140 billion m^3 yr^{-1} blue water ends up in the northern countries, leaving a mere 10% for the southern countries (Benoit & Comeau, 2006; Burak & Margat, 2016; Fader et al., 2020; OECD, 2012). Moreover, the transboundary nature of numerous river basins in the region along with the mounting uncertainties associated with climate change contribute to the complexity of addressing water scarcity challenges (IPCC, 2022).

Despite the endowment of Mediterranean countries in terms of hydrocarbons, the region still faces some challenges in securing its energy supply and matching demand. While access to electricity is universal in northern Mediterranean countries, this is not the case in many countries in other parts of the region (World Bank, 2022). However, in general, Mediterranean countries are still highly dependent on fossil fuels to produce electricity. Renewable energy consumption only comprises 11% of the total energy consumption in the region, which is less than the world average (OME, 2020). CO_2 emissions have doubled from 1971 in the Mediterranean, with France, Italy, and Spain generating almost half of them. Energy insecurity in the region is also driven by political conflicts between countries (Bartoletto, 2020) (*Table 4.1*).

Food insecurity, undernourishment and malnutrition are pressing issues in the Mediterranean too, especially in southern and eastern countries (FAO, 2022c). However, it should be highlighted that the food insecurity in the region is characterised by the triple burden of malnutrition (*Table 4.1*). That is, malnutrition is not only about food shortages, but also about poor and unbalanced diets, as over 20% of the adult population in almost all Mediterranean countries is obese (FAO, 2022c). The prevalence of overweight children is a matter of great concern, especially in southern and eastern regions (UNICEF et al., 2023). The Mediterranean region is also characterised by large disparities between sub-regions, with a significant gap between the northern and southern and eastern regions. Population growth and certain levels of political conflict in some areas have been identified as being behind food insecurity and malnutrition in the region (Abis, 2018; Abu Hatab & Hess, 2021; The Economist Intelligence Unit, 2016).

As for the WEFE ecosystem component, the Mediterranean region is considered a world biodiversity hotspot, in which biodiversity loss is taking place at a much more rapid pace than in other regions (IUCN, 2018, 2022). Biodiversity loss, deforestation, and land use changes, as well as pollution, are widely reported trends that are severely undermining Mediterranean ecosystems (*Table 4.2*). Overall, in the last few years, forests are slightly expanding in the basin. However, forest degradation is expanding too (Peñuelas & Sardans, 2021). The region is still subject to diverse forms of pollution, while some polluting sectors are undergoing rapid growth, such as coastal mass tourism or transport (UNEP/MAP and Plan Bleu, 2020).

According to the 2020 SDG dashboard, a global assessment tool for measuring countries' progress towards achieving the SDGs, the Mediterranean region has an overall SDG Index score of 73.5 but there are huge differences between the sub-regions (Riccaboni et al., 2020). The SDG index shows better performance in western Europe and lower values in eastern Europe, North Africa and the Middle East (*Table 4.3*). The SDG scores of Mediterranean countries range from 81.1 in France (ranked 4th globally) to 59.3 in Syria (global rank: 126). In particular, Mediterranean countries have not yet achieved the SDGs relating to food (SDG 2 – zero hunger), water (SDG 6 – clean water and sanitation), energy (SDG 7 – affordable and clean energy), and ecosystems, both marine ecosystems (SDG 14 – life below water) and terrestrial ecosystems (SDG 15 – life on land). Moreover, for most of these SDGs, moderate, significant and, even major challenges remain. In particular, the progress towards achieving SDG 2 presents a great concern, where none of the Mediterranean countries had achieved the SDG by 2020, and either significant or major challenges remain. The situation is worst among North African countries, where all countries face major challenges with achieving the SDG targets. The situation appears slightly better for water and energy. With water (SDG 6), only Libya faces major challenges (*Table 4.3*). For most Mediterranean countries,

Country	Water			Energy			Food		
	Freshwater withdrawal as % of total renewable water resources *2019*	Water stress (%) *2019*	Agricultural water withdrawal as % of total renewable water resources *2019*	Access to electricity (% of the population) *2020*	Access to electricity, rural (% of rural population) *2020*	Electricity production from oil, gas and coal sources (% of total) *2015*	Prevalence of undernourishment (% population) *2019–2021*	Prevalence of moderate or severe food insecurity (% population) *2019–21*	Prevalence of obesity in the adult population (% 18 years and older) *2016*
Albania	3.74	6.79	2.29	100.0	100.0	0.0	3.9	30.9	21.7
Algeria	84.01	137.92	57.17	99.8	99.6	99.7	< 2.5	19.0	27.4
Bosnia and Herzegovina	0.81	2.02	N/A	100.0	100.0	64.5	< 2.5	12.6	17.9
Croatia	0.63	1.48	0.075	100.0	100.0	33.2	< 2.5	11.4	24.4
Cyprus	25.89	27.61	21.28	100.0	100.0	91.2	< 2.5	N/A	21.8
Egypt	134.78	141.16	106.69	100.0	100.0	91.7	5.1	27.3	32.0
France	12.72	23.50	1.41	100.0	100.0	6.1	< 2.5	5.9	21.6
Greece	14.78	20.46	11.85	100.0	100.0	71.1	< 2.5	6.8	24.9
Israel	65.39	100.42	66.91	100.0	100.0	97.7	< 2.5	14.2	26.1
Italy	17.79	29.99	8.88	100.0	100.0	60.2	< 2.5	6.3	19.9
Jordan	100.51	104.31	60.89	99.9	98.8	99.0	16.9	43.0	35.5
Lebanon	40.23	58.79	15.54	100.0	100.0	97.4	10.9	29.1	32.0
Libya	817.14	817.14	692.85	69.7	7.8	100.0	N/A	39.4	32.5
Malta	81.18	81.18	45.54	100.0	100.0	92.3	< 2.5	5.2	28.9
Montenegro	N/A	N/A	N/A	100.0	100.0	50.3	< 2.5	14.0	23.3
Morocco	36.45	50.75	31.57	100.0	100.0	81.5	5.6	31.6	26.1
North Macedonia	16.31	25.26	5.14	100.0	100.0	64.1	3.3	20.9	22.4
Palestine	39.37	47.01	22.77	100.0	100.0	N/A	N/A	28.7	N/A
Portugal	7.91	12.31	4.41	100.0	100.0	51.9	< 2.5	11.6	20.8
Slovenia	2.96	6.38	0.009	100.0	100.0	32.4	< 2.5	7.4	20.2
Spain	26.42	40.17	17.26	100.0	100.0	44.1	< 2.5	8.6	23.8
Syria	83.11	124.36	87.31	89.1	75.6	97.7	N/A	N/A	27.8
Tunisia	81.92	95.99	63.54	100.0	100.0	96.1	3.1	28.0	26.9
Türkiye	29.08	45.70	25.647	100.0	100.0	67.8	< 2.5	N/A	32.1
Source	*FAO (2022a)*			*World Bank (2022)*			*FAO et al. (2022)*		

Table 4.1 | Water, energy, and food insecurities in the Mediterranean region.

reaching SDG 7 (affordable and clean energy) is still a challenge despite variable progress over time in some of them. Both marine and terrestrial ecosystems face significant challenges in the Mediterranean, where most countries are not on track to achieve SDGs 14 and 15. With SDG 14, twelve Mediterranean countries (Albania, Algeria, Italy, Lebanon, Libya, Malta, Montenegro, Morocco, Portugal, Slovenia, Syria, Türkiye) still face major challenges, while seven others (Cyprus, Egypt, France, Greece, Israel, Spain, Tunisia) face significant challenges. The situation is a bit better regarding terrestrial ecosystems (SDG 15), but 10 Mediterranean countries (Algeria, France, Greece, Italy, Lebanon, Libya, Montenegro, Portugal, Spain, Tunisia) nevertheless face significant challenges, whereas Jordan, Syria, and Türkiye have to address major challenges to achieve it. Of particular interest and requiring further monitoring is the fact that the SDG score decreased in most of the Mediterranean between 2020 and 2022, probably because of the impacts of the COVID-19 pandemic and its management (Bayoumi et al., 2022; Lafortune et al., 2022).

Country	Forests and deforestation			Biodiversity loss		Pollution
	Forest land 2000 (1000 ha)	Forest land 2020 (1000 ha)	Forest land change 2000–2020 (%)	Number of threatened coastal taxa *	Number of threatened marine taxa **	Plastic waste littered in the coastal belt (tonnes/day)
Albania	769.3	788.9	2.5	16	49	3.5
Algeria	1579	1949	23.4	36	55	47.5
Bosnia and Herzegovina	2111.65	2187.91	3.6	18	34	1.7
Croatia	1885	1939.11	2.9	27	56	8
Cyprus	171.61	172.53	0.5	15	40	4.2
Egypt	59.21	44.98	−24.0	24	44	77.2
France	15288	17253	12.9	62	63	66
Greece	3600.23	3901.8	8.4	39	64	39
Israel	153	140	−8.5	29	42	39.5
Italy	8369.25	9566.13	14.3	49	68	89.8
Jordan	97.5	97.5	0	-	-	-
Lebanon	138.18	143.33	3.7	20	37	7.3
Libya	217	217	0	14	43	11.6
Malta	0.35	0.46	31.4	16	37	1.7
Montenegro	827 (2010)	827	0	24	47	0.7
Morocco	5506.54	5742.49	4.28	48	56	25
North Macedonia	957.55	1001.49	4.59	-	-	-
Palestine	9.08	10.14	11.7	16	15	3.8
Portugal	3281	3312	0.9	-	-	-
Slovenia	1233	1237.83	0.4	18	43	1.0
Spain	17093.93	18572.17	8.6	63	72	125.6
Syria	432.08	522.08	20.8	24	38	12.9
Tunisia	667.85	702.73	5.2	26	54	20.9
Türkiye	20148.35	22220.36	10.3	34	53	144
Source	*FAO (2022b)*			*IUCN (2018), UNEP/MAP and Plan Bleu (2020)*		*UNEP/MAP (2015)*

* *Includes amphibians; birds; reptiles; mammals; freshwater fish; freshwater molluscs; freshwater crabs, shrimps, and crayfish; butterflies; dung beetles; saproxylic organisms and plants.*
** *Includes anthozoans, marine fish (bony fish and cartilaginous fish), marine mammals and marine reptiles.*

Table 4.2 | Ecosystem insecurities in the Mediterranean area.

Country/ Subregion	SDG index score 2020	Global rank 2020	SDG 2 2020	SDG 6 2020	SDG 7 2020	SDG 14 2020	SDG 15 2020	SDG index score 2022	
France	81.1	4	Significant challenges	Challenges remain	Challenges remain	Significant challenges	Significant challenges		73.1
Greece	74.3	43	Significant challenges	Challenges remain	Significant challenges	Significant challenges	Significant challenges		65.7
Italy	77.0	30	Significant challenges	Challenges remain	Challenges remain	Major challenges	Significant challenges		70.6
Malta	76.0	32	Major challenges	Significant challenges	SDG Achievement	Major challenges	Challenges remain		64.9
Portugal	77.6	25	Major challenges	Challenges remain	SDG Achievement	Major challenges	Significant challenges		70.6
Spain	78.1	22	Major challenges	Challenges remain	Challenges remain	Significant challenges	Significant challenges		70.1
Europe West	78.5	18							
Albania	70.8	68	Major challenges	Significant challenges	Challenges remain	Major challenges	Challenges remain		-
Bosnia and Herzegovina	73.5	50	Significant challenges	Significant challenges	Significant challenges	Unavalaible data	Challenges remain		-
Croatia	78.4	19	Significant challenges	SDG Achievement	Challenges remain	Challenges remain	Challenges remain		70.7
Cyprus	75.2	34	Significant challenges	Challenges remain	Challenges remain	Significant challenges	Challenges remain		60.7
Montenegro	70.2	72	Major challenges	Significant challenges	Challenges remain	Major challenges	Significant challenges		-
North Macedonia	71.4	62	Significant challenges	Significant challenges	Significant challenges	Unavalaible data	Challenges remain		62.9
Slovenia	79.8	12	Major challenges	Challenges remain	Challenges remain	Major challenges	Challenges remain		74.0
Europe East	74.8	38							
Israel	74.6	40	Major challenges	Significant challenges	Significant challenges	Significant challenges	Significant challenges	-	
Jordan	68.1	89	Significant challenges	Significant challenges	Challenges remain	Unavalaible data	Major challenges	67.4	
Lebanon	66.7	95	Major challenges	Significant challenges	Challenges remain	Major challenges	Significant challenges	63.6	
Palestine	-	-	Unavalaible data	Unavalaible data	Unavalaible data	Unavalaible data	Unavalaible data	-	
Syria	50.3	126	Major challenges	Significant challenges	Significant challenges	Major challenges	Major challenges	50.8	
Türkiye	70.3	70	Major challenges	Significant challenges	Significant challenges	Major challenges	Major challenges		56.7
Middle East (ME)	70.2	72							
Algeria	72.3	56	Major challenges	Significant challenges	Challenges remain	Major challenges	Significant challenges	67.0	
Egypt	66.8	83	Major challenges	Significant challenges	Challenges remain	Significant challenges	Challenges remain	63.6	
Lybia	-	-	Major challenges	Major challenges	Significant challenges	Major challenges	Significant challenges	57.1	
Morocco	71.3	64	Major challenges	Significant challenges	Challenges remain	Major challenges	Challenges remain	66.7	
Tunisia	71.4	63	Major challenges	Significant challenges	Challenges remain	Significant challenges	Significant challenges	67.3	
North Africa (NA)	70.2	72							
Mediterranean area	73.5	50							
Source	*Riccaboni et al.(2020)*							*Bayoumi et al. (2022)*	*Lafortune et al. (2022)*

SDG Achievement · *Challenges remain* · *Significant challenges* · *Major challenges* · *Unavalaible data*

SDG 2: *Zero hunger -* ***SDG 6:*** *Clean water and sanitation -* ***SDG 7:*** *Afordable and clean energy -* ***SDG 14:*** *Life below water -* ***SDG 15:*** *Life on land*

Table 4.3 | SDG scores in the Mediterranean region.

4.2 Nexus Solutions for Sustainable Development in the Mediterranean region

Traditionally, the approaches and efforts to address sustainability challenges in the Mediterranean water, energy, and food sectors, as well as ecosystems, have been supply-oriented and have often involved segmented planning and management frameworks (Malagó et al., 2021). In many cases, addressing one challenge has exacerbated others, underscoring the interconnected nature of these issues (Zarei, 2020). However, there has been increasing recognition among Mediterranean scholars and policymakers in recent years that achieving SDGs in the region requires systematic approaches and flexible forms of governance to account for interdependencies between sustainability challenges and approach them holistically (de Roo et al., 2021). Achieving SDG targets necessitates integrated approaches that offer innovative tools for tackling the complexities arising from multiple and often conflicting human needs. Such approaches should also foster an enabling environment for relevant stakeholders to collaborate effectively in managing the synergies and trade-offs between the food, water and energy sectors and their connections with the ecosystems (Magazzino & Cerulli, 2019).

The growing recognition of the need for such integrated approaches to address sustainable development challenges in the Mediterranean region has prompted the emergence of holistic approaches to analyse and manage the interactions between water, food, energy and ecosystems (WEFE). These approaches include, but are not limited to, soft path approaches for increasing water-use efficiency (Gleick, 2003), integrated water resource management (Biswas, 2008), integrated ecosystem management approaches (Botey & Garvin, 2010), multifunctional landscape approaches (Sayer et al., 2013), and more recently, nexus approaches (Bleischwitz et al., 2018; Weitz et al., 2014). Generally, these approaches are based on the underlying assumption that understanding the connections, synergies and trade-offs between WEFE components and sustainable development targets is crucial (Estoque, 2023; Hoff, 2011; Scott et al., 2015). The WEFE nexus has therefore evolved into an opportunity for achieving the SDGs by improving water, energy, food security and ecosystem functionality by increasing the efficiency of resource use, reducing trade-offs, strengthening synergies, and enhancing governance across different sectors (Malagó et al., 2021; Rasul, 2016).

Compared with most integrated approaches to sustainable development, nexus approaches offer comprehensive multi-sectoral frameworks for analysing the interactions between WEFE sectors, the identification of trade-offs and co-benefits that might otherwise be missed in complex production systems and supply chains and addressing institutional and policy implementation issues (Liu et al., 2018; van Zanten & van Tulder, 2021). Nexus approaches, such as the WEFE nexus, contribute to cross-sectoral cooperation and integrated planning and decision-making by accounting for the complex relationships between WEFE sectors and provide a framework for accounting for their driving forces which might be overlooked in single- or dual-sectoral approaches (Albrecht et al., 2018; Miralles-Wilhelm, 2016). In particular, the WEFE nexus approach has been largely embraced by Mediterranean stakeholders and decision makers due to its potential for improving governance across WEFE sectors by increasing efficiency, reducing trade-offs, and building synergies, which is particularly important in the context of Mediterranean countries where resource scarcity and sociodemographic pressures require efficient allocation, use and management of WEFE resources (Buchy et al., 2022; Endo et al., 2020). To ensure that the adoption of nexus approaches helps researchers and policymakers design and implement rigorous scientific assessments and effective policy interventions in relation to sustainable development objectives, key principles must be considered: (1) understanding the interlinkages between resources within a system across space and time and focus on the overall system's efficiency rather than the productivity of individual components; (2) offering integrated solutions, which contribute to achieving the sustainability goals and the security of water, energy and food resources; (3) accounting for the interdependence between water, energy, and food and promoting rational and inclusive dialogue and decision-making processes; (4) identifying integrated policy solutions to encourage mutually beneficial responses optimising trade-offs and maximising synergies across sectors; and (5) ensuring coordination across sectors and stakeholders for enhancing the potential for cooperation between all components (Carmona-Moreno et al., 2021).

Multiple frameworks and methodologies have been proposed to implement and operationalise the WEFE nexus approach (e.g. Afshar et al., 2022; Benson et al., 2015; Bizikova et al., 2013; Malagó et al., 2021; Mohtar & Daher, 2012), which put emphasis on multi-sectoral and non-linear system analysis and dynamic feedbacks across these sectors (Agrawal et al., 2022; Qin et al., 2022). Their applications reveal that renewable energies have a predominant role in achieving sustainability objectives in the Mediterranean region, especially SDGs 6.1 to 6.4 (clean water and sanitation) and 7.2, 7.3 (affordable and clean energy) that are strongly linked with 13.1 (climate action) (Malagó et al., 2021). The strongest interconnections between the SDGs and WEFE are for the categories of the renewable energy system, despite the tendency to focus on agriculture, so a more holistic nexus approach including end of supply chain options should be systematically integrated into the project design or evaluation. Trade-offs between agricultural production and environmental outcomes are intensifying, emphasising the importance of linking agricultural policies in the Mediterranean countries to environmental strategies and ecosystem protection programmes in order to resolve these trade-offs and ensure that food production goals are not achieved at the expense of ecosystems (Huang et al., 2023). More generally, applications of integrated assessment frameworks offer major policy implications for understanding the WEFE nexus in the region and the trade-offs between strategies to save water, reduce CO_2 emissions and/or intensify food production (Daccache et al., 2014).

As WEFE nexus frameworks continue to evolve, there have been some qualitative and less quantitative efforts in the Mediterranean region to explore whether the nexus approach, if properly designed and implemented, can effectively analyse the interconnections, identify synergies, and reveal trade-offs between WEFE sectors (e.g. Akinsete et al., 2022; Cristiano et al., 2021; de Roo et al., 2021). Nexus approaches proved the usefulness of assessing the impact of management strategies, policy interventions, and adaptation measures to climate-induced regional water constraints focusing on water availability, consumption and abstraction, and energy use (Espinosa-Tasón et al., 2020; Khan et al., 2016). In Spain, growing demand for irrigation water with limited supply has stimulated investments in water-saving and conservation technologies, with significant rebound effects (increased energy, irrigated area and water use), demonstrating the need for a change in the water policy paradigm from supply augmentation to demand management. At a larger scale, integrating the management of water and energy resources in Mediterranean countries is crucial to ensure the flexible operation of the energy system without affecting agriculture and water supply, and should include energy efficiency indicators and targets for the water sector (Adamovic et al., 2019). The WEFE nexus makes it possible to better identify potential synergies or conflicts between sector policies because it also provides a framework in which the role of ecosystem services is more explicit (Markantonis et al., 2019). Sustainable use of ecosystem services and conservation of biodiversity are indispensable pillars for successfully achieving sectoral development goals in the Mediterranean region.

An increasing number of regional organisations have launched or advanced regional programmes and initiatives to build mechanisms for supporting the WEFE nexus approach at various levels (Aboelnga et al., 2018), including the Association of Agricultural Research Institutions in the Near East & North Africa (AARINENA), the Center for Mediterranean Integration (CMI), the Global Water Partnership-Mediterranean (GWP-Med), the Union for the Mediterranean (UfM), the regional institutions of the League of the Arab States (LAS) such as the Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD), and the Arab Organization of Agricultural Development (AOAD). Involvement of stakeholders from the quadruple helix, (1) academia and education system, (2) economic system, (3) media-based and culture-based public (also civil society), (4) and the political system , in the development and implementation of nexus approaches is crucial to provide multiple perspectives, ensure political legitimacy and promote dialogue on the sustainability of WEFE components (Martinez et al., 2018).

A closer look at existing research undertakings and policy initiatives on the WEFE nexus in Mediterranean countries, however, reveals that most of these efforts have focused on assessments and analyses of the WEFE nexus, reaffirming the importance of the concept, but there is still a lack of concrete examples of actual implementation of the approach (Malagó et al., 2021). This limited effective implementation of WEFE nexus approaches in the region can be attributed to insufficient understanding of nexus trade-offs within science-policy-stakeholder interactions, insufficient incentives, limited vision, knowledge, development and investment, as well as the absence of strong empirical evidence of the potential benefits of a WEFE nexus approach (Hoff et al., 2019). Improving the gathering of data from different WEFE sectors is also a challenge to a better understanding and management of nexus interactions, and other interdependencies in the WEFE nexus, and a move from a general nexus thinking to an operational nexus concept (Laspidou et al., 2019). Indeed, WEFE nexus approaches are either data-driven or knowledge-based, and require widely accessible information and reliable data, which in many cases underpin the implementation of nexus approaches (Lawford, 2019; Simpson & Jewitt, 2019). The 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 wider adoption and application of the WEFE nexus in the Mediterranean region (Markantonis et al., 2019; Robling et al., 2023). Another key challenge is related to the costs of nexus approaches which are generally higher than those of silo approaches, due to the information, expertise, time, coordination and financial resources required (Liu et al., 2018).

4.3 From concept to implementation: the need for appropriate methodologies and sustainability indicators for the WEFE nexus

Nexus indicators are valuable tools for understanding the complex interactions within the WEFE nexus and contributing to informed and effective decision-making. The nexus literature includes a broad range of methodologies from different disciplines and indicators that quantify the interdependencies between the nexus components (Albrecht et al., 2018; Arthur et al., 2019; Endo et al., 2020; Newell et al., 2019; Opejin et al., 2020; Robling et al., 2023; Zhang et al., 2018) (*Figure 4.1*).

Transdisciplinary methods are frequently combined with collection and analysis of data from institutions, agencies and governments, if available. Econometric techniques are one possibility for this sort of analysis, generally using regression relationships between nexus indicators to quantify the influence of one nexus component on another (e.g. Zaman et

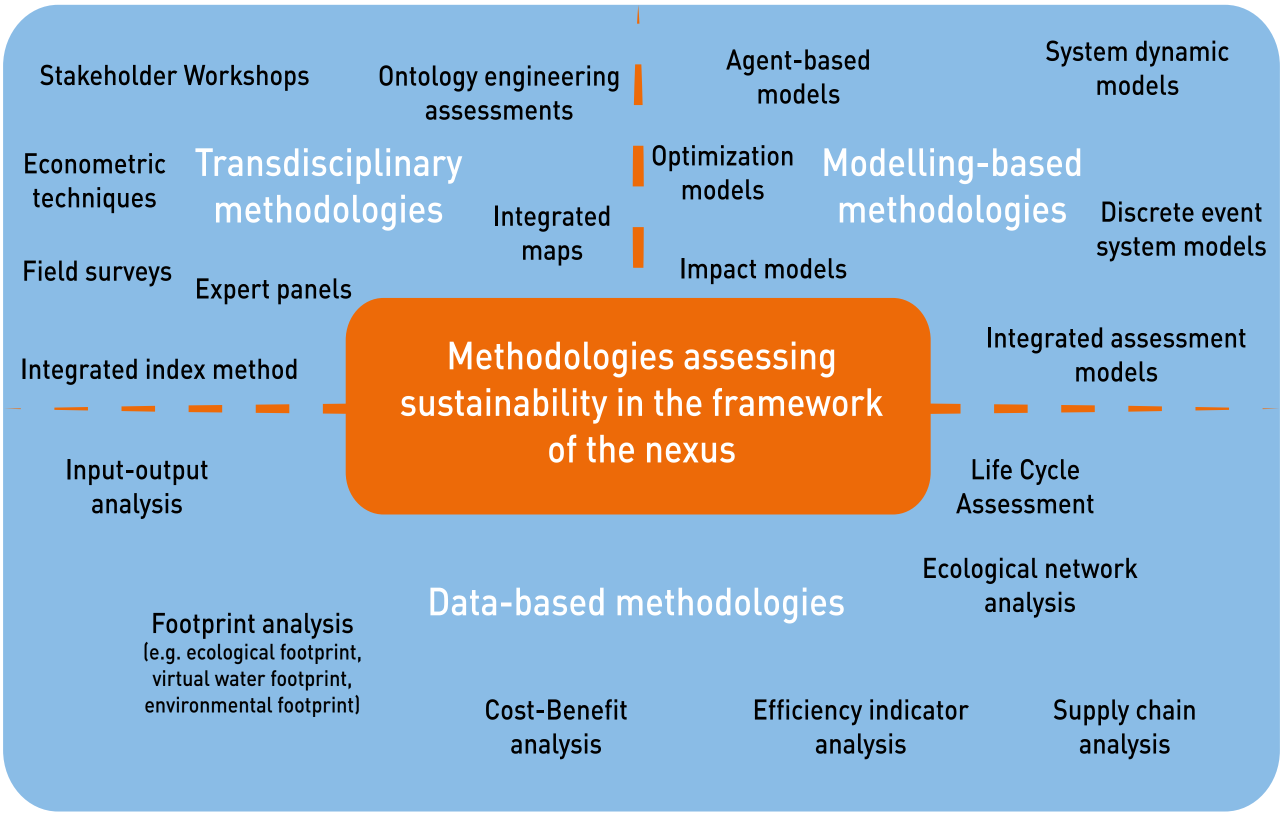

Figure 4.1 | Overview of the common methodologies used in the literature for sustainability analyses in the nexus.

al., 2016). The integrated index method is another possibility for capturing the characteristics of the nexus system by combining different indicators (e.g. de Vito et al., 2017; Endo et al., 2015; Schlör et al., 2018). Both options have the advantage of capturing current relationships observed in data but are rather static and not easily applicable for projections or predictions.

Field surveys, expert panels and stakeholder workshops are some of the most frequently used data gathering methodologies applicable for nexus assessments (e.g. Endo et al., 2015; Howarth & Monasterolo, 2016). They allow stakeholder dialogue and consider needs and views of interested groups. However, they are generally limited to the local scale and may be subject to bias originating from small or non-representative samples of participants.

In addition to transdisciplinary methods, a second group of methodologies can be identified as data-based approaches, including input-output analysis, material flow analysis, supply chain analysis, ecological network analysis, efficiency indicators, cost-benefit analysis (e.g. Endo et al., 2015), virtual water and water footprint studies (WF – e.g. Fader et al., 2011), environmental footprint (EF – e.g. Vanham et al., 2019) and life cycle assessments (LCA - e.g. Mannan et al., 2018). They focus primarily on measuring resource use, and in the case of LCA, the environmental impacts of production processes. These methods frequently compare and track outputs, inputs and production, in physical or monetary terms, making it possible to quantify performance and point out opportunities for efficiency increases. For more complete analyses within different sectors, the combined application of several indicators is recommended (Pacetti et al., 2015). However, these indicators are often applied to the present and past, since they rely mainly on measurement data, and lack projection power. For this reason, they are generally not suitable for the evaluation of future management practices or alternative scenarios.

In the modelling domain, a number of different modelling approaches have been applied to nexus research. For example, system dynamic models seek to demonstrate dependencies between variables (e.g. Sahin et al., 2014; Sušnik et al., 2018). Integrated assessment models are generally able to link interactions between nexus components and climate policies (e.g. the SEI nexus toolkit - Karlberg et al., 2015; MAgPIE and IMAGE Models - Doelman et al., 2022). Optimisation models, such as general and partial equilibrium models and land-use allocation models, seek to identify optimal solutions in interdependent systems with multiple possible solutions (e.g. MAgPIE and IMAGE Model – Doelman et al., 2022); GCE model - Teotónio et al., 2020). Impact models assess the consequences of actions in one system for other systems (e.g. Fader et al., 2013; CAPRI and E3ME - Trabucco et al., 2018), sometimes highlighting trade-offs and synergies (e.g. El-Gafy et al., 2017; Karabulut et al., 2019). Agent-based modelling simulates the behaviour of individuals or groups of individuals while allowing them to influence each other and learn from one another (e.g. Molajou et al., 2021). Each of these modelling frameworks has advantages and disadvantages described in the specific literature. Perhaps the largest advantage of models is the potential to run projections for the future and thereby help policy design and the avoidance of trade-offs before they happen. However, these methods require proper consideration of the linked parametric, input and model uncertainty encompassed in the results.

Finally, two methods are mostly used to visualise nexus relationships: (1) ontology engineering assesses terminology semantics on the internet and is a useful tool for depicting relationships between concepts (Endo et al., 2015); and (2) integrated maps depict the conditions of the nexus components at local level (Endo et al., 2015). They offer a useful tool for getting an overview of interdependencies and relationships.

4.3.1 Overview of applications of nexus indicators in the Mediterranean area

Several of the above-mentioned methodologies have been applied for nexus assessments in the Mediterranean region to estimate optimal cropping patterns that minimise water and energy consumption in Egypt (El-Gafy et al., 2017), assess benefits (Fader et al., 2016) or rebound effects neutralising water savings in irrigation modernisation projects in Egypt and Spain (El-Gafy, 2017; Mayor et al., 2015), or to evaluate energy strategy implementation (e.g. Karabulut et al., 2019). They show that increasing wind and solar energy in the Mediterranean as well as water use efficiency through modernisation of farms ranked high in terms of benefits for the water, food, ecosystem domain, benefits for socio-economic development, increase in resilience and green economy, and in the probability of implementation success (Karabulut et al., 2019). Linking renewable energy to desalinisation and wastewater treatment has positive effects on the environment, the economy and society, and brings benefits for the water, ecosystem, food and energy pillars (Lange, 2019; Malagó et al., 2021). Conversely, increasing bioenergy production, food production and promoting inland waterway transport are regarded as partially problematic or controversial for various nexus and sustainability areas (Karabulut et al., 2019; Pacetti et al., 2015). Energy for irrigation and the tourism sector may also strain the energy system if renewable energy does not replace energy production from fossil fuels (Sušnik et al., 2018). The example from Spain of combining stakeholder involvement, system dynamic modelling and ontology methods in a "serious games" framework has proved beneficial for estimating future irrigation water requirements (Sušnik et al., 2018), while in Cyprus, stakeholder dialogue has made it possible to analyse governance issues in nexus problems, compiling a list of practical innovations and their positive and negative impacts (Halbe et al., 2015).

The application of nexus methodologies briefly described above varies significantly in terms of (1) what sectors are considered, and (2) what temporal and spatial scales can be (and are in fact) covered. For example, nexus methodologies from the hydrological community are frequently applied and developed to assess problems at the watershed scale. In this case, nexus methodologies have much in common with Integrated Water Resources Management (IWRM) indicators (Kurian, 2017). Life cycle assessment (LCA) and footprinting are designed for past and present applications and can be applied to a variety of spatial scales or be focused on aggregation by products. LCA frequently accounts for the water and energy sector and some environmental issues. It is less often applied to the food sector. In general, it tends to be more applied to urban environments, highlighting the nature of cities as focused on consumption (e.g. Schlör et al., 2018; Yuan et al., 2021; Zhang et al., 2019).

Sustainability has economic, social and environmental components, but most nexus indicators combine only two of these areas. The social component, in particular, is frequently missing in most quantitative approaches. More emphasis on the combination of quantitative and qualitative analysis (Albrecht et al., 2018) as well as further development of agent-based models for nexus applications could partially close this gap in the years to come. However, developing new indicators involves the challenge of agreeing on which parameters to include as indicators due to the many different sectors involved in WEFE. Indicators that are too extensive or too complicated might be scientifically sound but not very applicable due to high data needs (Carvalho et al., 2022).

Indicators for local and regional scales and present and past times are widely applied to future projections and/or large scales (e.g. continental or global). Examples of these indicators include, for the nexus water component, total and per capita freshwater withdrawal, percentage of wastewater safely treated, proportion of population using safely managed drinking water services, agricultural water use efficiency, and level of agricultural, industrial and municipal water stress. Energy indicators include total primary energy consumption, percentage of investments in fixed assets in the energy sector in total volume of investments in fixed assets, total primary energy production, total primary energy consumption, oil production and consumption, electricity generation, gross electricity consumption, and biomass energy consumption. With regard to food, sustainability indicators include the food production index, fertiliser consumption, per-capita arable land, prevalence of undernourishment and food self-sufficiency ratio. For the ecological dimension of the nexus, indicators include ecological deficit, ecological footprint, biocapacity, CO_2 emissions per unit of GDP, forest area as a percentage of total land, urbanisation rate, and salinisation. Due to the limited capacity of some methodologies to assess future projection, as well as lack of data of sufficient quality, and since sustainability targets environmental, economic and societal well-being in the long term, not all nexus methodologies are able to contribute to sustainable development. Also, most nexus studies focus on the interactions between water, energy and food, with only a small number of them addressing nature or natural ecosystems as an additional "sector". There is therefore a clear need for increasing the role of holistic, predictive, transferable and upscalable methodologies for nexus research that include nature and environmental issues.

Nexus indicators are primarily a suitable tool for monitoring sustainability, but there is no perfect nexus methodology for all nexus questions and scales. There is a need for flexible indicators that make it possible to integrate additional components depending on case study, scale and question. One of the gaps in nexus synthesis research is the provision of decision support tools for stakeholders, managers and even researchers that offer an overview of which methodologies are best suited for which type of problems at different scales. Many measures are therefore still designed in "silos" (Lange, 2019; Malagó et al., 2021). Recommendations include taking a more holistic approach, considering complete supply chains, integrating modelling, and attempting more policymaking across national borders (Lange, 2019; Malagó et al., 2021; Saladini et al., 2018; Simpson et al., 2022). Strengthening governance, removing market distortions, promoting sustainable investments and raising awareness of the cross-sectoral consequences of policy design in the Mediterranean area are key to advancing water within the nexus approach while removing institutional, technical, regulatory and economic barriers (Kennou et al., 2018; Menichetti, 2018). New overarching policy approaches for management of energy, food and water resources are advocated to prevent potential trade-offs in climate change adaptation (Karabulut et al., 2018; Lakhdari, 2018).

4.4 Managing nexus synergies and trade-offs for sustainable resource use and management

Successful implementation of the WEFE nexus approach requires acknowledgement of the interdependence between water, energy, food, and ecosystems (Parsa et al., 2021; Robling et al., 2023). In order to adequately operationalise this approach, it is necessary to be aware of all trade-offs and synergies that might occur. To illustrate this, we take the example of the impact of sectoral sustainability policies on all SDGs, that is, beyond the SDGs these policies were designed for. To do so, representative sectoral sustainability policies designed to tackle sustainability in the different WEFE components' domains were identified from the literature. Then the impacts of each of these sectoral sustainability policies on the progress of all SDGs was estimated (*Table 4.4*). It should be underlined here that the criterion for selecting sectoral sustainability policies was neither exhaustivity, nor relevance, but representativity of the existing diversity of policies within each domain. The purpose of this qualitative analysis is to show that trade-offs and synergies are structurally present in the WEFE domain.

4.4.1 The WEFE ecosystems component

Five sectoral sustainability policies represent the existing diversity of policies within the Ecosystems component in the Mediterranean: (1) biodiversity and ecosystem conservation (CITES, 1983; RAMSAR, 2014); (2) action to minimise contamination and residues (UNEP, 2023); (3) sustainable intensification, that is saving land by separating production and preserved areas (FAO, 2011); (4) land sharing (European Commission, 2021), that is combining biodiversity preservation and agricultural production; and finally (5) payment for ecosystem services (e.g. REDD+). Biodiversity and ecosystem conservation policies tend to exert positive impacts on all SDGs except for those SDGs more linked to the promotion of economic activity (SDG 8), addressing climate change impact (SDG 13) and industry (SDG 9) or infrastructures (SDG 7, 11) where there can often be a clash of objectives. Action to minimise contamination and residue policies are largely in line with the previous groups of policies, and tend to show advantageous interactions with all SDGs, except for those more associated with the promotion of economic and industrial activity (SDGs 8, 9). The dual nature of sustainable intensification policies is largely reflected in the estimation of both detrimental and advantageous impacts on almost all SDGs. For land management, there is a longstanding tension between land sharing and sustainable intensification (e.g. Aubertin et al., 2022). This is clearly shown in *Table 4.4*, which displays the impacts of each of these sectoral sustainability policies on the progress of all SDGs. These two kinds of policies show radically opposed performance. Land sharing policies are largely aligned with biodiversity and conservation ones. Payment for ecosystem services policies perform quite ambivalently, with advantageous impacts on SDGs related to industrial, urban and economic activity (SDGs 8, 9, 11), and both detrimental and advantageous impacts coexisting in a good number of the remaining SDGs due to the money mediation inherent in this kind of policy, which frequently might not be the most effective way to minimise inequalities in multiple domains.

4.4.2 The WEFE water component

Six sectoral sustainability policies offer a good picture of the existing diversity of policies within the water component: (1) cooperation in the protection and use of transboundary water resources (UNECE, 2013); (2) conservation of aquatic ecosystems and wetlands (RAMSAR, 2014; WHO, 1999); (3) promotion of water efficiency (FAO, 2022c; Salman et al., 2019); (4) water footprint reduction (FAO, 2022c); (5) promotion of adequate water sanitation to protect human health and the environment (WHO, 1999); and finally (6) large water infrastructure development (e.g. groundwater wells, dams, aqueducts, storage tanks) to secure drinking water, hydroelectricity generation and/or irrigation (2030 WRG, 2022). As shown in *Table 4.4*, cooperation in the protection and use of transboundary water resources policies show advantageous impacts in the progress of all affected SDGs. The conservation of aquatic ecosystems, as might be expected, shows the same performance as biodiversity and ecosystem conservation and is also largely aligned with land sharing policies, with generally advantageous impacts except for SDGs 7, 8, 9 and 11. Promotion of water efficiency and water footprint reduction policies are two types of highly related policies that impact the same SDGs. However, while the former attempts to improve water use without questioning the number of utilisations, the latter implies a change in water consumption patterns. This explains the existing differences in the SDGs related to economic growth and industry (SDGs 8, 9), as well as those related to equity (SDGs 1, 2, 6, 10, 12), and to natural resource conservation (SDGs 14, 15). Water sanitation policies are estimated to exert advantageous effects on all SDGs impacted. Finally, large water infrastructure development policies (e.g. groundwater wells, dams, aqueducts, storage tanks), are characterised by exerting a dual impact on most of the SDGs, except for SDGs 8, 9 and 11, which are focused on urbanisation and economic and industrial development.

4.4.3 The WEFE food component

Four sectoral sustainability policies, according to the specialised literature, depict the existing diversity within the food component: (1) food security (CFS, 2020; FAO, 2022c); (2) food safety (WHO, 2022); (3) equity in nutrition (Development Initiatives, 2020); and finally (4) agroecology for food security (FAO, 2018). Food security policies aim to guarantee basic needs by reducing hunger, poverty, and enhancing well-being (SDGs 1, 2, 3). However, they have ambiguous impacts on SDGs that incorporate equity issues, due to the multiple options for enhancing food production and distribution (SDGs 4, 5, 6, 8, 9, 10, 11, 16). Food safety policies aim to ensure safe and healthy food consumption to minimise foodborne diseases. These policies are largely in line with food security policies. However, they show more ambivalent performance in guaranteeing access to food (SDGs 1, 2). Implementation of these policies tends to be associated with positive interactions with economic growth, industrialisation, urbanisation and responsible consumption (SDGs 8, 9, 11, 12). The emphasis of agroecology on enhancing equity and environmental awareness in the promotion of sustainable food systems means that implementation of agroecological policies is associated with advantageous interactions with almost all SDGs. The only negative interactions identified are with economic growth, industrialisation, and urbanisation (SDGs 8, 9, 11). Equity in nutrition policies aim to guarantee access to nutritious and culturally appropriate food for all people, but less focus on environmental issues explains the more ambiguous performance of these policies in SDGs 13, 14 and 15.

4.4.4 The WEFE energy component

The following group of sectoral sustainability policies provide a fair overview of the existing diversity of policies within the energy component: (1) decarbonisation (European Commission, 2021; IEA, 2021); (2) energy efficiency (European Commission, 2019); and (3) renewable energies (IRENA, 2014; REN21, 2014; SDSN, 2019). As shown in *Table 4.4*, decarbonisation policies show advantageous interaction with all SDGs as a consequence of the environmental awareness they are based on, but also because of their focus on reducing fossil fuel dependence, with multiple implications in terms of equity enhancement. Trade-offs seem to take place with SDGs 8 and 9, as decarbonisation is not well aligned with economic growth and industrialisation. And it also shows some negative interactions with urbanisation (SDG 11). Largely in line with decarbonisation policies, the adoption of policies to support renewable energy tends to entail synergistic interactions with most SDGs. However, trade-offs can be identified with

Sectoral sustainability policies		Relationship to SDGs																
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Ecosystem	Biodiversity and Ecosystem Conservation *(CITES, 1983; RAMSAR, 2014)*	+	+	+	+	+	+	*	-	-	+	*	+	+	+	+	+	+
	Preventing contamination *(UNEP, 2023)*	+	+	+	+	+	+	+	*	-	+	+	+	+	+	+	+	+
	Sustainable intensification *(FAO, 2011)*	*	*	*		*	*		+	+	*	+	*	*	*	*		
	Land sharing *(European Commission, 2021)*	+	+	+		+	+		-	-	+	-	+	+	+	+		
	Payment for ecosystem services *(e.g. REDD +)*	*	*	*		*	*		+	+	-	+	*	+	*	*		+
Water	Cooperation in transboundary waters *(UNECE, 2013)*	+	+				+	+	+	+	+				+		+	+
	Conservation of aquatic ecosystems *(RAMSAR, 2014; WHO, 1999)*	+	+	+	+	+	+	*	-	-	+	*	+	+	+	+	+	+
	Water efficiency *(FAO, 2022c; Salman et al., 2019)*	*	*				*		+	+	*	+	*	+	*	*		
	Water footprint reduction *(FAO, 2022c)*	+	+				+		-	-	+	+	+	+	+	+		
	Water sanitation *(WHO, 1999)*	+	+	+	+	+	+		+	+	+	+	+		+	+	+	
	Water infrastructure development *(2030 WRG, 2022)*	*	*	*		*	*	*	+	+	*	+	*	*	*	-		
Food	Food security *(CFS, 2020; FAO et al., 2022)*	+	+	+	*	*	*		*	*	+	*					+	
	Food safety *(WHO, 2022)*	*	+	+	*	*	*		+	+	*	+	+					
	Equity in nutrition *(Development Initiative, 2020)*	+	+	+	+	+	+		*	*	+	+	+	*	*	*	+	
	Agroecology for food security *(FAO, 2018)*	+	+	+	+	+	+		*	-	+	*	+	+	+	+	+	+
Energy	Decarbonisation *(European Commission, 2021; IEA, 2021)*	+	+	+	+	+	+	+	-	-	+	*	+	+	+	+	+	
	Energy efficiency *(European Commission, 2019)*	*	*	+	+	*	+	+	+	+	*	+	*	*	*	*	*	
	Renewable energies *(IRENA, 2014; REN21, 2014; SDSN, 2019)*	*	*	+	+	+	*	+	*	*	+	+	+	+	+	+	+	

Note: *+ means positive interaction; - means negative interaction; and * means both positive and negative interactions occur; empty cell means that data to show relevant interaction are not available.*

Table 4.4 | Qualitative examination of the synergies and trade–offs between the effects on the progress of SDGs arising from sectoral sustainability policies.

SDGs 1, 2, and 6. If an expansion of renewables leads to large-scale bioenergy production globally, then there is a risk of competition with land for food production (SDG 2) and water for multiple uses (SDG 6). Increased food prices could potentially result in such a scenario, which would be to the detriment of the poor worldwide (SDG 1). Also, the fact that renewable energies are still not always very competitive can generate trade-offs with certain objectives linked to economic growth and industrialisation (SDGs 8, 9). The potential rebound effect that might occur when efficiency is enhanced, together with the variable degree of equity regarding energy efficiency for all people, lie behind the potential trade-offs between several SDGs, particularly those more directly linked to ecological integrity (SDGs 12, 13, 14, 15) and equity (SDGs 1, 2, 5, 10, 16).

4.4.5 Synergies and trade-offs between the WEFE components

All the sectoral sustainability policies examined show multiple trade-offs and synergies when their impact is assessed for all SDGs (see *Table 4.4*). The examination also shows that this is independent of both the WEFE component the given policy was initially designed to tackle, and the nature of the policy orientation the given policy belongs to. The existence of trade-offs and synergies is the norm rather than the exception, that is, interdependence between WEFE components is a structural feature. Adequate operationalisation of the WEFE nexus approach needs to take this into account. In line with this, the examination also shows that sustainability policies with a focus on the preservation of both ecological integrity and social equity tend to perform in a more synergistic manner than those that do not. The existence of synergies and trade-offs between sectoral sustainability policies is not something specific to the Mediterranean region, as the diverse policies examined are present worldwide. However, it is also true that the Mediterranean is home to some specific features that put this region under even more pressure than others. The huge and multiple (cultural, socio-economic, orographic, bioclimatic, etc.) diversity within the Mediterranean, over a relatively small area of land and sea, makes this region particularly vulnerable to undesirable cross-effects between sectoral sustainability policies. Consensus around policy priorities might be more difficult to attain in such a heterogeneous region, where cross-effects between policies might be more abundant and less obvious. In this kind of context, integrated and holistic approaches to sustainability, such as the WEFE nexus approach, become more difficult to attain and therefore more necessary.

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